Monetary Policy, Heterogeneity, and the Housing Channel

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Abstract

We investigate the role of housing and mortgage debt in the transmission of monetary policy to household consumption and the aggregate economy. In order to do so, we first document empirically how mortgage debt and housing liquidity impact the response of consumption to monetary policy shocks. Second, we develop a heterogenous agents model featuring a frictional housing market, nominal long-term borrowing, default, and price rigidities to be consistent with these facts. The model is able to capture the rich heterogeneity in home ownership, leverage and marginal propensity to consume out of liquid wealth. Endogenous cyclical movements in house prices as well as counter-cyclical dynamics in the liquidity of housing allows us to explore the various indirect mechanisms through which monetary policy affects consumption. Nominal long-term mortgage debt implies that changes in monetary policy will result in redistribution between lenders and borrowers. Further, a contractionary monetary policy shock raises the cost of borrowing which reduces *liquidity* in the housing market, depresses house prices and feeds back into increasing the cost of borrowing. We find that this amplification channel disproportionally affects households with high leverage and high marginal propensities to consume. Finally, we investigate how booms and busts in the housing market asymmetrically affect the efficacy of monetary policy.

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1 Introduction

The recent Great Recession has brought to light the importance of housing and household debt for 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. Furthermore, housing is not only quite illiquid, but also the extent of the illiquidity is countercyclical. In this paper, we investigate the rich role that housing and nominal mortgage borrowing jointly play in the transmission of monetary policy. Understanding this transmission channel is important for shaping the way that macroeconomists and policy makers think about key issues such as consumption insurance, the amplification of aggregate shocks, and the role of policy in mitigating the costs of aggregate fluctuations.

In addition to the direct effect of monetary policy on consumption, changes in interest rates generate several indirect effects related to housing. First, the fact that household portfolios are tilted toward a real asset financed with long-term nominal debt implies that declines in interest rates may affect disposable incomes through increased refinancing activity. This, in turn, 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.

Second, changes in interest rates can generate real movements in house prices. A reduction in interest rates reduces the cost of borrowing, alleviates credit constraints and increases the demand for housing. The increase in demand for housing increases real house prices and makes the housing market more *liquid*, meaning that households can sell their homes faster and at a higher price. Financially distressed households are more likely to sell their homes before having to default. This, in turn, further alleviates borrowing constraints because banks internalize that mortgage lending is now less risky. The 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.*

Heterogeneity is crucial for accurately evaluating the importance of the redistribution and house price channels. The distribution of mortgage debt across agents with different consumption propensities is critical for the consumption effects through redistribution.

Similarly, the distribution of liquid wealth is a key driver of the responsiveness of housing demand with respect to financing costs. Further, generating a realistic distribution of marginal propensities to consume will enable 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. We contribute to a growing body of literature in several ways. First, we show empirically the rich role that housing plays in the transmission of monetary policy. We document how the consumption response to monetary policy shocks depends on household mortgage debt and the liquidity of the housing market. To empirically estimate the response of consumption to monetary policy shocks, we generate exogenous variation in policy using high-frequency variation in Federal Funds futures in a narrow window around FOMC announcements. We then use data from the Consumer Expenditure Survey (CEX) to estimate the consumption response. Rich information about households in the CEX allows us to examine how mortgage debt affects this consumption response. To understand the effect of housing market liquidity, we exploit state-level variation in the time to sell a housing unit.

Consistent with previous studies, we find that monetary shocks have significant and persistent effects on consumption. Interestingly, these effects are concentrated on households with mortgage debt, and households who have paid down their mortgage debt do not respond. Lastly, consumption effects are smaller in housing markets with higher illiquidity.

Our second contribution is on the modeling front. To better understand the workings of monetary policy, we develop a heterogenous-agent model with search frictions in the housing market, nominal long-term borrowing, default and New Keynesian-style price rigidities. Search in the housing market is necessary to study the effect of monetary policy on housing liquidity. 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 provides a useful framework to understand the role of housing in the effectiveness of monetary policy.

We calibrate the model to match several important United States macroeconomic

statistics from 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 distribution of mortgage leverage as well as statistics related to sales behavior in the housing market. In steady state, the model generates several quantitatively important deviations from standard incomplete markets models where households are able to costlessly 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 impared consumption smoothing is manifested by wide 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.

Outside of steady state, the interaction of housing illiquidity and endogenous mortgage supply has even larger dynamic effects. 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. A similar economic response occurs following a loosening of monetary policy. However, because of the widespread use of long term, fixed rate mortgages, the economic response to monetary shocks is asymmetric. When rates increase, existing borrowers continue to take advantage of the low rates they locked in before the rate hike, whereas when rates decline, borrowers have the option to refinance to the lower rate. Because of the strong link between housing, debt, and consumption in the model, this asymmetry has quantitatively significant implications for the transmission of monetary policy to the dynamics of the macroeconomy.

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 nondurable 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[1] 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 and exciting 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 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 heterogenous-agent New-Keynesian (HANK) models (Challe *et al.* (2015); Gornemann *et al.* (2014); Kaplan *et al.* (2016b); McKay and Reis (Forthcoming)).

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

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 Empirical Analysis

2.1 Data

We use data from the CEX, which is a rotating panel of representative households that are interviewed for up to four consecutive quarters. In addition to demographics, family structure, and earnings, these households are asked detailed questions about detailed expenditures on very detailed categories encompassing durable goods, non-durable goods and services. In this paper, we focus on total non-durable expenditures. We focus on households whose head is between 18 and 70. This leaves us with 84,795 households over the period 1999–2009.

Identification of unanticipated exogenous innovations to monetary policy is crucial to reliably estimate how individuals adjust their consumption expenditures in response to monetary policy. To achieve this, we follow Weber and Gorodnichenko (2016) and Wong (2015) and use the behavior of Federal Funds futures contracts in a narrow time window around FOMC press releases. The key idea that has been utilized in these papers is that changes in the traded rate on the Federal Funds futures would mostly due to FOMC announcements within this narrow time window. More specifically, we consider a 60 minute window that starts $\Delta^- = 15$ minutes prior to the announcement. Following Weber and Gorodnichenko (2016), our monetary shock in time t is defined as follows:

$$\epsilon_t = \frac{D}{D-t}\left(ff^0_{t+\Delta^+} - ff^0_{t-\Delta^-}\right),$$

where t is the time of the announcement and ff^0_x is the Federal Funds futures rate at time x. We use a quarterly measure of the shock and sum up the identified shocks over

a quarter. One standard deviation of the quarterly shock is around 12 basis points.

2.2 Consumption Effects of Monetary Policy Shocks

Impulse response of consumption to monetary policy shocks Our main goal is to study consumption responses of households against monetary policy shocks and the heterogeneity in this with respect to leverage. For this purpose, we start by running the following regression:

$$\Delta C_{it} = \alpha_0 + \alpha_1 X_{it} + \sum_{k=1}^{K} \beta_k \epsilon^{-}_{t-k} + \sum_{k=1}^{K} \gamma_k \epsilon^{+}_{t-k} + \lambda_{s(t)} + \eta_{it}, \tag{1}$$

where ΔC_{it} is the quarterly change in log consumption for household i in quarter t. X_{it} denotes household-level controls such as dummies for the age of the household head, quarterly change in log income, quarterly change in family size. To control for seasonality in consumption expenditures, we include quarter dummies, $\lambda_{s(t)}$.

Monetary shocks are modeled separately as expansionary and contractionary innovations. $\epsilon^{-}_{t-k} = \min(\epsilon_{t-k}, 0)$ is the expansionary shock, whereas $\epsilon^{+}_{t-k} = \max(\epsilon_{t-k}, 0)$ is the contractionary shock.

The mechanisms that we pursue in the paper, such as the mortgage refinancing channel and borrowing constraints may generate asymmetric responses to policy shocks. The specification in (1) allows us to study the impulse response to negative and positive shocks separately. More specifically, the consumption elasticity T periods after an expansionary shock is given by:

$$\frac{\partial C_{i,t+T}}{\partial \epsilon^{-}_{t}} = \sum \beta_k \tag{2}$$

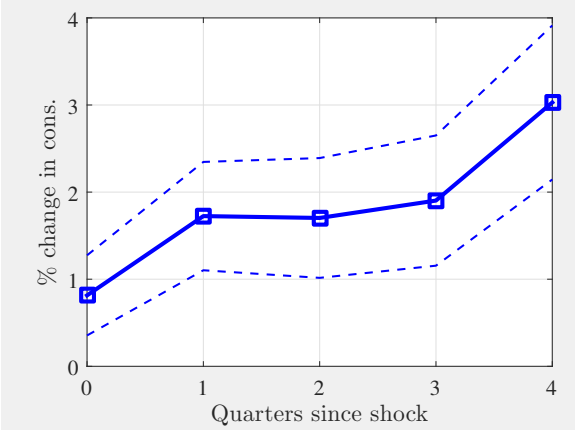
Similarly, the same for a contractionary shock is given by:

$$\frac{\partial C_{i,t+T}}{\partial \epsilon^{+}_{t}} = \sum \gamma_k \tag{3}$$

The left panel of figure 1 shows clearly that expansionary monetary policy shocks have a persistent effect. More specifically, in response to a one standard deviation shock to monetary policy, consumption grows by 2 percent in 2 quarters. The right panel shows the same for a contractionary shock. The results are qualitatively similar: a one standard deviation contractionary shock has a persistent and significant effect on consumption.

FIGURE 1 – Consumption Response to a Monetary Shock

(A) Expansionary



(B) Contractionary



Note: This figure shows the impulse response function to a 1 standard deviation monetary policy shock. The solid lines plot the estimated impulse responses given by 2 and 3 and the dashed lines plot the 90 percent confidence intervals.

Does the consumption elasticity depend on household leverage? Next, we are interested in the extent to which household leverage matters for the transmission of monetary policy on consumption. In other words, we ask whether the consumption elasticity may vary among groups of households with different leverage. For this purpose, we include household leverage and the interaction of household leverage and monetary policy shocks as explanatory variables in the regression. We estimate the following specification:

$$\Delta C_{it} = \alpha_0 + \alpha_1 X_{it} + \sum_{j=1}^{J} \beta_j Lev_{itj} \times \epsilon_t^- + \sum_{j=1}^{J} \gamma_j Lev_{itj} \times \epsilon_t^+ + \sum_{j=1}^{J} \delta_j Lev_{itj} + \lambda_{s(t)} + \eta_{it}, \quad (4)$$

where Lev_{itk} is a set of leverage dummies. As a first pass, we look at the consumption effects for people with and without mortgages separately.[2]

Column (1) of table I shows the results for a simpler specification to measure the average elasticity of consumption. Shocks are standardized so that the coefficients measure the percent change in consumption in response to a one standard deviation shock. We

[2]We have also experimented with a richer specification, where we allow for quintiles of the leverage distribution. While the coefficients are imprecisely estimated, the results are very similar.

find evidence for significant asymmetry: A contractionary shock decreases consumption by almost 1.5%, while an expansionary shock raises it only by 0.4%. To investigate heterogeneity, column (2) estimates equation (4). Interestingly, we find that the effect of a monetary policy shock is entirely due to households with positive mortgage debt. Consumption of those that do not have a mortgage does not respond to expansionary or contractionary shocks. Note that all specifications control for changes in income; therefore if monetary policy has an effect on consumption by raising incomes, this is already controlled for in the specification.

TABLE I – Elasticity of consumption with respect to monetary policy shocks

	(1) Overall	(2) Leverage	(3) Liquidity
expansionary shock, ϵ_t^-	0.434^{*}		1.249^{***}
	(0.231)		(0.427)
$\epsilon_t^- \times lev_{it} = 0$		0.266	
		(0.418)	
$\epsilon_t^- \times lev_{it} > 0$		0.505^{*}	
		(0.271)	
$\epsilon_t^- \times tom_{st}$			-0.107^{*}
			(0.062)
contractionary shock, ϵ_t^+	-1.453^{*}		-3.862^{*}
	(0.813)		(2.325)
$\epsilon_t^+ \times lev_{it} = 0$		-0.323	
		(1.444)	
$\epsilon_t^+ \times lev_{it} > 0$		-1.959^{**}	
		(0.977)	
$\epsilon_t^+ \times tom_{st}$			0.437
			(0.443)
income change, Δy_{it}	0.004^{***}	0.004^{***}	0.004^{***}
	(0.001)	(0.001)	(0.001)
change in family size, Δn_{it}	0.047^{***}	0.047^{***}	0.047^{***}
	(0.007)	(0.007)	(0.007)
R^2	0.002	0.002	0.002
N	83,977	83,977	64,305

Table I shows the estimated effects of expansionary and contractionary monetary policy shocks. Shocks are standardized so that the coefficients measure the percent change in consumption in response to a one standard deviation shock. Column (1) provides the benchmark estimates, column (2) investigates potential heterogeneity with respect to mortgage borrowing, and column (3) investigates if the liquidity of the housing market has an effect on the consumption response. While not shown, all columns include dummies for the age of household head and quarter dummies. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Does the consumption elasticity depend on the liquidity of the housing market? Lastly, we investigate if consumption elasticities depend on the state of the housing market, in particular on its liquidity. For this purpose, we obtain data on the time it takes to sell a single family home by state and quarter. Column (3) of table I allows for an interaction of monetary shocks with the time on the market (measured in months). More specifically, we estimate the following specification:

$$\Delta C_{it} = \alpha_0 + \alpha_1 X_{it} + \beta \epsilon_t^- + \zeta TOM_{itj} \times \epsilon_t^- + \gamma \epsilon_t^+ + \eta TOM_{itj} \times \epsilon_t^+ + \delta TOM_{itj} + \lambda_{s(t)} + \eta_{it}, \quad (5)$$

where TOM_{itj} measures in months the time it takes to sell a single family home. The results in column (3) suggest that the effects of monetary shocks on consumption are dampened in markets where the liquidity of the housing market is lower.

Our main findings in this section can be summarized as follows: i) monetary shocks have significant and persistent effects on consumption, ii) these effects are concentrated on households with mortgage debt, iii) these effects are smaller in less liquid housing markets. We now write down a model to better understand the causes and consequences of these findings for the conduct of monetary policy.

3 Model

In this section, we develop a a model of infinite horizon closed economy with production sector. To investigate the effect of the housing channel in the transmission of monetary policy, we further include the following ingredients: (1) nominal rigidities, so as to provide a role for aggregate demand in determining output; (2) a frictional housing market that allows monetary policy to affect the price and liquidity of the housing market; (3) nominal long-term mortgages to generate redistribution across households and allow monetary policy to affect credit constraints.

3.1 Households

We assume that the population is composed of two types of households. The first group of households, **capitalists,** own the intermediate sector firms in the economy. The second group of households, **laborers,** supply labor services to the economy and are the ones who enjoy houses as owners or renters. We now describe each group of households in more detail.

Capitalist Households There is a measure ν of infinitely lived capitalist households in the population. Capitalist households are the entrepreneurs in the economy who own and manage all the intermediate goods sector firms in the economy. The profits from these firms do not exhibit any idiosyncratic risk, which allows us to define a representative capitalist household with the following time-separable preferences:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_C^{t-1} \frac{c_t^{1-\sigma_C}}{1-\sigma_C},$$

where c_t is the representative capitalist household's consumption in period t. The parameters β_C and σ_C measure the discount factor and relative risk aversion, respectively. In addition to owning the firms, they can also trade bonds b_t with the laborer households and the government. Then the budget constraint of the representative capitalist household is given by:

$$\begin{aligned} b_t + p_t d_t^F &\geq p_t c_t + q_t^B b_{t+1} \\ b_{t+1} &\geq \underline{\mathrm{B}}, \end{aligned}$$

where p_t is the nominal price of a unit of final good, d_t^F is the real dividends from owning firms, and q_t^B is the nominal price of bonds in period t.[3] They can borrow up to a limit $\underline{\mathrm{B}}$.

Laborer Households There is a measure $1-\nu$ of infinitely lived laborer households in the economy. Laborers provide labor supply to the intermediate firms and are subject to uninsurable idiosyncratic labor productivity risk. In particular, their labor productivity z follows an exogenous finite state Markov according to the transition matrix $\Gamma(z' \mid z)$. When they are born, they draw their initial productivity from the ergodic distribution Π.

Laborers enjoy housing services s either by owning and occupying a house of size h or renting from a competitive market in the form of apartment space. We assume that if a household owns a house of size h, it generates $s = h\omega_h$, where in general $\omega_h \geq 1$ to represent pride of ownership. We do not allow homeowners to own multiple houses or to

[3] In the steady state, discount factor of the capitalist, β_C determines the price of the risk free bond, q^B:

$$q^B u_c^C(c_t = c) = \frac{\beta_C}{\pi} u_c^C(c_{t+1} = c) \Rightarrow q^B = \frac{\beta_C}{\pi}.$$

rent out their house to a tenant. Furthermore, we assume all owners choose to occupy their house.

Laborers have preferences over consumption, c, leisure, l, and housing services, s. Preferences are time-separable and the future is discounted at rate $\beta_L < \beta_C$. In particular, their expected lifetime utility is defined by:

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

The parameters β_L, 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.

Laborers can accumulate and borrow risk free bond, b with q_t^B. Homeowners can borrow in the form of long term, fixed rate nominal mortgage contracts. Mortgage size is denoted by M and the fixed mortgage interest rate is denoted by r_m.

3.2 Housing Market

We assumed that there is a fixed supply of housing in the economy and no depreciation in housing. Due to the presence of trading frictions, owners cannot sell their houses directly to buyers. Instead, they search in a decentralized housing market for real estate brokers whose job it is to purchase houses to turn around and sell to buyers. Homeowners cannot own two houses at the same time. If they want a different house, they must first sell their existing house and temporarily become renters. Renters (including people who just sold their house) purchase houses from the real estate brokers in a competitive market at price p_h per unit of housing. Buyers immediately move into their house and switch from apartment-dweller ("renter") status to homeowner status. 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.

3.2.1 Directed Search in the Housing Market

We assume that the seller side of the housing market is decentralized and there are search frictions. Real estate brokers intermediate all trades in the decentralized seller market whereas buyers can buy houses in a centralized market at the price of p_h per

unit of housing. Owners of house $h \in H$ list their house to sell at a price x_s of their choice and enter submarket (x_s, h) in hopes of matching with a broker. With probability $p_s(\theta_s(x_s, h))$, a seller successfully matches with a broker and sells the house, *provided that they have the ability to pay off any outstanding mortgage debt.* The probability that a broker finds a seller is $\alpha_s(\theta_s(x_s, h)) = \frac{p_s(\theta_s(x_s,h))}{\theta_s(x_s,h)}$. The function $p_s : \mathbb{R}_+ \to [0, 1]$ is continuous and strictly increasing with $p_s(0) = 0$; α_s is strictly decreasing. It is possible that $\alpha_s > 1$, in which case the same broker finds multiple sellers, from which the broker buys one house each. Each broker incurs an entry cost $\kappa_s h$, and owners that try and fail to sell pay a small utility cost ξ.

The profit maximization condition of the real estate brokers becomes:

$$\kappa_s h \geq \overbrace{\alpha_s(\theta_s(x_s, h))}^{\text{prob of match}} \overbrace{(p_h h - x_s)}^{\text{broker revenue}} \tag{6}$$

with $\theta_s(x_s, h) \geq 0$ and complementary slackness holding. The revenue to a seller-broker that purchases a house from a seller is $p_h h - x_s$. Therefore, brokers continue to enter submarket (x_s, h) until the cost $\kappa_s h$ exceeds the expected revenue.

3.2.2 Block Recursivity

We employ the block recursivity result so that the menu of market tightnesses does not depend directly on the distribution of household states (income, assets, and debt). Instead, $\theta_s(x_s, h)$ depends only on p_h:

$$\theta_s(x_s, h) = \alpha_s^{-1}\left(\frac{\kappa_s h}{p_h h - x_s}\right) \tag{7}$$

This *block recursivity* result greatly increases computational tractability without altering the substance of the selling problem of the households. In particular, solving for the dynamics of the market tightnesses reduces to finding the equilibrium path of p_h and then substituting into – (7). As explained later, solving for p_h amounts to equating two Walrasian-esque equations for housing supply and housing demand.

3.3 Apartments

We assume that apartment space can be produced using final good. In particular, landlords have access to a linear, reversible technology that converts one unit of the final good into A_h units of apartment space. Each period, apartment-dwellers purchase

apartment space from these landlords at unit price r_h. Market for renting apartment is assumed to be competitive. Then, optimality condition of a landlord implies that $r_h = \frac{1}{A_h}$.

3.4 Mortgage Markets

Banks issue long-term, fixed rate mortgage contracts. Each mortgage contract specifies the amount of loan issued M', the interest rate that will be applied to the loan r_m, and the mortgage price q_m^0. In other words, at origination, a borrowers chooses the amount of loan M', is assigned an interest rate r_m, and receives nominal resources of $q_m^0 M'$. The mortgage price q_m^0 incorporates all idiosyncratic and aggregate risk to the bank from issuing contract (r_m, M). Mortgages have no pre-defined maturity date. Instead, borrowers choose how quickly to pay down their mortgage so long as they make at least the pre-specified minimum payment, i.e. $M' \leq (1-\chi)M$. Banks incur a proportional origination cost ζ and servicing costs ϕ over the life of each mortgage. Borrowers have the foreclosure option, in which case they lose their house, have their debt erased, and incur a utility cost ξ_f.[4] They also have the option of refinancing the loan by paying off their old mortgage and taking out a new one.

To summarize, a borrower with existing contract (r_m, m) that chooses a new balance of M' owes $(1+r_m)M - M'$ if $M' \leq (1-\chi)M$ or else $(1+r_m)M - q_m^0((r_m, M'), b', h, s)M'$ if $M' > (1-\chi)M$, where (r'_m, M') is the refinanced contract at the new prevailing rate r'_m.

The fixed rate r_m set at origination satisfies $1+r_m = \underbrace{(1+\phi)}_{\text{spread}} \underbrace{(1+r^*)(1+\pi^*)}_{\text{long-run nominal risk-free rate}}$. Mortgage prices for contract (r_m, M') satisfy the following recursive relationship:

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

$$q_m((r_m, M'), b', h, s)M' = \frac{1}{(1+r_m)}\mathbb{E}\left\{\overbrace{p_s(\theta_s(x'_s, h))M'}^{\text{sell + repay}} + \overbrace{[1 - p_s(\theta_s(x'_s, h))]}^{\text{no sale (do not try/fail)}}\right.$$
$$\times \left[\underbrace{d' \min\left\{P' J_{REO}(h), M'\right\}}_{\text{default + repossession}} + Refi' M'\right. \tag{8}$$
$$\left.\left. + (1 - d' - Refi')\left(\underbrace{M' - \frac{M''}{(1+r_m)}}_{\text{borrower payment net of servicing costs}} + \underbrace{q_m((r_m, M''), b'', h, s')M''}_{\text{continuation value of new } M''}\right)\right]\right\}$$

where P' is the price level and x'_s, d', b'', and M'' are the policy functions for list price, mortgage default ($\in \{0, 1\}$), bonds, and new mortgage balance next period, respectively. At origination, $q_m^0 = \frac{1}{(1+\zeta)} q_m$

By defining $m' = \frac{M'}{P}$ and $m'' = \frac{M''}{P'}$ and dividing through by Pm', q_m becomes

$$q_m((r_m, m'), b', h, s) = \frac{1}{(1+r_m)}\mathbb{E}\left\{p_s(\theta_s(x'_s, h)) + [1 - p_s(\theta_s(x'_s, h))]\right.$$
$$\times \left[d' \min\left\{\frac{(1+\pi)J_{REO}(h)}{m'}, 1\right\} + Refi'\right. \tag{9}$$
$$\left.\left. + (1 - d' - Refi')\left(1 - \left[\frac{1}{1+r_m} - q_m((r_m, m''), b'', h, s')\right]\frac{(1+\pi)m''}{m'}\right)\right]\right\}$$

If the borrower never sells or defaults, mortgage prices in the steady state reduce to $q_m((r_m, m'), b', h, s) = \frac{1}{(1+r_m)}$. We can see that higher inflation π reduces mortgage prices. Intuitively, for a given promised sequence of nominal repayments, banks reduce lending as expected inflation increases.

3.5 Banks

Banks' only role in our model is to issue long-term, fixed rate mortgage contracts. Banks face risks, specifically, inflation risk due to monetary shocks and foreclosure risk. If a borrower defaults by not making a payment, the bank forecloses on the borrower. In the event of foreclosure, banks sell repossessed houses (REO properties) in the decentralized housing market and incur a proportion γ of sales revenue loss due to the various costs of selling foreclosed houses. When the bank repossess a house, it absorbs all losses but must pass along profits to the borrower in the unlikely event that sales revenues exceed

the remaining mortgage balance. The value to a lender in repossessing a house h is

$$\begin{aligned} J_{REO}(h) &= R_{REO}(h) - \eta h + \frac{1}{1+r} J_{REO}(h) \\ R_{REO}(h) &= \max\left\{0, \max_{x_s \geq 0} p_s(\theta_s(x_s, h)) \left[(1-\gamma)x_s - \left(-\eta h + \frac{1}{1+r} J_{REO}(h)\right)\right]\right\} \end{aligned} \tag{10}$$

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

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, they insure themselves against inflation and foreclosure risk. Thus, in addition to making zero expected profit loan-by-loan, the banks realized ex-post profit will also be zero loan by loan. The nature of the GSEs is discussed in the next section.

3.6 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-less mortgage backed securities. The GSEs are assumed to be owned by the government (who effectively guarantee the MBS issuances), as such the return on mortgage backed securities will equal that of government bonds. The borrowing advantage of the GSEs is assumed to be fully passed through to banks (See Jeske *et al.* (2013) for a discussion of the pass through of the government subsidy to the GSEs). Thus, any ex-post profits of losses by the GSEs are completely absorbed into the government budget. This assumption, importantly, does not preclude the state of the housing market and monetary policy from affecting contemporaneous pricing of mortgages. The assumption alleviates having to price the mortgage-backed securities when there are ex-post profits and losses which depend on the aggregate state and the complete distribution of mortgages held on the GSE balance sheet.

The balance sheet of the GSEs is thus given by:

$$B^m_{t+1} + T_{GSE} + \int \begin{bmatrix} Refi(a,(r_m,m),h,dz)m \\ +Sell(a,(r_m,m),h,dz)m \\ +Fore(a,(r_m,m),h,dz)P'J_{REO}(h) \\ +Pay(a,(r_m,m),h,dz)(m - m'(a,(r_m,m),h,dz) \end{bmatrix} d\Phi_{OWN}$$

$$= \tag{11}$$

$$(1+r)B^m_t + \int \begin{bmatrix} Refi \times q_m((r_m,M'),b',h,s)M' \\ +Sell \times Buy \times q_m((r_m,M'),b',h',s)M' \\ +Buy \times q_m((r_m,M'),b',h',s)M' \end{bmatrix} d\Phi_{OWN} + \int Buy \times q_m((r_m,M'),b',h',s)M' d\Phi_{RENT}$$

Where B_m are the MBS issued by the GSE and T_{GSE} are transfers from the government.

Price of insurance against default on mortgage of amount M is given by the following recursive equation:

$$q_I((r_m,M),b',h,s)M = \frac{1}{(1+r_m)}\mathbb{E}\left\{ \overbrace{[1-p_s(\theta_s(x'_s,h))]}^{\text{no sale (do not try/fail)}} \left[\underbrace{d' \max\{0, M - P'J_{REO}(h)\}}_{\text{default + repossession}} + (1-d'-Refi') \left(\underbrace{q_I((r_m,M'),b',h,s')M'}_{\text{continuation value of new } M'} \right) \right] \right\}$$

3.7 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_j:

$$Y = \left(\int_0^1 y_j^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}.$$

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

$$y_j\left(p_j\right)=\left(\frac{p_j}{P}\right)^{-\epsilon},$$

where P is the (equilibrium) price of the final good and can be expressed as

$$P=\left(\int_0^1 p_j^{1-\epsilon}dj\right)^{\frac{1}{1-\epsilon}}.$$

Final good producer's problem:

$$\max_{y_j} \quad \left(\int_0^1 y_j{}^{\frac{\epsilon-1}{\epsilon}}dj\right)^{\frac{\epsilon}{\epsilon-1}}-\int_0^1 p_j y_j dj$$

3.8 Intermediate Good Producers

Each intermediate good j is produced by a monopolistically competitive producer using labor input n_j. Production technology is linear.

$$y_j=Zn_j$$

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

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 relative prices, $\left(\tilde{p}_j^-,\tilde{p}_j\right)$ where $\tilde{p}_j=p_j/P$.

$$\Theta\left(p_j',p_j\right)=\frac{\theta}{2}\left(\frac{p_j'}{p_j}-(1+\pi)\right)^2 PY$$

Given last period's individual price p_j^- and the aggregate price level P^-, and a rational expectation function $P=G(P^-)$ the firm chooses this period's price p_j to maximizes the present discounted value of future profits:

$$V\left(p_j^-,P^-;G\right)\equiv\max_{p_j,n_j} p_j y_j\left(\tilde{p}_j\right)-Pwn_j-\Theta\left(p_j,p_j^-\right)+\frac{1}{1+r}V\left(p_j,P;G\right)$$

Let's first derive the nominal marginal cost (even though it is very obvious in this problem). For this purpose we write down the cost minimization problem for which the Lagrange multiplier will be the nominal marginal cost:

$$\begin{aligned} \min_{n_j} \quad & Pwn_j \\ y_j \quad \leq \quad & Zn_j \Rightarrow \\ \min_{n_j, m_j} \quad & Pwn_j + m_j \left(y_j - Zn_j\right) \Rightarrow \\ Pw \quad = \quad & m_j Z \end{aligned}$$

3.9 Government

The government levies a progressive tax on household labor income y that consists of a lump-sum transfer T_t and a proportional tax τ:

$$\tilde{T}(y) = -T + \tau y.$$

The government issues bonds denoted by B^g, with negative values denoting government debt. The government finances exogenous government expenditures, G, interest payments on bonds and transfers to the GSEs.

The government budget constraint is therefore given by:

$$r^b B_t^g + G_t = \int \tilde{T}_t(w_t z_t l_t) d\Phi + T_{GSE} + B_{t+1}^g \tag{12}$$

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

4 Recursive Equilibrium without Aggregate Shocks

In our model we assume MIT shocks, i.e., at time $t = 0$ central bank hit the economy with an unexpected temporary shock to nominal interest rate and then we study the transition of the economy back to the steady state. Thus we do not have to solve for aggregate fluctuations.

4.1 Households' Dynamic Problem

4.1.1 Capitalist's Recursive Problem

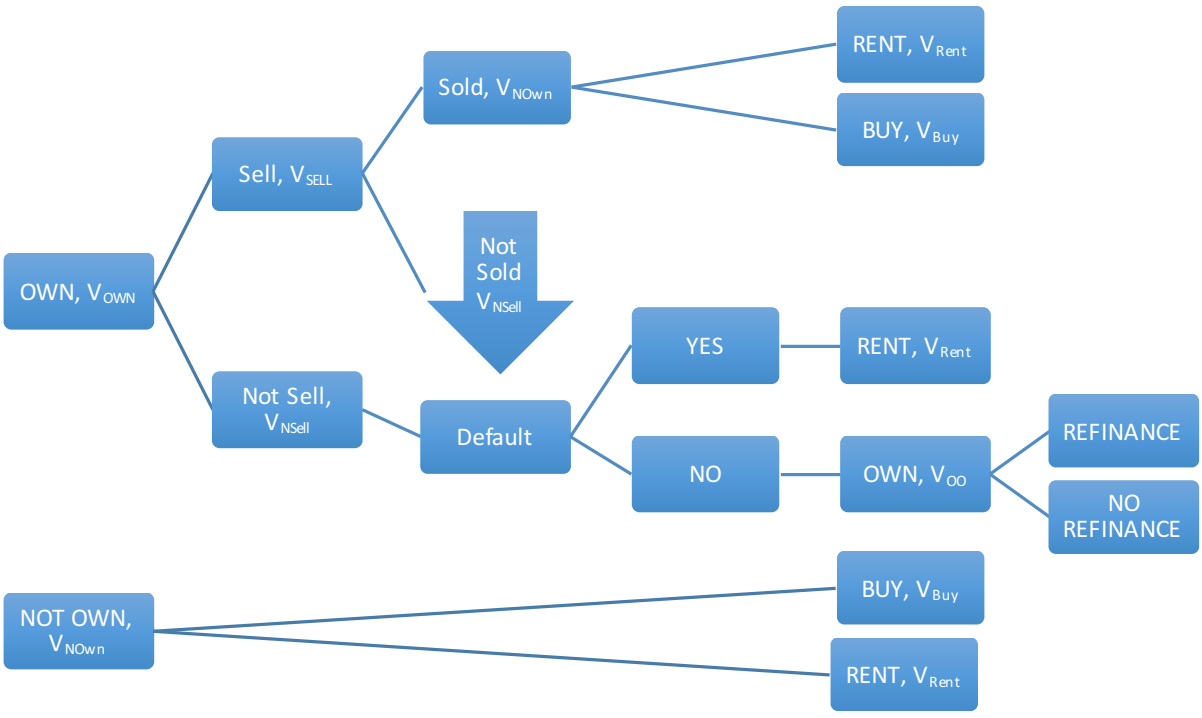
Since capitalists are the only owners of the intermediate firms, we just add the dividends of intermediate firms to her resource constraint and let her choose between consumption and bond (banks don't make any profit not even during the transition):

$$\begin{aligned} V(b) &= \max_{c,b'} u^C(c) + \beta^C V(b') \\ b + wz^C + d^F &\geq c + q^B b' \\ b' &\geq \underline{B} \end{aligned}$$

Then the FOC w.r.t b':

$$q^B u_c^C(c) = \beta^C V'(b') = \beta^C u_c^C(c')$$

FIGURE 2 – Timeline



4.1.2 Laborer's Recursive Problem

Laborers take the prices as given: w, q^B, p^H. Laborers dynamic problem can be summarized by the timeline shown in figure 2.

Value function of a household who owns a house in the beginning of the period and keeps the same house at the portfolio and refinance choice stage.

$$\begin{aligned}
V_{OO}(a,(r_m,m),h,z) &= \max_{m',b',c,l\geq 0} u(c,h,l)+\beta_L \mathbb{E}\left[V_{own}(a',(r'_m,m'),h,z')\right] \\
\text{subject to} & \\
c+q^B b'+\frac{m}{1+\pi} &\leq a+m' \text{ if } m'\leq \frac{(1-\chi)}{1+\pi}m \\
c+q^B b'+\frac{m}{1+\pi} &\leq a+q^0_m((r'_m,m'),b',h,z')m' \text{ if } m'>\frac{(1-\chi)}{1+\pi}m \\
r'_m &= \begin{cases} r_m & \text{if } m'\leq \frac{(1-\chi)}{1+\pi}m \\ r'_m & \text{o/w} \end{cases} \\
a' &= wz'+b'
\end{aligned}$$

Value function of a household who buys a house:

$$\begin{aligned}
V_{Buy}(a,z) &= \max_{m',b',h',c,l\geq 0} u(c,h',l)+\beta_L \mathbb{E}\left[V_{OWN}(a',(r'_m,m'),h',z')\right] \\
\text{subject to} & \\
c+q^B b'+p_h h' &\leq a+q^0_m((r'_m,m'),b',h',z')m' \\
h &\in H=\{h_0,h_1,h_2\} \\
a' &= wz'+b'
\end{aligned}$$

Value function of a household who rents:

$$\begin{aligned}
V_{Rent}(a,z) &= \max_{b',s,c,l\geq 0} u(c,s,l)+\beta_L \mathbb{E}\left[V_{NOwn}(a',z')\right] \\
\text{subject to} & \\
c+q^B b'+r_s s &\leq a \\
s &\leq \bar{s} \\
a' &= wz'+b'
\end{aligned}$$

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

come after liquid assets of the household):

$$V_{NSell}(a,(r_m,m),h,z) = \max_{d\in\{0,1\}} d(V_{Rent}(a,z)-\chi_f)+(1-d)V_{OO}(a,(r_m,m),h,z)$$

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

$$V_{NOwn}(a,z,f) = \max_{Buy\in\{0,1\}} BuyV_{Buy}(a,z)+(1-Buy)V_{Rent}(a,z)$$

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

$$\begin{aligned} V_{SELL}(a,(r_m,m),h,z,f) &= \max_{x_s} -\xi + p(\theta(x_s,h))V_{NOwn}(a+x_s-m,z) \\ &+ (1-p(\theta(x_s,h)))V_{NSell}(a,(r_m,m),h,z) \end{aligned}$$

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

$$V_{OWN}(a,(r_m,m),h,z) = \max_{\varsigma\in\{0,1\}} \varsigma V_{SELL}(a,(r_m,m),h,z)+(1-\varsigma)V_{NSell}(a,(r_m,m),h,z)$$

4.2 Equilibrium

4.2.1 Housing Market Clearing

Housing supply $S_h(p_h)$ equals the sum of owner-occupied and foreclosed properties that are successfully sold to real estate brokers:

$$S_h(p_h) = S_{REO}(p_h) + \int hp_s(\theta_s(x_s^*,h;p_h))\Phi(da,d(\overline{q_m},m),dh,dz)$$

where

$$S_{REO}(p_h) = \sum_h hp_s(\theta_s(x_s^{REO},h;p_h))\left\{H_{REO}(h)+\int\left[1-p_s(\theta_s(x_s^*,h;p_h))\right]d^*\Phi(da,d(r_m,m),h,dz)\right\}$$

is the supply of foreclosed properties (existing inventories + new repossessions).

Housing demand $D_h(p_h)$ equals housing purchased by buyers,

$$D_h(p_h) = \int h^* \Phi(da, dz)$$

Equating these two Walrasian-esque expressions gives p_h:

$$D_h(p_h) = S_h(p_h)$$

The market for mortgages clears:

$$\begin{aligned}
\int b_m^{'} &= \int q_m^0((r_m^{'}, M^{'}), b^{'}, h, s) M^{'} \Phi(da, d(r_m, m), dh, dz) Refi(a, (r_m, m), h, dz) \\
&+ \int q_m^0((r_m^{'}, M^{'}), b^{'}, h^{'}, s) M^{'} \Phi(da, d(r_m, m), dh, dz) \\
&* Sell(a, (r_m, m), h, dz, df) Buy_O(a, (r_m, m), h, dz) \\
&+ \int q_m^0((r_m^{'}, M^{'}), b^{'}, h^{'}, s) M^{'} \Phi(da, dz) Buy_R(a, dz)
\end{aligned}$$

The government budget constraint (need to add in all of the aggregate gains/losses from the mortgage sector):

$$w\tau \int z + [Insert] = T + \int b_m + (1+r)B^g + G$$

4.2.2 Characterizing the Intermediate Firms Problem

We can write the dynamic pricing problem of the firm using relative prices, $\tilde{p}_j$ and y_j:

$$\begin{aligned}
V\left(p_j^-; P^-\right) &\equiv \max_{p_j} p_j y_j \left(\frac{p_j}{P}\right) - m_j y_j (\frac{p_j}{P}) - \Theta\left(p_j, p_j^-\right) + \frac{1}{1+r} V\left(p_j; P\right) \\
\tilde{V}\left(\tilde{p}_j^-; P^-\right) &\equiv \max_{\tilde{p}_j} \tilde{p}_j y_j\left(\tilde{p}_j\right) - m_j y_j\left(\tilde{p}_j\right) - \frac{\theta}{2}\left(\frac{\tilde{p}_j P}{\tilde{p}_j^- P^-} - (1+\pi)\right)^2 Y + \frac{1}{1+r}\tilde{V}\left(\tilde{p}_j; P\right) \\
&\equiv \max_{\tilde{p}_j} \left(\tilde{p}_j\right)^{1-\epsilon} Y - \tilde{m}_j \left(\tilde{p}_j\right)^{-\epsilon} Y - \frac{\theta}{2}\left(\frac{\tilde{p}_j P}{\tilde{p}_j^- P^-} - (1+\pi)\right)^2 Y + \frac{1}{1+r}\tilde{V}\left(\tilde{p}_j; P\right)
\end{aligned}$$

where $\tilde{m}_j = \frac{m_j}{P}$ is the real marginal cost of the intermediate firm. Now let's derive the FOC w.r.t p_j and the envelope condition:

$$\begin{aligned}
0 &= (1-\epsilon)\left(\tilde{p}_j\right)^{-\epsilon} Y + \epsilon \tilde{m}_j \left(\tilde{p}_j\right)^{-\epsilon-1} Y - \theta \frac{(1+\pi)}{\tilde{p}_j^-}\left(\frac{\tilde{p}_j P}{\tilde{p}_j^- P^-} - (1+\pi)\right) Y + \frac{1}{1+r}\tilde{V}_{\tilde{p}}\left(\tilde{p}_j; P\right) \\
\tilde{V}_{\tilde{p}}\left(\tilde{p}_j^-; P^-\right) &= \theta \frac{\tilde{p}_j P}{\left(\tilde{p}_j^-\right)^2 P^-}\left(\frac{\tilde{p}_j P}{\tilde{p}_j^- P^-} - (1+\pi)\right) Y \Rightarrow \\
0 &= (1-\epsilon)\left(\tilde{p}_j\right)^{-\epsilon} Y + \epsilon \tilde{m}_j \left(\tilde{p}_j\right)^{-\epsilon-1} Y - \theta \frac{(1+\pi)}{\tilde{p}_j^-}\left(\frac{\tilde{p}_j P}{\tilde{p}_j^- P^-} - (1+\pi)\right) Y \\
&\quad + \frac{1}{1+r}\theta \frac{\tilde{p}_j' P'}{\left(\tilde{p}_j\right)^2 P}\left(\frac{\tilde{p}_j' P'}{\tilde{p}_j P} - (1+\pi)\right) Y'
\end{aligned}$$

In the steady state $\tilde{p}_j = \tilde{p}_j^-$, then marginal:

$$\begin{aligned}
0 &= (1-\epsilon)\left(\tilde{p}_j\right)^{-\epsilon} Y + \epsilon \tilde{m}_j \left(\tilde{p}_j\right)^{-\epsilon-1} Y \\
\tilde{m}_j &= \frac{\epsilon-1}{\epsilon}\tilde{p}_j \\
m_j &= \frac{\epsilon-1}{\epsilon} p_j, \text{ in the steady state} p_j = 1 \\
m_j^* &= \frac{\epsilon-1}{\epsilon}, \text{ for } \epsilon > 1. \\
w^* &= Z\frac{\epsilon-1}{\epsilon} \text{ (in the steady state we don't even have to solve for } w)
\end{aligned}$$

In the steady state firm's profit equals to:

$$d_j = (p_j - m_j) y_j(p_j) = \frac{1}{\epsilon} Y.$$

5 Calibration

The model is calibrated to replicate key features of the United States economy during 2003 – 2005, prior to the Great Recession. The calibration puts heavy 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 within the model.

5.1 Independent Parameters

Households Following Storesletten (2004), the log of the persistent component of labor efficiency follows an AR(1) process, while the transitory component is log-normal. We then convert the annual estimates from Storesletten (2004) to quarterly values. The persistent component is discretized using a 3-state Markov chain.

For preferences, households have CES period utility with an intratemporal elasticity of substitution of $\nu = 0.13$. Risk aversion is set to $\sigma = 2$, while the consumption share ω and discount factor β are determined in the joint calibration.

Technology Steady state TFP in the consumption good sector is set to normalize mean quarterly earnings to 0.25. Meanwhile, housing construction is Cobb-Douglas with a structures share of $\alpha_S = 0.3$ and a land share of $\alpha_L = 0.33$, based on data from the Lincoln Institute of Land Policy. Housing depreciates at an annual rate of 1.4%. Lastly, the apartment technology A_h is set to generate an annual rent-price ratio of 3.5%.

Housing Market Matching is Cobb Douglas, i.e. $p_s(\theta_s) = \min\{\theta^{\gamma_s}, 1\}$. Substituting in the equation for market tightnesses gives

$$p_s(\theta_s) = \begin{cases} 0 & \text{if } x_s > p_h h \\ \left(\frac{p_h h - x_s}{\kappa_s h}\right)^{\frac{\gamma_s}{1-\gamma_s}} & \text{if } (p_h - \kappa_s)h \leq x_s \leq p_h h \\ 1 & \text{if } x_s < (p_h - \kappa_s)h \end{cases}$$

The joint calibration determines the parameters κ_b, κ_s, γ_s, γ_b, and disutility ξ. Holding costs (maintenance, property taxes, etc.) are $\eta = 0.007$.

Financial Markets To match values in the U.S. during 2003 – 2005, the real risk-free rate is set to 1%, and the mortgage origination cost is 0.4%. The mortgage servicing cost ϕ is set to generate a 2.5% spread between the real mortgage rate and risk-free rate. Lastly, the exogenous LTV limit is $\vartheta = 1.25$ (125%), which makes it *non-binding* in the steady state.[5]

5.2 Joint Calibration and Model Fit

The joint calibration determines the remaining parameters. First, the calibration targets select household portfolio moments calculated from the 2004 Survey of Consumer

[5] 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 χ are determined in the joint calibration.

TABLE II – Externally Calibrated Parameters

Parameter	Interpretation	Value	Target
β^C	Capitalist Discount Factor	0.99	Risk-free rate 1%
σ^C	Capitalist Risk Aversion	1	Standard
ψ	Level disutility labor	0.5	Target $l = 1/3$
φ	Frisch elasticity	1/2	Standard (Chetty?)
ε	Elasticity of substitution of intermediates	11	Markup of 10%
θ	Cost of price adjustment	110	Slope of NKPC=0.1
χ	Minimum payment	1/30	30 year mortgage
ν	Measure of capitalists	20%	Top wealth quintile
τ_L	Labor Income Tax	25%	
ϑ	Max LTV	100%	
r_h	Rental price	0.05	
η	Holding costs	0.7%	Moody's
ζ	Origination cost	0.4%	Federal Reserve
r_m	Nominal amortization rate	5.5%	2.5% real int rate spread
r^*	Long-run risk-free rate target	1%	
π^*	Long-run inflation target	1.9%	
ϕ_T	Taylor-rule inflation response		
ρ, σ_s, σ_e	Income process		Storesletten *et al.* (2004)

Note: This table reports the values for the parameters that are externally calibrated.

Finances (SCF). Specifically, the calibration aims to match average housing wealth and the proportion of borrowers with leverage exceeding 90%, because these households have the highest likelihood of ending up underwater on their mortgages and in danger of foreclosure during the Great Recession. The calibration also targets certain key moments of the housing market such as sales volume, average search duration for buyers and mismatched sellers, and maximum price spreads. Lastly, the model is calibrated to match foreclosure starts and the average foreclosure discount.

6 Results

6.1 Steady State Results

Search-induced housing illiquidity has several economically significant effects on the behavior of both the housing and mortgage markets. First, illiquidity creates substantial selling risk for homeowners, and in particular, for homeowners with substantial outstand-

TABLE III – Internally Calibrated Parameters

Parameter	Interpretation	Value	Target value	Model
β^L	Laborer Discount Factor	0.95	Median LTV 61%	
σ^L	Laborer Risk Aversion	2	Standard	
γ_h	Elasticity of substitution c, h	8	Flavin, Nagawa	
ϕ_h	Taste for housing	0.116		
ω_h	Extra utility of ownership	1.29	Home ownership rate	
ξ_N	Utility cost of not selling	0.0047	Months supply	
ξ_F	Utility cost of foreclosure	0.05	Mean equity conditional on foreclosure	
$\underline{h}$	Smallest house	2.71	Corbae and Quintin (2015)	
κ_s	Posting cost in selling	0.1256	Maximum list discount 15%	
ω	Bank search penalty	0.155	Foreclosure Discount 20%	
λ_s	Elasticity of matching function	0.6550	Foreclosure starts	

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

ing mortgage debt. Panel 1 of figure 3 shows list price choice as a function of leverage for a homeowner with low liquid assets, and panel 2 shows expected time on the market. At low levels of leverage, this homeowner would like to sell and downsize, but their equity cushion allows them to exhibit patience as they try to fetch a reasonable price for their house. If they happen to get hit by a negative income shock, they retain the ability to extract equity via the mortgage market.

However, as leverage rises close to 75% - 80%, the bank cuts back on lending to these asset-poor homeowners because of higher default risk. As a result, these homeowners become distressed sellers who are forced to cut into their equity by lowering the list price. These distressed sellers end up posting fire sale prices that guarantee a rapid sale. As debt rises still further, the constraint, the constraint $x_s + y \geq \frac{m}{1+\pi}$ starts to bind. As their equity cushion evaporates, debt-constrained sellers lose the flexibility to price their house to sell quickly. 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 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 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

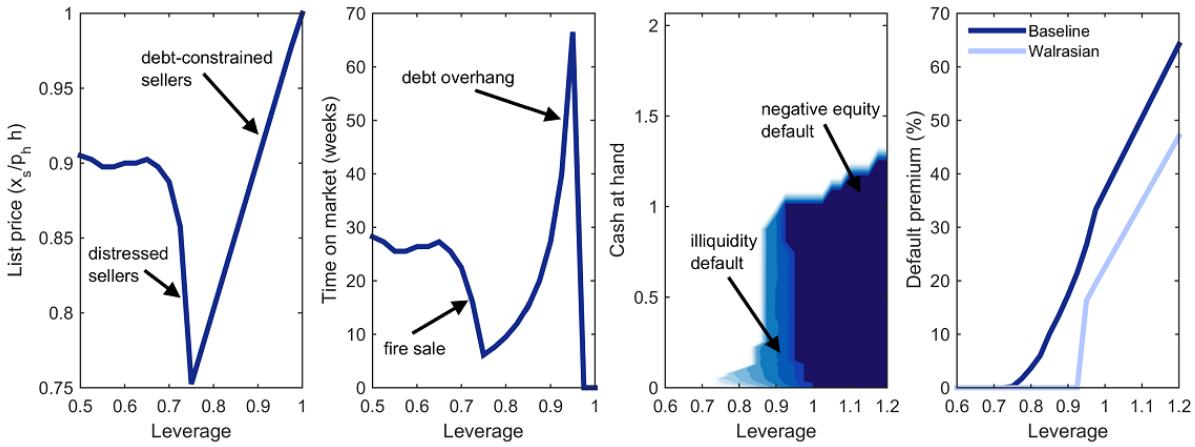


FIGURE 3 – (1) List price by LTV; (2) time on the market by LTV; (3) mortgage default heat map; (4) default premia.

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 3 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 4 plots some individual-level simulations to illustrate the mechanisms described above. In each case, I 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 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.

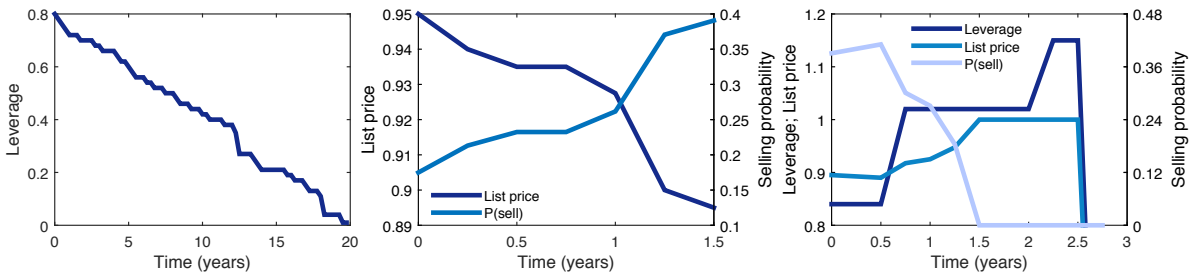


FIGURE 4 – Simulations over time of different individual homeowners who (1) pay down their mortgage; (2) use their equity cushion to cut their price; (3) engage in "distressed borrowing," raise their price, experience selling delays, and then default.

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. Figure 5 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. However, these steady state results underestimate the implications of illiquid housing on consumption behavior because they ignore the dynamic amplification between selling delays and endogenous credit costs that occurs in response to economic shocks. It is this dynamic behavior that has significant implications regarding the effects of monetary policy during times where households are highly leveraged.

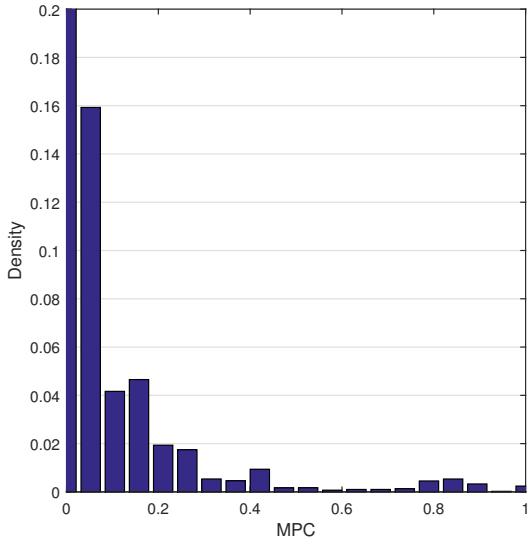


FIGURE 5 – The distribution of marginal propensities to consume.

References

Attanasio, O. P., Blow, L., Hamilton, R. and Leicester, A. (2009). Booms and busts: Consumption, house prices and expectations. *Economica*, **76** (301), 20–50.

Auclert, A. (2015). Monetary policy and the redistribution channel. *Unpublished Manuscript, Massachusetts Institute of Technology*.

Browning, M., Gørtz, M. and Leth-Petersen, S. (2013). Housing wealth and consumption: a micro panel study. *The Economic Journal*, **123** (568), 401–428.

Calomiris, C., Longhofer, S. D. and Miles, W. (2009). *The (mythical?) housing wealth effect*. Tech. rep., National Bureau of Economic Research.

Campbell, J. Y. and Cocco, J. F. (2007). How do house prices affect consumption? evidence from micro data. *Journal of Monetary Economics*, **54** (3), 591–621.

Carroll, C. D., Otsuka, M. and Slacalek, J. (2011). How large are housing and financial wealth effects? a new approach. *Journal of Money, Credit and Banking*, **43** (1), 55–79.

Case, K. E., Quigley, J. M. and Shiller, R. J. (2011). *Wealth effects revisited 1978-2009*. Tech. rep., National Bureau of Economic Research.

Challe, E., Matheron, J., Ragot, X. and Rubio-Ramirez, J. F. (2015). Precautionary saving and aggregate demand.

Chatterjee, S. and Eyigungor, B. (2011). *A Quantitative Analysis of the US Housing and Mortgage Markets and the Foreclosure Crisis*. Tech. rep., Federal Reserve Bank of Philadelphia.

Cloyne, J., Ferreira, C. and Surico, P. (2015). *Housing debt and the transmission of monetary policy*. Tech. rep., mimeo.

Corbae, D. and Quintin, E. (2015). Leverage and the foreclosure crisis. *Journal of Political Economy*, **123** (1), 1–65.

Di Maggio, M., Kermani, A. and Ramcharan, R. (2014). Monetary policy pass-through: Household consumption and voluntary deleveraging. *Columbia Business School Research Paper*, (14-24).

Favilukis, J., Ludvigson, S. C. and Van Nieuwerburgh, S. (2010). *The macroeconomic effects of housing wealth, housing finance, and limited risk-sharing in general equilibrium*. Tech. rep., National Bureau of Economic Research.

Flodén, M., Kilström, M., Sigurdsson, J. and Vestman, R. (2016). Household debt and monetary policy: Revealing the cash-flow channel. *Available at SSRN 2748232*.

Garriga, C. and Hedlund, A. (2016). Mortgage debt, consumption, and illiquid housing markets in the great recession.

—, Kydland, F. and Sustek, R. (2015). *Mortgages and Monetary Policy*. Working paper.

Gornemann, N., Kuester, K. and Nakajima, M. (2014). Doves for the rich, hawks for the poor? distributional consequences of monetary policy. *Federal Reserve Bank of Philadelphia*.

Hedlund, A. (2015). Failure to launch: Housing, debt overhang, and the inflation option during the great recession.

Huo, Z. and Rios-Rull, J.-V. (2013). *Balance sheet recessions*. Tech. rep., Working Paper, Federal Reserve Bank of Minneapolis.

Jeske, K., Krueger, D. and Mitman, K. (2013). Housing, mortgage bailout guarantees and the macro economy. *Journal of Monetary Economics*, **60** (8), 917–935.

Kaplan, G., Mitman, K. and Violante, G. (2015). *Consumption and House Prices in the Great Recession: Model Meets Evidence*. 2015 Meeting Papers 275, Society for Economic Dynamics.

—, — and — (2016a). *Non-durable Consumption and Housing Net Worth in the Great Recession: Evidence from Easily Accessible Data*. Tech. rep., Department of Economics, Princeton University.

—, Moll, B. and Violante, G. (2016b). Monetary policy according to hank.

Keys, B. J., Piskorski, T., Seru, A. and Yao, V. (2014). *Mortgage Rates, Household Balance Sheets, and the Real Economy*. Working paper.

McKay, A. and Reis, R. (Forthcoming). The role of automatic stabilizers in the u.s. business cycle. *Econometrica*.

Menzio, G. and Shi, S. (2010). Block recursive equilibria for stochastic models of search on the job. *Journal of Economic Theory*, **145** (4), 1453–1494.

Mian, A., Rao, K. and Sufi, A. (2013). Household balance sheets, consumption, and the economic slump. *Quarterly Journal of Economics*, pp. 1–40.

Rotemberg, J. J. (1982). Sticky prices in the united states. *The Journal of Political Economy*, pp. 1187–1211.

Storesletten, K., Telmer, C. I. and Yaron, A. (2004). Cyclical dynamics in idiosyncratic labor market risk. *Journal of Political Economy*, **112** (3), 695–717.

Stroebel, J. and Vavra, J. (2014). *House prices, local demand, and retail prices*. Tech. rep., National Bureau of Economic Research.

Weber, M. and Gorodnichenko, Y. (2016). Are sticky prices costly? evidence from the stock market. *American Economic Review*, **106**, 165–199.

Wong, A. (2015). *Population Aging and the Transmission of Monetary Policy to Consumption*. Working paper.

Appendix

7 Computation

Step 0: Start with an initial guess for prices: $\{\{p_h\}_{\forall h}, r^*$, and $w\}$.

Step 1.0: Start with an initial guess for mortgage pricing function, $q_{m,0}$ and set $i = 0$.

Step 1.1: For given prices, $\{\{p_h\}_{\forall h}, r^*$, and $w\}$, and $q_{m,i}$ solve the household's problem.

Step 1.2: Given household's behavior from Step 1.1, and prices $\{\{p_h\}_{\forall h}, r^*$, and $w\}$, solve the mortgage pricing function, $q_{m,i+1}$, using equation 8.

Step 1.3: Check whether $q_{m,i} \simeq q_{m,i+1}$. If they are close enough to each other go to Step 2. If not, update $i = i + 1$ and go to Step 1.1.

Step 2 : Given household's behavior and mortgage prices from Step 1 check whether bond, labor and housing markets clear. If not, update prices $\{\{p_h\}_{\forall h}, r^*$, and $w\}$ and go to Step 1.0. Namely,

Step 2.1 : Solve for intermediate firms' problem. Check whether labor demand equals to labor supply.

Step 2.2 : Aggregate bond demand and aggregate bond supply. Check whether bond market clears.

Step 2.3 : Aggregate housing demand and check whether it equals to fixed housing supply.