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

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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, 38, 22 and 29 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 use this framework to analyze the impact of debt forgiveness and banks' recapitalization to mitigate the drop in housing prices and consumption. I also present empirical evidence that balance sheet mechanism implied by 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

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1 Introduction

Between 2006 and 2009, housing prices in the United States fell by 17 percent, 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 a powerful mechanism for transmitting and amplifying shocks originated in the housing market. Moreover, during this period, several 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 impacts are still an open question. The framework developed in this paper allows us to compare different policies and guide policy interventions.

A growing empirical literature has shown that consumption responds strongly to housing price shocks. One influential paper, 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 used as collateral. Collateral and wealth effects are the main mechanisms in play in these prior models. On the quantitative side, 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 housing prices.

This paper, instead, uses a model with an endogenous credit supply, improving upon prior models that have been used to study the response of consumption to housing price fluctuations. Negative housing price shocks may also have a negative impact on bank balance sheets and induce banks to contract the credit supply. Therefore, I look, both empirically and theoretically, at the extent to which bank balance sheets transmit and amplify shocks that originate in the housing market. Do real estate shocks affect the balance sheets of banks, and do the banks respond by reducing credit availability? In other words, is the bank balance sheet channel present, and, if so, how potent is it? Do frictions in the credit supply affect real outcomes, and, if so, through which mechanisms? Is there a feedback effect that amplifies the original shock from the housing market?

The paper addresses these questions in three parts. In the first part of the paper I 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.

Households live infinitely and face uninsurable idiosyncratic income risk, which gives rise to endogenous heterogeneity by income, assets and debt level. Households that decide to purchase a home have access to collateralized long-term mortgages. Mortgages are modeled as a sequence of payments that follow a geometrically declining path, which implies that homeowners accumulate equity over time. Borrowers are allowed to extract equity through refinancing and to default.

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 an exogenously determined dividend policy. Moreover, banks face a quadratic cost function when their leverage goes above 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 do not have to deleverage immediately. They can sustain high leverage for some amount of time and adjust their leverage over time, as occurred during the Great Recession.

However, there is a secondary market where banks can trade mortgages among themselves. This market allows banks to diversify their idiosyncratic risk and adjust their balance sheet every period. This secondary 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. Therefore, mortgage spreads do not depend only on the evolution of housing prices and household creditworthiness, but also on the overall leverage of the financial system. 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 also increase, leading to a contraction in the credit supply and an increase in mortgage spreads. Therefore, individual mortgages are priced taking into account the individual risk of default as well as the capitalization of the financial system at the time of origination. By decreasing credit availability, banks amplify the original shock.

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 lower tail of the 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. Motivated by the construction boom that preceded the housing crash and led to overbuilding (McNulty (2009)), I assume that the supply of housing increases unexpectedly. 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 17 percent, matching the observed decrease in the U.S. between 2006 and 2009. The model also generates an increase in foreclosure of 10.7p.p. and a decrease in consumption of 10.1 percent. This compares with a change in foreclosures and consumption in the data of 13p.p. and 11.5 percent, respectively. The leverage of the financial system increases 0.63p.p. in the model, implying an increase of 120 basis points in banks' cost of funding. Between 2006 and 2009, bank leverage increased 0.55p.p. and spreads increased approximately 108 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 38 percent, the increase in foreclosures by 22 percent and the decrease in consumption by 29 percent. Bank balance sheet conditions are an important factor in the changes in housing prices and consumption. If the cost of funding had not increased, housing prices would only have dropped by 12.9 percent and consumption by only 7.2 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.

In the second part of the paper, motivated by observed policy interventions in the housing and credit markets that were designed to mitigate the decline in consumption and house prices, I model and evaluate two policies. Although there have been a few attempts in the literature to estimate the magnitudes and channels of these policies' effects, these issues remain unresolved. Endogenizing financial sector decision making in a model with a realistic mortgage structure makes this framework suitable for analyzing policies that target different kinds of agents.

The first policy considered focuses on the housing market and consists of debt forgiveness. The government forgives the excess debt of homeowners whose home equity dropped below 10 percent. This policy significantly reduces the number of foreclosures but has only a minor impact on the drop in housing prices and consumption. The second policy consists of bank recapitalization. An increase in bank equity mitigates the drop in housing prices, but the effect on the rate of foreclosure is smaller than under debt's forgiveness.

I conclude that although both policies had similar goals, their impacts were different. Debt forgiveness increased the household home equity, avoiding a large number of defaults (the default rate is about half of what it would be without the intervention). However, household leverage is still very high, and home values are still depressed, which prevents refinancing and reduces consumption. Equity injections improve banks' health and prevent a large increase in mortgage spreads, which ameliorates the drop in housing prices, preventing the loss of equity and an even larger increase in foreclosures. However, household leverage remains high and, although refinancing conditions improve, consumption does not.

In the third part, I present empirical evidence of frictions in the financial sector that drive changes in the credit supply in response to shocks to bank balance sheets. In other words, I show that banks reduce the mortgage credit supply in response to real estate shocks and that the banks' balance sheets play a role in this process. The empirical strategy employed here allows me to disentangle credit demand and supply and identify the credit supply response to exogenous variation in housing prices. I do so by implementing an instrumental variable approach.

By exploiting the variation in banks' exposure to different local housing markets, 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 the measure of housing supply elasticity developed by Saiz (2010) as an instrumental variable to correct for potential biases. 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 are not able to diversify away their own idiosyncratic 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 19 percent decrease in the total mortgage supply. Separating mortgages by new house purchases and refinances, I find decreases of approximately 8.5 percent and 29 percent, respectively.

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. Therefore, 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.

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. Section 3 sets up the model and section 4 solves it. Section 5 describes the calibration process and analyzes the model fit and steady state. Section 6 discusses the results of an experiment in the model. Section

7 analyzes policies. In section 8, I describe the data, outline the empirical strategy and discuss the empirical results. Section 9 concludes.

2 Related Work

At a broader level, 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. Although these papers use two different sources of consumption and housing prices, they estimate very similar elasticities, reinforcing the robustness of these findings. Mian and Sufi (2011) and Mian and Sufi (2014) 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 The Model

3.1 Households

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 h. The per-period utility is given by

$$\frac{\left(c_{it}^{\alpha} h_{it}^{1-\alpha}\right)^{1-\sigma} - 1}{1-\sigma}$$

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 $h \in \mathcal{H}^h$. The set of owner-occupied houses sizes is discrete. Agents are not allowed to simultaneously own and rent a house. There are two 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.

Households face an idiosyncratic exogenous income process given by

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

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

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

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.

The idiosyncratic income shocks and incomplete insurance markets generate endogenous heterogeneity by income, assets, consumption and debt. Moreover, it will induce different propensities to consume, borrowing, refinancing, as well as the extensive margin of switching between renting and owning a house.

3.2 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.

Houses

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.

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. Renting allows households to keep their savings in the form of liquid assets, providing a better buffer against income shocks.

Mortgages

Mortgages are long-term collateralized debt contracts with geometrically declining coupon payments, following Chatterjee and Eyigungor (2012, 2015) and Hatchondo and Martinez (2009). A mortgage contract signed at time t with face value $m_t = m$ corresponds to a sequence of payments starting at time $t+1$.

The borrower promises to pay, unless he defaults or terminates the contract, the fraction $\mu + x$ of the outstanding principal, where μ corresponds to the amortization term and x the coupon (or interest) term. These payments X_{t+j}, are given by

$$X_{t+j} = (\mu + x)m_{t+j-1} = (\mu + x)(1-\mu)^{j-1}m$$

and the mortgage's face value, or outstanding principal, evolves according to:

$$m_{t+j} = (1-\mu)m_{t+j-1} = (1-\mu)^j m, \qquad j \geq 1$$

The sequence of payments and the outstanding principal decline at rate μ as long as there is no default or contract termination. 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.

The long-term mortgages incorporate default and refinancing options. Mortgages are non-recourse, so in the case of default, the lender receives ownership of the house used as collateral and the borrower's obligations to the lender are extinguished. X^d_{t+j} denotes the total amount that the lender receives if the borrower defaults, defined as:

$$X^d_{t+j} = x^d_{t+j} m_{t+j-1}$$

$$x^d_{t+j} = \frac{min\left\{(1-\chi_d)\, p_{t+j} h_t, (1+x)m_{t+j-1}\right\}}{m_{t+j-1}}$$

where x^d_{t+j} stands for the fraction of the outstanding principal that the lender receives when default occurs. χ_d is the liquidation cost faced by the lender in case of default. 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.

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 $0 < \theta < 1$.

If the borrower sells the property used as collateral or wants to adjust his home equity or another aspect the mortgage contract such as the coupon rate, the borrower must terminate the contract and pay the outstanding principal plus the period coupon:

$$X^s_{t+j} = (1 + x)m_{t+j-1}$$

Borrowers can refinance by signing a new mortgage that uses the same house as collateral but has a different face value and coupon rate.

The lender faces a mortgage origination cost proportional to the debt's face value at origination, $\chi_m m$, and a refinancing cost of $\chi_r m$. These costs are paid up front by the borrower at the time the contract is signed.

The ability to default and prepay mortgages implies that the lender prices mortgages based on the individual default risk of each borrower. If household i with savings a_i, housing stock h_i used as collateral and current income y_i takes a mortgage in period t with face value m_i, the bank delivers $q_t(y_i, a_i, h_i, m_i)m_i$ units of the consumption good at origination. In Section 5 we see how the price of each mortgage is determined. $q_t(y_i, a_i, h_i, m_i)m_i$ also denotes the the market value of a mortgage with an outstanding principal m_i, with m_i also being the book value of that mortgage. This is true at any time, not only at origination. For simplicity, I use $q_{it}(m)$ and $q_t(y_i, a_i, h_i, m_i)m_i$ interchangeably.

3.3 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

$$Y^\tau_t(y_t, h_t, m_{t-1}) = max\left\{y_t - \tau_h p_t h_t - x m_{t-1}, 0\right\}$$

and total tax payments are

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

Taxable income and tax payments for renters and borrowers who default are given by $Y^\tau_t(y_t, 0, 0)$ and $T_t(y_t, 0, 0)$, respectively.

3.4 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[1].

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 also a secondary market where banks can trade loans among themselves. An originating bank can keep mortgages in its portfolio or sell some or all of its mortgages to other banks in the system, even in the period of origination of a given mortgage. 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, consider a mortgage held by individual i with outstanding principal at time t of m_t, the current value per unit principal of which is given by q_{it}. $q_{it}m_{it}$ is the value of this mortgage at time t. A bank can acquire a fraction ι of this mortgage at $\iota p_t^m q_{it} m_{it}$ in exchange for a fraction ι of all future payments on that mortgage.

Since each mortgage has a different risk profile, the portfolio of mortgages owned by each bank has its own risk profile. $\iota_{kt} = [\iota_{kit}]_{i\in\Omega_i}$ is a vector that denotes the fraction of the mortgage owned by agent i that bank k holds in its balane sheet at time t. The book value of the mortgages that bank k has in its portfolio at time t is denoted by $M(\iota_{kt})$ while $Q_t(\iota_{kt})M(\iota_{kt})$ denotes the market value of this portfolio. $M(\iota_{kt})$ and $Q_t(\iota_{kt})M(\iota_{kt})$ are defined as

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

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

where Ω_i denotes the set of households. Although it is an abuse of notation, for simplicity, I use $M(\iota_{kt}) = M_{kt}$ and $Q_t(\iota_{kt})M(\iota_{kt}) = Q_t(M_{kt})M_{kt}$. A given mortgage portfolio is secured by

$$H(\iota_{kt}) = M_{kt} = \int_{\Omega_{it}} \iota_{kit} h_{it} di$$

$\mathbf{d}_{k,t+1}$ and $\mathbf{s}_{k,t+1}$ are the share of principal defaulted and prepaid, respectively, that solve

$$\mathbf{d}_{k,t+1} M_{kt} = \int_{\Omega_{it}} \mathbf{1}_{\{\mathbf{d_{it+1}=1}\}} \iota_{kit} m_{it} di \Longleftrightarrow \mathbf{d}_{k,t+1} = \int \mathbf{1}_{\{\mathbf{d_{it+1}=1}\}} \iota_{kit} \frac{m_{it}}{M_{kt}} di$$

[1]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

$$\mathbf{s}_{k,t+1} M_t = \int \mathbf{1}_{\{\mathbf{s_{it+1}=1}\}} \iota_{kit} m_{it} di \Longleftrightarrow s_{t+1} = \int \mathbf{1}_{\{\mathbf{s_{it+1}=1}\}} \iota_{kit} \frac{m_{it}}{M_{kt}} di$$

where $\mathbf{1}_{\{\mathbf{d_{it+1}=1}\}}$ is an indicator function that equals 1 if household i defaults in period $t+1$ and zero otherwise. $\mathbf{1}_{\{\mathbf{s_{it+1}=1}\}}$ follows the same reasoning for the case of prepayment. 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.

The total income flow to bank k from a mortgage portfolio with principal $M_{k,t}$ is given by $Z_{k,t+1} M_{k,t}$ where

$$Z_{k,t+1} = (1 - \mathbf{d}_{k,t+1} - \mathbf{s}_{k,t+1}) (\mu + x) + \mathbf{d}_{k,t+1} x^d_{k,t+1} + \mathbf{s}_{k,t+1} (1 + x) \tag{1}$$

and $x^d_{k,t+1} = \frac{min\left\{p_{t+1} H_{k,t}, (1+x) M_{k,t}\right\}}{M_{k,t}}$[2].

The outstanding principal of a given portfolio of mortgages owned by bank k evolves according to:

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

and $Q_{t+1}(\tilde{M}_{k,t+1}) \tilde{M}_{k,t+1}$ denotes its market value.

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

$$Q_t(\iota) M_{kt}(\iota) = B_{kt} + N_{kt} \tag{2}$$

Frictions

There are two main frictions. Net worth is accumulated solely through retained earnings. Each bank follows an 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

$$N_{kt} = (1 - \omega) \left[N_{kt-1} + \Pi_{kt}\right] \tag{3}$$

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

As in Gertler and Karadi (2011) and Gertler and Kiyotaki (2011), I introduce frictions into the

[2] Note that $d_{k,t+1} x^d_{k,t+1} M_{k,t} = d_{k,t+1} min\left\{(1-\chi_d) p_{t+1} H_{k,t}, (1+x) M_{k,t}\right\} = min\left\{\int_{\Omega_{it}} \mathbf{1}_{\{\mathbf{d_{i,,t+1}=1}\}} \iota_{kit} (1-\chi_d) p_{t+1} h_{it} di, \int_{\Omega_{it}} \mathbf{1}_{\{\mathbf{d_{i,t+1}=1}\}} \iota_{kit} (1+x) m_{i,t} di\right\} = \int \mathbf{1}_{\{\mathbf{d_{i,t+1}=1}\}} \iota_{kit} min\left\{(1-\chi_d) p_{t+1} h_{i,t}, (1+x) m_{i,t}\right\}$

banks' balance sheets. Banks pay a quadratic cost, $\Phi(.)$, whenever the leverage ratio, $L = \frac{QM}{N}$, is above $\tilde{L}$. Similarly to Gerali et al. (2010), $\Phi(.)$ is assumed to have the functional form:

$$\Phi\left(\frac{QM}{N}\right) = \begin{cases} \kappa\left(\frac{QM}{N} - \tilde{L}\right)^2 & if\ \frac{QM}{N} > \tilde{L} \\ 0 & otherwise \end{cases} \tag{4}$$

This constitutes an alternative way of imposing an endogenous and flexible leverage constraint[3]. This cost function can be motivated as follows: suppose that the regulator finds it optimal for banks to keep their leverage below $\tilde{L}$. Given resource limitations and the cost of supervision, regulators tend to not intervene when bank leverage is only slightly greater than $\tilde{L}$. However, when the leverage 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 take some time to 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:

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

3.5 Technology

Composite Consumption

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

$$Y_c = Z N_c$$

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

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

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:

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

The aggregate supply of housing is then given by

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

and the equilibrium permit price is $p_t^k = (1-\alpha_h) p_t \left(\frac{Y_{c,t}}{K_t}\right)^{\alpha_h}$. When a house is sold, the government issues leases 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 bought from homeowners 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. 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 .

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

3.6 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.

4 Decision Problems

4.1 Household Decisions

Households can be either homeowners or renters. The individual state of a homeowner corresponds to current income y, asset holdings a, housing units h, outstanding mortgage principal m and maintenance cost δ_h. To use a compact notation, I summarize the individual homeowner state as $\Lambda_h = (y, a, m, h, \delta_h)$. 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. 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.

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 other 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. $V^H(\Lambda_h, \Lambda_{at}), V^{GR}(\Lambda_h, \Lambda_{at})$ and $V^{BR}(\Lambda_h, \Lambda_{at})$ 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

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

$$
\begin{aligned}
c + a' + \delta_h p_t h = y + a(1+r) &+ \left[(1-\chi_r)\, q(y, a', m', h', \Lambda_{at})m' - (1+x)\, m\right]_{m' \neq (1-\mu)m, h'=h} \\
&+ \left[(1-\chi_s)\, p_t h - (1+\chi_b)\, p_t h' + (1-\chi_m)\, q(y, a', m', h', \Lambda_{at})m' - (1+x)\, m\right]_{h' \neq h} \\
&- \left[(\mu + x)\, m\right]_{m'=(1-\mu)m, h'=h} - T(y, m, h')
\end{aligned}
$$

If the individual decides not to change his house or mortgage, the individual budget constraint is reduced to

$$
c + a' + \delta_h p_t h = y + a(1+r) - (\mu + x)\, m - T(y, m, h)
$$

The household pays the bank $(\mu + x)\, m$ and is left with outstanding debt of $m' = (1-\mu)m$. The state space tomorrow is $\Lambda_h' = \left(y', a', (1-\mu)m, h, \delta_h'\right)$.

If the household decides to refinance, it keeps the same housing stock, $h' = h$ but can freely adjust its outstanding mortgage at a new price.

$$
c + a' + \delta_h p_t h = y + a(1+r) + (1-\chi_r)\, q(y, a', m', h, \Lambda_{at})m' - (1+x)\, m - T(y, m, h')
$$

To refinance, the borrower has to pay the coupon rate xm and the remaining principal xm, and obtain a new mortgage with face value m' at price $q(y, a', m', h', \Lambda_{at})$. Given that refinancing is subject to a proportional cost of χ_r, the borrower receives from the bank $(1-\chi_r)\, q(y, a', m', h', \Lambda_{at})m'$. The state space in the following period is $\Lambda_h' = \left(y', a', m', h, \delta_h'\right)$.

If a household wants to adjust the size of its house, it must sell its current house and pay a sales cost, $(1-\chi_s)\, p_t h$ and terminate the current mortgage, paying $(1+x)\, m$ to the bank. The purchase of a new house is also subject to transaction costs, which are the total payment $(1+\chi_b)\, p_t h'$. With this new collateral, the household assumes a new mortgage $q(y, a', m', h', \Lambda_{at})m'$.

$$
s.t.\ c + a' + \delta_h p_t h = y + a(1+r) + (1-\chi_s)\, p_t h - (1+\chi_b)\, p_t h' + (1-\chi_m)\, q(y, a', m', h', \Lambda_{at})m' - (1+x)\, m - T(y, m, h')
$$

The state space for tomorrow becomes $\Lambda_h' = \left(y', a', m', h', \delta_h'\right)$.

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

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

$$s.t.\ c+p_{t}^{r}h'+a'=y+a(1+r)+max\left\{\left(1-\chi_{d}\right)p_{t}h-\left(1+x\right)m,0\right\}-T(y,0,0)$$

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 a sale cost, and, if his house is subject to a mortgage, terminate the current contract. The value function is given by

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

$$s.t.\ c+p_{t}^{r}h'+a'=y+a(1+r)+\left(1-\delta_{h}-\chi_{s}\right)p_{t}h-\left(1+x\right)m$$

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

The value function of a homeowner is then given by

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

$\mathbf{d}\left(\Lambda_{h},\Lambda_{at}\right)$ is an indicator function that equals one in case of default and $\mathbf{s}\left(\Lambda_{h},\Lambda_{at}\right)$ 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.

Renter who purchases

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

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

$$s.t.\ c+a'+\left(1+\chi_{b}\right)p_{t}h'=y+a(1+r)+q(y,a',m',h',\Lambda_{at})m'-T(y,0,h')$$

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

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 $\Lambda_h^{'} = \left(y', a', 0, h', \delta_h^{'}\right)$. The future state space of a renter with good credit is given by $\Lambda_h^{'} = \left(y', a', m', h', \delta_h^{'}\right)$.

Renting

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

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

$$c + p_t^r h' + a' = y + aR$$

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

Therefore, a renter not excluded from the mortgage market solves

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

and a renter excluded from the mortgage markets solves

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

4.2 Financial Intermediaries

Every period, each bank, given its net worth, decides the size of its mortgage portfolio. The bank 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 part of a mortgage or the full mortgage in the secondary market. As stated above, mortgages are traded in the secondary market at p_t^m per unit of mortgage value, $q_t(m)m$. $q_t(y, a, m, h)m$ is the current value of a mortgage with outstanding principal m loaned to a borrower with income y, assets a and collateral h. The value of this mortgage depends on the individual state space as well as on the aggregate state of the economy at time t,. Therefore, the value of a given mortgage may change over time, even if the risk profile of the borrower does not change. 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 4.2.1, $q_t m_t$ corresponds to the expected discount value of all future payments. Therefore, the bank is willing to sell this mortgage for any $p_t^m : p_t^m q_t m_t \geq q_t m_t \Leftrightarrow p_t^m \geq 1$. 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 this 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, and therefore 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

$$\Pi_{k,t+1} = r_{k,t+1}^m Q_t(M_{kt})M_{kt} - rB_{kt} - \Phi\left(\frac{Q_t(M_{kt})M_{kt}}{N_{kt}}\right) \tag{5}$$

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

$$r_{t+1}^m = \frac{Z_{k,t+1} + Q_{t+1}\left(\left(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1}\right)(1-\mu)M_{kt}\right)\left(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1}\right)(1-\mu)}{Q_t(M_{kt})} - 1 \tag{6}$$

$r_{k,t+1}^m$ is indexed by k, since banks may have different risks, and therefore, returns. $Z_{k,t+1}$, defined in (1), gives 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 $\left(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1}\right)(1-\mu)M_{kt}$ 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. $Q_{t+1}\left(\left(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1}\right)(1-\mu)M_{kt}\right)\left(1 - \mathbf{d}_{t+1} - \mathbf{s}_{t+1}\right)(1-\mu)$ 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. Therefore, each bank's 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 (5).

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

$$
E_t \Omega_{k,t+1} \left[r_{k,t+1}^m - r - \Phi\left(L_{kt}\right) - \Phi'\left(L_{kt}\right) L_{kt}\right] = 0, \qquad l_{kt} = \frac{Q_t(M_{kt}) M_{kt}}{N_{kt}} \tag{7}
$$

$$
\Omega_{k,t+1} = \beta_b \left[\omega + (1-\omega) \frac{\partial V_{t+1}}{\partial N_{t+1}}\right] \tag{8}
$$

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

where 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 $r + \Phi'\left(L_t\right) L_t^2$.

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 leverage ratio, $L_{kt} = L_t$, regardless of their net worth N_{kt-1} and the face value of the current mortgages in their balance sheet M_{kt-1}.

$$
E_t \Omega_{t+1} \left[r_{t+1}^m - r - \Phi\left(L_t\right) - \Phi'\left(L_t\right) L_t\right] = 0, \qquad L_t = \frac{Q_t(M_t) M_t}{N_t} \tag{9}
$$

where L_t denotes the leverage 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 and lead to an equilibrium with positive excess returns over the risk-free rate. Alternatively, we can define the funding cost at time t as

$$r^c_{t+1}=r+\Phi\left(L_t\right)+\Phi'\left(L_t\right)L_t \tag{10}$$

which corresponds to the payments on short-term liabilities plus the marginal cost of deviating from the leverage target $\tilde{L}$. 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}

$$E_t\Omega_{t+1}\left(r^m_{t+1}-r^c_{t+1}\right)=0 \tag{11}$$

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, $\frac{\partial V}{\partial N}>1\Rightarrow \Omega_{t+1}>\beta_b$. 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:

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

The equation above 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 leverage increases above $\tilde{L}$, financing costs start increasing. The optimal choice for banks is to choose a level of leverage such that the marginal cost of increasing leverage exactly equals the expected excess return over the riskless rate.

The equilibrium condition (9) determines the value of a mortgage portfolio in each period. To clarify, let us replace (6) into (9):

$$Q_t(M_t)M_t = \frac{1}{E_t\Omega_{t+1}\left(1+r_{t+1}^c\right)} E_t\Omega_{t+1}\left[Z_{t+1}M_t + \tilde{Q}_{t+1}\left(1-\mathbf{d}_{t+1}-\mathbf{s}_{t+1}\right)(1-\mu)M_t\right] \qquad (12)$$

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. The main difference between this formulation and that of the current literature that assumes a frictionless banking system is that Q_t is a function of the leverage ratio of the banking system, through the impact of leverage on the cost of funding r_t^c and the discount factor Ω_{t+1}. In the absence of leverage costs, funding costs are constant and equal to the risk-free rate r, $r_t^c = r$ 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. When banks' net worth decreases, they are less willing to buy loans in the secondary market. As the demand for loans in this market decreases, the value of such mortgages decrease as they become less liquid. 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 is in a given time period.

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

$$\tilde{M}_t = \left(1-\mathbf{d}_t-\mathbf{s}_t\right)(1-\mu)M_{t-1} \qquad (13)$$

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

$$\underline{L_t} = \frac{Q_t(M_t)M_t}{N_t} \geq \frac{Q_t\left(\left(1-\mathbf{d}_t-\mathbf{s}_t\right)(1-\mu)M_{t-1}\right)\left(1-\mathbf{d}_t-\mathbf{s}_t\right)(1-\mu)M_{t-1}}{N_t}$$

Long-term mortgages limit the portfolio adjustments available to banks, imposing a lower bound on bank leverage and therefore, funding costs, when the banking system is undercapitalized. In such a scenario, mortgage prices have to fall even further as liquidity in the secondary market dries up.

4.2.1 Price of Individual Mortgages

Equation (12) 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 (12) 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

$$\begin{aligned} q_t(y,a',h',m')m' = & \frac{1}{E_t\Omega_{t+1}\left(1+r^c_{t+1}\right)} E^i_t\Omega_{t+1}\left\{s_{it+1}(1+\mu)m'\right. \\ & + d_{it+1} min\left\{(1-\chi_d)\,p_{t+1}h', (1+x)\,m'\right\} \\ & \left. + (1-d_{it+1}-s_{it+1})\left[(\mu+x)\,m' + q_{t+1}(y',a'',h',(1-x)m')(1-x)m'\right]\right\} \end{aligned} \tag{14}$$

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

Proof: Note that condition (14) 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

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

Suppose that bank k sets price $q_{kt}(y,a',h',m')$ 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 (14) 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 $d_{it+1} min\left\{(1-\chi_d)\,p_{t+1}h', (1+x)\,m'\right\}$. If the borrower sells her house or wants to refinance, the bank receives $(1+\mu)m'$. And if neither happens, the intermediary receives $(\mu + x)\, m'$ and the value of continuing holding the mortgage, or equivalently, the value received if the mortgage is sold in the secondary market, $q_{t+1}(y', a'', h', (1{-}x)m')(1{-}x)m'$. 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^c_t 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 $q_{t+1}(y', a'', h', (1-x)m')$.

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^*) that households will pay on the mortgage if they never default and the riskless interest rate:

$$S_{it} = r^*_{it} - r = \frac{1}{q_t(y, a', h', m')} + \mu + k - (1 + r) \tag{15}$$

where r^* is the solution to :

$$q_t(y, a', h', m')m' = \frac{m'}{1 + r^*_{it}} \sum_{j \geq 0} \left(\frac{\mu + k}{1 + r^*_{it}} \right)^j \tag{16}$$

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

4.3 Equilibrium

Given an initial distribution of homeowners $\Gamma_H(\Lambda_h, 0)$, initial distributions of renters not excluded from the mortgage markets (M) $\Gamma_M(\Lambda_r, 0)$ and renters excluded from the mortgage markets (NM) $\Gamma_{NM}(\Lambda_r, 0)$ over the individual states $\Lambda_h = (y, a, h, m, \delta_h)$ and $\Lambda_r = (y, a)$; initial aggregate net worth N_0 and asset composition Q_0M_0 of the banking sector; initial stock of owner-occupied houses H^o_0, the initial stock of rental housing H^R_0, 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 $\{p^r_t\}$, mortgage price function $\{q_t(y, a', m', h')\}$ and bank funding cost $\{r^c_t\}$ 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
- Distributions are implied by the sequence of optimal decision rules and initial distributions

The demand for owner-occupied houses is given by the number 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 net demand in the rental sector $H_t^r - H_{t-1}^r$. On the supply side, we have new housing supplied by the construction sector, S_t^h and the net supply of homeowners (difference between the total number of houses sold and bought), $\int h_H^o(\Lambda_h, \Lambda_{at})\, d\Gamma_H(d\Lambda_h, t)$.

5 Model Calibration

The model is calibrated to replicate key features of United States economy during 2003-2006, 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 $\sigma_z = 0.2$. The AR(1) process is approximated with a 9 state Markov chain using Tauchen (1986) procedure. The intertemporal elasticity of substitution σ equals 2, a standard value in macro studies and α is set to 0.85 based on the NIPA share of housing expenditure. Discount factor is determined in the joint calibration.

Housing market

The house occupied set is defined as $\mathcal{H}^h = \{1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5\}$. 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 0.06 and χ_b to 0.01 as in Chatterjee and Eyigungor (2015). The hight maintenace cost for housing owned is set to 0.17 as as in Chatterjee and Eyigungor (2015) and the maintenance cost for rental units is set to 0.0165. The probability that such cost arises in jointly calibrated. Regarding the foreclosures losses, Pennington-Cross (2006) report a loss in foreclosure of 22% and χ_d is set to 0.22. The property tax rate equals 0.0138 as Chatterjee and Eyigungor (2015). 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% as in Kaplan et al. (2016). The parameter λ is set to 0.25 which implies an average exclusion period following default of 4 years. The exogenous leverage target is set to 7.0 which implies a equity capital to assets ratio of 14.3%, 0.3p.p. above the equity capital ratio observed in 2006.

5.1 Joint Calibration

The parameters internal calibrated are the maximum rental size unit is set to $\bar{h}$, the household discount factor β, amortization rate μ, probability of depreciation shocks p_δ and refinance cost χ_r. These parameters are estimated to target the home-ownership rate of 68 percent in SCF, fraction of borrowers with LTV above 90 percent of 7.02 percent from SCF data, the median home equity of 62 percent from SCF data, foreclosure rate of 1.5 percent and refinancing fraction of 24 percent in Wong (2015)[4]. The top 3 percent were excluded from the statistics obtained from SFC 2004. The average maintenance cost of owned houses is 0.014, which is lower than the maintenace costs of rental units of 0.0165.

The leverage cost and the dividend policy have direct implications on mortgage spreads. The diference between the expected returns on mortgage and the risk free rates must equate the marginal cost of increasing the asset side by one unit:

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

Without aggregate uncertainty and asuming that $L_t \geq \tilde{L}$, this equation can be simplified to:

$$r^m_{t+1} - r = \Phi(L_t) + \Phi'(L_t) L_t = \kappa \left(L_t - \tilde{L} \right)^2 + 2\kappa \left(L_t - \tilde{L} \right) L_t$$

Moreover, in the steady state, banking system networth must satify

[4]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).

$$1 = (1-\omega)\left(1+r+\Phi'(L)\,L^2\right) \Longleftrightarrow 1 = (1-\omega)\left(1+r+2\kappa\left(L-\tilde{L}\right)L^2\right)$$

I use these two equations in order to calibrate the leverage target, $\tilde{L}$, the sensitivity parameter κ of the leverage cost function and the dividend policy ω. These three parameters are estimated in order to match a steady state spread rate of 0.07 and a change in the spread rate of 1.08p.p. when the leverage ratio increases from 7.16 to 7.72. As stated before, the leverage steady state is chosen to be 7.16, which corresponds to a capital to assets ratio of 14% as observed in the data in 2006. Hall (2011) reports that the spread between AAA corporate bonds and constant maturity 20 years treasuries rose 1.08 percentage points during the crisis. As shown in figure 8, between 2006 and 2009, the capital ratio decreased about 1p.p., which implies an increase in the leverage ratio from 7.16 to 7.72. These parameters are then set to $\omega = 0.0324$, $\tilde{L} = 7.0$ and $\kappa = 0.0031$.

Table 2 presents all the parameter values jointly calibrated.

5.2 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 3.34 times higher than renters. This a direct consequence of the fact that owned houses are, on average, larger and that households face transaction costs any time they buy or sell a house, which makes it harder for a homeowner to smooth consumption in response to an income shock. Moreover, in order to obtain a mortgage to buy a house, banks may require a down payment, which low-income households may not be able to afford. Figure 2 shows that the home ownership rate and housing consumption are 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 2.54 in the model. In figure 3, we see that the share of homeowners with a mortgage is decreasing in liquid wealth. Figure 3 shows that households with higher financial wealth have higher home equity. Low-income households are, on average, more leveraged than high-income households.

The model also provides a reasonable match with home equity distribution, as seen in table 10. However, it overestimates the share of mortgagors with negative equity. Note that, unlike much of the literature, I do not assume any exogenous collateral constraint.

Due to income shocks and random maintenance costs, both default and refinancing occur in equilibrium. As we can see in figure 4 default decreases with income. Refinance is higher in the extremes of the wealth distribution.

6 Great Recession

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. In order to simulate the crisis between 2006 and 2009, I use a combination of unanticipated shocks in period 1. Although the shocks are unanticipated, agents have rational expectations about the transition path.

I consider three shocks: an increase in the supply of housing, 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. Unlike most of the prior literature, 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.

Increase in Housing Supply

As in Chatterjee and Eyigungor (2015), I generate a shock in the housing market that drives down housing prices. This shock is caused by the construction boom that preceded the housing crash, which led to overbuilding. According to McNulty (2009), between 2005 and 2007, the housing stock increased by 3.8 million units, but the number of occupied units only increased by 1.8 million. After considering "frictional" vacancies, the same paper estimates an excess housing supply of approximately 2.3 percent relative to the total stock of owner-occupied units in 2005. In the model, the government unanticipatedly increases housing permits such that the stock of new houses increases by 2.3 percent. However, in contrast to Chatterjee and Eyigungor (2015), I do not restrict new houses to being owner-occupied. Instead, the rental sector may acquire some of the new housing stock.

Productivity Shock

Total factor productivity drops by 6.1 percent, which results in a decrease in wages of the same amount. 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 17 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.

6.1 Baseline Results

The combination of shocks described above replicates the observed 17p.p. drop in housing prices between 2006 and 2009, as well as changes in other key variables over the same period, as reported in Table 4. Although housing prices recover over time, the permanent increase in the housing supply leads to lower prices in the long run and therefore a permanent decrease in the value of a household's collateral. The decrease in housing 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. Moreover, persistent negative income shocks (aggregate or idiosyncratic) may imply that a household's consumption of housing is too high. The household has then an incentive to sell its current house and acquire a smaller one or become a renter. 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 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 increase in their leverage. 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 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. This effect further decreases banks' net worth. Since banks face higher costs as their leverage increases, they have an incentive to sell some of the long-term mortgages on their balance sheets. Given that losses are spread across banks, liquidity in the secondary market decreases, and mortgage values decrease even further. As discussed in detail above, as banking system capitalization decreases, banks have an incentive to decrease the amount of their assets. But when all banks want to sell in the secondary market to mitigate the costs of increasing their leverage, mortgage prices are forced to decline even further. To compensate for these higher leverage costs and increased risk, banks require higher expected returns. This effect is translates to lower credit supply, higher mortgage spreads and higher down payment requirements. As mortgage loans for new purchases become more expensive, the demand for housing falls, 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, banks' loss of net worth leads to a decrease in the supply of credit and an increase in mortgage spreads, which 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 increase in the housing supply is absorbed by an increase in the average size of owned houses and a slight increase in homeownership. The consumption of rental units also increases since rents fall along with housing prices. As homeowners adjust the size of their house they incur transaction costs in both buying and selling. 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.

6.2 Bank Balance Sheet Channel

The interaction between balance sheet frictions and long-term mortgages is a strong amplification force in the model. Column 2 of Table 4 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 leverage goes up. 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 12.9 percent, the default rate would rise 8.3p.p. and consumption would fall by 7.2 percent. By construction, mortgage spreads do not increase (controlling for changes in borrower creditworthiness), banks' leverage increases 0.52p.p. and refinancing decreases by 21.7 percent.

The bank balance sheet channel appears to be a key factor driving the drop in housing prices in the model. The endogenous change in the credit supply due to the increase in banks' cost of funds banks explains approximately 38 percent of housing price changes in the baseline case. As prices drop following the unexpected increase in the housing supply, homeowners have an incentive to move to a bigger house and renters are more willing to buy. However, the presence of the financial accelerator means that banks demand higher collateral (down payment) and higher spreads, for new mortgages or refinancing, which discourages homeowners from expanding to bigger houses. 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 8.3p.p., compared to 10.7p.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 0.52p.p. increase in their leverage. 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 21.7 percent after the crisis, as opposed to 36.4 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 2.9p.p. less than in the baseline case, which means that the balance sheet channel accounts for approximately 29 percent of the change in consumption.

In sum, the bank balance sheet channel is an important explanation of the drop in housing prices and consumption during the great recession. Shutting down the endogenous effect of bank balance sheets on lending decisions implies more access to credit and with better conditions. Homeowners and renters are able to obtain new mortgages with more favorable conditions and absorb the increase in the housing supply. Refinancing allows homeowners to smooth income shocks and sustain higher levels of consumption than they would have otherwise.

In standard macroeconomic models, shocks to household balance sheets have little impact on consumption dynamics. By introducing housing to the household utility function, households become more sensitive to shocks due because a house is an illiquid asset that is costly to modify. Household balance sheets become relevant to their decision making and are qualitatively important in explaining changes in consumption and foreclosures after housing price shocks. However, this paper highlights a new channel not present in the current literature: the interaction household balance sheets and those of banks. This paper quantifies the amplification effect caused by bank balance sheet fluctuations. The endogenous increase in banks' funding costs amplifies the drop in housing prices, foreclosures and consumption by 38, 22 and 29 percent, respectively. The contraction in the credit supply that impacts households' ability to obtain new loans and refinance affects their ability to take advantage of low prices by increasing their housing consumption and to smooth their consumption of other goods.

6.3 Heterogeneity

The response to housing price shocks is heterogeneous across households with different levels of home equity. The baseline model generates a drop in aggregate consumption of 10.1 percent, but the consumption change distribution among homeowners exhibits a strong left skew. Consumption drops, on average, 28.3 percent for households with LTV higher than 90 percent and 19.1 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 7.6 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 60.4 percent for households with an LTV higher than 90 percent, 46.2 percent for those with an LTV between 80 and 90 percent and 21.7 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 6 and 7, we can see the changes in refinancing and consumption across home equity that would occur across home equity levels 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 more than their less-leveraged counterparts. For homeowners with an LTV greater than 90%, consumption falls 33 percent more in the baseline model than in the one without the bank balance sheet channel. For the refinancing, the difference is even larger, 52 percent. However, for homeowners with an LTV lower than 80%, consumption and refinancing only fall 16 percent and 10 percent more, respectively, under the baseline scenario.

7 Policy Interventions

In this section, I analyze and compare the effects of two policies that resemble two of the policies implemented by the U.S. government during the last recession. I consider a debt forgiveness program and a banks recapitalization program. I choose these two policies to contribute to the ongoing debate about the effectiveness of policies that provide a direct transfer of resources to highly indebted household versus those that support financial institutions. Mian and Sufi (2014) argue that the government has focused too much on preserving the financial system rather than addressing excessive household debt. Christina Romer[5] also believes that the fiscal stimulus implemented during the great recession would have been more effective if it had included a more effective housing plan. On the other side, Geithner (2015) and Bernanke (2008) defend the position that it would not be possible to save the main street without saving Wall Street. They argue that, in contrast to previous crises when household wealth declined, this crisis was characterized by a housing crisis that precipitated a financial crisis. Therefore, not taking into account the disruption of the financial sector would have led to a deeper recession.

In this paper, I evaluate these two views within the same framework. I focus how such policies could mitigate the drop in housing prices and consumption, as well as the mechanisms through which they work.

Debt forgiveness

Following the argument advanced by Mian and Sufi, I consider a policy that tackles excessive household debt. The government forgives the excess debt of homeowners whose loan to value

[5] http://www.nytimes.com/2014/05/18/business/the-case-against-the-bernanke-obama-financial-rescue.html

ratio rises above 90 percent. This consists of a direct equity injection to the most-leveraged and constrained households. In other words, all borrowers with an LTV above 90 percent see their debt reduced to 90 percent of their home's value. This differs from a direct wealth transfer, since recipients are not able to decide how to spend these resources. Nevertheless, this policy targets the excessive debt problem among more constrained households, which have a higher marginal propensity to consume, as highlighted by Mian and Sufi (2014). In Table 5 we see the impact of this policy on housing prices, foreclosure rates and consumption.

Debt forgiveness tends to have a strong impact on foreclosures, but a minimal impact on housing prices and consumption. Default necessarily requires low equity. As homeowners who were likely to default received an equity injection, the benefits of default fell considerably, and thus the foreclosure rate only increases 4.3p.p., compared to 10.7p.p. without the policy intervention. However, consumption only improves marginally. Despite the debt forgiveness policy, the disposable income of these homeowners decreases considerably since their mortgage payments are unchanged. Deciding not to default actually implies lower consumption than defaulting. Therefore, the aggregate change in consumption comes from less-leveraged households that were not direct recipients of the policy. They benefit in two ways. First, as defaults decrease considerably, banks' net worth is less affected. Mortgage spreads increase less, allowing a higher share of households to refinance. Moreover, as credit conditions improve, more renter households take advantage of low housing prices and become homeowners, mitigating the drop in house prices. This leads to lower default risk and therefore lower spreads, as well as a positive wealth effect that attenuates the consumption drop.

Equity Injections

TARP (The Troubled Asset Relief Program) included equity injections for financial institutions. According to the Congressional Budget Office, by January 2009 (CBO (2009)), the Secretary of the Treasury had purchased $178 billion in shares of preferred stock and warrants from 214 U.S. financial institutions through its Capital Purchase Program (CPP). I model equity injections as a direct transfer from the government to the financial sector. Consider a bank with net worth N_{kt} that receives an equity injection of N^g_{kt}. The government obtains an equity share of $\nu_{kt} = \frac{N^g_{kt}}{N_{kt+N^g_{kt}}}$. I assume that the government injects equity into each bank such that it acquires the same share in all institutions, $\nu_{kt} = \nu_t$. This is equivalent to the government injecting equity proportional to the current equity of each bank:

$$N^g_{kt} = \tilde{\nu}_t N_{kt} \qquad \tilde{\nu}_t = \frac{\nu_t}{1-\nu_t}$$

The aggregation is then straightforward, given the proportionality assumption:

$$N^g_t = \tilde{\nu}_t N_t$$

I assume that the dividend policy stays constant, but bankers now receive only a fraction $1 - \tilde{\nu}_t$ of the total dividends. The evolution of net worth and the banks' first order conditions stay unchanged, but the equity injection provides additional funds that can be used to issue new mortgages

$$Q_t M_t = B_t + N_t + N_t^g \Longleftrightarrow Q_t M_t = B_t + (1 + \tilde{\nu}_t) N_t$$

Equity injections directly reduce bank leverage by increasing their net worth. An indirect effect of this policy comes from mortgage prices. When the capitalization of the financial system increases, banks are more willing to keep a larger fraction of their current loans in their portfolio, which reduces the pressure on the secondary markets. Therefore, the value of outstanding mortgages decreases less, which improves banks' net worth and leverage ratio. Thus, the cost of funding increases by less, attenuating the increase in spreads. As banks discount future dividends at a lower rate than they would in the absence of such a policy, credit flows decrease less and the increase in mortgage spreads is mitigated. This allows higher refinancing rates and more mortgage originations. Housing prices fall less than they would if the policy had not been implemented. Higher housing prices translate into lower default rates, as a smaller fraction of homeowners end up with negative home equity. However, the default rate is still high, at 7.9p.p., approximately 2.8p.p. lower than if no policy were introduced. As banks lend more and refinancing becomes possible with better terms, households are able to smooth consumption. Consumption falls 8.5 percent under this scenario, as opposed to 10.1 percent if no policy were be implemented.

Although these two policies require the same amount of government resources, they impact consumption and housing prices in different ways. While debt forgiveness has a strong impact on foreclosures, bank recapitalization is more effective in mitigating the drop in housing prices. Both policies are able to attenuate the drop in consumption, but their impact is not significant. Nevertheless, although debt forgiveness directly addresses excess household debt, an equity injection in the banking system has a greater impact on consumption. The reason for this effect is related to the sensitivity of consumption to changes in housing prices. With equity injections, housing prices fall by less than with debt forgiveness. Housing wealth thus decreases less, and the negative wealth effect is attenuated. Moreover, the bank balance sheet channel is less powerful, allowing households to smooth their consumption.

8 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[6]. Second, I find that banks changed their mortgage loan supply by showing that the volume of new mortgages and refinance loans decreased more in counties with a larger presence of affected banks. The strategy used to identify this effect 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.

8.1 Data

The analysis in this section focuses on the 2006-2010 period, the period with the sharpest housing price declines and the largest changes in bank balance sheets. 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.[7] 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.

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.

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

[7] 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.

8.2 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:

$$\Delta Y_{k,t} = \beta_1 + \beta_2 \Delta S^p_{k.t} + \beta_3 X_{k,06} + \epsilon_{k,t} \tag{17}$$

where $\Delta Y_{k,t}$ denotes the change between time $t-1$ and t of the capital to assets ratio of bank k, $\Delta S^p_{k.t}$ is the real state shock faced by bank k between time $t-1$ and t and $X_{i,06}$ 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 14.1 percent in 2006 to 12.1 percent in 2008. In 2009 it started increasing again, mainly due to forced recapitalizations. The difference across banks is significant. 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.

The real estate shock to bank k at time t, ΔS^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, 2006.

$$\Delta S^p_{kt} = \sum_j \omega_{kj06} \Delta P_{jt} \tag{18}$$

The cross-sectional weights ω_{kj06} 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 housing 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 6 shows summary statistics for nationwide housing price growth and for the real estate shocks faced by each bank. Between 2006 and 2009, the median home price in the Zillow data set decreased, on average, 5.2 percent per year, with a cumulative change of -17.3 percent over the entire period. When weighted by bank assets, the average housing price shock for each bank was -4.3 percent per year and -16.8 percent cumulative over the 2006-2009 period. Housing price changes are very heterogeneous across counties. The 90th-10th percentile differential is 0.18p.p. My index of exposure for each bank, while it averages across locations, it is still very heterogeneous. The 90-10th percentile difference is 0.12p.p.

The set of controls is summarized in Table 7. They consist of indicators of a bank's performance in 2006, before the national decline in housing prices. They capture variation in lending standards among banks.

The specification in (17) 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. I instrument housing price changes in equation (18) by the housing supply elasticity developed by Saiz (2010). The resulting instrumental variable is the weighted average elasticity relevant to each bank. The weights are defined by the deposits of each bank at the MSA level. The Saiz measure is based on geographical characteristics, so the instrument captures local variation in housing prices that are not correlated neither with local economic conditions nor with changes in lending policies induced by bank's losses.

Table 8 shows that this elasticity measure can explain a large portion of the real estate shocks faced by the banks. Since areas with more inelastic supply suffered the biggest drop in housing prices and household net worth (Mian et al. (2013)), banks with a larger presence in MSAs with more inelastic housing supply saw a larger decline in their housing price index. Moreover, Mian et al. (2013) show that housing supply elasticity is not correlated with a number of local variables important for determining housing price dynamics in the study period. These include permanent income (proxied by wage growth), population and employment growth. Therefore, this elasticity measure seems to be a useful instrument to identify the exogenous real estate shock experienced by each bank.

8.3 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. A common challenge in this area is disentangling 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:

$$\Delta \text{MortgageOriginated}_{j,t} = \beta_1 + \beta_2 \Delta \Upsilon_{j,t-1} + \beta_3 \Delta H_{j,t-1} + \beta_3 W_{j,06} + \epsilon_{j,t} \tag{19}$$

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 (17) 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

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

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 $\widehat{\Delta Y_{i,t}}$ is the change in capital of the bank as a whole, not the change in capital attributed to that specific county[8]. 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 several different locations. To be more specific, I construct an index of banks' geographical presence across the U.S. (Herfindahl-type index). The index value for banks that operate in only a few counties will be close to 1, and it will be smaller for banks that are more geographically diverse. Then, I restrict the sample to those counties where the banks have an average spatial Herfindahl index lower than the median[9]. 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

[8]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

[9]The results do not change significantly if I change the threshold

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.

8.4 Results

Change in Housing Prices and Bank Balance Sheets

Table 9 reports the coefficients of the regression (17) where standard errors are clustered at the bank level. 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.

In column (2), 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 2006, 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 (3) shows the same specifications but with the real estate shock instrumentalized with the housing supply elasticity 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 0.95p.p.. If we consider the average shock (-4.3 percent per year), the same ratios change by -0.4p.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 (-11.78 percent) implies that the capital ratio decreases 1.12p.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), where the real estate shock is instrumentalized. This variable captures the exogenous change in bank balance sheets induced by the real estate shock.

The dependent variable is the the percentage change in mortgage loan origination in each county. 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.

From Table 10 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. Column (2) repeats the specification of Column (1) but adds state fixed effects. Elasticities are statistically significant at the 1 percent confidence level and economically significant. The elasticity of credit supply to changes in capital ratio is approximately 0.19. 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 19 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 total mortgages of 10.83 percent.

Approximately 53 percent of the total loans originated during the study period were refinance loans. In Table 11, I present the results for refinance loans. The estimates without and with state fixed effects are 0.28 and 0.29, respectively. Therefore, 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 16.5 percent.

Regarding home purchase loans (table 12), which constitute 43 percent of mortgages originated in this period, the median elasticity across both specifications varies from 0.09 to 0.1. 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 new home mortgages of 5.4 percent.

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 than new loans. Given the government guarantees on new conventional loans, these results are not surprising. The unemployment rate and housing prices are also very important contributors to changes in mortgage credit at the county level, suggesting that demand for mortgages was also a factor during this period.

9 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 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 resembles the great recession, 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, 38 percent, 22 percent and 29 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.

I also analyze the mechanism and impact of two policies that resemble those implemented during the great recession: debt forgiveness and bank recapitalization. This contributes to the ongoing debate about the effectiveness of government policies that target the financial sector rather than indebted households.

At last, I provide 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. Next, I present evidence that banks more affected by the decline in housing prices reduced their credit supply more than less-affected banks, and this decrease principally affected refinancing loans. 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.

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11 Tables and Graphs

Table 1: Model Parameters

Parameters	Value
Share of Consumption	$\alpha = 0.85$
Risk aversion	$\sigma = 2$
House sizes	$\mathcal{H}^h = \{1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5\}$
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	$\chi_d = 0.22$
High Maintenance cost	$\delta = 0.17$
Rental Maintenance cost	$\delta_r = 0.0165$
World Interest Rate	$r = 0.03$
Coupon Payment	$x = r + 0.007$
Mortgage Origination Cost	$\chi_m = 0.01$
Bank Leverage - SS	$L = 6.9$
Probability of reentering credit mkt	$\theta = 0.25$

Table 2: Model's Calibration

Moments	Data	Model	Parameters	Value
Homeownership	68%	68.55%	max renting house	$\overline{h} = 3.25$
LTV$\geq$ 90%	7.02%	9.07%	Discount Factor	$\beta = 0.976$
Average Equity	62%	61.2%	Amortization rate	$\mu = 0.027$
Default Rate	1.5%	1.44%	Prob High Maintenance	$p_\delta = 0.082$
Refinance Rate	24%	25.7%	Refinance Cost	$\chi_r = 5.1\%$
Steady State Spread	70b.p.	70b.p.	Leverage Target	$\tilde{L} = 7.14$
Increase in spread	108b.p.		Leverage Cost Param.	$\kappa = 0.00324$
			Dividend	$\omega = 0.0324$

Table 3: 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
% Homeowners with $\leq$ 0% equity	1.81	4.76
% Homeowners with $\leq$ 10% equity	7.02	9.07
% Homeowners with $\leq$ 20% equity	14.07	14.01
% Homeowners with 100% equity	28.75	33.03

Table 4: Model Simulation

△Cumulative	**Data**	**Model (a)**	**No Fric (b)**	**(a-b)/a**
House prices	-17%	-17%	-12.9%	38%
Default Rate	13p.p.	10.7p.p.	8.3p.p.	22%
Consumption	-11.5%	-10.1%	-7.2%	29%
Refinancing*	-43%	-36.4%	-21.7%	40%
Bank Leverage	0.55p.p.	0.63p.p.	0.52p.p.	17.5%
Spread	108b.p.	120b.p.	0	

Table 5: Policies

△Cumulative	**Model**	**Debt Forgiveness**	**Recapitalization**
House prices	-17%	-16.1%	-14.1%
Default Rate	10.7p.p.	4.3p.p.	7.9p.p.
Consumption	-10.1%	-9.3%	-8.5%

Table 6: Real Estate Shocks and Change in House Prices (county level)

	Mean	Median	Std. Dev.	p10	p90
Panel A - Real Estate Shock					
Yearly 2006-09	-.0427469	-.0438664	.0528421	-.0977825	.0200382
Cumulative 2006-09	-.1678913	-.1362822	.1412416	-.3015917	-.0258537
Observations (Banks x Year)	19756				
Panel B - House Price Changes					
Yearly 2006-09	-.0521465	-.0267075	.0761275	-.1256742	.0516333
Cumulative 2006-09	-.172691	-.0888161	.2317358	-.4048964	.0734694
Observations (Counties x Year)	2932				

Table 7: Banks' Controls

	Mean	Std. Dev.	Median	p10	p90
Panel A - 2006					
Assets	4.66e+08	5.06e+08	1.48e+08	645510	1.20e+09
Cash	.0433001	.0367497	.0411442	.0207532	.0561983
Deposits	.6688742	.1416703	.6553624	.551653	.8344826
Loans	.5898153	.1614928	.5848901	.3576705	.7861794
Real Estate Loans	.3366368	.1797281	.3258097	.1574628	.577239
Capital	.1400219	.053447	.1289842	.1015314	.188747
ROA	.0126799	.0091358	.0116398	.00782	.0195517
Retained Earnings	.0387813	.0247278	.0297774	.0208907	.0665043
NCO	.002337	.004679	.0012379	.0000923	.0033566
Late Loans	.0020352	.0035579	.0006224	0	.0076362
Provisions	.0025297	.0053269	.0014329	.0001627	.0033742
Loss Income	.0002309	.0009281	0	0	.0005423
Allowances	.0068422	.0054683	.0053633	.0033994	.0103607
Panel B - Yearly Change 2006 -2009					
Assets	.0944623	.3334177	.0725499	-.0678932	.2778005
Cash	.0127914	.0549973	.0001326	-.0295934	.0589247
Deposits	.0145285	.0679932	.0191851	-.0468031	.0636001
Loans	-.0098165	.0563816	-.0093101	-.0673441	.0479069
Capital	-.0036242	.0336811	.0022444	-.0315779	.0244176
ROA	-.005663	.0198344	-.0033004	-.0121323	.0026592
Retain Earnings	-.0062615	.019344	-.0025025	-.0166711	.0040422
NCO	.0044118	.0079154	.002236	-3.83e-06	.0085653
Late Loans	.0028362	.0045714	.0010503	-.0001184	.0114667
Provisions	.0060559	.0093551	.0043339	0	.0111497
Loss Income	.0000175	.0004738	0	-.000101	.0000793
Allowance	.0040073	.0054545	.003462	-.0001102	.008799

Note: All variables are divided by Total assets. All variables are weighted by total assets.

Table 8: First Stage: Real Estate Shock on Saiz Housing Elasticity

Saiz Elasticity	0.013***	0.013***	0.013***	0.013***
	(0.001)	(0.001)	(0.001)	(0.001)
Log(Assets), 2006			0.002***	0.001
			(0.001)	(0.001)
Liquidity Ratio, 2006			-0.088***	-0.088***
			(0.026)	(0.025)
Deposits Ratio, 2006			0.067***	0.062***
			(0.011)	(0.011)
Loans to Assets Ratio, 2006			-0.030***	-0.021***
			(0.006)	(0.007)
Real Estate Loans Share, 2006			-0.035***	-0.033***
			(0.005)	(0.005)
Loan Lates Ratio, 2006				0.126
				(0.270)
Loss Income Ratio, 2006				-2.243**
				(0.875)
Provisions Ratio, 2006				-1.365***
				(0.261)
Allowances Ratio, 2006				-0.482**
				(0.230)
NCO Ratio, 2006				2.258***
				(0.459)
ROA, 2006				0.119*
				(0.064)
Constant	-0.059***	-0.033***	-0.062***	-0.048***
	(0.002)	(0.002)	(0.015)	(0.016)
Year FE	No	Yes	Yes	Yes
Observations	9404	9404	9292	9292
$R^2 Adjusted$	0.043	0.153	0.176	0.187
Cluster	Bank	Bank	Bank	Bank
N-Clust	3328	3328	3287	3287
F-statistic	338.824	971.558	370.281	214.954

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 9: Bank's Capital Ratio and Real Estate Shock

	(1)	(2)	(3) IV
Real Estate Shock (t)	0.097***	0.062***	0.095***
	(0.008)	(0.008)	(0.034)
Log(Assets), 2006		0.001***	0.001
		(0.000)	(0.001)
Liquidity Ratio, 2006		-0.006	-0.000
		(0.007)	(0.015)
Deposits Ratio, 2006		0.047***	0.041***
		(0.012)	(0.016)
Loans to Assets Ratio, 2006		-0.005	-0.008
		(0.003)	(0.007)
Real Estate Loans Share, 2006		-0.004	-0.006
		(0.003)	(0.006)
Late Loans Ratio, 2006		0.032	-0.028
		(0.091)	(0.183)
Loss Income Ratio, 2006		-0.404**	-0.312
		(0.163)	(0.253)
Provisions Ratio, 2006		-1.510***	-1.622***
		(0.157)	(0.267)
Allowances Ratio, 2006		-0.064	-0.091
		(0.116)	(0.208)
NCO Ratio, 2006		1.688***	1.725***
		(0.248)	(0.476)
ROA, 2006		0.460***	0.435***
		(0.067)	(0.098)
Constant	-0.004***	-0.053***	-0.041*
	(0.001)	(0.015)	(0.025)
Year FE	No	Yes	Yes
Observations	19713	19623	9292
R^2 *Adjusted*	0.008	0.081	0.079
Cluster	Bank	Bank	Bank
N-Clust	7066	7032	3287

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 10: Total Mortgages

	(1)	(2)
Δ Capital Ratio (Predicted) (t-1)	18.796***	18.804***
	(4.100)	(4.439)
Δ Unemployment Rate (t-1)	-0.038***	-0.029***
	(0.010)	(0.009)
Δ House Prices (County) (t-1)	0.290*	0.320**
	(0.157)	(0.132)
Δ Household Income (t-1)	-0.218	-0.206
	(0.199)	(0.179)
Log(Assets), 2006	-0.010	0.008*
	(0.007)	(0.004)
Liquidity Ratio, 2006	-0.024	0.461
	(0.491)	(0.436)
Deposits Ratio, 2006	-0.135	0.064
	(0.142)	(0.073)
Loans to Assets Ratio, 2006	0.293**	0.092
	(0.122)	(0.075)
Real Estate Loans Share, 2006	-0.203*	0.057
	(0.109)	(0.069)
Late Loans Ratio, 2006	7.765	3.913
	(7.595)	(4.688)
Provisions Ratio, 2006	7.049	7.862
	(10.514)	(9.803)
Allowances Ratio, 2006	-4.930	-5.012
	(6.150)	(3.182)
Loss Income Ratio, 2006	-11.782***	-0.111
	(4.027)	(2.083)
NCO Ratio, 2006	-2.688	-4.394
	(8.552)	(10.484)
ROA, 2006	-5.754**	-2.037
	(2.680)	(1.530)
Constant	0.017	-0.393
	(0.251)	(0.255)
State FE	No	Yes
Year FE	Yes	Yes
Observations	2450	2450
R^2 *Adjusted*	0.669	0.710
Cluster	state	state
N-Clust	50	50

Notes. Dependent variable: Growth rate of all loans. The unit of observation is a county. ΔCapital Ratio reflects the predicted change in Capital Ratio obtained from regression (3) in table 4. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

Table 11: Refinance Mortgages

	(1)	(2)
Δ Capital Ratio (Predicted) (t-1)	28.237***	29.361***
	(6.608)	(6.241)
Δ Unemployment Rate (t-1)	-0.061***	-0.044***
	(0.015)	(0.015)
Δ House Prices (County) (t-1)	0.477*	0.488**
	(0.272)	(0.209)
Δ Household Income (t-1)	-0.082	-0.148
	(0.261)	(0.229)
Log(Assets), 2006	-0.006	0.021***
	(0.012)	(0.007)
Liquidity Ratio, 2006	0.561	0.868
	(0.876)	(0.794)
Deposits Ratio, 2006	-0.125	0.071
	(0.233)	(0.160)
Loans to Assets Ratio, 2006	0.398**	0.221
	(0.178)	(0.163)
Real Estate Loans Share, 2006	-0.242	0.162
	(0.177)	(0.098)
Late Loans Ratio, 2006	13.526	4.409
	(11.886)	(6.647)
Provisions Ratio, 2006	38.342**	26.642*
	(16.277)	(15.057)
Allowances Ratio, 2006	-16.178*	-12.499**
	(8.665)	(4.947)
Loss Income Ratio, 2006	-20.096***	-1.578
	(5.440)	(6.010)
NCO Ratio, 2006	-26.482**	-22.808
	(12.522)	(17.243)
ROA, 2006	-6.052	-1.194
	(4.862)	(3.114)
Constant	0.021	-0.265
	(0.433)	(0.457)
State FE	No	Yes
Year FE	Yes	Yes
Observations	2450	2450
R^2 *Adjusted*	0.684	0.717
Cluster	state	state
N-Clust	50	50

Notes. Dependent variable: Growth rate of Refinance loans. The unit of observation is a county. ΔCapital Ratio reflects the predicted change in Capital Ratio obtained from regression (3) in table 4. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

Table 12: Home Purchase Mortgages

	(1)	(2)
Δ Capital Ratio (Predicted) (t-1)	8.774**	7.935**
	(3.299)	(3.439)
Δ Unemployment Rate (t-1)	-0.001	0.004
	(0.004)	(0.005)
Δ House Prices (County) (t-1)	-0.189***	-0.136*
	(0.058)	(0.072)
Δ Household Income (t-1)	-0.041	-0.031
	(0.085)	(0.096)
Log(Assets), 2006	-0.009***	-0.006
	(0.003)	(0.005)
Liquidity Ratio, 2006	-0.232	0.175
	(0.231)	(0.319)
Deposits Ratio, 2006	0.009	-0.020
	(0.077)	(0.093)
Loans to Assets Ratio, 2006	-0.060	-0.053
	(0.078)	(0.059)
Real Estate Loans Share, 2006	-0.077	-0.027
	(0.075)	(0.090)
Late Loans Ratio, 2006	3.446	0.666
	(3.994)	(3.557)
Provisions Ratio, 2006	-4.984	-4.684
	(6.139)	(5.642)
Allowances Ratio, 2006	1.422	0.903
	(3.254)	(2.882)
Loss Income Ratio, 2006	3.258	2.773
(2.735) (2.799)		
NCO Ratio, 2006	2.115	3.125
	(5.883)	(6.342)
ROA, 2006	-2.875**	-3.761***
	(1.261)	(1.100)
Constant	-0.094	0.005
	(0.119)	(0.242)
State FE	No	Yes
Year FE	Yes	Yes
Observations	2450	2450
R^2 *Adjusted*	0.473	0.492
Cluster	state	state
N-Clust	50	50

Notes. Dependent variable: Growth rate of Home Purchase loans. The unit of observation is a county. ΔCapital Ratio reflects the predicted change in Capital Ratio obtained from regression (3) in table 4. ***,**,* Coefficients significant at the 1%, 5% and 10% levels, respectively.

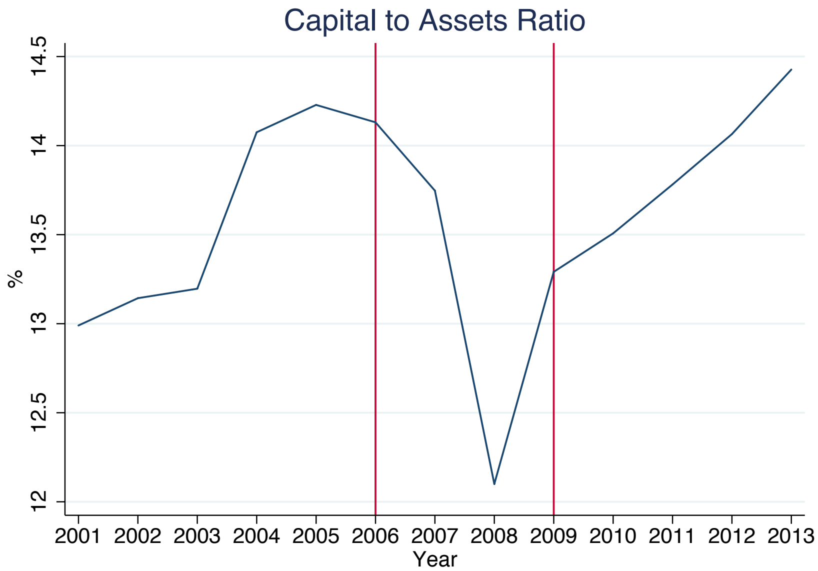

Figure 1: Evolution of Capital Ratio

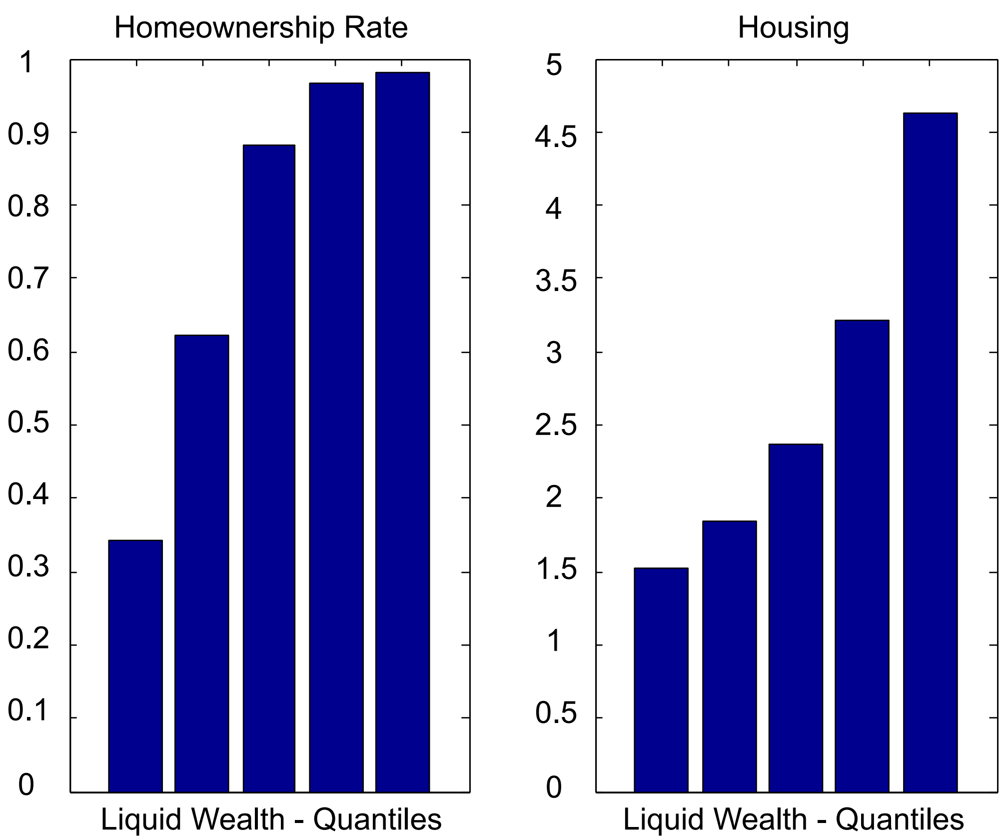

Figure 2: Ownership Rate and Housing Consumption

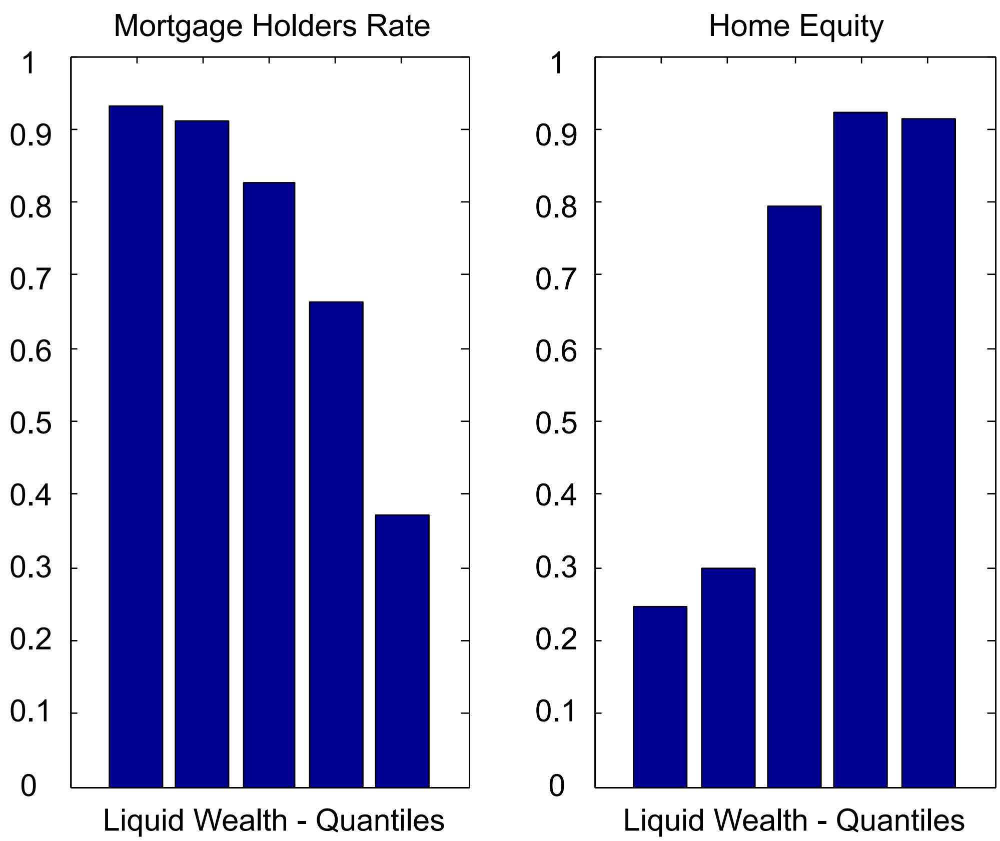

Figure 3: Mortgage Holders rate and Home Equity Distribution

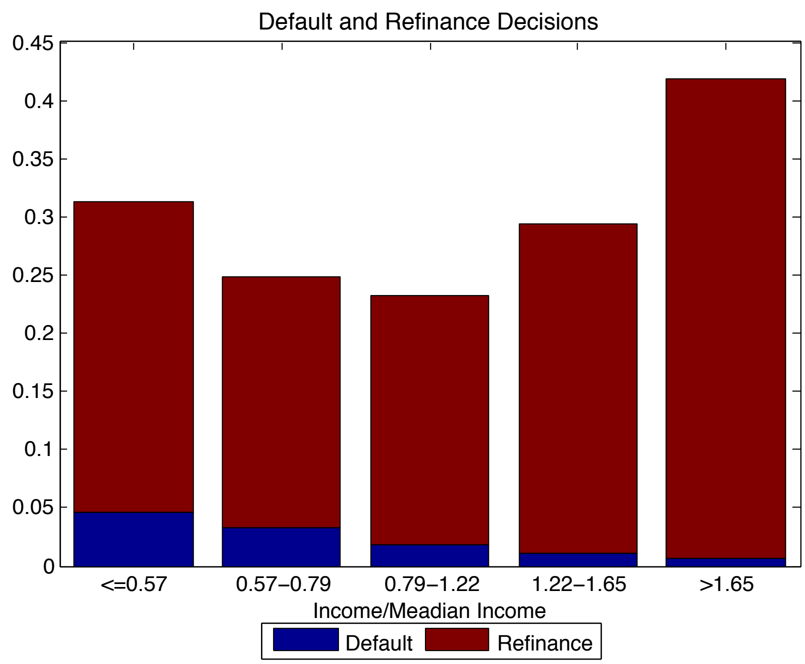

Figure 4: Default and Refinance Decisions at the steady state

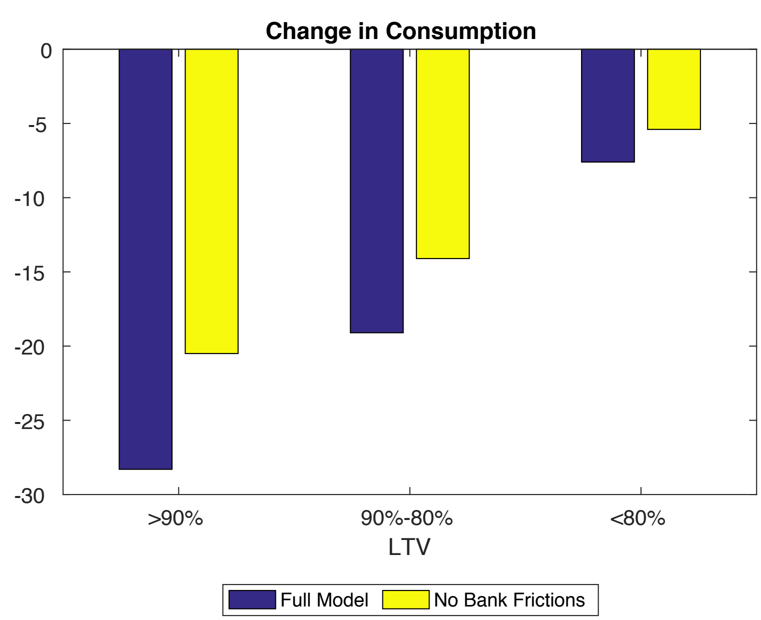

Figure 5: Heterogeneity - Consumption

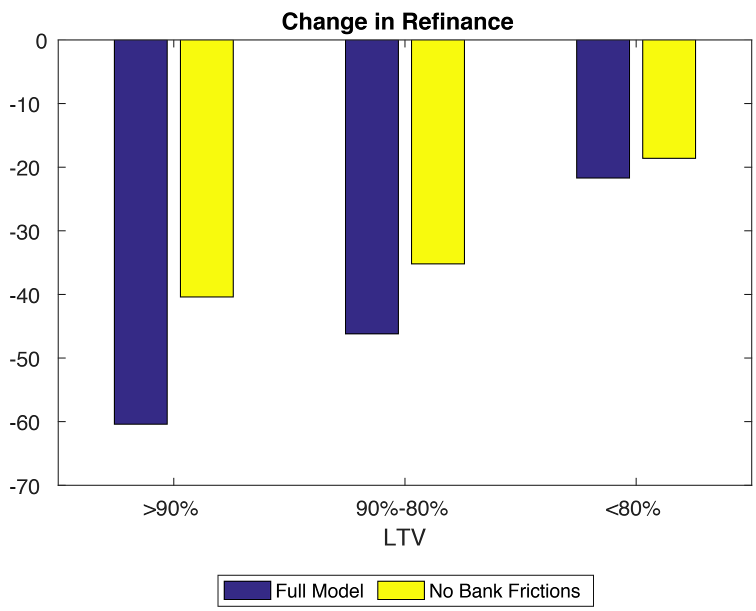

Figure 6: Heterogeneity - Refinance