Monetary Policy, Heterogeneity, and the Housing Channel[*]

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Abstract

We investigate the role of housing and mortgage debt in the transmission and effectiveness of monetary policy. First, monetary policy induced-movements in house prices translate into consumption changes because of wealth effects. Second, a contractionary monetary shock raises the cost of borrowing which reduces the demand and as a result the *liquidity* of the housing market, further depressing house prices and further increases the cost of borrowing. Furthermore, nominal long-term mortgage debt implies that changes in monetary policy result in redistribution between lenders and borrowers and generate cash-flow effects that are larger for borrowing constrained households. We build a heterogenous agent New Keynesian model with a frictional housing market to quantify the various mechanisms. The model is able to match the rich empirical heterogeneity in home ownership, leverage and MPC across households. In particular, our model is consistent with the significant difference in MPC between low- and high-LTV households that we document in the data. Our quantitative findings are as follows: First, we find that about 20% of the drop in aggregate consumption against a contractionary monetary shock is due to declining house prices. Second, we find asymmetric responses of the economy to shocks, with contractionary shocks yielding a larger response of all variables. Finally, we investigate how the transmission of monetary policy depends on the distribution of mortgage debt and find that monetary policy is more effective in stimulating the economy in an high-LTV environment.

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1 Introduction

The recent Great Recession has brought to light the importance of housing and household debt for the propagation of shocks in the macroeconomy. For a majority of US households, owner-occupied housing represents the single most important asset in the household portfolio and is tied to the single largest liability—the mortgage. In this paper, we investigate the rich role that housing and nominal mortgage borrowing jointly play in the transmission of monetary policy.

In addition to the direct intertemporal substitution effect of monetary policy on consumption, changes in interest rates generate several indirect effects related to housing and mortgages. First, changes in interest rates can generate movements in real house prices. A reduction in the interest rate reduces the cost of borrowing, alleviates credit constraints and increases the demand for housing. The increase in demand for housing increases real house prices. This indirect effect on house prices can translate into significant movements in household consumption, as recent empirical research finds large effects of house prices changes on household durable spending and non-durable consumption (for example, Mian *et al.* (2013); Kaplan *et al.* (2016a)). We refer to this as the *house price channel*. Furthermore, an increase in demand makes the housing market more *liquid*, meaning that households can sell their homes faster and at a higher price. As a result, financially distressed households are more likely to sell their homes and thus less likely to default. This, in turn, further alleviates borrowing constraints as banks internalize the decline in the riskiness of mortgage lending. This *liquidity channel* disproportionally affects households with high-leverage, who have a higher marginal propensity to consume (MPC) relative to those with less mortgage debt.

Moreover, the fact that houses are financed with long-term nominal debt implies that declines in interest rates may affect disposable incomes through increased refinancing activity, i.e., *cash-flow channel* (see, e.g., Flodén *et al.* (2016)). Furthermore, a change in real interest rate results in significant redistribution between households that are net debtors in nominal assets and net lenders. If debtors and lenders have different propensities to consume, this *redistribution channel* through balance sheets could have large effects on aggregate consumption (see, e.g., Auclert (2015)).

Heterogeneity is crucial for accurately evaluating the importance of these different channels in understanding the role of monetary policy on aggregate demand. The fact that some households have borrowed more than others is not random, and clearly not

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orthogonal to their MPC. Thus, it is the joint distribution of mortgage debt and MPC that determines the relative contribution of the redistribution, cash-flow, and liquidity channels. Similarly, the distribution of liquid wealth is a key driver of the responsiveness of housing demand with respect to financing costs. Finally, generating a realistic distribution of marginal propensities to consume enables us to accurately capture indirect effects of monetary policy through the *income channel*—the consumption response to changes in labor demand (see, e.g. Kaplan *et al.* (2016b)).

The goal of this paper is to understand and quantify the extent to which the joint distribution of housing and mortgage debt affects the transmission of monetary policy through the above mechanisms. Answering this question requires developing a new framework that combines elements from heterogenous-agent macro models, models with nominal rigidities and frictional models of the housing market. In particular, our framework features (1) incomplete financial markets with uninsurable idiosyncratic labor income risk; (2) a frictional housing market that endogenizes the price and liquidity of the housing market;[1] (3) long-term nominal mortgages that generate nominal rigidity in household budget constraint and redistribution across borrowers and lenders; (4) price rigidities due to monopolistically competitive producers that face quadratic price adjustment costs à la Rotemberg (1982).

We calibrate the steady state of the model to match United States microeconomic and macroeconomic data over the past twenty years. Given the importance of housing and debt in the mechanisms we emphasize in this paper, the calibration pays particularly close attention to matching the important dimensions of the joint distribution of assets, housing wealth, and mortgage debt as well as key moments related to household price posting and selling behavior in the housing market, households choices related to mortgage debt and default. The model generates the empirically relevant difference in MPC between low- and high-loan-to-value (LTV) households. Namely, using data from the Panel Study of Income Dynamics (PSID) we estimate the consumption response of households to transitory income shocks conditional on their LTV ratios. We find that the elasticity of consumption with respect to income shocks to be 0.27 for households with a LTV ratio above 85 percent, whereas the corresponding figure for households with a LTV ratio below 85 percent is significantly lower (in a statistical sense) at 0.19.

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[1]We employ directed search in the housing market and show that our formulation admits block recursivity in the spirit of Menzio and Shi (2010), greatly increasing the computational tractability and allowing us to conduct rich experiments to isolate the economic forces.

The model generates several quantitatively important deviations from standard incomplete markets models where households are able to easily access their entire portfolio of wealth. First, heavily leveraged homeowners experience long selling delays in the housing market because their outstanding debt acts as a binding lower bound on the list price. This inability to quickly sell increases the exposure of such homeowners to idiosyncratic and aggregate risk, thereby making mortgage default more likely. This elevated default risk from housing illiquidity causes access to mortgage credit to tighten, thereby further impeding consumption smoothing. This impaired consumption smoothing generates as a result significant dispersion in the distribution of the marginal propensity to consume. Renters, and homeowners with substantial equity are relatively insensitive to income fluctuations, while heavily indebted homeowners stuck with houses they cannot quickly sell are far more responsive to shocks.

We then use this model to study the transmission of the monetary policy. Our quantitative findings are as follows: First, house prices decline in response to a monetary tightening, which causes an endogenous cascade of declining housing liquidity, elevated foreclosure risk, tighter credit, and further price declines. As this cycle unfolds, the consumption of leveraged homeowners responds strongly, which then impacts aggregate demand, income, and output. We find that about 20% of the consumption response is due to the movements in house prices.

Second, we investigate asymmetric effects of policy. We find that contractionary monetary shocks have larger effects on aggregate demand than expansionary shocks. This is mostly due to the shape of the leverage distribution: When rates do down, this relaxes fewer households' budget constraint than the number of households that fall into trouble with their mortgages when rates go up. Because of this underlying heterogeneity, the foreclosure rate disproportionately increases in response to monetary tightening, causing an asymmetric response in house prices. The asymmetry in house prices then feeds back into consumption.

Lastly, we investigate how the effectiveness of the monetary policy depends on the distribution of mortgage debt. For this purpose, we conduct a simple experiment and reduce the maximum LTV households are allowed to take from 125%, which is not binding in the calibration, to 85%. This generates nontrivial changes to the LTV distribution. The high-LTV economy implies a wider distribution of MPC with more households having high MPCs. As a result we find that expansionary monetary policy is more effective in an high-LTV economy.

Related Literature   This paper is related to several strands of the literature. Several papers examine the role of house prices in driving aggregate fluctuations through consumption. Mian *et al.* (2013) and Kaplan *et al.* (2016a) study the response of spending on cars and non-durable consumption, respectively, to housing net worth prices by exploiting geographical variation in the housing collapse of 2006—2009. They find an elasticity in the range of 0.6 to 0.8 for spending on cars and 0.2 to 0.4 for non-durable expenditures. Furthermore, they show that this elasticity is higher for poorer households and those with higher loan-to-value on their mortgages. In addition, Kaplan *et al.* (2016a) decompose the response of non-durable spending into changes in prices versus quantities and show that price movements can account for one fifth of the consumption response[2] The elasticities of consumption to house price changes documented in the Great Recession, however, are much larger than previously estimated in the literature using different data and over different time periods that generally found an elasticity in the range of 0 to 0.10 (Carroll *et al.* (2011); Attanasio *et al.* (2009); Calomiris *et al.* (2009); Browning *et al.* (2013); Case *et al.* (2011); Campbell and Cocco (2007)).

There is a nascent empirical literature that investigates how household balance sheets affect the transmission of monetary policy. Di Maggio *et al.* (2014) show a significant consumption response to monetary policy, but they highlight how voluntary deleveraging attenuates the effect of rate reductions on consumption. Consistent with other work, they show that the marginal propensity to consume is higher for low income or underwater borrowers, and that the effect is larger in counties with a greater fraction of adjustable rate mortgages. In other words, debt rigidity reduces the effectiveness of monetary policy in their setting. Keys *et al.* (2014) also show that voluntary deleveraging mutes the response of consumption to lower mortgage rates. They also show that regions that were more exposed to mortgage rate declines saw faster recovery of house prices, consumption, and employment, particularly in the non-tradable sector. In short, these papers provide empirical support for the key result that the effectiveness of monetary policy crucially depends on the distribution of liquid wealth and mortgage debt. Auclert (2015) documents the importance of the redistribution channel and develops a sufficient statistic approach for quantifying it, but abstracts from housing in the household portfolio. A number of other papers have focused on how different dimension of heterogeneity such as age (Wong (2015)), debt-to-income ratio (Flodén *et al.* (2016)), and housing and

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[2]Stroebel and Vavra (2014) have previously shown that these movements in prices should be interpreted as changes in local mark-ups to demand shocks.

mortgage tenure (Cloyne *et al.* (2015)).

Our paper also contributes to several strands of the modeling literature. First, our framework is the first to introduce housing, long-term debt and a frictional housing maker with the new class of heterogeneous-agent New-Keynesian (HANK) models (Challe *et al.* (2015); Gornemann *et al.* (2014); Kaplan *et al.* (2016b); McKay and Reis (Forthcoming)). Second, our paper contributes to the modeling literature that has investigated the role of housing and household debt in understanding the consumption and foreclosure dynamics (e.g. Garriga and Hedlund (2016); Garriga *et al.* (2015); Huo and Rıos-Rull (2013); Kaplan *et al.* (2015); Favilukis *et al.* (2010); Corbae and Quintin (2015); Chatterjee and Eyigungor (2011); Hedlund (2015)) by jointly modeling heterogeneity, monetary policy and long-term debt. Our paper is closely related to Hedlund (2015), which looks at what impact higher inflation could have had in potentially mitigating the Great Recession by inflating away nominal mortgage debt. But that paper abstracts from the conduct of monetary policy, nominal rigidities and production in the economy.

2 Model

In this section, we develop a heterogeneous agents New Keynesian model with housing and mortgages. To investigate the effect of the housing channel in the transmission of monetary policy, we include the following key ingredients: (1) a frictional housing market that endogenizes the price and liquidity of the housing market; (2) long-term nominal mortgages that generate nominal rigidity in household budget constraint and redistribution across borrowers and lenders; (3) sticky prices in goods market à la Rotemberg (1982), so as to provide a role for aggregate demand in determining output.

The economy is populated by *(i)* a measure one of infinitely lived households, *(ii)* real estate brokers that facilitate transactions in the housing market, *(iii)* banks that issue long-term adjustable rate mortgages, *(iv)* government sponsored enterprises that provide insurance to the banks against the default risk of mortgages, *(v)* a set of intermediate goods producers in a monopolistically competitive market producing a product of variety $j \in (0, 1)$, *(vi)* a representative final goods producer aggregating intermediate goods into the final consumption good in a competitive market, *(vii)* a government that sets fiscal policy, and *(viii)* a monetary authority that sets the nominal interest rate. Time is discrete.

Below, we present the details of the model. Wherever non-essential, the technical

details and equations are relegated to appendix A.

2.1 Households

There is a continuum of infinitely lived households that are subject to uninsurable idiosyncratic labor productivity risk. Their labor productivity z_t follows an exogenous finite state Markov according to the transition matrix $\Gamma(z_{t+1} \mid z_t)$. Households have preferences over non-durable consumption c, leisure l, and housing services s and are endowed with one unit of time every period, which they allocate between market work and leisure. Preferences are time-separable and the future is discounted at rate β. The expected lifetime utility of a household is given by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^{t-1} \frac{\left[(1 - \phi_h)\left(c_t + g(1 - l_t)\right)^{1 - \gamma_h} + \phi_h s_t^{1 - \gamma_h}\right]^{\frac{1 - \sigma}{1 - \gamma_h}}}{1 - \sigma}, \text{ with } g(1 - l_t) = \psi z \frac{(1 - l_t)^{1 + \frac{1}{\varphi}}}{1 + \frac{1}{\varphi}}.$$

The utility over consumption and leisure is given by Greenwood *et al.* (1988) preferences so that the marginal rate of substitution is independent of consumption and only depends on the real wage rate. This implies that there are no wealth effects on labor supply.[3] Furthermore, we assume that the utility from leisure is proportional to labor productivity so that only aggregate movements in the wage rate affect the labor supply of households. We use the CES aggregator between the consumption-leisure bundle and the housing services. The parameters β, σ_L, γ_h, and φ measure the discount factor and relative risk aversion, elasticity of substitution between consumption and housing services, and Frisch elasticity of labor supply, respectively. ϕ_h determines the share of housing services in total consumption.

The households enjoy housing services s either by owning and occupying a house or by renting from a competitive market in the form of apartment space. Owner-occupied housing comes in a set of discrete sizes, $h \in \mathcal{H} = \{h_1, h_2, ...h_n\}$. Living in an owner-occupied house of size h generates a service flow of $s = h\omega_h$, whereas living in a rental unit of the same size generates a service flow of $s = h$. $\omega_h \geq 1$ captures the motives towards ownership beyond those that are explicitly modeled. Homeowners are not allowed to rent out their housing unit to a tenant.

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[3]A large class of New Keynesian models, including the one in this paper, have counter-cyclical markups. This implies that profits go up in recessions, and households that receive these profits as lump-sum transfers tend to respond by supplying *less* labor. We find this counter intuitive and therefore employ GHH preferences to kill such wealth effects.

Households can save in a risk free bond, b_{t+1} at a price of q_t^B. Renters are not allowed to borrow. Homeowners can borrow in the form of long term, adjustable rate nominal mortgage contracts. In other words, homeownership allows households to extend their borrowing limit. Mortgage size and the mortgage interest rate in period t are denoted by M_t and r_{mt}, respectively.

2.2 Real estate brokers and the housing market

There is a fixed supply of housing in the economy that does not depreciate. Homeowners are allowed to sell their houses *provided that they have the ability to pay off any outstanding mortgage debt.* Houses are sold in a decentralized market subject to search frictions. Search is directed: A seller with a house size of h decides on the posting price x_s to put it on the market. She then meets a real estate broker who has entered the (x_s, h)-submarket by paying an entry cost of κh. A meeting between a real estate broker and a seller happens with probability $\tilde{p}_t(\theta_t(x_s, h))$, where $\theta_t(x_s, h)$ is the tightness of the submarket for houses of size h that are listed at a price of x_s in period t. Homeowners that try and fail to sell their houses pay a utility cost ξ.

After buying the houses from sellers, real estate brokers turn around and sell them to buyers in a centralized market. Real estate brokers have access to a technology that allows them to splice houses into a few smaller houses as well as to combine several into a larger unit. The implication of this assumption is that houses in the buying market are priced per unit, i.e., renters (including people who just sold their house) can purchase houses from the real estate brokers at a unit price p_t^H. Therefore, a renter buys a house of size h at price $p_t^H h$. To keep the problem simple, we do not allow homeowners to own multiple houses at the same time. If they want a house of different size, they must first sell their existing house in the frictional market. Buyers immediately move into their house and switch from apartment-dweller ("renter") status to homeowner status. Note that brokers are not permitted to carry housing inventories into future periods, but inventories *do* arise in equilibrium from the portion of the housing stock that owners put on the market but fail to sell.

Directed search and block-recursive structure We assume free entry of real estate brokers in every market. Letting $\alpha_t(\theta_t(x_s, h)) = \frac{\tilde{p}_t(\theta_t(x_s,h))}{\theta_t(x_s,h)}$ denote the probability that a

broker finds a seller in period t, the free entry condition can be written as:

$$\kappa h = \overbrace{\alpha_t(\theta_t(x_s, h))}^{\text{prob of match}} \overbrace{(p_t^H h - x_s)}^{\text{broker revenue}} \tag{1}$$

for all markets with $\theta_t(x_s, h) > 0$. The revenue to a broker of purchasing a house is $p_t^H h - x_s$. Therefore, brokers continue to enter the submarket (x_s, h) until the cost κh exceeds the expected revenue.

The use of directed search and real estate brokers borrows a key idea from the labor search literature. As in Menzio and Shi (2010) and Menzio and Shi (2011), directed search with risk-neutral agents on one side of the market (real estate brokers in this model) gives rise to the simple condition in (1). This condition pins down the tightness of each market independent of household characteristics that decide to trade in that market, as shown in (2). The latter is important, because it allows us to solve market tightnesses as a function of p_t^H, without having to solve the maximization problem of households.

$$\theta_t(x_s, h) = \alpha_t^{-1} \left(\frac{\kappa h}{p_t^H h - x_s} \right) \tag{2}$$

This feature would not arise in random search models with bargaining. In such models, the outcome of bargaining depends on the characteristics of market participants (e.g. wealth and income of households). Price posting solves this problem. Free entry of risk-neutral agents insures a simple relationship between price and liquidity that is independent of household characteristics. These insights were previously used in Hedlund (2016b), Hedlund (2016a), Karahan and Rhee (2013), and Garriga and Hedlund (2016) to study different issues about housing.

Apartments We assume that apartment space can be produced using the final good. In particular, landlords have access to a linear technology that converts one unit of the final good into A_h units of apartment space (and vice versa). Market for apartments is competitive. Letting r_h denote the rental price of a unit of apartment, the technology implies that $r_h = \frac{1}{A_h}$. Thus a renter who rents a_h units of apartment space pays $r_h a_h$ units of final good as rent. It is important to note that the rental rate is pinned down by the technology and does not respond, among others, to changes in house prices. We also assume that the largest apartment one can rent is smaller than the maximum size

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of owner-occupied house, which implies a partial segmentation in the housing market. This is going to be one of the reasons why households would become home owners.

2.3 Mortgages and banks

Banks issue long-term, adjustable rate mortgage contracts. Each mortgage contract issued in period t specifies the amount of nominal loan issued M_{t+1} and the mortgage price at origination q_{mt}^0. To be more precise, a borrower that chooses the amount of loan M_{t+1} receives nominal resources of $q_{mt}^0 M_{t+1}$. The mortgage price q_{mt}^0 incorporates all risks associated with the loan. The interest rate that is applied to the loan r_{mt} is adjusted each period t based on changes in the nominal rate according to:

$$1 + r_{mt} = \underbrace{(1 + \phi)}_{\text{spread}} \underbrace{(1 + r_t)(1 + \pi_t)}_{\text{nominal risk-free rate}}$$

where ϕ, r_t, π_t are the service cost, the risk-free real rate of return and the inflation in period t, respectively.

Mortgages have no pre-defined maturity date. Borrowers are free to choose how quickly to pay down their mortgage so long as they keep making a minimum payment, which is a pre-specified fraction of the loan; i.e. $M_{t+1} \leq (1 - \chi)M_t$. Thus, $1/\chi$ controls the effective duration of the mortgage.

To summarize, a borrower with an existing contract amount of M_t that chooses $M_{t+1} \leq (1 - \chi)M_t$ has to make a mortgage payment of $(1 + r_{mt})M_t - M_{t+1}$. A borrower also has the option to make a smaller payment by "refinancing", so that $M_{t+1} > (1-\chi)M_t$. To do so, she has to pay off the existing loan by withdrawing a new loan of size M_{t+1} and has to pay $(1 + r_{mt})M_t - q_{mt}^0(M_{t+1}, b_t, h_t, z_t)M_{t+1}$.

When issuing mortgages, banks incur a proportional origination cost ζ. Banks take into account two types of risks when issuing loans. First, borrowers have the default option, in which case they lose their house, incur a utility cost ξ_f, and have their debt discharged.[4] In the event of foreclosure, the bank sells the repossessed house (REO properties) in the frictional decentralized housing market (as individual sellers do) and incurs a loss γ^{REO}, proportional to the selling price. This cost is meant to capture the various costs to the banks of selling foreclosed houses. When the bank sells a foreclosed

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[4]The utility cost is meant to represent, among other things, the stigma associated with foreclosure and non-monetary moving costs.

house, it absorbs all losses but must pass along all profits to the borrower in the (unlikely) event that sales revenues exceed the remaining mortgage balance. The value to a lender of repossessing a house of size h is given by equation (5) in appendix A.

Second, as explained above, households also have the option of prepayment and refinancing the loan by paying off their old mortgage and taking out a new one. Banks have to price in these risks and determine the price of mortgage q_{mt}^0 accordingly. Thus, mortgage prices depend on borrower characteristics. The recursive equation that determines the mortgage pricing is given by equation (6) in appendix A.

Banks finance themselves by selling the future streams of payments net of servicing costs from the mortgages they issue to Government Sponsored Enterprises (GSEs), who bundle the payment streams into mortgage backed securities (MBS). As a result, banks insure themselves against all risks, in turn, they make zero ex-post profits on a loan-by-loan basis in all states of the world. All profits and losses are absorbed by the GSEs that we discuss next.

2.4 Government sponsored enterprises

The GSEs serve as intermediaries between households and banks. A form of the law of large numbers is assumed to hold, such that the bank can perfectly diversify the idiosyncratic mortgage risk. The GSEs purchase mortgages from banks and finance themselves by issuing one-period risk-free mortgage backed securities, B_t^m. The GSEs are owned by the government (which effectively guarantees the payments on MBSs). In this setup, the return on mortgage backed securities equals that of the government bonds. The borrowing advantage of the GSEs is assumed to be fully passed through to banks.[5] Thus, any ex-post profits or losses by the GSEs are completely absorbed into the government budget. Importantly, this assumption does not prevent the state of the housing market and monetary policy from affecting contemporaneous pricing of mortgages, but alleviates the need to price mortgage-backed securities when there are ex-post profits and losses, which would depend on the aggregate state of the economy as well as on the distribution of mortgages on the GSE balance sheet. The balance sheet of the GSEs is given by (7) in appendix A.

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[5]See Jeske *et al.* (2013) for a discussion of the pass through of the government subsidy to the GSEs.

2.5 Final good producer

A competitive representative final goods producer aggregates a continuum of intermediate goods indexed by $j \in [0, 1]$ and with prices p_{jt}:

$$Y_t = \left(\int_0^1 y_{jt}^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}},$$

where ϵ is the elasticity of substitution across goods. Given a level of aggregate demand Y, cost minimization for the final goods producer implies that the demand for the intermediate good j is given by:

$$y_{jt}(p_{jt}) = \left(\frac{p_{jt}}{P_t} \right)^{-\epsilon},$$

where P_t is the (equilibrium) price of the final good in period t and can be expressed as:

$$P_t = \left(\int_0^1 p_{jt}^{1-\epsilon} dj \right)^{\frac{1}{1-\epsilon}}.$$

2.6 Intermediate goods producers

Each intermediate good j is produced by a monopolistically competitive producer using labor input n_{jt}. Production technology is linear.

$$y_{jt} = Z_t n_{jt},$$

where Z_t is aggregate productivity in period t. Intermediate producers hire labor at (real) wage w_t in a competitive labor market. With this technology, the marginal cost of a unit of intermediate good is w_t/Z_t.

Each firm chooses its price to maximize profits subject to price adjustment costs as in Rotemberg (1982). These adjustment costs are quadratic function of last period's and this period's prices, (p_{jt-1}, p_{jt}):

$$\Theta(p_{jt}, p_{jt-1}) = \frac{\theta}{2} \left(\frac{p_{jt}}{p_{jt-1}} - (1 + \bar{\pi}) \right)^2 P_t Y_t,$$

where $\bar{\pi}$ is the steady state (target) inflation rate.

Given last period's individual price p_{jt-1} and the aggregate price level P_{t-1}, and a rational expectation function for aggregate price $P_t = G_t(P_{t-1})$ the firm chooses this period's price p_{jt} to maximizes the present discounted value of future profits:

$$V_t\left(p_{jt-1}, P_{t-1}; G_t\right) \equiv \max_{p_{jt},n_{jt}} \underbrace{\frac{p_{jt}y_{jt}\left(p_{jt}\right) - P_t w_t n_{jt} - \Theta\left(p_{jt}, p_{jt-1}\right)}{P_t}}_{\text{profit, } d_{jt}} + \frac{1}{1+r_t} V_{t+1}\left(p_{jt}, P_t; G_{t+1}\right).$$

2.7 Government

The government fully taxes intermediate firm profits, $P_t d_t$ and levies a progressive tax on household labor income y that consists of a lump-sum transfer T_t and a proportional tax τ:

$$\tilde{T}_t(w_t z_t l_t) = -T_t + \tau P_t w_t z_t l_t.$$

The government issues nominal bonds denoted by B_t^g, with negative values corresponding to government debt. The government finances exogenous nominal government expenditures, G_t, interest payments on bonds and transfers to the GSEs, T_t^{GSE}.

The government budget constraint is therefore given by:

$$B_{t+1}^g = (1+i_t)B_t^g + G_t + T_t^{GSE} - P_t d_t - \int \tilde{T}_t(w_t z_t l_t)d\Omega_t. \tag{3}$$

Furthermore, there is a monetary authority that sets the nominal interest rate on bonds, i_t according to a Taylor rule:

$$(1 + i_{t+1}) = (1 + i_t)\left(\frac{1 + \pi_t}{1 + \bar{\pi}}\right)^{\phi_T} e^{\epsilon_t},$$

where π_t is the inflation rate in period t, $\bar{\pi}$ is the inflation target, and ϕ_T is the Taylor rule coefficient. We assume the economy is at its steady state in period $t = 0$ with $\epsilon_0 = 0$. Later on, we analyze the response of this economy to policy shocks, where we allow nonzero shocks ($\epsilon_t \neq 0$, $t > 0$) to the Taylor rule. In this case, we assume that ϵ_t follows an AR(1) process.

In this model Ricardian equivalence breaks down because of the heterogeneity across households. As a result, the specifics of the monetary-fiscal coordination is not an innocuous assumption and affects the allocation and prices. Here we assume that the

government keeps the real government debt constant and adjusts lumpsum transfers in order to balance the budget every period.

Finally, the real interest rate follows from the Fisher equation:

$$(1 + i_t) = (1 + r_t)(1 + \pi_t).$$

2.8 Timing of events

Below, we describe the timing of the events within a period.

1. Shocks: In the beginning of the period households learn about their idiosyncratic productivity and choose how much to work.

2. Market for house selling: Homeowners decide whether to put their houses up for sale and if so, at what price. Real estate brokers enter the various submarkets by paying the entry cost. Sellers meet with real estate brokers and transfer the ownership of their house.

3. Default decisions: Homeowners who have not sold their houses make default decisions. Banks take the ownership of the foreclosed houses and try to sell it to real estate brokers. Homeowners that do not default on their mortgage debt, choose the mortgage payment for the current period. This decision also encompasses the refinancing decision.

4. Market for house buying: Renters, including those that recently sold their houses, decide whether to buy a house. Buyers also decide on how much mortgage debt to take out, if any.

5. Production, consumption and savings: Intermediate goods producers make production decisions. These goods are then aggregated into the final good by final goods producers. Households choose how much to consume and how much to save using the risk free bonds.

2.9 Equilibrium

For given level of real government debt, exogenous government expenditures G_t, proportional tax rate levied on labor income τ and monetary policy, an equilibrium path for

this economy is given by a set of paths of prices $\{P_t, w_t, p_t^H, r_{ht}, r_{mt}, q_t^B, r_t\}_{t \geq 0}$, mortgage price functions $\{q_{mt}(.)\}_{t \geq 0}$, lumpsum transfers $\{T_t\}_{t \geq 0}$, distribution of households over labor productivity, bond holdings, owned house size, mortgage debt $\Omega_t(z, b, h, M)$ and corresponding quantities, such that at every period t given aggregate prices:

(i) households, firms, banks, and real estate brokers maximize their objective value,

(ii) the government budget holds

(iii) the following markets clear:

1. Labor market: $\int n_{tj} dj = \int z_t l_t d\Omega_t$,

2. Housing market: $\int h_t d\Omega_t = 1$,

3. Bond market: $B_t^m + B_t^g + \int b_t d\Omega_t = 0$

4. Final good market: $\underbrace{\int c_t d\Omega_t}_{\text{Nondurable cons.}} + \underbrace{\int r_{ht} a_{ht} d\Omega_t}_{\text{Rental spending}} + S_{\phi t} + S_{\zeta t} + G_t = Y_t$, where $S_{\phi t}$ and $S_{\zeta t}$

   denote the aggregate spending on service and origination costs by the banks in period t, respectively.

3 Calibration

We assume the economy is in steady state in period $t = 0$ and calibrate it to the US economy prior to the Great Recession during $2003 - 2005$. The calibration puts emphasis on matching key housing moments related to sales, time on the market, and foreclosures, as well as important dimensions of the joint distribution of assets, housing wealth, and mortgage debt. Some parameters are drawn from the literature or from external sources, but the remainder are determined jointly in the calibration.

3.1 Parameters set outside the model

Income process Using administrative data, Guvenen *et al.* (2016) estimate a canonical income process for the life cycle annual earnings risk which consists of a random walk and an i.i.d transitory component. Since our model is not a life-cycle model, we cannot directly use this income process in our calibration. Instead, we target the variance of log

earnings in the working age population implied by this income process, which is 80 log points. More specifically, we first set the variance of transitory shocks to 0.16.[6] Second, in order to have a stationary distribution of earnings, we set the persistence parameter of persistent component ρ to 0.99, which is close to a random walk. Next, we choose the variance of innovations to the persistent component σ_η^2 by targeting the variance of log earnings in the population. In particular, out of 80 log points, transitory shocks account for 16 log points. Then, variance of persistent shocks is chosen to generate 0.64 unconditional variance:

$$0.64 = \frac{\sigma_\eta^2}{1 - \rho^2} \Rightarrow \sigma_\eta^2 = 0.0127.$$

However these values are for annual earnings whereas our model period is a quarter. Therefore, we convert these annual values to their corresponding quarterly values. In particular, we estimate a quarterly income process such that the resulting aggregated annual income process has a transitory component with variance 0.16 and a persistent component with persistence 0.99 and variance 0.0127. Finally, we employ Rouwenhorst (1995) method to discretize the persistent and transitory components of the income process. We use 3 grid points for the transitory component and 7 for the persistent component.

Preference parameters Risk aversion is set to $\sigma = 2$. The Frisch elasticity of labor supply (φ) is set to 0.33 (Chetty 2008). Preference parameter governing housing (ϕ_h), the value of housing services (ω_h), the intratemporal elasticity of substitution (γ_h), and the discount factor (β) are determined jointly in the calibration.

Technology Steady state TFP in the consumption good sector is set to normalize mean quarterly earnings to 0.25. The apartment technology A_h is set to generate an annual rent-price ratio of 3.5%.

Housing Market Matching function in the selling markets is governed by a Cobb Douglas function, i.e. $\tilde{p}(\theta) = \min\{\theta^\gamma, 1\}$. Substituting in the equation for market tightnesses gives

$$\tilde{p}(\theta) = \begin{cases} 0 & \text{if } x_s > p^H h \\ \left(\frac{p^H h - x_s}{\kappa h}\right)^{\frac{\gamma}{1-\gamma}} & \text{if } (p^H - \kappa)h \leq x_s \leq p^H h \\ 1 & \text{if } x_s < (p^H - \kappa)h \end{cases}$$

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[6]Guvenen *et al.* (2016) estimate this parameter to be 0.25 for annual earnings. Since our model generates endogenous fluctuations in labor hours, and in turn in annual earnings, we calibrate this parameter to a smaller value of 0.16.

The joint calibration determines the parameters κ, and γ. Holding costs (maintenance, property taxes, etc.) are set to 0.007 ($\eta = 0.007$).

Financial Markets To match values in the U.S. over the period 2003–2005, the real risk-free rate is set to 1%, and the mortgage origination cost is set to 0.4%. The mortgage servicing cost ϕ is set to generate a 2.5% spread between the real mortgage rate and risk-free rate. The minimum payment is calibrated so that households can rollover their mortgage debt by paying interest only ($\chi = 0$). Lastly, the exogenous LTV limit is set to 125%, which makes it *non-binding* in the steady state.[7]

3.2 Joint calibration and model fit

The remaining parameters to be calibrated are the discount factor β, the share of housing in the utility function ϕ_h, the intratemporal elasticity of substitution γ_h, matching function elasticity γ, real estate market entry fee κ, size of the largest rental unit, smallest house size, utility cost of foreclosure ξ_f, and the efficiency loss that accrues to banks (γ^{REO}) are determined jointly in the calibration. The calibration targets various moments in the data that we explain below.

First, we target selected household portfolio moments calculated from the 2004 Survey of Consumer Finances (SCF) for prime-age households. Specifically, the calibration aims to match a homeownership rate of 62.7%, a median net worth of 1.06 (in terms of annual mean income), a mean value of housing (in terms of annual median income) of 3.37, a mean mortgage debt (in terms of annual median income) of 1.87, and a median mortgage debt (in terms of annual median income) of 1.55. In addition, we also target a host of moments about mortgage holders. More specifically, we target the fraction of homeowners that have a mortgage (82%), median loan-to-value ratio (LTV), the fraction of mortgage holders with an LTV larger than 70%, 80%, 90%, and 95%. We also target a quarterly foreclosure rate of 0.4%. Lastly, we target a set of moments about the housing market. More specifically, we target the (mean) time it takes to buy a house, the time it takes to sell a house, and the fraction of the housing stock that is transacted every quarter. These set of moments are obtained from the National Association of Realtors. The calibration minimizes the percentage deviation from these moments and their model counterparts. The values of the targeted moments and the model's fit are reported in

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[7]At the peak of the housing boom in 2005, the popularity of cash-out refinancing led to many instances of new mortgages with loan-to-value ratios in excess of 100%. The foreclosure penalty and the REO discount γ^{REO} are determined in the joint calibration.

TABLE I – Targeted Moments and Model Fit

Moment	Model	Data
Home ownership rate	66%	63%
Median net worth (rel. to mean income)	0.79	1.06
Mean housing (rel. to median income)	3.12	3.37
Mean mortgage debt (rel. to median income)	2.10	1.87
Median mortgage debt (rel. to median income	1.54	1.55
Fraction of homeowners with a mortgage	99%	82%
Median LTV	0.68	0.49
Percent with LTV>70%	44.7	28.5
Percent with LTV>80%	14.6	18.1
Percent with LTV>90%	9.6	9.4
Percent with LTV>95%	5.4	5.8
Foreclosure rate (%)	0.4	0.4
Mean buyer time on the market (weeks)	10.7	10.0
Mean seller time on the market (weeks)	17.1	17.3
Mean REO time on the market (weeks)	29	52
Turnover (share of housing stock transacted, %)	0.9	2.5

table I. Values of parameters that are set outside the model are shown in table II, and the values of internally calibrated parameters are reported in table III.

4   Steady-state properties of the calibrated model

We start by investigating the steady state properties of the calibrated model. We focus on two aspects of our model that are important for the transmission of monetary policy. The first is about the liquidity of the housing market induced by search frictions and how this liquidity affects consumption. The second is about the distribution of consumption propensities of households.

4.1   Housing illiquidity and consumption behavior

The illiquidity of the housing market induced by search frictions has several effects on the behavior of consumption at the individual level. First, illiquidity creates selling risk for homeowners, and in particular for homeowners with substantial outstanding mortgage debt. Panel 1 of figure 1 displays the optimal listing price as a function of leverage for a homeowner with zero liquid assets, a low level of income so that cash at hand is about one quarter's income, and a median sized house (worth 2.9 times annual income) and

TABLE II – Externally Calibrated Parameters

Parameter(s)	Interpretation	Value(s)	Source
Γ	Income process	see text	Guvenen *et al.* (2016)
σ	Risk aversion	2	Standard
φ	Frisch elasticity	0.33	Chetty (2008)
ϕ	Mortgage servicing cost	0.025	
ς	Mortgage initiation cost	0.4%	
ν	Maximum LTV	125%	
ϕ_T	Taylor rule coefficient	1.25	
τ	Tax rate	0.2	
	Government spending (quarterly)	0.0425	

Note: This table reports the values for the parameters that are jointly calibrated within the model.

TABLE III – Internally Calibrated Parameters

Parameter(s)	Interpretation	Value(s)
β	Discount factor	0.95
ϕ_h	Taste for housing	0.4244
γ_h	Elasticity of substitution c, h	0.5
λ_s	Elasticity of matching fnc. in selling market	0.8922
λ_b	Elasticity of matching fnc. in buying market	0.0894
κ_s	Minimum house price that sells w. prob 1	0.7538
$\underline{h}$	Size of smallest house	2.9486
$\overline{h_r}$	Size of largest rental apartment	2.4287
ξ_F	Utility cost of foreclosure	0.0153
η	Efficiency loss due to foreclosure	1.53%

Note: This table reports the values for the parameters that are jointly calibrated within the model.

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panel 2 shows the corresponding expected time to sell. This homeowner has a motive for selling and downsizing to smooth consumption. In case of an unsuccessful search for a buyer, the homeowner has the option to go to the bank, obtain a new mortgage, and extract equity, the value of which crucially depends on the outstanding mortgage debt. Panel 1 of figure 1 shows that, for low levels of mortgage debt (leverage ratio below 70%), the equity cushion allows this household to be patient and look for a good price for the house.

However, as leverage rises close to 75%–80%, the default risk rises (shown on panel 3), which manifests itself in the rising mortgage premium (panel 4), reducing the option value of going to the banks and asking to refinance. As a result, these homeowners become distressed sellers who optimally choose lower list prices ("fire sales") in search of liquidity. For homeowners with higher debt values (above 80% leverage), the constraint $x_s + y \geq \frac{m}{1+\pi}$ starts binding. As their equity cushion is non-existent, these debt-constrained sellers don't have the flexibility to price their house to sell quickly and end up having to list their unit at high prices. These homeowners experience debt overhang as their houses take longer to sell. Quantitatively, time on the market can exceed one year for the most indebted homeowners.

In fact, these debt-induced selling delays have ramifications for mortgage default behavior, the supply of credit, and ultimately, for consumption behavior. By increasing the risk that a financially distressed and indebted homeowner fails to sell their house, selling delays spill over into higher foreclosure risk. Panel 3 shows a heat map for mortgage default as a function of leverage and cash at hand. In standard Walrasian models of housing, only the "negative equity default" region exists, because having negative equity is a necessary condition for default. Intuitively, as long as the market clearing price is sufficiently high to repay the mortgage, owners with even a sliver of equity can always instantly sell their house to avoid default. However, longer endogenous selling delays in the model with housing search frictions have a direct impact on foreclosure activity. In short, having equity on paper is less relevant than being able to actualize that effort by selling at a particular price in a short time window.

As a result, endogenous housing illiquidity creates a new, graduated region of mortgage default, labeled as "illiquidity default" in panel 3. Notice that, depending on an owner's asset position, even having 6%, 10%, or 15% equity does not inoculate owners against the risk of default. This behavior is consistent with empirical evidence on subprime mortgage data that finds repossession rates of 50% for delinquent mortgages
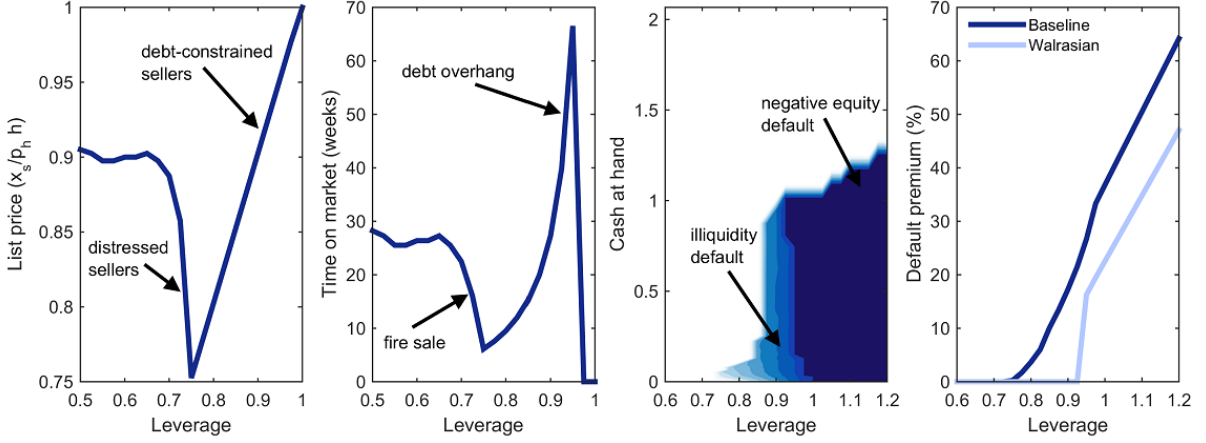
FIGURE 1 – (1) List price by LTV; (2) time on the market by LTV; (3) mortgage default heat map; (4) default premia.

with LTV ratios between 80% - 90% and 55% for delinquent mortgages with LTV ratios between 90% - 100%. In a Walrasian world, one would expect 0% repossession rates for such mortgages.

The heightened foreclosure risk that arises from housing illiquidity has a substantial effect on the supply of mortgage credit. Panel 4 of figure 1 plots sample default premia for new loans as a function of leverage. For clarity, a 10% default premium adds 10% to the cost of a loan over its lifetime. Default premia in the baseline economy with illiquid housing considerably exceed those in the Walrasian economy. This link between housing illiquidity and the availability of mortgage credit creates a powerful channel in the dynamic economy. If a shock hits the economy and drives down house prices, housing illiquidity will deteriorate endogenously and create longer selling delays. In turn, heightened time on the market increases foreclosures, leading banks to cut back on credit, which causes demand for housing to fall even further. In other words, endogenous housing illiquidity acts both as an amplification and propagation mechanism for economic shocks via the link between housing and mortgage market conditions.

Figure 2 plots some individual-level simulations to illustrate the mechanisms described above. In each case, we simulate the behavior of a homeowner who receives a constant stream of income. Panel 1 shows the path of mortgage leverage over time for a typical homeowner who does not experience any financial difficulty. Panel 2 shows the dynamic selling behavior of a homeowner who receives a sequence of low income realizations. This "distressed seller" lacks access to credit to extract equity but has sufficient
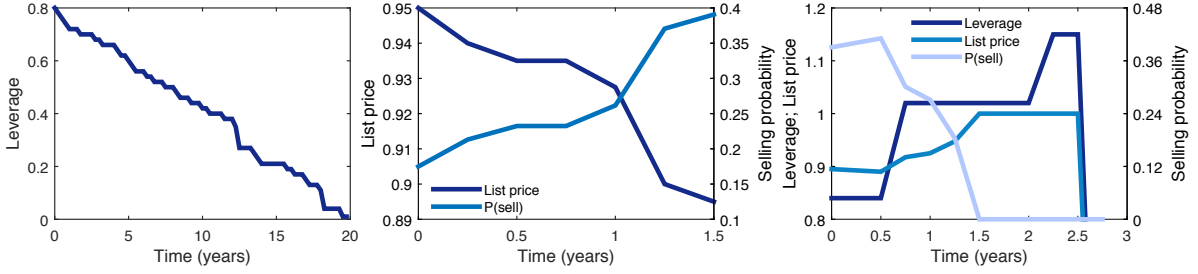
FIGURE 2 – Simulations over time of different individual homeowners who (1) pay down their mortgage; (2) use their equity cushion to cut their price; (3) engage in "distressed borrowing," raise their price, experience selling delays, and then default.

equity to gradually lower the list price as financial duress intensifies. Lastly, panel 3 plots an example of "distressed borrowing" followed by debt overhang and default.

The illiquidity of housing, in conjunction with endogenous credit supply, generates substantial deviations in consumption behavior from standard incomplete markets models that assume households can costlessly access all of their wealth to smooth consumption. By explicitly modeling these important features of housing and mortgage markets, we allow monetary policy to affect consumption and output through changes in the liquidity of the housing market.

4.2 MPC Heterogeneity and household leverage

As shown in Kaplan *et al.* (2016b), the marginal propensity to consume out of liquid wealth and its distribution in the economy is important for the transmission of monetary policy. In our setup, housing is an illiquid asset that is hard to adjust due to various reasons discussed above. This feature generates a nontrivial fraction of homeowners that act as hand-to-mouth consumers, thereby allowing our model to generate a rich distribution of consumption propensities across households. Figure 3 plots the distribution of marginal propensities to consume, and it is evident that a non-trivial percentage of households respond strongly to changes in income.

To illustrate how the model is able to generate this rich heterogeneity, we now show that the MPC is systematically related to mortgage debt. Furthermore, we estimate empirically how the MPC is linked to mortgage debt and compare the model to the data. This comparison allows us to test an untargeted feature of the data. We first start by describing how we estimate the empirical relationship.
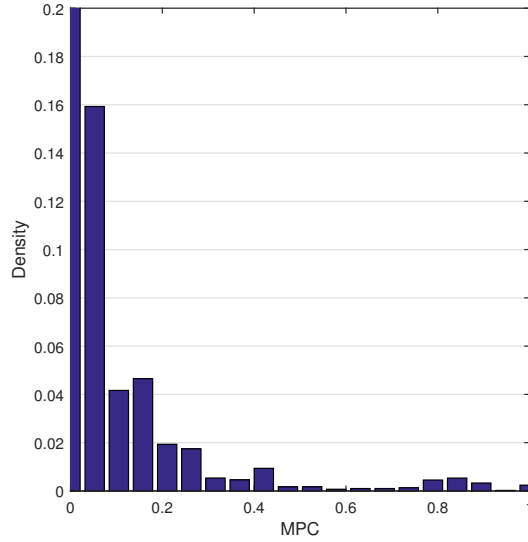
FIGURE 3 – The distribution of marginal propensities to consume.

4.2.1 MPC and leverage in the data

In this section, we estimate the consumption response of highly leveraged households to transitory income shocks. We show evidence that, consistent with the model presented in the next section, such households have a larger marginal propensity to consume out of transitory income shocks. We also estimate the elasticity of consumption with respect to house prices.

Data and sample We use data from the Panel Study of Income Dynamics, which is a panel of households and, starting in 1999, contains information on income, consumption and wealth. The PSID started collecting information on a sample of about 5,000 households in 1968. These families along with their split-offs have been interviewed annually until 1996. Starting in 1996, the survey became biennial. Further, the information collected about consumption expenditures was enriched to cover about 70 percent of all consumption items available in the Consumer Expenditure Survey (CEX).

From the PSID Core sample, we drop households with missing race, education or state of residence information. We also drop those whose annual income is below \$100 and changes by more than a certain threshold.[8] We also drop households with top-coded income and consumption. Our identification, as we discuss below, requires us to have at

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[8] More specifically, we drop households whose income grows by more than 500 percent or declines by more than 80 percent.

least three consecutive observations on each household. Therefore, we also drop those that do not satisfy this criterion. Our baseline sample consists of 25 to 60 year olds. Our sample and its construction closely mimics that of Kaplan *et al.* (2014).[9]

Our consumption measure follows Blundell *et al.* (2012) and includes food at home, food away from home, utilities, gasoline, car maintenance, public transportation, childcare, health expenditures, and education. Household income is measured as the sum of labor earnings of the household and government transfers. The categorization of wealthy and poor hand to mouth households follows Kaplan *et al.* (2014), therefore we refer the reader to this paper. The PSID contains questions about the value of home equity as well as a subjective assessment of the value of the house. These questions allow us to construct measures of home equity ratios.

Methodology To estimate the consumption response to transitory income shocks, we follow the methodology of Blundell *et al.* (2008). Here, we provide and overview of the methodology and refer the reader to Blundell *et al.* (2008) for a detailed description.

First, we strip log consumption and log income of observable differences and obtain residuals. To this end, we regress log consumption and log income on a full set of year and cohort dummies, college dummy, race dummies, employment, geographic variables, and allow education, race, employment, and region to have year-specific effects. We then construct changes of residuals of log consumption and log income, Δc_{it} and Δy_{it}, respectively.

We postulate that log income comprises of a permanent component z_{it}, and a transitory component, ε_{it}:

$$z_{it} = z_{it-1} + \eta_{it}$$

With this structure, the change in log income is given by

$$\Delta y_{it} = \eta_{it} + \Delta \varepsilon_{it}$$

The true marginal propensity to consume is given by

$$MPC_i = \frac{cov\left(\Delta c_{it}, \varepsilon_{it}\right)}{var\left(\varepsilon_{it}\right)}$$

We use the following estimator of the transmission of transitory income shocks to con-

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[9]We are grateful to the authors for sharing their dataset.

TABLE IV – MPC Heterogeneity by leverage ratio

	All Sample	Hand-to-mouth	Wealthy Hand-to-mouth
High leverage(≥ 0.85)	0.27	0.31	0.37
	(0.01)	(0.01)	(0.01)
Low leverage(< 0.85)	0.19	0.23	0.24
	(0.00)	(0.00)	(0.00)

sumption derived in Blundell *et al.* (2008):

$$MPC_i = \frac{cov\left(\Delta c_{it}, \Delta y_{i,t}\right)}{cov\left(\Delta y_{it}, \Delta y_{i,t+1}\right)}$$

We implement this estimator with an IV regression of Δc_{it} on Δy_{it}, with $\Delta y_{i,t+1}$ as an instrument. The main idea behind this instrument is that $\Delta y_{i,t+1}$ is correlated with the transitory shock at time t, but is uncorrelated with the permanent shock. Kaplan and Violante (2010) study the robustness of this to the presence of borrowing constraints and find that tight borrowing constraints do not bias the estimate of the transmission coefficient. All regressions use PSID weights.

Results We are mainly interested in understanding differences between households with different leverage ratios. Using the information in the PSID on self-reported house values and housing equity, we construct household-level measures of leverage ratio. We classify households into two groups, depending on this measure: Households with a leverage ratio above 85 percent are labeled high leverage and those with below this threshold are labeled low leverage households.

The first column in table IV shows the results for our baseline sample. We estimate an elasticity of consumption with respect to income shocks of 0.27 for high leverage households. The corresponding figure for low leverage households is considerably lower at 0.19. This difference is economically (and statistically) sizable. It suggests that the distribution of housing debt and wealth in the economy could be an important determinant of the economy's response to shocks. In this paper, we propose a model that is consistent with this form of MPC heterogeneity and then study the response of the economy to monetary policy shocks with different distributions of wealth.

We now investigate the robustness of this main result. One simple explanation for our main finding is that high leverage households have little liquid wealth to smooth transitory income fluctuations. In column 2, we restrict our sample to only such house-

TABLE V – Elasticity of consumption wrt house prices

	(1)	(2)
House price change, Δh_{it}	0.218	0.217
	(0.01)	(0.01)
Controls	No	Yes

holds and find the high leverage households within this group to have higher MPCs.[10] Finally, the last column repeats the same estimation for a sample of wealthy hand to mouth households; i.e. those that have a net worth about a certain threshold but little wealth in liquid assets.

Lastly, we estimate consumption elasticity to house price changes. We estimate the following equation:

$$\Delta c_{it} = \alpha + \beta X_{it} + \delta \Delta h_{it} + \xi_{it} \qquad (4)$$

Column (1) in table V estimates equation (4) without additional controls. The estimates suggest that the elasticity of nondurable consumption with respect to house prices is around 0.2. Column (2) controls for gender, a full set of age controls and education dummies, and shows that the resulting elasticity is essentially the same.

Our main findings in this section can be summarized as follows: i) Household leverage ratios are an important determinant of how much consumption responds to transitory income changes, with highly-levered households having the largest responses, ii) as estimated by a body of literature, consumption responds strongly to changes in house prices, with an elasticity around 0.2. We now turn to the model counterparts of these objects and measure them in the model.

4.2.2 MPC and leverage in the model

We initialize the economy to its steady state and simulate a sample of 100,000 individuals for 500 periods. We separate the sample of homeowners in the model into two groups as those with below and above 85% LTV ratio. Note that a period in the model is a quarter, whereas data is measured every other year and asks about annual measures of income and consumption. To mimic the empirical setup as close as possible, we aggregate quarterly measures to annual frequency. We then throw out every other year to mimic the biannual nature of the PSID data. Finally, for each group of households,

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[10]The classification of hand to mouth households in the PSID follows Kaplan *et al.* (2014).

TABLE VI – Model vs. Data: MPC Heterogeneity by leverage ratio

	Data (All Sample)	Model
High LTV(≥ 0.85)	0.27	0.17
Low LTV(< 0.85)	0.19	0.07

we compute the average MPC following the same methodology used in estimating its empirical counterpart.

Table VI compares the model generated MPCs against their empirical counterparts. The model generates substantial differences in the MPCs between these groups, consistent with the data. In particular, households with a high LTV ratio respond about two times stronger than low LTV households.

5 Effectiveness of monetary policy and the role of housing and heterogeneity

We now study the effectiveness of monetary policy in our setting and focus on the role of housing in transmitting policy shocks. We first start with a contractionary shock and then turn to an expansionary one. We assume the economy is at its steady state, following a Taylor rule with $\epsilon_t = 0$, $t < 1$, where ϵ_t is the innovation to the Taylor rule assumed to follow an AR(1) process with persistence $\rho_\epsilon = 0.6$.

$$\epsilon_t = \rho\epsilon_{t-1} + \eta_t$$

In period 1, this economy is hit by a one-time unexpected monetary policy shock so that the nominal rate goes up by 100 basis points. The nominal rate then recovers according to the dynamics dictated by the Taylor rule. We compute the perfect foresight transition of the economy in response to this shock.

Figure 4 shows the response of various variables. Similar to representative agent New Keynesian models, a fall in the nominal rate in the model generates a fall in inflation and real wages, a rise in the real rate, and a contraction in consumption. There are various channels that account for the fall in aggregate consumption. The first is the usual New Keynesian channel that amplifies declines in consumption coming through the intertemporal substitution channel. Note that, in addition to this standard transmission

channel of monetary policy, housing market plays a rich and important role, which we explain below.

First, the increase in the nominal rate increases the financing costs of houses, which puts a downward pressure on house prices. The decline in house prices then generates a decline in nondurable consumption for homeowners, because it restricts the equity cushion that homeowners occasionally tap into ("the collateral channel"). The second channel is the so-called cash-flow channel. The fact that all mortgage contracts have adjustable rates implies that an increase in the nominal rate maps into an increase in financing costs. Lastly, the decline in house prices, along with an increase in the average time it takes to sell a house, increases default risk, and through a precautionary motive contributes to the contraction of consumption.

Note that the various mechanisms embedded in the model have different implications across the LTV distribution. For example, the collateral channel implies that people with more equity (i.e. lower LTV) are more affected, whereas the cash-flow channel implies the opposite. To better understand which force is stronger, figure 5 plots the consumption response for three LTV groups. We find that the high LTV households respond the strongest to a contractionary monetary policy shock.

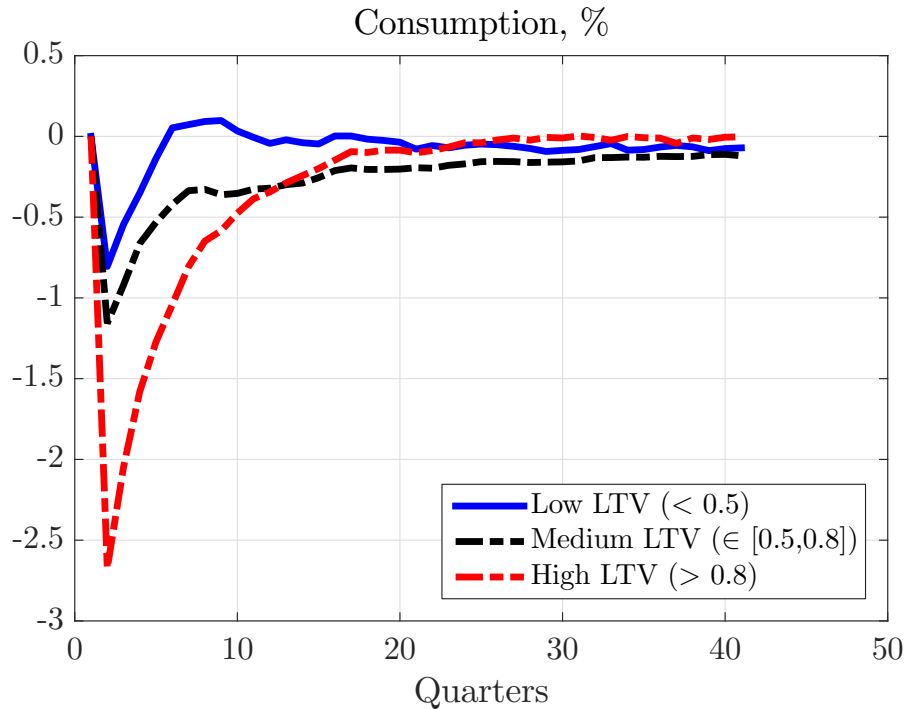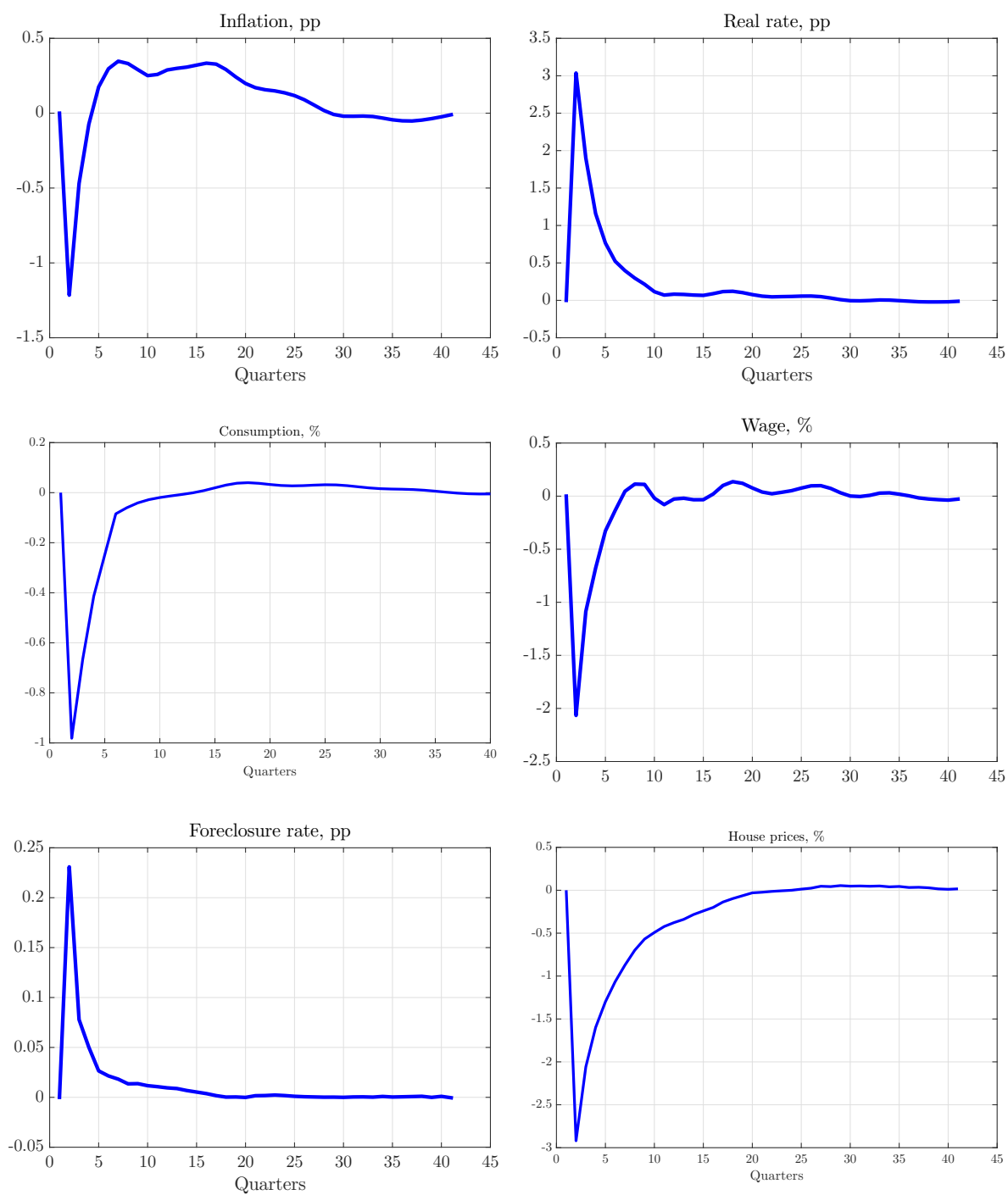FIGURE 5 – Heterogeneous effects of monetary policy

FIGURE 4 – Contractionary policy shock

While it is a nontrivial task to decompose the quantitative magnitudes of all the various interplays of housing and monetary policy, we conduct a simple exercise to quantify the role of house prices. Simply put, we ask by how much would have consumption moved, had house prices remained fixed. To get at this, we exogenously fix house prices at the steady state values and resolve the model. Figure 6 shows the response of aggregate consumption under this setting. We find that the endogenous response of house prices accounts for about 20 percent of the response of aggregate consumption.

FIGURE 6 – Role of house prices
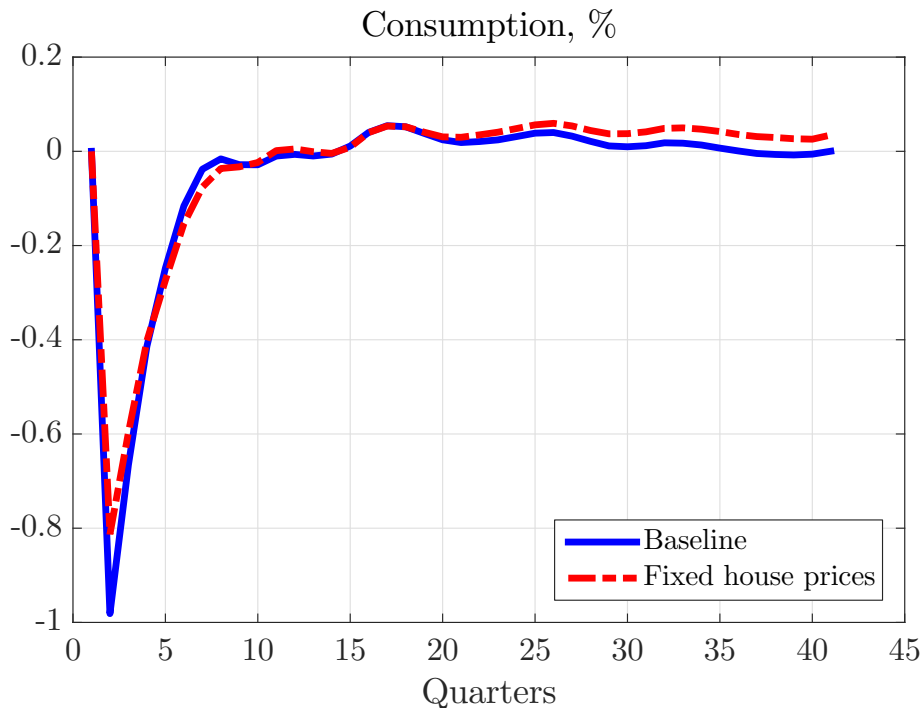
5.1 Asymmetric effects of monetary policy

One advantage of our model (and of our solution technique) is to allow for nonlinear dynamics. This allows us to contrast the response of the economy to contractionary and expansionary shocks. We compute the transition path of the economy in response to a

FIGURE 7 – Asymmetric effects of monetary policy
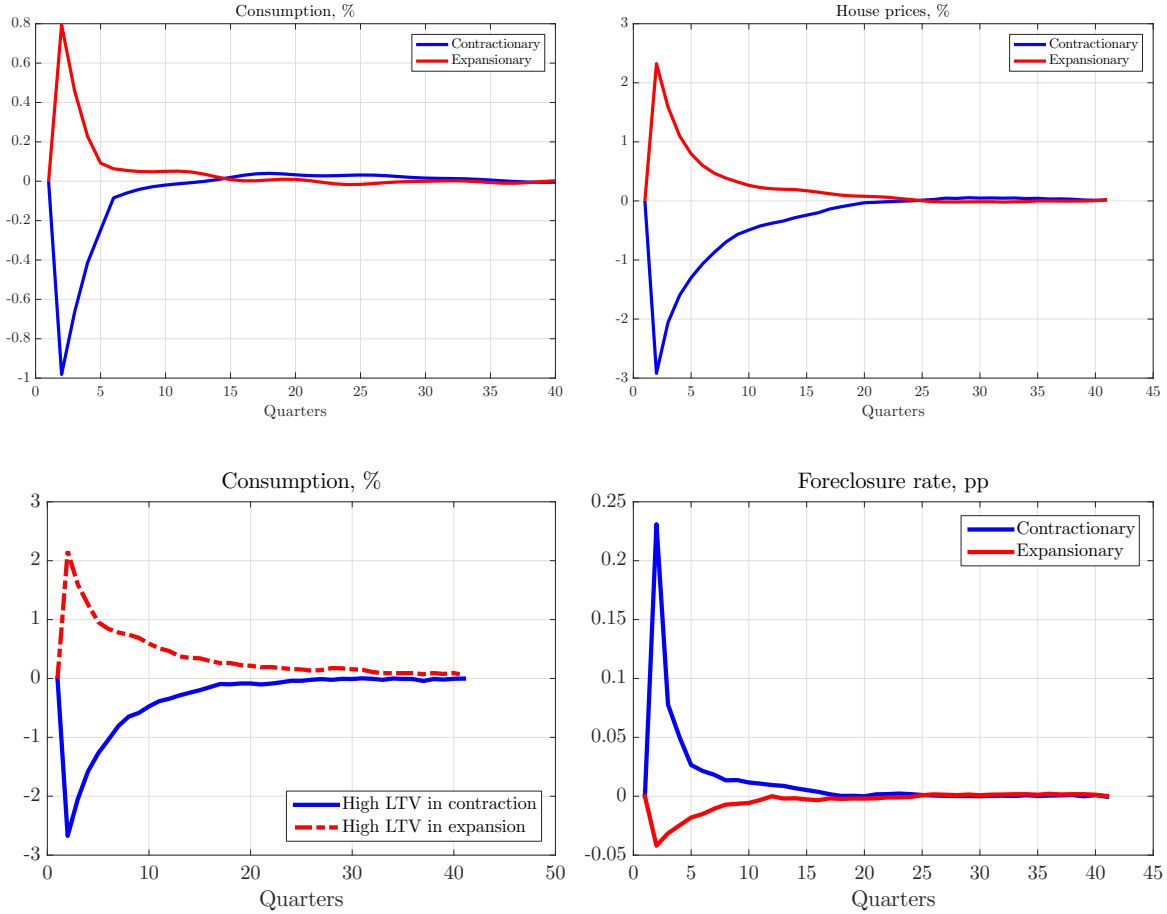
100bp expansionary shock. Figure 7 contrasts the response of consumption and house prices to the contractionary case.

We find important asymmetries: For example, the top left panel in figure 7 shows that consumption increases by about 20% less in response to an expansionary shock than it falls in response to a contractionary shock of the same size. A similar asymmetry exists for house prices (top right panel) and foreclosures (bottom right panel).

What explains these asymmetries? There are several forces through which this happens, but to facilitate understanding, we will explain them in two steps. The first is that the heterogeneity in the joint distribution of liquid and housing wealth generates an asymmetric response in the demand for housing, which then generates an asymmetric response in house prices. Consider a decline in the nominal interest rate. This decline stimulates the demand for housing due to falling financing costs. If renters are liquidity

FIGURE 8 – LTV Distribution

Histogram of LTV Distribution
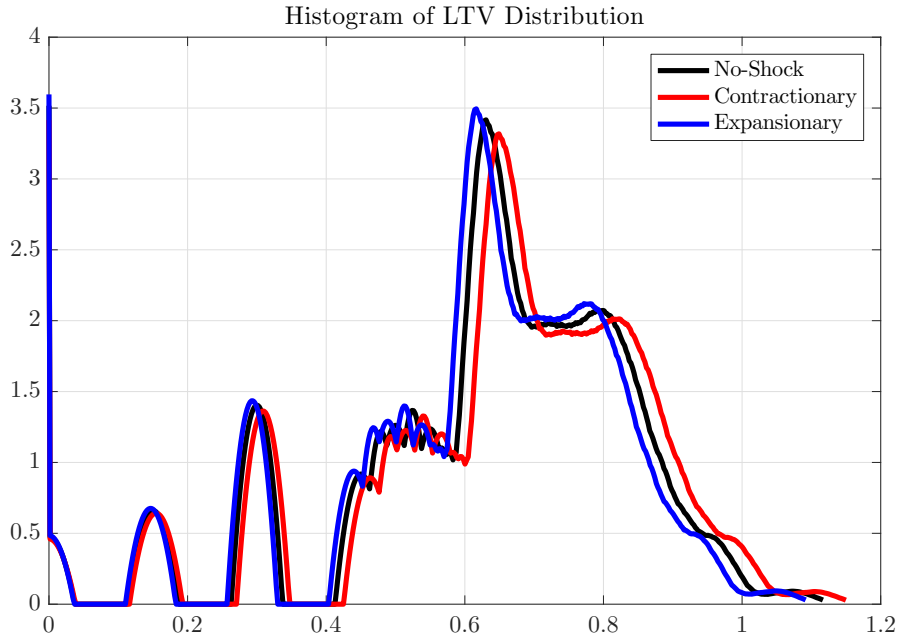
constrained, they won't be able to obtain decent mortgages, which limits their ability to take advantage of lower rates. Similarly, existing homeowners that might be interested in upgrading to larger units may be constrained by existing mortgage debt if they high leverage ratios. Thus, the joint distribution of liquid and housing net wealth affects how much housing demand (and thus house prices) respond to changes in interest rates. A similar argument can be made for why foreclosure rates respond asymmetrically (bottom right panel of figure 7). In short, the precise shape of this distribution generates an asymmetric response in house prices, which then generates an asymmetric consumption response through the collateral channel.

However, even fixing house prices, changes in consumption are asymmetric. This is because the extent of transmission from housing wealth to consumption also depends on mortgage debt. As we have shown above, MPC out of net worth is much higher for high debt households. Figure 8 shows the shifts in the LTV distribution under contractionary and expansionary shocks. Changes in the LTV distribution, coupled with the heterogeneity in the MPCs generates an asymmetric response of consumption to house price changes.

FIGURE 9 – Monetary policy in economies with different mortgage debt
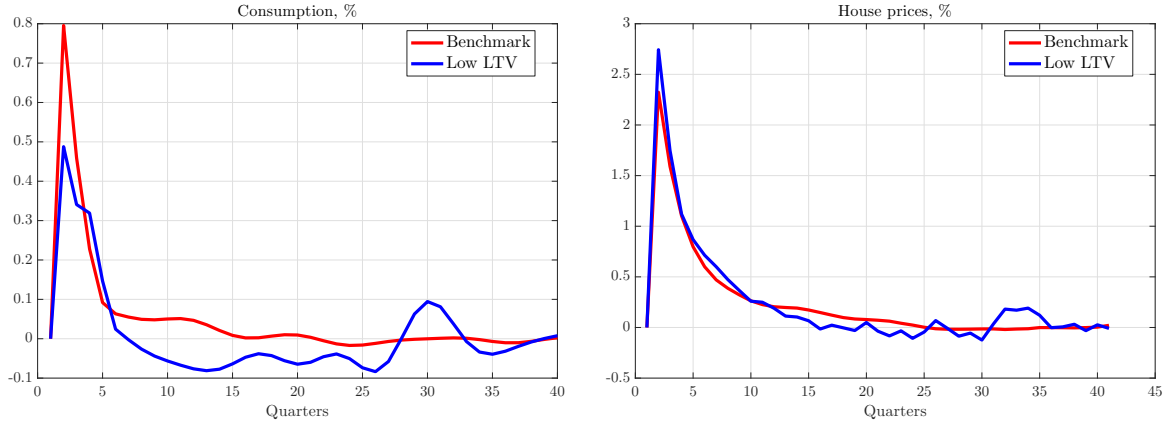
These discussions highlight the role of heterogeneity in the transmission mechanism and the effectiveness of monetary policy.

5.2 The role of heterogeneity [in progress]

Given the role of heterogeneity in the transmission of monetary policy, we ask if standard monetary policy would be more or less effective in an economy with lower mortgage debt. To answer this question, we conduct a simple experiment and reduce the maximum LTV households are allowed to take from 125%, which is not binding in the calibration, to 85%. This generates nontrivial changes to the LTV distribution. We then compare the effect of an expansionary monetary policy in this economy to the original calibration. Figure 9 shows the response of consumption and house prices. Interestingly, we find that the response of house prices is nearly identical across the two economies, whereas the consumption response is drastically higher in the high LTV economy (benchmark). This result is consistent with the previous explanation that the cash-flow channel is quantitatively very important in the transmission of monetary policy. A decline in mortgage financing costs generates a relaxation in the budget constraint of households in both economies. However, these changes in the cash flow map into much larger consumption responses in the high LTV economy because of the higher average MPC in this economy.

6 Conclusion

In this paper we study the role of the joint distribution of housing and mortgage debt in the transmission of monetary policy using a quantitative heterogeneous agents New Keynesian model with a frictional housing market and and long-term nominal mortgages. In addition to the direct intertemporal substitution effect of monetary policy on consumption, our model allows for various indirect mechanisms through housing and mortgages. We calibrate this model to match the US macroeconomic statistics from over the past twenty years, specifically, the joint distribution of assets, housing wealth, and mortgage debt as well as key housing moments related to sales, time on the market, and foreclosures. The model is able to capture the rich heterogeneity in MPCs between low- and high-LTV households observed in the data.

We then use this model to study the transmission of the monetary policy. We, first, find that decline in house prices explain 20% of the drop in aggregate consumption against a contractionary monetary shock. Second, in our model contractionary monetary shocks have larger effects on aggregate demand than expansionary shocks. This is mostly because house prices and foreclosures respond to contractionary shocks more due to the shape of the leverage distribution: When rates do down, this relaxes fewer households' budget constraint than the number of households that fall into trouble with their mortgages when rates go up. Finally, we investigate how the effectiveness of the monetary policy depends on the distribution of mortgage debt and find that expansionary monetary policy is more effective in an high-LTV economy. These results highlight the role of heterogeneity in balance sheets of households in the transmission mechanism and the effectiveness of monetary policy.

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A   Details of the model

This section presents the technical details that were omitted in the main text.

Value to banks of repossessing a house   The value to a lender of repossessing a house of size h is

$$J^t_{REO}(h) = R^t_{REO}(h) - \eta h + \frac{1}{1 + r_{t+1}} J^{t+1}_{REO}(h)$$

$$R^t_{REO}(h) = \max \left\{ 0, \max_{x_s \geq 0} \tilde{p}_t(\theta_t(x_s, h)) \left[(1 - \gamma^{REO}) x_s - \left(-\eta h + \frac{1}{1 + r_{t+1}} J^{t+1}_{REO}(h) \right) \right] \right\}$$

$$(5)$$

where η is the cost of holding onto the house (maintenance, property taxes, etc.) and $R^t_{REO}(h)$ is the option value of trying to sell the house in period t.

Mortgage pricing   Mortgage prices for the amount of M_{t+1} for the household with risk-free saving b_{t+1}, house size h_t, and idiosyncratic labor productivity z_t satisfy the following recursive relationship:

$$q_{mt}(M_{t+1}, b_{t+1}, h_t, z_t) M_{t+1} = \frac{1}{(1 + r_{mt})} \mathbb{E} \left\{ \overbrace{\tilde{p}_{t+1}(\theta_{t+1}(x_{st+1}, h_t)) M_{t+1}}^{\text{sell + repay}} + \overbrace{[1 - \tilde{p}_{t+1}(\theta_{t+1}(x_{st+1}, h_t))]}^{\text{no sale (do not try/fail)}} \right.$$

$$\times \left[\underbrace{d_{t+1} \min\{P_{t+1} J_{REO}(h), M_{t+1}\}}_{\text{default + repossession}} + Refi_{t+1} M_{t+1} \right.$$

$$+ (1 - d_{t+1} - Refi_{t+1}) \left(\underbrace{M_{t+1} - \frac{M_{t+2}}{(1 + r_{mt+1})}}_{\text{borrower payment net of servicing costs}} + \underbrace{q_{mt+1}(M_{t+2}, b_{t+2}, h_t, z_{t+1}) M_{t+2}}_{\text{continuation value of new } M''} \right) \Bigg] \Bigg\}$$

$$(6)$$

where P_{t+1} is the price level and x_{st+1}, d_{t+1}, b_{t+2}, and M_{t+2} are the policy functions for list price, mortgage default ($\in \{0, 1\}$), bonds, and new mortgage balance next period, respectively. At origination, $q^0_{mt} = \frac{1}{(1 + \zeta)} q_{mt}$. If the borrower never sells or defaults, mortgage prices in the steady state reduce to $q_{mt}(M_{t+1}, b_{t+1}, h_t, z_t) = \frac{1}{(1 + r_{mt})}$.

Balance sheet of the GSEs   The balance sheet of the GSEs is given by:

$$B_{t+1}^m + T_{GSE}^t + \int \begin{bmatrix} Refi(b_t, M_t, h_t, z_t)M_t \\ +Sell(b_t, M_t, h_t, z_t)M_t \\ +Fore(b_t, M_t, h_t, z_t)P_{t+1}J_{REO}(h_t) \\ +Pay(b_t, M_t, h_t, z_t)(M_t - M_{t+1}(b_t, M_t, h_t, z_t)) \end{bmatrix} d\Phi_{OWN}^t$$

$$=$$

$$(1+r)B_t^m + \int \begin{bmatrix} Refi \times q_{mt}^0(M_{t+1}, b_{t+1}, h_t, z_{t+1})M_{t+1} \\ +Sell \times Buy \times q_{mt}^0(M_{t+1}, b_{t+1}, h_{t+1}, z_{t+1})M_{t+1} \\ +Buy \times q_{mt}^0(M_{t+1}, b_{t+1}, h_{t+1}, z_{t+1})M_{t+1} \end{bmatrix} d\Phi_{OWN}^t$$

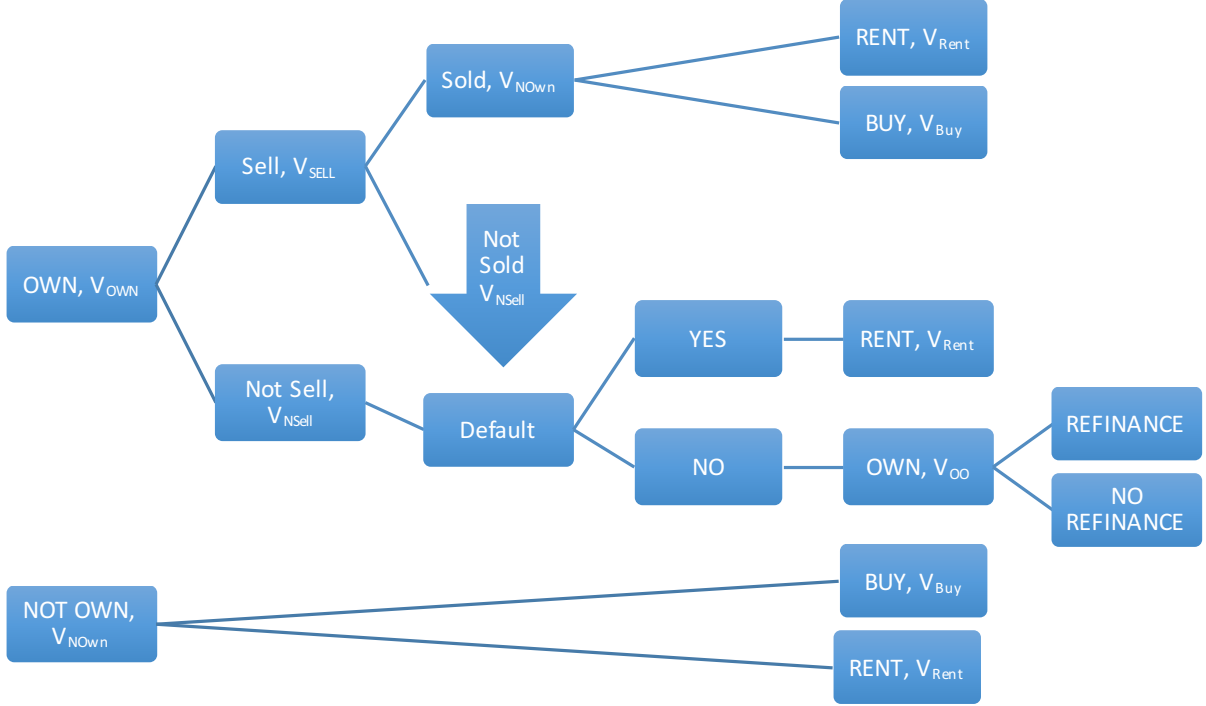$$+ \int Buy \times q_{mt}^0(M_{t+1}, b_{t+1}, h_{t+1}, z_{t+1})M_{t+1}d\Phi_{RENT}^t \qquad (7)$$

where B_t^m are the MBS issued by the GSE and T_{GSE}^t are transfers from the government in period t. $Refi$, $Fore$, and Pay denote the indicator functions for households who refinanced, foreclosed, and pre-paid their mortgages in period t, respectively. Similarly, $Sell$ and Buy denote the indicator functions for households who successfully sold and bought their houses in period t, respectively.

Household's Dynamic Problem Households take the paths of prices $\{P_t, w_t, p_t^H, r_{ht}, r_{mt}, r_t\}_{t\geq 0}$, mortgage price functions $\{q_{mt}(.)\}_{t\geq 0}$, lumpsum transfers $\{T_t\}_{t\geq 0}$ as given. Household dynamic problem can be summarized by the timeline shown in Figure 10.

Value function of a household who owns a house in the beginning of the period and has already decided to keep it in her portfolio involves decisions of consumption, labor supply, bond holdings, refinance, and mortgage debt payment:

$$V_{OO}^t(a_t, M_t, h_t, z_t) = \max_{M_{t+1}, b_{t+1}, c_t, l_t \geq 0} u(c_t, h_t, l_t) + \beta_L \mathbb{E}\left[V_{own}^{t+1}(a_{t+1}, M_{t+1}, h_{t+1}, z_{t+1})\right]$$

subject to

$$P_t c_t + q_t^B b_{t+1} + M_t \leq a_t + \frac{M_{t+1}}{1+r_{mt}} \text{ if } M_{t+1} \leq (1-\chi)M_t$$

$$P_t c_t + q_t^B b_{t+1} + M_t \leq a_t + q_{mt}^0 M_{t+1} \text{ if } M_{t+1} > (1-\chi)M_t$$

$$a_{t+1} = P_{t+1}w_{t+1}z_{t+1}l_{t+1} + b_{t+1}$$

$$h_{t+1} = h_t$$

Figure 10 – Timeline

Value function of a household who buys a house:

$$V_{Buy}^t(a_t, z_t) = \max_{h_t, M_{t+1}, b_{t+1}, c_t, l_t \geq 0} u(c_t, h_t, l_t) + \beta_L \mathbb{E}\left[V_{own}^{t+1}(a_{t+1}, M_{t+1}, h_{t+1}, z_{t+1})\right]$$

subject to

$$P_t c_t + q_t^B b_{t+1} + p_t^H h_t \leq a_t + q_{mt}^0 M_{t+1}$$

$$a_{t+1} = P_{t+1} w_{t+1} z_{t+1} l_{t+1} + b_{t+1}$$

Value function of a household who rents:

$$V_{Rent}^t(a_t, z_t) = \max_{b_{t+1}, s_t, c_t, l_t \geq 0} u(c_t, h_t, l_t) + \beta_L \mathbb{E}\left[V_{NOwn}^{t+1}(a_{t+1}, z_{t+1})\right]$$

subject to

$$P_t c + q_t^B b_{t+1} + P_t r_s s_t \leq a_t$$

$$s_t \leq \bar{s}$$

$$a_{t+1} = P_{t+1} w_{t+1} z_{t+1} l_{t+1} + b_{t+1}$$

Default decision (when household defaults it is always foreclosed and banks do not

come after liquid assets of the household):

$$V_{NSell}^t(a_t, M_t, h_t, z_t) = \max_{d_t \in \{0,1\}} d_t(V_{Rent}^t(a_t, z_t) - \chi_f) + (1 - d_t)V_{OO}^t(a_t, M_t, h_t, z_t)$$

Buying decision a household who doesn't own a house (either recently sold or never owned):

$$V_{NOwn}^t(a_t, z_t) = \max_{Buy_t \in \{0,1\}} Buy_t V_{Buy}^t(a_t, z_t) + (1 - Buy_t)V_{Rent}^t(a_t, z_t)$$

Choosing a list price x_s for a household who wants to sell her house:

$$V_{SELL}(a_t, M_t, h_t, z_t) = \max_{x_{st}} -\xi + \tilde{p}_t(\theta_t(x_s, h))V_{NOwn}^t(a_t + x_{st} - M_t, z_t)$$
$$+ \tilde{p}_t(\theta_t(x_s, h))V_{NSell}(a_t, M_t, h_t, z_t)$$

Selling decision of a household which defines V_{OWN}:

$$V_{OWN}(a_t, M_t, h_t, z_t) = \max_{\varsigma_t \in \{0,1\}} \varsigma_t V_{SELL}(a_t, M_t, h_t, z_t) + (1 - \varsigma_t)V_{NSell}(a_t, M_t, h_t, z_t)$$