HOUSE PRICES AND CONSUMER SPENDING

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ABSTRACT

Recent empirical work shows large consumption responses to house price movements. This is at odds with a prominent theoretical view which, using the logic of the permanent income hypothesis, argues that consumption responses should be small. We show that, in contrast to this view, workhorse models of consumption with incomplete markets calibrated to rich cross-sectional micro facts actually predict large consumption responses, in line with the data. To explain this result, we show that consumption responses to permanent house price shocks can be approximated by a simple and robust rule-of-thumb formula: the marginal propensity to consume out of temporary income times the value of housing. In our model, consumption responses depend on a number of factors such as the level and distribution of debt, the size and history of house price shocks, and the level of credit supply. Each of these effects is naturally explained with our simple formula.

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1   Introduction

A growing empirical literature argues that house price movements can have large effects on consumption. This finding gives support to a widespread policy concern that boom-bust cycles in house prices can end with large contractions in consumer spending.[1] However, the theoretical rationale for house price effects on consumption is less clear. In particular, it is a commonly held view that these effects should be small, because increases in the value of an individual's house are offset by increases in future implicit rental costs, leaving the expected lifetime budget constraint unchanged. If households make consumption decisions based on the expected net present value of their resources, as in the basic permanent income hypothesis model, then consumption effects should be small.[2]

In this paper, we explore the effects of house prices on consumption in a more realistic workhorse incomplete markets model with income and house price uncertainty. Our baseline model includes a fixed adjustment cost of trading houses, the choice between renting and owning, and the possibility to borrow against the value of the house. The model is able to match a variety of life-cycle and cross-sectional facts on the distribution of wealth, leverage, and housing. In contrast to the basic permanent income model: (i) Our model produces large aggregate consumption responses to house price changes—the elasticity of aggregate consumption to a two-standard deviation (9.2%) increase in house prices is 0.23, in line with the recent empirical literature; (ii) The size of these responses depends crucially on the economy's joint distribution of housing and debt; (iii) The response of consumption to a house price shock today depends on the history of previous house price shocks.

What explains these results? To provide intuition, we begin by deriving a simple formula for the individual consumption response to an unexpected, permanent house price shock in a special case of our model with no adjustment costs in housing. In this case, we show that the consumption response is given by the marginal propensity to consume out of temporary income shocks (MPC) times individual housing values (PH). The aggregate response is then determined by the endogenous joint distribution of MPC and PH. Three assumptions are crucial for this result: no adjustment costs in housing, Cobb-Douglas utility, and permanent house price shocks. Under these three assumptions, we show that three effects of house prices on consumption decisions cancel each other out: the collateral effect, the substitution effect, and the ordinary income effect due to changes in future implicit rental costs. The only remaining effect of house prices on consumption is the endowment income effect coming from the revaluation of the initial

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[1]See Mian et al. (2013) and Cerutti et al. (2015).

[2]Sinai and Souleles (2005) p. 773 clearly formulate this view: "increases in house prices reflect a commensurate increase in the present value of expected future rents" and "for homeowners with infinite horizons, this increase in implicit liabilities would exactly offset the increase in the house value, leaving their effective expected net worth unchanged." Similar arguments are made in Glaeser (2000), Campbell and Cocco (2007), and Buiter (2008), which is emphatically titled "Housing Wealth isn't Wealth".

housing endowment, and this effect works just like a transitory shock to income.

The assumption of no adjustment costs is needed for our simple formula to hold exactly, but we show that the formula still holds approximately in our baseline model with adjustment costs.[3] In that context, the formula then provides a good rule of thumb that can be used to map the quantitative analysis of house price effects to the much better understood analysis of MPCs.[4] To show the goodness of the approximation, for each household in the model we compute both the actual elasticity of consumption to house price shocks and the approximate elasticity computed with the rule-of-thumb formula. The cross-sectional variation in actual elasticities is large, ranging from 0 to almost 1, and the rule-of-thumb approximation is quite accurate: regressing actual elasticities on approximate elasticities produces and R^2 of 0.95.

Next, we use our formula to explain a variety of results in our baseline model and how they contrast with results in simpler models. For example, the basic permanent income model with no income uncertainty and no borrowing constraints generates small MPCs that have little correlation with housing. In contrast, our baseline model features income uncertainty and borrowing constraints, which increase MPCs, and the presence of leverage makes MPCs strongly correlated with housing values. Our baseline model also generates consumption elasticities that vary substantially with income, age, housing, liquid assets and rental decisions, each of which can be explained by how MPC and PH jointly vary with these variables. For example, responses in the model are first increasing then decreasing in income. The reason is that low income households tend to rent, in which case they have PH = 0 and so a zero response.[5] Households with higher income tend to own using substantial leverage, leading to higher values of both PH and MPC, while agents with the highest income still tend to own but are less levered, leading to lower MPCs. Finally, aggregate elasticities can depend on the size and direction of house price shocks, which can be understood through our formula since the presence of borrowing constraints makes MPCs depend on the sign and size of income shocks.

We explore a number of extensions of our baseline model to show that consumption responses remain both large and well-explained by our rule-of-thumb formula under a variety of assumptions. The most important extension is the introduction of long-term mortgages. For simplicity our baseline model assumes one-period frictionless debt. In reality, home-equity extraction is costly, mortgages are long-term, and loan-to-value constraints only bind at origination. This means that lenders cannot demand new collateral even if house price declines push households underwater. In important recent work, Ganong and Noel (2016) present empirical evidence that underwater borrowers respond little to mortgage debt relief unless it affects current budget

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[3]In extensions, we also show that our rule of thumb is robust to relaxations of the other two assumptions: Cobb-Douglas utility (in Section 5.3) and permanent house price shocks (in Section 7).

[4]Note that the calculation of MPCs still requires solving the model, so our rule of thumb is not a computational tool but rather a tool for interpreting quantitative consumption responses to house price movements.

[5]We discuss the intuition for zero renter response in detail in the body of the paper.

constraints, suggesting that our rule of thumb does not work well when households are underwater. In order to address these issues, we introduce long-term amortizing mortgages with costly refinancing. We find that the accuracy of our formula remains good overall, with an R^2 of 0.9 in the regression of actual elasticities on approximate elasticities. But consistent with Ganong and Noel (2016), the rule of thumb breaks down for underwater households since these households have very high MPCs but have little response to house price shocks. This is an important caveat to our rule of thumb and shows that it does not work for all households in all situations. This is an important caveat to our rule of thumb and shows that it does not work for all households in all situations. However, such highly leveraged households represent a very small share of households during normal times, and even during the Great Recession, most households still had substantial housing equity. This means allowing for long-term debt does not have a large effect on the accuracy of our formula at the aggregate level.

We view our rule-of-thumb formula largely as an analytical device rather than as a tool for measuring housing wealth effects in the data, but in the paper we also explore the measurement of our rule-of-thumb statistic in micro data. By constructing measures of the MPC by housing values using PSID data, we are able to construct a microeconomic estimate of our rule-of-thumb formula. This provides both an over-identification test of our quantitative model as well as an alternative empirical measure of housing wealth effects that relies only on the broad structure of this class of models. Reassuringly, we find that this microeconomic estimate is highly consistent with our baseline model and is in line with empirical estimates using completely different identification strategies, such as those in Mian et al. (2013).

Most of our paper focuses on impact effects of house prices on consumption, in a stationary environment. The final section then moves beyond impact effects and also explores out-of-steady-state dynamics. First, we show that the impact effects described by our rule of thumb are useful for understanding the entire impulse response function. More specifically, we compute the full impulse response function of consumption to a house price shock as we change model parameters such as the level of credit supply or house price growth, and we show that impact effects move in lock-step with the entire impulse response function. In particular, raising credit supply or house price growth monotonically shifts the impulse response function up, leading to greater consumption responses both on impact and at future dates.

We next show that dynamics can lead to important time-varying responses of consumption to house price shocks. For example, we simulate a house price boom in our model and show that consumption becomes progressively more sensitive to house price shocks as the boom proceeds. This can be understood using our rule of thumb since higher house price growth leads households to purchase more housing using debt, which in turn raises MPCs. Interestingly, the strength of this effect depends crucially on household expectations: consumption sensitivity rises much more over housing booms in which households expect high house price growth to persist, since

this leads to a larger increase in housing demand and leverage. The fact that the endogenous distribution of housing and debt matters for the strength of house price effects is important for interpreting empirical evidence from different time periods and when contemplating potential policy intervention into housing markets. Both shocks and policy interventions may have effects on consumption that differ dramatically with the distribution of household state-variables at the time the policy is enacted. In this sense, our result joins a growing literature arguing that the economy may exhibit time-varying responses to aggregate shocks.[6]

Finally, we explore the role of house price persistence for our results. When house price shocks are less than fully persistent, we actually find moderately *larger* consumption responses on impact,[7] but that total consumption responses are somewhat reduced since effects wear off more rapidly with transitory shocks. However, quantitative magnitudes are generally quite similar to the permanent shocks explored in the rest of the paper for plausible parameter values.

Our paper is motivated by the empirical literature studying house price effects on consumption. While methodological and data differences have led to a wide range of estimates for the relationship between house prices and consumption, the literature has generally found strong relationships. Whether or not such relationships are causal is more contentious, but recent papers with new sources of identification have argued for such causality.[8] We contribute to this debate both by showing that theory is completely consistent with large causal effects and by constructing an empirical measure of these effects using our rule-of-thumb formula.

The first empirical studies of the relationship between consumption and house prices focused on aggregate data and typically found elasticities of 0.1 to 0.2.[9] The greatest challenge for these studies is finding exogenous variation in house prices which can be used to separate direct house price effects on consumption from the effects of common factors. For example, expectations about future income growth may drive both house prices and consumption.[10] A number of recent papers have used micro level evidence to confront this identification challenge. For example, Mian et al. (2013) use credit card data together with the Saiz (2010) housing supply instrument to isolate the effects of exogenous changes in house prices on local measures of spending.[11] Their

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[6]See e.g. Berger and Vavra (2015) for applications to durable goods, Vavra (2014) for applications to prices and Caballero and Engel (1999) and Winberry (2015) for applications to investment.

[7]This is because households can take advantage of partially predictable house price movements by selling/buying housing and repurchasing/reselling it in the future.

[8]While there are different ways of measuring housing price effects, for consistency we will focus the discussion on estimates of the consumption elasticity to house prices—the percentage change in non-durable consumption due to a one percent change in house prices.

[9]Case et al. (2013) find elasticities from 0.03 to 0.18, with most of the their estimates centered around 0.10, while Carroll et al. (2011) find an immediate (next-quarter) elasticity of 0.047, with an eventual elasticity of 0.21. They report results in terms of MPCs of 2 and 9 cents (in 2007 dollars) respectively. In 2007, housing assets from the Flow of Funds were $22,830.5 billion and personal consumption expenditures from the BEA were $9,750.5 billion. Multiplying MPCs by this ratio delivers the reported elasticities.

[10]See Attanasio and Weber (1994).

[11]See also Campbell and Cocco (2007) and Attanasio et al. (2009) for other recent micro studies.

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baseline estimates of the non-durable consumption elasticity are between 0.13 and 0.26.[12] We view these estimates as the closest empirical analogue to the direct house price effects in our theory, so we will often compare our theoretical results to these numbers. Several recent papers such as Kaplan et al. (2016) and Stroebel and Vavra (2016) also arrive at similar numbers using new scanner spending data and additional identification strategies.

Our paper is part of a large literature studying the theoretical response of consumption to house prices in quantitative heterogeneous agent models. A number of papers have explored increasingly rich models with housing and debt, using them to both address aggregate questions and draw cross sectional predictions, e.g., Carroll and Dunn (1998), Campbell and Cocco (2007), and Attanasio et al. (2011).[13] More recently, models with these features have been embedded into general equilibrium frameworks, to study the role of households' balance sheets and debt capacity in the Great Recession.[14] In particular, several papers have pointed to house values as prime determinants of households' debt capacity.[15] Gorea and Midrigan (2017) study the effects of illiquid housing on consumption and savings. Huo and Ríos-Rull (2013) and Kaplan et al. (2016) build heterogeneous agent equilibrium models with endogenous house prices.

We view our theoretical analysis as highly complementary to this line of work. Our rule-of-thumb formula and decompositions help identify the channels at play and show the crucial role of the endogenous distribution of housing and debt for the size of house price effects. Our analysis is conducted taking house prices and income as given. As emphasized by Kaplan et al. (2016), house prices are equilibrium objects, which complicates the interpretation of correlations between house prices and consumption. This is because structural shocks which move house prices may themselves have direct effects on consumption so that the simple correlation between house prices and consumption will reflect both the causal effect of house prices on consumption plus any confounding effect from the underlying structural shock. In this paper, we are interested in whether housing markets themselves play an important role in shaping consumption and propagating underlying shocks. As such, we want to isolate the causal effects of house price movements, which fundamentally require modeling housing, from any confounding effects of structural shocks on consumption, which occur independently of housing. If housing markets

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[12]They report estimates between 0.5-0.8. However, given their methodology these estimates need to be scaled by housing wealth/total wealth to be comparable to the other estimates listed above. Since the mean housing wealth to total wealth ratio in their data is between 0.25-0.33, this implies elasticity estimates ranging from 0.13 to 0.26. Although these estimates can be interpreted as consumption responses to exogenous house price shocks, it is important to note that they are not pure partial equilibrium responses, since they reflect both direct house price effects plus any local general equilibrium responses. In particular, they include the additional effect on consumption due to increases in local incomes driven by greater non-tradable spending.

[13]While the focus is very different, similar models have also been used to explore housing choice with borrowing constraints in Cocco (2005) and Yao and Zhang (2005).

[14]Good examples are Favilukis et al. (2015) and Chen et al. (2013). Early work in this direction—that does not model housing—includes Hall (2011), Guerrieri and Lorenzoni (2011), Eggertsson and Krugman (2012).

[15]See, Midrigan and Philippon (2011) and Justiniano et al. (2015).

play a causal role in shaping consumption, then disruptions in these markets can potentially cause broader business cycle downturns. Importantly, isolating the causal effects of house price shocks on consumption requires eliminating all confounding factors by holding other prices and shocks constant, so this is the approach we take throughout the paper. Since there are strong relationships between house prices and consumption in our model when holding all confounding factors constant, this means our model implies an important causal effect of house prices on consumption. Importantly, our rule-of-thumb formula measures the strength of this causal effect and how it changes with economic conditions or across models. It does not provide a formula for the simple correlation between house prices and consumption in equilibrium, which will depend on the underlying structural shocks which drive house prices.

Our emphasis on simple rules of thumb and sufficient statistics connects our paper to recent work by Auclert (2015). Work in public finance has widely developed the use of sufficient statistics to characterize welfare effects and optimal policy (see Chetty (2009)).[16] In macro, the idea is to use a similar approach to express aggregate responses to some hard to identify aggregate shock in terms of individual level statistics which can potentially be more easily measured. Of course, some further steps may be necessary to translate partial equilibrium responses into general equilibrium effects. However, we see this as a promising avenue to investigate increasingly complex heterogeneous agents models and connect them to the data.

The remainder of the paper proceeds as follows: In Section 2 we present the baseline model, calibrate it, and compute baseline consumption response to house price shocks. In Section 3 we derive our rule-of-thumb formula in the model with frictionless housing in which it holds exactly. Section 4 goes back to the full model with adjustment costs, shows the accuracy of the rule-of-thumb formula and uses it to interpret a variety of results in that model. Section 5 shows that these conclusions hold under a variety of robustness checks including the presence of long-term debt and relaxing the Cobb-Douglas utility specification. Section 6 estimates our rule of thumb directly in micro data as an over-identification test of our model. Finally, Section 7 introduces dynamics and shows that the model can generate substantial time-variation in the strength of house price effects on consumption.

2   Baseline Model

We consider a dynamic, incomplete markets model of household consumption. Households have finite lives and face uninsurable idiosyncratic income risk. The main distinguishing feature of the model is that households trade houses that provide housing services but which are subject to adjustment costs and they can borrow against the value of their houses.

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[16]This approach has also been applied to characterizing optimal macro and financial policy; c.f. Davila (2016).

2.1 Set Up

Time is discrete and runs forever. There is a constant population of overlapping generations of households, each living for J periods. The first J_y periods correspond to working age, the next J_o periods to retirement.

Households invest in two assets: a risk-free asset and housing. Let A_{it} and H_{it} denote the holdings of the two assets by household i at time t. The risk-free asset is perfectly liquid and yields a constant interest rate r. Housing yields housing services one-for-one, depreciates at rate δ, and trades at the price P_t. In most our analysis we assume that house prices follow a geometric random walk with drift: $P_t = x_t P_{t-1}$, where x_t is an i.i.d. shock with $E[x_t] = e^\mu$ so that μ is the trend growth rate of house prices.[17] Assuming a random walk simplifies our analysis, but in Section 7, we show that modeling house prices as an autoregressive process with mean reverting shocks delivers similar results for empirically realistic degrees of persistence.

We assume that in each period a household must choose whether to be a homeowner or a renter. Renters pay a flow rental cost R_t per unit of housing services. Rental housing can be adjusted costlessly but cannot be used as collateral. We assume that the rental cost R_t is proportional to house prices, $R_t = \phi P_t$. That is, in our baseline, we assume a constant price-rent ratio which takes on parameter value ϕ.[18] In Section 5.3, we show that elasticities are mildly amplified if we instead make the opposite extreme assumption that R_t is fixed while P_t varies, so that our baseline choice is relatively conservative.

In contrast to rental housing, we assume that buying and selling houses is costly, to match the fact that households trade houses only infrequently.[19] We model adjustment costs as a fixed cost, incurred whenever the household changes its stock of housing. In particular, if household i decides to trade housing at time t, it pays a cost proportional to the value of the house sold $\kappa_{it} = F \cdot P_t H_{it-1} \mathbb{1}_{H_{it} \neq H_{it-1}}$, where $\mathbb{1}$ is an indicator function equal to 1 if $H_{it} \neq H_{it-1}$.

In addition to providing housing services, owner occupied housing can be used as collateral for borrowing. In particular, households can borrow but must satisfy the borrowing constraint

$$-A_{it} \leq (1-\theta)\frac{1-\delta}{1+r}P_t H_{it}, \tag{1}$$

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[17]National house prices series are highly persistent in FHFA, Case-Shiller and CoreLogic. The exact value depends on the particular series, time window and price deflator used but across a variety of choices, real house prices exhibit annual persistence of between 0.93 and 0.96, and a random walk cannot be rejected.

[18]At retirement, income risk falls to zero. This substantially changes the trade-off between liquid and illiquid assets. With a constant rental rate this would imply a large jump up in the homeownership rate at retirement. To eliminate this jump, we introduce a different rental-to-price ratio at retirement $\hat{\phi} < \phi$, and we pick this additional parameter to match homeownership rates after retirement. This is isomorphic to a lower utility of housing in retirement, perhaps due to no longer having children at home or to greater challenges to home maintenance. We concentrate on results for working-age households, so $\hat{\phi}$ has little effect on any of our results.

[19]Berger and Vavra (2015) show that the average annual frequency of housing adjustment in the PSID is 4.3% in data from 1968-1996 and 5.8% in data from 1999-2011.

where $(1 - \theta)$ is the fraction of a house's value that can be used as collateral.

Households born at time t maximize the expected utility function

$$E\left[\sum_{j=1}^{J} \beta^j U(C_{it+j}, H_{it+j}) + \beta^{J+1} B(\tilde{W}_{it+J+1})\right],$$

where C_{it} is consumption of non-durable goods and $\tilde{W}_{it+J+1}$ is the offspring's real wealth. The per-period utility function and the bequest function are, respectively,

$$U\left(C_{it}, H_{it}\right) = \frac{1}{1-\sigma}(C_{it}^{\alpha} H_{it}^{1-\alpha})^{1-\sigma}, \qquad B(\tilde{W}_{it+J+1}) = \Psi\frac{1}{1-\sigma}\tilde{W}_{it+J+1}^{1-\sigma}.$$

The offspring's real wealth is

$$\tilde{W}_{it+J+1} = \frac{P_{t+J+1}(1-\delta)H_{it+J} + (1+r)A_{it+J}}{P_{Xt+J+1}},$$

where $P_{t+J+1}(1-\delta)H_{it+J} + (1+r)A_{it+J}$ are bequests, and $P_{Xt+J+1} = \Omega P_{t+J+1}^{1-\alpha}$ is a price index that adjusts for changes in the cost of housing.[20]

The assumption of Cobb-Douglas preferences for non-durable consumption and housing services plays an important role in simplifying computations and for interpreting some of our results. While estimates of the elasticity of substitution between non-durables and housing based on macro data are somewhat varied, more relevant evidence from micro data consistently finds support for an elasticity close to unity (Piazzesi et al. (2007), Davis and Ortalo-Magné (2011), and Aguiar and Hurst (2013)). Furthermore, in Section 5.3 we show quantitative results are robust to using using CES preferences with elasticity of substitution in a reasonable range.

Households face an exogenous income process. Working age households have income

$$Y_{it} = \exp\{\chi(j_{it}) + z_{it}\},$$

where $\chi(j_{it})$ is a deterministic age-dependent parameter, j_{it} is the age of household i at time t, and z_{it} is a transitory shock that follows an AR(1) process

$$z_{it} = \rho z_{it-1} + \varepsilon_{it}.$$

When the household is retired, income is given by a social security transfer, which is a function of income in the last working-age period, which we specify following Guvenen and Smith (2014).

The full household problem and computational solution are detailed in Appendix A.4.

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[20]In particular, $\Omega = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}(1 - \frac{(1-\theta)(1-\delta)e^g}{1+r})$

2.2 Calibration

We now calibrate the model in order to assess its quantitative implications for consumption responses to house prices.

Table 1: *Parameter Values*

Calibrated to External Evidence:	σ	r	μ	σ_P	δ	θ	F	ρ_z	σ_z
	2	2.4%	1.2%	4.59%	2.2%	0.20	0.05	0.91	0.21
Chosen to Hit Life-Cycle:	α	β	Ψ	Ξ	ϕ	$\hat{\phi}$			
	0.8875	0.9175	2,550	1.60	0.06	0.034			

The baseline model parameters are shown in Table 1. The model is annual. We interpret the first period of life as age 25.[21] Households work for $J_y = 35$ years (between 25 and 59) and are retired for $J_o = 25$ years (between 60 and 84). We set the interest rate $r = 2.4\%$.[22] In our baseline calibration, we use a coefficient of relative risk aversion σ equal to 2.[23]

We assume that our permanent house price shocks $x_t \sim N(\mu, \sigma_P)$. House price movements in our model should be interpreted as aggregate shocks since they affect both the price of a household's existing house but also the price of any new house that household might purchase. As such, we calibrate our house price process by setting $\mu = .012$ and $\sigma_P = .0459$ to match the annual standard deviation and real growth rate of aggregate house prices in FHFA data.[24] In Section 5.2 we show that instead calibrating to match the larger standard deviation of house prices observed within highly disaggregated census tracts has little effect on our results.[25]

We choose a depreciation rate of housing $\delta = 2.2\%$ to match the depreciation rate in BEA data from 1960-2014. The collateral constraint parameter θ determines the minimum mortgage down payment, and we choose a value of 0.2 in our baseline calibration.[26] We also set $F = 0.05$. This transaction cost is equal to the value of housing adjustment costs calibrated in Díaz and Luengo-Prado (2010) and is close to the adjustment costs of 0.0525 estimated in Berger and Vavra (2015) for a broad measure of durable spending. In addition, we show below that our conclusions are not particularly sensitive to changes in the size of this cost.

The working age income process has a life-cycle and a transitory component. The life-cycle component is chosen to fit a quadratic regression of yearly earnings on age in the PSID as in

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[21]We begin the model at this age in order to abstract from complications with schooling decisions.

[22]We target interest rates from 1990-2000, which we view as the steady-state for our simulations but results are not sensitive to the level r.

[23]Using other reasonable values of σ did not substantively change our conclusions.

[24]This data contains nominal house prices from 1991-2016. We compute real house price growth deflating by the CPI. Deflating by the PCE or GDP deflator delivers slightly larger growth rates. Using alternative house price series from Corelogic or Case-Shiller also delivers similar parameter values.

[25]There are nearly 70,000 census tracts, and each tract typically contains only 4,000 households, so they are more disaggregated than the 45,000 zip codes in the U.S.

[26]In reality, many mortgages originate with down payments less than 20%. Using a lower θ amplifies the size of consumption responses.

Kaplan and Violante (2010). Following Floden and Lindé (2001), the temporary component z follows an AR1 process with autocorrelation $\rho_z = 0.91$ and standard deviation $\sigma_z = 0.21$ to match PSID earnings statistics (after removing life-cycle components). In retirement, households receive a social security income payment which is modeled as in Guvenen and Smith (2014).

We choose the remaining parameters jointly to match life-cycle profiles of housing wealth, non-housing wealth and homeownership in the data. Namely, from the 2001 Survey of Consumer Finances (SCF) we compute average housing wealth and average liquid wealth net of debt for households in 9 age bins (25-29, 30-34, ..., 60-64, 65 and over).[27] Our model is very stylized for retired agents since they face no sources of risk. Therefore, we focus our calibration and predictions on working-age agents. Our notion of liquid wealth net of debt in the SCF excludes retirement accounts for agents before retirement, but includes them for agents above age 60. In the model, we assume that retirement accounts take the form of a lump sum transfer at retirement, which is calibrated to equal a fraction Ξ of labor income prior to retirement.

We initialize the model by giving age 25 agents housing, liquid assets and income to match the distribution of age 23-27 households in the 2001 SCF. We then choose the parameters $\alpha, \beta, \Psi, \Xi, \phi$ and $\hat{\phi}$ to minimize the quadratic distance between housing, liquid wealth and homeownership by age bin in the data and the corresponding values generated by the model. We target liquid wealth rather than total non-housing wealth because this delivers MPCs which are more in line with empirical estimates. This is consistent with the observation in Kaplan and Violante (2014) that many households are "wealthy-hand-to-mouth". While it would be desirable to separately model liquid and illiquid wealth in addition to the choice of housing, this would substantially complicate the analysis. The majority of non-housing illiquid wealth is held in retirement accounts, which have large withdrawal penalties prior to retirement but become fully liquid after retirement. Thus, we believe that our calibration strategy reasonably matches the fraction of wealth that can be easily accessed both prior to and after retirement.[28]

Figure 1 shows the fit of the calibrated model in terms of average housing wealth (top panel), average liquid wealth net of debt (middle panel), and homeownership (bottom panel), by age bin.[29] Blue circles are model predictions and red squares are 2001 SCF data. Despite its simplicity the model delivers a reasonable fit, the main discrepancy being a homeownership rate

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[27]More specifically, following Kaplan and Violante (2014), we define liquid wealth net of debt in the data as the sum of cash, money market, checking, savings, and call accounts as well as directly held mutual funds, stocks, bonds and T-bills, net of credit card and mortgage debt and pick this to match net liquid assets in the model. For retired households we also include retirement accounts in liquid assets. Note that we subtract mortgage debt since households can borrow frictionlessly against housing in the model, so a household with the same financial assets but less mortgage debt has more ability to smooth consumption. Housing wealth in the data is defined as the gross value of primary residences, other residential real estate and nonresidential real estate, and is matched to H in the model. In order to normalize the data and model, we divide liquid assets net of debt and housing wealth by the overall average income of age 25-59 year old households.

[28]Nevertheless, targeting total wealth rather than liquid wealth still produces large elasticities.

[29]The point for the age bin 65 and over is plotted at age 70.

Figure 1: Life-cycle Calibration: Model vs. Data

The data come from the SCF 2001. See footnote 27 for the definitions of liquid assets and housing values.

which is slightly too large near retirement and too much debt in the mid 30s and 40s. Overall, with six parameters we are able to closely fit a total of twenty seven life-cycle moments.

Table 2 shows that our model also reasonably matches a variety of untargeted wealth and housing statistics in the cross-section for both homeowners and renters from the SCF. In particular, we show that our model roughly reproduces the distribution of housing values for owners, LTV ratios, liquid assets for both owners and renters and total net worth for both owners and renters.[30] The richest renters in the model are poorer than in reality, but this is because we have no idiosyncratic preferences for renting vs. owning so all households in the model choose to own once they become rich enough. However, since, as we show below, renters of all wealth levels have zero consumption responses to house price movements, this modest discrepancy is unimportant for our conclusions. Overall, we conclude that our model is a reasonable fit to the wealth distribution and so we have some confidence in using the model to assess the quantitative implications of house price shocks for consumption.

2.3   Consumption Elasticities

Our model is thus able to match a variety of facts in the cross-section as well as over the life-cycle. What are its implications for consumption responses to house price shocks?

Overall, we find that consumption responses to house price shocks in this model are large. For example, the model delivers an aggregate elasticity of 0.23 for working age households in response to a two standard deviation increase in house prices.[31] This number is in line with

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[30]In the model liquid assets and net worth are identical for renters since all non-housing assets are liquid, but liquid assets and total net worth for renters in the data are also extremely similar.

[31]We discuss how implications change with the size of house price shocks below. We focus on working age

Table 2: Untargeted Moments, Selected Characteristics of Wealth Distribution

	Data	Model		Data	Model
Housing Values/Mean Income; Homeowners			LTV Ratio; Borrowers		
10th percentile	0.80	1.42	10th percentile	0	0
25th percentile	1.42	1.88	25th percentile	0.17	0.39
50th percentile	2.34	2.60	50th percentile	0.53	0.64
75th percentile	3.71	3.51	75th percentile	0.75	0.72
90th percentile	5.50	4.44	90th percentile	0.89	0.76
Liquid Assets net of debt/Mean Income; Homeowners			Liquid Assets/Mean Income; Renters		
10th percentile	-2.74	-2.16	10th percentile	-0.058	0
25th percentile	-1.80	-1.72	25th percentile	0	0
50th percentile	-0.92	-1.29	50th percentile	0.005	0.003
75th percentile	-0.07	-0.88	75th percentile	0.049	0.016
90th percentile	0.22	0.52	90th percentile	0.226	0.063
Net Worth/Mean Income; Homeowners			Net Worth/Mean Income; Renters		
10th percentile	0.21	0.37	10th percentile	-0.033	0
25th percentile	0.56	0.54	25th percentile	0	0
50th percentile	1.44	0.95	50th percentile	0.011	0.003
75th percentile	2.92	2.09	75th percentile	0.121	0.016
90th percentile	4.67	4.62	90th percentile	0.566	0.060

Each sub-panel orders households by the labeled statistic and displays various percentiles. See footnote 27 for the definitions of liquid assets and housing values. Liquid assets are net of debt (including mortgage debt for homeowners). The LTV ratio is computed as the value of mortgage debt divided by housing values. Net worth is the sum of liquid assets (net of all debt) plus housing values. For consistency with our other analysis, statistics in this table are restricted to working age households ages 25-59. Following Kaplan et al. (2014) and Gorea and Midrigan (2017), we trim the upper tail of the income distribution in the SCF. Kaplan et al. (2014) trim the top 5% while Gorea and Midrigan (2017) trim the top 20%. We use an intermediate value of 10%, but results are similar when using alternative thresholds.

empirical estimates summarized in the introduction and is large relative to elasticities delivered by PIH models. For example, in Appendix A.1, we show that a similarly calibrated PIH model delivers an elasticity of only 0.047.

There is also substantial household heterogeneity: the standard deviation of elasticities across households is 0.25 and the interquartile range is 0.32. In the following sections we explore this heterogeneity along many dimensions such as age, income, liquid wealth, house size and rental status. However, we defer these results until after deriving our rule-of-thumb formula in the next section, since we use this formula extensively in their interpretation.

Why are consumption elasticities in this model so large relative to PIH intuition that says effects should be small? To understand both the large aggregate response as well as variation in responses across households, we turn now to the derivation of our primary analytical result.

households for reasons discussed above, but if we include all households, we find a similar value of 0.2

3 Frictionless Adjustment: an Analytical Result

We now turn to a simplified version of the model and derive an analytical result that helps us understand the consumption elasticities computed in the last section. In a version of the model with frictionless housing adjustment, the individual consumption response to a permanent house price shock is given by a simple formula: the marginal propensity to consume out of temporary income shocks times the value of the housing stock. After deriving this result in the simplified model, we return to the more realistic model with adjustment costs and show that, although the formula no longer holds exactly, it gives a good approximation, so we can use it as a rule of thumb for understanding consumption responses.

The only changes from our baseline model are that we make housing costless to transact and we shut off the rental market. In particular, we set $F = 0$, so housing adjustment is frictionless. We keep the assumption that house prices follow a geometric random walk with drift: $P_t = x_t P_{t-1}$, where x_t is an i.i.d. shock with arbitrary distribution and $E[x_t] = e^\mu$. Importantly, we continue to assume CRRA preferences with unit elasticity of substitution between H and C.

To set the stage for our result, we represent the household problem recursively. Define total wealth $W_{it} \equiv (1 - \delta)P_t H_{it-1} + (1 + r)A_{it-1}$. The household's Bellman equation is then

$$V\left(W_{it}, z_{it}, j_{it}, P_t\right) = \max_{C_{it}, H_{it}, A_{it}} U\left(C_{it}, H_{it}\right) + \beta E\left[V\left(W_{it+1}, z_{it+1}, j_{it} + 1, x_{t+1}P_t\right)|z_{it}\right] \quad (2)$$

$$\text{subject to} \quad C_{it} + P_t H_{it} + A_{it} = Y_{it} + W_{it},$$
$$W_{it+1} = (1 - \delta)\, x_{t+1} P_t H_{it} + (1 + r)\, A_{it} \quad \forall x_{t+1},$$
$$(1 - \theta)(1 - \delta)\, x_{t+1} P_t H_{it} + (1 + r)\, A_{it} \geq 0 \quad \forall x_{t+1}.$$

The bequest motive gives the terminal condition

$$V(W_{it}, z_{it}, J + 1, P_t) = \frac{\Psi}{1 - \sigma}\left(\frac{W_{it}}{P_{Xt}}\right)^{1-\sigma}.$$

We are now ready to prove our main analytical result.

Proposition 1 *In the model with no adjustment costs, the individual response of non-durable consumption to the permanent house price shock x_t is*

$$MPC_{it} \times (1 - \delta)\, P_{t-1} H_{it-1}, \quad (3)$$

where MPC_{it} is the individual marginal propensity to consume out of transitory income shocks.

Proof. First, we prove by induction that the value function can be written as

$$V\left(W, z, j, P\right) = P^{-(1-\sigma)(1-\alpha)} v\left(W, z, j\right),$$

for all (W, z, j, P), where for $j < J + 1$ the function v satisfies the Bellman equation

$$v(W, z, j) = \max_{C, \tilde{H}, A, W'} U(C, \tilde{H}) + \beta E\left[x^{-(1-\sigma)(1-\alpha)} v\left(W', z', j+1\right)\right],$$

$$\begin{aligned}
\text{subject to} \quad & C + \tilde{H} + A = Y(s) + W, \\
& W' = (1 - \delta) x\tilde{H} + (1 + r) A, \\
& (1 - \theta)(1 - \delta) x\tilde{H} + (1 + r) A \geq 0, \\
& z' = \rho z + \epsilon.
\end{aligned}$$

The property holds immediately for $V(W, z, J+1, P)$ since $P_{Xt} = \Omega P_t^{1-\alpha}$. Next, we prove that if the property holds for $V(W, z, j+1, P)$ then it holds for $V(W, z, j, P)$. Rewrite the Bellman equation (2) in terms of the variable $\tilde{H}_t = P_t H_t$. The property $U(C, \tilde{H}/P) = P^{-(1-\sigma)(1-\alpha)} U(C, \tilde{H})$ and the induction hypothesis imply that $P_t^{-(1-\sigma)(1-\alpha)}$ can be factored out of the objective function without affecting the optimization problem. This completes the induction step.

Let $C(W, z, j)$ denote the policy function associated with the last optimization problem and notice that, by construction, it is independent of the current price P. We can then derive two versions of the result. For infinitesimal house price shocks the consumption response is:

$$\frac{\partial C\left(W_{it}, z_{it}, j_{it}\right)}{\partial W} \times (1 - \delta) P_{t-1} H_{it-1},$$

For a discrete house price shock $\Delta P / P_{t-1}$ the response is:

$$\frac{C\left(W_{it} + \Delta W, z_{it}, j_{it}\right) - C\left(W_{it}, z_{it}, j_{it}\right)}{\Delta W} \times (1 - \delta) P_{t-1} H_{it-1},$$

where $\Delta W = (1 - \delta) H_{it} \Delta P$. In both expressions, the first term is equal to the MPC. In the first case it is the local MPC. In the second case it is the MPC out of discrete (transitory) income changes, which takes into account the non-linearity of the consumption function and its interaction with the size of the income shock. ∎

Consumption responses to house price changes can be measured in different ways. Expression (3) gives the response in dollar terms to a percentage increase in house values and has the advantage that it can be aggregated over individuals. On the other hand, the elasticity of consumption to house prices η_{it} has the advantage of being unit free. We generally focus on

elasticities throughout the paper, which immediately follow from our previous result:

$$\eta_{it} = MPC_{it} \times \frac{(1-\delta)\,P_{t-1}H_{it-1}}{C_{it}}.$$

The simple formula in Proposition 1 contains two endogenous objects, so it is not a closed form solution. Its primary advantage is in providing insight into how endogenous forces shape the sensitivity of an economy to house price shocks. In particular, house price shocks will have bigger effects when MPCs are larger, when gross housing wealth is larger, and when there is a stronger positive correlation between MPCs and housing values in the economy. The proposition also tells us that any changes in the model's parameters *only* affect consumption responses to house price shocks through their effects on MPCs and housing values. In this sense, MPC $\times$ PH is a sufficient statistic for the model-implied response of consumption to house price shocks.

While formula (3) may at first sight appear tautological, the non-obvious content arises because we are considering the consumption response to a change in house prices which, in general, has additional effects on top of changing the value of housing holdings. In particular, when house prices increase, there are four effects: (1) the substitution effect that makes the consumer substitute away from housing—which is now more expensive—towards other goods; (2) the ordinary income effect, which makes the consumer poorer because the implicit rental cost of housing is higher today and in all future dates; (3) the endowment income effect, which makes households richer in proportion to their initial holdings of housing; (4) the collateral effect, which implies that—for given housing choices—households can borrow more. The proposition shows that effects (1), (2) and (4) cancel out, so we are left with the endowment income effect (3). In Appendix A.2 we formally define these effects, extending the textbook definition of income and substitution effects to the dynamic, incomplete market economy analyzed here. In Appendix Figure A-1 we plot the four effects for a calibrated version of the model with frictionless housing adjustment to illustrate that each effect is individually large but that three exactly cancel.

When the collateral constraint is not binding the intuition for the result comes straight from Cobb-Douglas preferences under which the substitution effect and the (ordinary) income effect cancel out. When the collateral constraint is binding the intuition for the result is more subtle and has to do with the fact that when choosing the optimal ratio of housing to non-durable consumption, consumers internalize the fact that housing has the extra marginal benefit of relaxing the collateral constraint. When we include that benefit in the consumer's marginal calculations, it is the combined substitution and collateral effect which then cancel with the income effect, again due to Cobb-Douglas preferences.

The absence of adjustment costs in housing is clearly also important for the result above. Due to that assumption, one can think of a house price increase as leading to an immediate sale of housing to convert the capital gain to liquid wealth, followed by spending the liquid wealth

on consumption and on housing services as dictated by the appropriate marginal propensities to spend out of liquid wealth (with all other price effects muted because of Cobb-Douglas preferences). In the rest of the paper, we shall see that this assumption can be relaxed substantially but the result remains approximately true. The reason is that even if households do not sell their houses they still have room to respond by adjusting their liquid wealth position, e.g., by running down liquid holdings or borrowing more.

Another important assumption behind the proposition is that we focus on permanent shocks to house prices. If shocks are not permanent, then they also change the expected future path of house appreciation or depreciation. Even with frictionless housing adjustment and Cobb-Douglas preferences, changes in expected appreciation or depreciation will generate additional consumption effects by altering the user-cost-of-housing and so changing the choice of housing vs. non durables. We explore these quantitative effects in Section 7.

Our result also holds in a PIH version of the model in which income uncertainty and borrowing constraints are eliminated (see Appendix A.1). The low consumption responses in the PIH model can then be interpreted in the light of formula (3) and arise from the fact that no income uncertainty and no borrowing constraints lead to low MPCs for all households.

Another way to interpret low responses in the PIH model is that the ordinary income effect and the endowment income effect roughly cancel out for consumers with stable levels of housing, reflecting the intuition mentioned in the introduction. The collateral effect is absent, as borrowing is unconstrained. This leaves only the substitution effect which tends to be small.[32] In contrast, in environments with income uncertainty and borrowing constraints, like our baseline model, the endowment effect is larger than the ordinary income effect, because a permanent increase in house prices leads to an immediate increase in financial resources while the increase in implicit rental costs occurs mostly in the future. House price movements remain neutral for a household's lifetime budget constraint, but borrowing constraints mean that consumption responds more to current than future income, so the endowment effect dominates.

4 Understanding Elasticities in the Baseline Model

While our simple formula only holds exactly with frictionless housing adjustment, we now show that it remains highly informative in our baseline model with adjustment costs and rent and so serves as a useful rule of thumb in this more general model. We begin by comparing the elasticity predicted by the rule of thumb to the actual elasticity over the model's entire state space. To do this, for each combination of household states realized in the model, we compare the true elasticity to the elasticity predicted by the rule of thumb. In order to reduce simulation error and to produce a readable scatter plot, we pool households into 625 bins dividing the state space into

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[32]Sinai and Souleles (2005) eliminate substitution effects by fixing housing, leading to zero responses.

Figure 2: Accuracy of the Rule of Thumb over the State Space
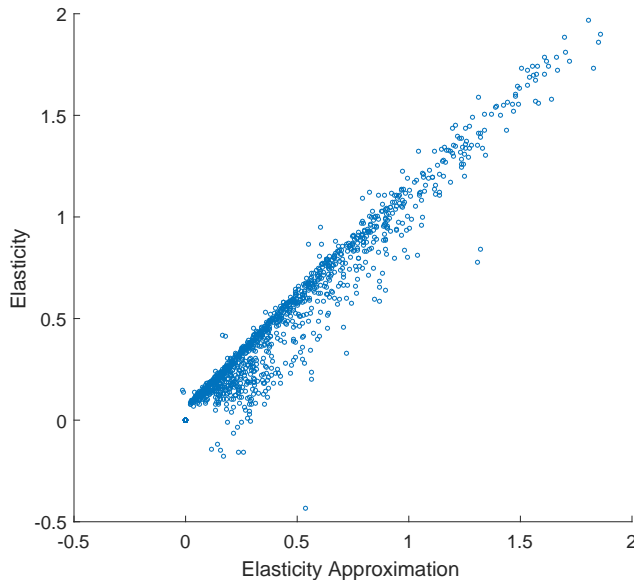
This figure shows how the actual elasticity and the approximate elasticity vary over the endogenous distribution of states. Each point represents a bin of household states and plots the actual elasticity for that household state against the elasticity implied by the rule-of-thumb formula. The R^2 of a linear regression is 0.95.

quintiles by assets, housing, age, and income and then taking the average of the actual elasticity and of the approximate elasticity in each bin.[33] Figure 2 shows that the rule-of-thumb formula is very accurate by displaying a scatter plot of the true elasticity against the approximation for each point in the state-space. The R^2 from a linear regression of the actual elasticity on the approximation is 0.95, meaning that the approximation formula formally explains 95% of the variance in actual elasticities across households.

In the rest of this section, we look at how elasticities vary across the state space and use our approximation to interpret this variation. Figure 3 shows how elasticities (actual and approximate) vary along one dimension of the state space at a time. For example, the upper left sub-figure in each panel divides the sample into twenty ventiles by income and plots elasticities in each bin.[34] The upper right sub-figure divides the sample into twenty housing bins, the lower right panel shows results for each age from 25-60 and the lower left panel shows results dividing the sample into 20 bins by "voluntary equity", which is a convenient transformation of assets A. In particular, voluntary equity is defined as $Q \equiv A + (1 - \theta) \frac{1-\delta}{1+r} PH$. As discussed in A.4, since the borrowing constraint changes with the value of PH, this is a more relevant summary statistic of liquidity constraints than is A alone. Panel (a) shows this for all households while Panel (b) restricts to homeowners.

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[33]The formula is very accurate also when we compute it for each household-year observation, without grouping in bins. In that case, we get an R^2 of 0.934.

[34]Note that we condition only on one-state variable at a time, but since several of these states are endogenous, they will also vary across bins. For example, older households also have more housing.

Figure 3: Elasticities Along Various Dimensions of State-Space
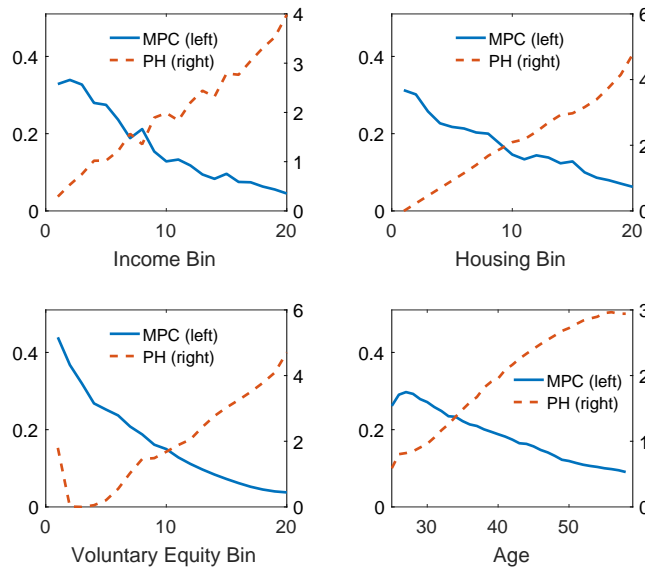
(a) All households
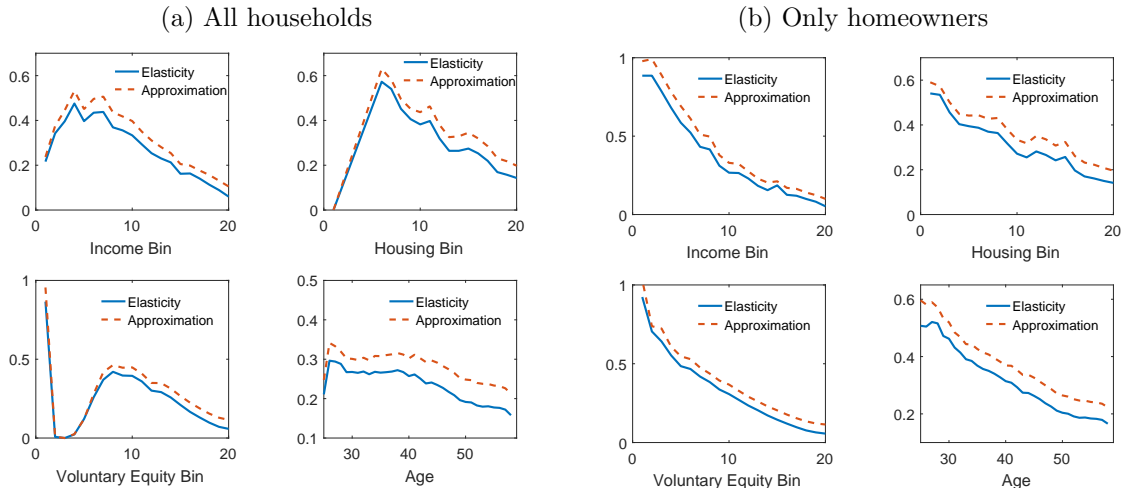
(b) Only homeowners

This figure shows how the true elasticity and the approximation vary with each dimension of the individual state-space in our baseline model. Panel (a) shows these results for all households while Panel (b) shows results only for homeowners. Separately for each state except age, we divide the total sample of household observations into 20 equal sized bins. We then calculate the average elasticity as well as the average value of the rule-of-thumb formula for each bin and plot these values against the index of the bin. We include only age 25-59 households in these calculations. Results are similar when instead calculating the median elasticity or the aggregate elasticity in each bin or when including households of all ages. Since age is already discretized, we compute results for each household age from 25-59 rather than binning results by age.

Focusing first on panel (b), which restricts attention to homeowners, it is clear that elasticities are declining with income, assets (measured as voluntary equity), housing and age. The patterns in panel (a) are more complicated and exhibit non-monotonicity but can be readily understood using our rule-of-thumb formula. In particular Figure 4 shows how the two components of our rule-of-thumb formula, MPC and PH vary with different states.

This figure makes it clear that elasticities are non-monotonic in income because housing values fall rapidly as income declines. More specifically, low income households are much more likely to choose to rent rather than own, and our rule-of-thumb formula shows that renters have *zero* response to house price movements.[35] One might think that house price increases would lower renters' consumption since they induce negative income effects with no offsetting endowment effect. However, this is not the case, since income and substitution effects exactly cancel with Cobb-Douglas preferences: renters respond to house price increases by living in smaller houses, not by reducing consumption. Since they also have no collateral effect, renters' consumption does not respond to house prices. It is interesting to note that our model is thus consistent with the empirical findings in Campbell and Cocco (2007) and Guiso et al. (2005) that renters of all ages exhibit small responses of consumption to house price movements.

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[35]Here we define renters based on start-of-the-period status. Households who begin as owners and switch to renting do have positive elasticities to house price shocks, but this is again understood through our formula since these households have a positive value of housing endowment. Since we concentrate on age 25-59 households, very few switch from owning to renting and so these households are unimportant quantitatively.

Figure 4: MPC and H (Including Renters and Homeowners)

This figure shows how the MPCs and housing values vary with each dimension of the individual state-space in our baseline model. These results are computed including all households (both renters and owners) of ages 25-59. The construction parallels that in Figure 3, so see those figure notes for additional details.

The steep elasticity decline in the first few voluntary equity bins in Figure 3 can be understood similarly: the first few bins contain highly levered homeowners with large MPCs and elasticities while the next bins contain renters with zero elasticities, who have little liquid wealth but also no debt. Similarly, the relatively flat age profile of elasticities reflects the fact that MPCs decline substantially with age, while homeownership rates and housing values increase substantially with age, and that these effects roughly offset each other.

All of the results thus far are computed in response to a two standard deviation increase in house prices. Figure 5 shows how the aggregate elasticity of consumption to house prices and the accuracy of the approximation varies with the size of house price shocks. Clearly, the true elasticity declines with the size of house price shocks. This occurs because the presence of borrowing constraints induces non-linearities in MPCs. Positive shocks relax borrowing constraints and reduce the MPC while negative shocks instead tighten borrowing constraints and increase the MPC. However, as long as we calculate the MPC using the correct shock size, then the rule of thumb remains accurate.[36] The fact that MPCs are non-linear in models with borrowing constraints does not affect our rule of thumb, it just means that consumption responses to wealth shocks will depend on the size and sign of the shocks. However, these non-linearities are relatively small for typical house price shocks. The standard deviation of house price shocks is 4.59% in FHFA data so the elasticity of consumption on impact is between 0.23 and 0.3 for most house price shocks. Thus, our model delivers asymmetries to house price increases and

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[36]See the proof of Proposition 1 for the appropriate definition of MPC.

Figure 5: How Does Actual Elasticity and Approximation Vary with Size of House Price Shock?
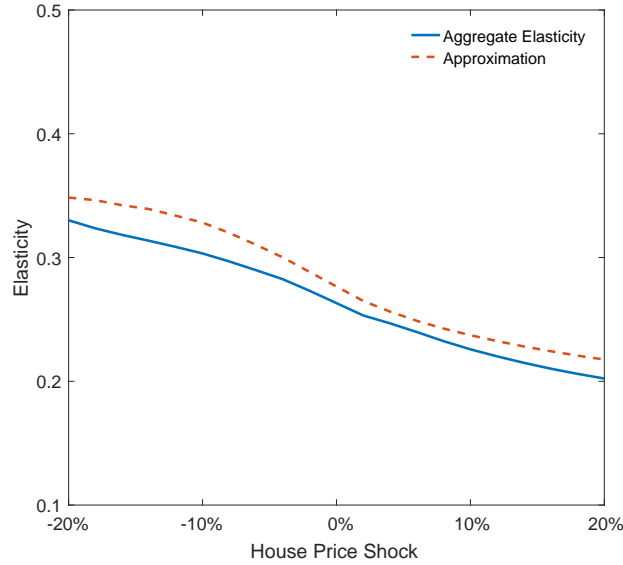
This figure shows how the true elasticity and approximation vary with the size of the house price shock in our baseline model. Results are computed including all households (both renters and owners) of ages 25-59 as the shock size varies from -20% to 20%. The standard deviation of house price shocks in our calibration is 4.59%.

decreases, but these are much smaller than those in Guerrieri and Iacoviello (2014)'s representative agent model because whether or not borrowing constraints bind in our model is largely determined by idiosyncratic shocks rather than aggregate house price movements. House price shocks do move some households in and out of borrowing constraints in our environment, but unless these shocks are extremely large, these effects are fairly modest.

How are elasticities and the accuracy of approximations affected by other model features and non-linearities? Figure 6 shows the effect of first eliminating the rental option and then eliminating fixed costs of housing adjustment. We recalibrate these models following the same strategy discussed in Section 2.2 with the exception of no longer targeting homeownership rates. The fit and parameters are shown in Appendix A.3. After recalibrating the models, we again compute the true elasticity on impact to a two-standard deviation house price increase.

Solid lines in Figure 6 show the true elasticity in the model as a function of age and dashed lines of the same color show the approximation from our rule of thumb.[37] The rental option has little effect on the accuracy of our rule-of-thumb formula, but has large effects on elasticities: eliminating the option to rent raises the aggregate elasticity from 0.23 to 0.39. Our MPC × PH formula helps to provide intuition for why the elasticity is so much lower in our baseline model with renters than in a model with no rental option. First, since renters do not own a house, their consumption does not respond to house price movements. Hence, if we match the homeownership

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[37]Note that we do not plot an approximation line for the model with no fixed costs, since the rule-of-thumb formula holds exactly. For expositional purposes we show only results by age, but conclusions are similar when cutting along other dimensions of the state-space.

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Figure 6: Effects of Rental Option and Fixed Costs
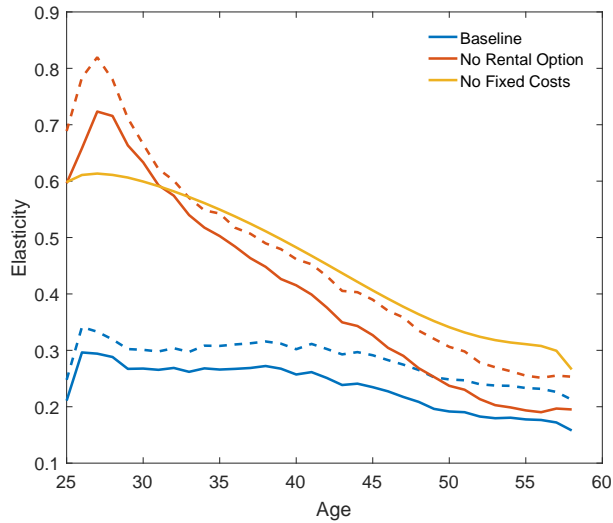
This figure shows how the true elasticity (solid line) and the approximation (dashed line) vary over the life-cycle for three different models: our baseline specification (blue), a model with no rental option (red) and model with no fixed costs on housing transactions where the formula holds exactly (yellow).

rate in our data set of roughly 70%, the average elasticity of consumption to house prices will mechanically fall, even if all households are otherwise identical. However, this mechanical effect cannot explain the entire increase from 0.23 to 0.39. The rest of the difference occurs because households are not identical and home ownership is not randomly distributed in the population. Households with high MPCs tend to choose to rent, given that they are closer to being constrained and thus prefer liquid wealth over illiquid housing. This selection effect into renting explains the remainder of the elasticity differences between the two models.

In contrast to the rental option, eliminating the fixed cost of housing adjustment has almost no effect on consumption responses to house price movements. Elasticities are slightly lower early in life and slightly higher later in life, but the overall aggregate elasticity is identical at 0.39 in the model with and without fixed costs. Thus, we conclude that modeling rent is important for getting consumption responses to house price shocks correct. In contrast, fixed costs matter for matching the empirical frequency of housing adjustment and homeownership rates but have little direct effect on consumption responses to house prices. As we show now this is explained in part by the fact that households can borrow against their housing equity, which increases the liquidity of housing wealth even in the presence of transaction costs on buying and selling.

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5 Robustness and Extensions

5.1 Long-Term Debt

So far we have modeled borrowing as one-period loans subject to a collateral constraint. We now introduce long-term debt into the model in order to assess its effects on consumption elasticities and the accuracy of our rule-of-thumb formula. This is important for several reasons. First, we want to assess the extent to which realistic frictions on home-equity extraction affect our conclusions. With frictionless one-period debt, households can adjust their borrowing costlessly every period, while in reality there are costs to home-equity extraction which make housing wealth illiquid. Second, and more importantly, Ganong and Noel (2016) present empirical evidence that underwater borrowers respond little to mortgage debt relief which does not affect households' current budget constraints. The implication is that house price shocks may not be equivalent to cash payments when households are underwater or cannot easily refinance. Our baseline model with one-period debt cannot capture these effects since households must satisfy the collateral constraint period by period.

While we do not attempt to model all the details of fixed-rate mortgages and home-equity loans, we introduce three important elements of U.S. mortgages: 1) equity extraction costs, 2) collateral constraints which only bind at origination and 3) amortization.[38]

We model equity extraction costs by making the following assumption: if a household chooses positive holdings of the risk-free asset A_t or chooses any $A_t \geq A_{t-1}$ it can do so at no cost; but if the household chooses a negative A_t smaller than A_{t-1}—i.e., if it increases its debt level—it must pay a fixed cost F^{refi} proportional to the current value of the house.[39] We pick this refinancing cost to match the frequency of refinancing observed in Bhutta and Keys (2014), which implies a fixed cost of 0.012. In our baseline model, roughly 30% of households increase debt each year while with the refinancing cost, this number falls to a realistic 10%.[40] Thus, refinancing costs substantially reduce the number of households who extract equity.

U.S. mortgages are also long-term amortizing loans with collateral constraints that only bind at the time of origination: when house prices rise and households gain equity, households have the option to extract this equity and borrow more. In contrast, when house prices fall, lenders cannot force households to put up additional collateral. That is, households are not forced to repay their mortgage faster, even if their loan-to-value ratios go above the maximum allowed for new loans. Since interest rates are constant in our model, long-term mortgages with amortization can be introduced with a simple change to the collateral constraint for households

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[38]Note that since interest rates are fixed in our model, long-term mortgages in our environment are equivalent to the fixed rate mortgages prevalent in U.S. borrowing.

[39]Versions of the model with fixed numeraire costs instead of costs proportional to the house value produce extremely similar results.

[40]Our model has no distinction between forms of equity extraction, so we match total shares.

who are not adjusting their stock of housing. In particular, when refinancing, households face the previous collateral constraint in (1):

$$-A_{it} \leq (1 - \theta)\frac{1-\delta}{1+r}P_t H_{it},$$

but when not refinancing, they instead face the constraint:

$$A_{it} \geq \begin{cases} \chi A_{it-1}, & \text{if } A_{it-1} < 0 \\ 0, & \text{if } A_{it-1} \geq 0 \end{cases}$$

where χ is the required minimum amortization rate on mortgages, which, following Gorea and Midrigan (2017) we set equal to 0.969 to match the half-life of a 30-year mortgage. Intuitively, when not refinancing, households with negative A_{it} must pay down their debt at at least rate χ but can also prepay costlessly. Households with positive A_{it} can save or dis-save costlessly but must pay the fixed cost of refinancing a mortgage in order to move to negative A_{it}.

In our baseline model, assets and debt are both fully liquid so that, as usual, only net positions are well-defined. Introducing long-term debt and liquid assets typically means that gross-positions become relevant, which substantially complicates the computational problem by introducing a second endogenous state-variable. Fully introducing this more complicated asset structure would substantially increase the computational burden and thus require eliminating other features of the model which we think are essential for our analysis.[41] We instead substantially simplify by assuming that households always exhaust liquid assets before taking on any mortgage debt. This allows us to introduce long-term debt without adding any new state-variables, but it means that no households with mortgage debt in the model have any liquid assets. As shown in the bottom panel of Table A-4, this is a reasonable description of homeowners in the bottom half of the liquid wealth distribution, but it is clearly counterfactual for homeowners between the 50th and 85th percentile of the liquid wealth distribution. This is why we do not use this setup in our baseline model, but we nevertheless think it is quite useful for getting some sense of how long-term debt changes elasticities and the accuracy of our rule-of-thumb formula. If anything, it is likely to overstate the extent to which the rule-of-thumb

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[41]Many models introduce complicated asset structures of this form but then simplify in some important dimensions relative to our model. For example, Ganong and Noel (2016) and Gorea and Midrigan (2017) have no house price shocks, which are the heart of our paper, and the former does not model housing choices. Beraja et al. (2017) assume an exogenous fixed housing size as do Campbell and Cocco (2015) except when defaulting. Greenwald (2016) works with a representative borrower model and so abstracts from heterogeneity in income shocks, MPCs and housing values. Kaplan et al. (2016) work with a general equilibrium model with richer mortgages than our own but then limit houses to one of six sizes for computational tractability, which limits the strength of substitution effects. Wong (2016) also features an extremely rich quantitative environment but does not allow for separate refinancing and moving decisions and computational tractability requires working with a 2-state income process and small number of house price values, limiting the MPC heterogeneity which we show is important for house price effects on consumption.

formula fails for high leverage households, because these households will have higher MPCs to income shocks in the model than in reality since they hold no liquid assets in the model. For the same reason, highly levered households in the model have no way to respond to house prices.

Aside from the refinancing cost discussed above, we recalibrate this model following exactly the same strategy as in Section 2.2. The fit is shown in Appendix Figure A-7, parameters in Table A-3 and additional untargeted moments in Table A-4. Figure 7 shows the accuracy of the rule-of-thumb formula in this model with long-term debt with costly refinancing. Overall, the formula is mildly less accurate, with the R^2 falling from 0.95 to 0.90, but this means it still explain 90% of the variation in true elasticities over the state-space in the model.

Figure 7: Accuracy for Individual Points in State-Space
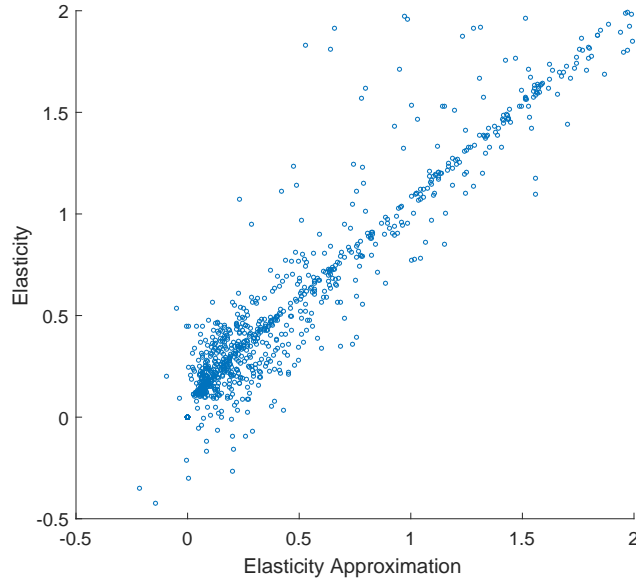
This figure shows how the true elasticity and the approximation vary over the entire endogenous joint-distribution of the state-space in a model with long-term debt. Each point represents a particular combination of all the endogenous household states and shows the true elasticity for that household state compared to that implied by the rule-of-thumb formula. The R^2 for a simple linear regression is 0.90.

Why does frictional long-term debt affect the accuracy of the rule-of-thumb formula and where is the formula least accurate? This can be seen most clearly in Figure 8, which plots the true elasticity and approximation as a function of leverage for the baseline model with frictionless one-period debt as well as the model with long-term debt and refinancing costs. The accuracy of the formula is somewhat reduced for lower leverage households since the presence of refinancing costs mean that households do not respond to house price shocks exactly as predicted by their pure endowment effects. However, the quantitatively important breakdown of the formula clearly occurs for households with leverage greater than the maximum allowed at origination $(1-\theta)\frac{1-\delta}{1+r}$, which is shown as the vertical dashed line in the figure. This occurs exactly because households that are far from the required downpayment for refinancing are

unable to borrow and increase consumption in response to house price increases.[42] However, these highly leveraged households have no liquid assets in our model and so have high MPCs and thus large predicted elasticities under the rule of thumb. Thus, the presence of long-term debt and the ability for borrowers to remain underwater breaks the equivalence between house price shocks and liquid income shocks. This same point holds in the model of Ganong and Noel (2016) and is used to explain their empirical finding that the consumption of highly leveraged households does not respond to mortgage debt forgiveness. Their model does not include house price shocks but features a richer asset structure together with strategic default, so the fact that we reach essentially identical conclusions is reassuring.

Figure 8: How Does Accuracy Vary with Leverage?
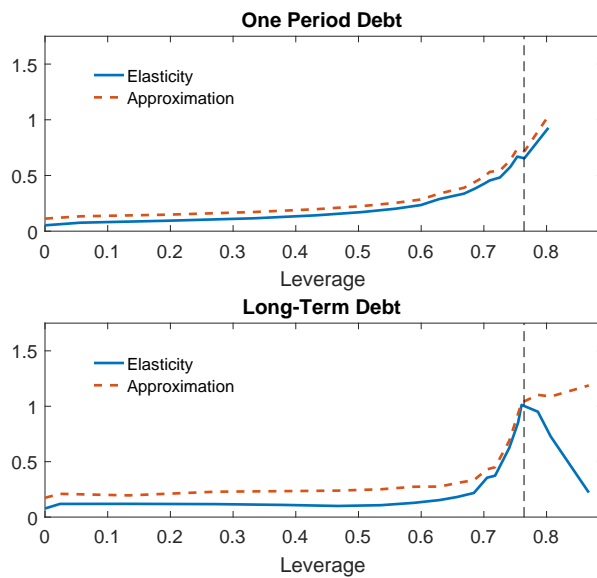
This figure shows how the true elasticity (solid line) and the approximation (dashed line) vary with leverage for our baseline model (top panel) and for our extended model with long-term debt (bottom panel). The maximum LTV at origination is shown as the vertical dashed line.

Although our rule-of-thumb formula clearly breaks down for households who are unable to refinance, the previous Figure 7 shows that this has little effect on the overall accuracy of the formula. This is because in our baseline calibration matched to the long-run behavior of the U.S. economy, there are very few households with leverage in this region. Our baseline model features stochastic house price shocks, but the presence of mortgage amortization plus modest trend growth in house prices pushes households away from this region. It is also worth noting that in the high leverage region where the rule-of-thumb formula fails, the true elasticity rapidly declines towards zero. This means that even though the rule-of-thumb no longer works in this region, we do not really need this formula in order to predict elasticities: once households become underwater, the true elasticity rapidly declines to zero. Of course, during periods of

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[42]Conversely, they are not required to put up additional collateral and reduce consumption when prices fall.

time such as the Great Recession when more households are underwater, the accuracy of the rule-of- thumb will decline. However, even during this extreme event, our rule-of-thumb formula would still apply for the typical homeowner since most homeowners were not underwater.[43]

In addition to our finding that long-term frictional debt has only a modest effect on the accuracy of our rule of thumb, it is also worth noting that its presence only reduces the true aggregate elasticity from 0.23 to 0.20. The introduction of refinancing costs and allowing households to remain underwater both reduce the true elasticity of consumption to house prices, but like housing transaction costs, these effects are not quantitatively large. Since there are few households in the very high leverage region, the presence of long-term debt and underwater borrowers has little effect on aggregates. Refinancing costs are relevant over the whole leverage distribution, but the decisions of households with the highest MPCs who contribute most to the aggregate elasticity are relatively unaffected by a moderate cost of refinancing.[44]

5.2   House Price Volatility

Our baseline model is calibrated to match the annual standard deviation of aggregate house prices in FHFA data of 4.59% since house prices in our model are aggregate. Instead calibrating house price shocks to match the larger standard deviation of house prices of 8% observed at very disaggregated census tracts has a negligible effect in our baseline model, lowering the aggregate elasticity from 0.23 to 0.22 and leaving the R^2 from a regression of the true elasticity on the rule-of-thumb approximation unchanged at 0.95. Appendix Figures A-2 and A-3 show the effects of increasing the volatility of house prices in the model with long-term debt. The R^2 falls from 0.90 to 0.87 as more volatile house price shocks push more households underwater, but clearly we can still explain the vast majority of true elasticity variation using our formula. Results in a version of the model without stochastic house prices are also similar.

5.3   Preferences and Price-Rent Ratio

Our baseline model features Cobb-Douglas preferences and the derivation of our rule-of-thumb in the version of the model with no adjustment costs relies crucially on that assumption. As discussed in the model setup, there are a range of estimates for the elasticity of substitution between housing and non-housing consumption, but the bulk of micro-oriented studies tend to

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[43]Fuster et al. (2016) show that outside of the housing crisis, very few homeowners are underwater. In 2009, just over 20% of mortgage holders are underwater. Since roughly 1/3 of homeowners own outright, this means that the peak fraction of homeowners underwater in the crisis was around 15%.

[44]This is due to extensive margin effects arising from fixed adjustment costs. These costs reduce cash-out activity substantially, but this reduction is concentrated amongst households who would have only extracted small amounts of equity with small resulting effects on consumption. Households who need to extract substantial housing equity in order to increase consumption will still do so even in the presence of adjustment costs.

support the Cobb-Douglas specification. The use of Cobb-Douglas preferences also substantially simplifies computations in our model with random walk house price shocks, as shown in Appendix A.4, since it allows us to eliminate the current house price as a state-variable. Nevertheless, since there is some disagreement over this elasticity of substitution, it is important to explore the robustness of our results to this elasticity of substitution. We do so by extending our utility function to a CES specification:

$$U\left(C_{it}, H_{it}\right) = \frac{1}{1-\sigma} \left(\alpha C_{it}^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha) H_{it}^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon(1-\sigma)}{\epsilon-1}}$$

where ϵ is the intra-temporal elasticity of substitution between non-durable consumption and housing services. We then compute results for two cases which bound typical empirical estimates, $\epsilon = 0.8$ and $\epsilon = 1.25$.[45] Raising the elasticity of substitution from 1 to 1.25 raises the aggregate elasticity from 0.23 to 0.28 and lowers the R^2 from the approximation formula from 0.95 to 0.91. Lowering the elasticity of substitution to 0.8 reduces the aggregate elasticity from 0.23 to 0.19 and actually raises the R^2 from 0.95 to 0.97. Thus, reasonable changes in the elasticity of substitution do not affect our broad conclusion that the response of consumption to house prices is large and that our rule-of-thumb is useful for predicting this response.[46]

Our baseline model also assumes a constant price-rent ratio $R_t = \phi P_t$. Like the Cobb-Douglas preferences, this assumption is necessary to eliminate house prices as a state-variable and so substantially simplifies computations, but it is again important to assess the robustness of our results on this dimension. If we make the opposite extreme assumption that R_t is fixed while P_t varies, then the aggregate elasticity rises to 0.27 and the R^2 remains high at 0.92; so if anything our baseline model likely understates consumption responses to house prices.

6   Taking the Rule of Thumb to the Data

The previous sections show that a simple rule-of-thumb formula provides a good approximation to the consumption response on impact to a permanent house price shock in a wide class of life-cycle models with uninsurable idiosyncratic income risk and borrowing constraints. We view this largely as a theoretical result that is useful for understanding the large elasticities delivered by these models. However, the rule-of-thumb formula can be measured in the data given information on MPCs by housing values. Doing so provides both an important over-identification test of our quantitative model as well as an alternative empirical measure of

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[45]For computational simplicity, we also set $\mu = 0$ in these results, but this has little effect in the baseline model when recalibrated to hit the same moments.

[46]Since this model is substantially more computationally burdensome, we first recalibrate parameters with $\mu = 0$ using our baseline model but then do not recalibrate the model as we change ϵ, which leads to slightly different life-cycle moments and may in turn explain some of the changes.

housing wealth effects that relies only on the broad structure of this class of models. In this section we measure our rule of thumb in micro data and show that its value is consistent with both our model and with empirical estimates of housing wealth effects measured under different identification assumptions.

6.1   BPP Approach

Estimating our rule of thumb requires data on both MPCs out of transitory income shocks and on home values. While home values are easily obtained, estimating MPCs is more difficult. To estimate MPCs we follow the identification approach of Blundell et al. (2008) (henceforth BPP).

BPP show that if income follows a process with a permanent and an i.i.d. component, then, given individual level panel data on income and consumption, one can identify the MPC out of transitory shocks. In particular, assume that log income is $y_{it} = z_{it} + \varepsilon_{it}$, where z_{it} follows a random walk with innovation η_{it} and ε_{it} is an i.i.d. shock. It follows that the change in log income is equal to $\Delta y_{it} = \eta_{it} + \Delta \varepsilon_{it}$.[47] Given this income process, the elasticity of consumption to transitory shocks is equal to

$$E_t = \frac{cov(\Delta c_{it}, \varepsilon_{it})}{var(\varepsilon_{it})}.$$

Under the assumption that households have no advanced information about future shocks, a consistent estimator of this elasticity is

$$\widehat{E_t} = \frac{cov(\Delta c_{it}, \Delta y_{it+1})}{cov(\Delta y_{it}, \Delta y_{it+1})}.$$

With panel data containing at least three time periods, one can implement this estimator with an instrumental variable regression of the change in consumption Δc_{it} on the change in income Δy_{it}, instrumenting for the current change in income with the future change in income, Δy_{it+1}. We then convert this elasticity to the MPC in levels relevant for our theory by multiplying by C/Y. Since this requires individual level panel data on income and consumption, we use data from the Panel Study of Income Dynamics (PSID).[48]

Kaplan and Violante (2010) show that BPP is highly robust at recovering the true MPC to temporary shocks in a variety of models. However, they do not explore models with housing, so one might wonder whether BPP recovers the true MPC to temporary income shocks in our environment. We have performed exercises similar to Kaplan and Violante (2010) in our model

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[47]Abowd and Card (1989) show that this parsimonious specification fits income data well.

[48]An alternative approach to estimate MPCs, used by Johnson et al. (2006), uses random government rebate timing and CEX data. Unfortunately, it is well known that the resulting standard errors on MPCS are large since CEX data has smaller sample sizes than PSID, no panel structure to disentangle true changes in consumption from measurement error, and covers a smaller fraction of consumption. Large standard errors are especially problematic for us, since we need to estimate MPCs conditional on different levels of housing wealth.

and indeed found that this procedure continues to work well even in the presence of housing with transaction costs and rental markets.[49]

6.2 PSID Data

Implementing our sufficient statistic empirically requires a longitudinal data set with information on income, consumption, and housing values at the household level. Starting from the 1999 wave, the PSID contains the necessary data. The PSID started collecting information on a sample of roughly 5,000 households in 1968. Thereafter, both the original families and their split-offs (children of the original family forming a family of their own) have been followed. The survey was annual until 1996 and became biennial starting in 1997. In 1999 the survey augmented the consumption information available to researchers so that it now covers over 70 percent of all consumption items available in the Consumer Expenditure Survey (CEX). This is why we use 1999 as the first year of our sample.

Since we use almost the same underlying sample as Kaplan et al. (2014), our description of the PSID mirrors theirs. We start with the PSID Core Sample and drop households with missing information on race, education, or state of residence, and those whose income grows more than 500 percent, falls by more than 80 percent, or is below $100. We drop households who have top-coded income or consumption. We drop households not in the sample at least three consecutive times, because identification of the coefficients of interest requires at least three periods. In our baseline calculations, we keep households whose head is 25-60 years old. Our final sample has 30,462 observations over the years 1999-2011 (seven sample years).

We use the same consumption definition as Blundell et al. (2014) including food at and away from home, utilities, gasoline, car maintenance, public transportation, childcare, health expenditures and education. This data covers approximately 70% of consumption in the CEX. We define income as the sum of labor income and government transfers. We purge the data of non-model features by regressing $\ln c_{it}$ and $\ln y_{it}$ on year and cohort dummies, education, race, family structure, employment, geographic variables, and interactions of year dummies with education, race, employment, and region.

6.3 Results

In order to compute the elasticity implied by our rule-of-thumb formula, we must first calculate MPCs by housing. To implement this in practice, we break the sample into 6 bins by housing, pool all households in each bin and run the BPP procedure separately for each bin. We then convert to MPCs by multiplying by the median value of C/Y in each bin. The first bin includes

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[49]Our baseline income process is also different, but we can verify that the BPP procedure recovers the correct MPC to transitory shocks if they are added to the model, and other results are unchanged.

Figure 9: Elasticities in PSID Data
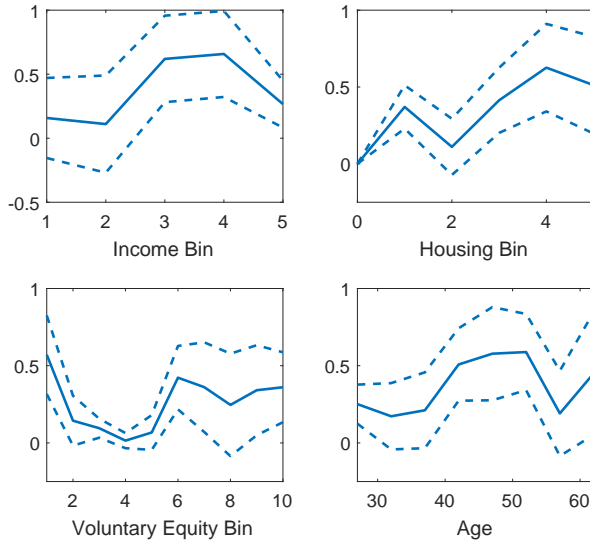
This figure shows how the rule-of-thumb formula varies with income, home values, liquid wealth and age in the PSID. For all plots except those by home value, we partition the data into 5 equal sized bins and run the BPP procedure within each bin. For home values, all renters are assigned to bin "0" and homeowners are partitioned into 5 equal bins. As in Figure 3 the horizontal axis in each panel shows the value of the bin index, except for the age panel which shows the actual value

only renters—that is, households who own zero housing. The other five bins are quintiles of the home value distribution and so are of equal size by construction. In total, we have approximately 11,000 renters and 19,000 home owners. After computing how MPCs vary with housing, we aggregate these results across bins to compute the implied aggregate elasticity using our rule-of-thumb formula. Following this procedure, we arrive at an aggregate elasticity of 0.33 with a 95% confidence interval of (0.15,0.52). Although standard errors are obviously large, this is reasonably close to the 0.23 value implied by our baseline model and is in line with empirical estimates using completely identification strategies such as those in Mian et al. (2013).

Figure 9 computes how elasticities vary by different observable dimensions in the PSID.[50] Although standard errors are again large, comparing this to Figure 3 shows that the model and PSID estimates broadly line up with each other. The most prominent point of departure is the elasticity as a function of housing. In the model, elasticities for homeowners decline with housing while they are essentially flat or even mildly increasing with housing in the data. Since our model reproduces the distribution of housing in the data, this difference is driven by an MPC in the data that declines less with housing than in the model. This also explains the fact that the point estimate for the aggregate elasticity in PSID data is moderately larger than our model estimate. The fact that average MPCs decline relatively slowly with wealth in the data

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[50]Voluntary equity is more difficult to compute in the PSID than in the model since households in reality face heterogeneous borrowing constraints. We assume that households face the same downpayment requirement as in the model and measure voluntary equity as net-liquid assets $+0.8PH-$mortgage debt.

has been widely recognized and is a central theme of recent work on wealthy-hand-to-mouth households pioneered by Kaplan and Violante (2014). While it would substantially complicate the analysis, introducing a more complicated asset structure of this form could likely generate more households with substantial housing wealth but large MPCs and so help further improve the fit of our model. It might also help to better match the age profile of elasticities in the model and the data. In the model, elasticities decline with age as households accumulate assets over the life-cycle, while they have a mild hump shape in the data.

7 Dynamics

Our results up to now focus on impact effects of house prices on consumption, in a stationary environment. In this section, we explore dynamic results to highlight three important implications: 1) The consumption responses on impact that are the focus of our analysis are useful summary statistics for the full impulse response function to shocks. 2) The response of consumption to a given house price shock depends on previous shocks which have hit the economy, since they change the distribution of leverage and MPCs across time. 3) Less-than-permanent shocks to house prices lead to *larger* consumption responses on impact, but the total cumulative effect over time is somewhat reduced as effects wear off more rapidly. However, effects are similar to the permanent shocks in the rest of the paper for plausible persistence values.

We begin by moving from impact effects to full impulse-response functions. In particular, we explore a number of comparative statics exercises in the model, changing parameter values of interest and plotting the effects on the full impulse response function. Figure 10 shows the impulse response to the same two standard deviation positive house price shock in economies with different down-payment requirements θ.[51] The first thing to note is that impulse responses revert to zero. That is a *permanent* house price shock causes a *temporary* increase in non-housing consumption. To get intuition for this result, note that in a model with precautionary savings, agents tend to revert to some (stochastic) wealth path after a one-time capital gain.[52] The next thing to note is that the impulse response functions for different parametrizations do not cross each other, so a larger consumption response on impact predicts a larger effect at future dates and, by implication, a larger cumulative impulse response.
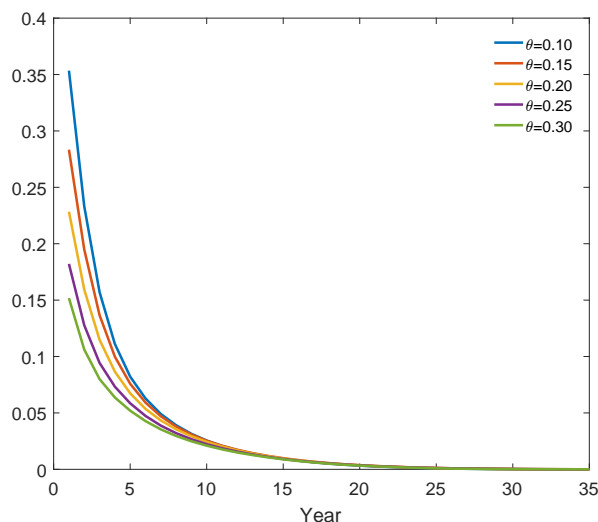
Consumption responses to house price shocks are larger in economies with a lower downpayment requirement θ. Since we do not recalibrate the model as we change θ, one can interpret this as showing that a structural increase in credit supply increases consumption sensitivity to house price shocks in steady state. For example, moving from our baseline downpayment of 20%

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[51]Similar to other figures throughout the paper, we include only working-age households in our consumption measure when computing responses.

[52]Household death is a second force which drives transitory effects.

Figure 10: Impulse Response of Consumption to One-Time-Shock: Downpayment Effects

This figure plots the full impulse response function of consumption to a one-time two standard deviation positive house price shock, for various values of the required downpayment θ. The vertical units are consumption elasticities showing the percentage change in aggregate consumption in years 1-35 divided by the percentage change in house prices in year 1: $(\%\Delta C_t / \%\Delta P_1)$.

to a lower downpayment requirement of 15% increases the elasticity of consumption to house price shocks on impact by 24% and increases the discounted cumulative impulse response by 18%.[53] Thus, our model implies that as downpayment requirements in the U.S. have broadly trended downwards over several decades, consumption has likely become more sensitive to house price shocks. Since our rule of thumb works well in each of these economies, we can understand these effects in a straightforward way through this formula: as θ declines, households purchase larger houses using more leverage, which increases both MPC and PH.

Figure A-4 in the Appendix shows that these same conclusions hold in the model with long-term debt, although they are mildly attenuated. This attenuation arises because highly levered households are more likely to receive shocks which push them underwater and thus into the region where consumption elasticities are reduced substantially. However, these effects are not strong enough to undo the amplification for households who are not underwater.

Figure 11 performs a similar comparative statics exercise, but now varying the trend growth rate of house prices μ instead of θ. Again, impulse responses on impact are a useful summary of consumption responses at future dates since impulse response functions never cross. Increasing house price growth in the model has an even more powerful effect in the model than lowering downpayments. This is because higher house price growth substantially lowers the effective user cost of housing, leading to even larger increases in housing and leverage. This suggests that consumption may be particularly sensitive to house price shocks during house price booms.

However, it is important to note that this comparative statics exercise compares consumption

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[53]We discount future consumption in this calculation using the household discount factor β.

Figure 11: Impulse Response of Consumption to One-Time-Shock
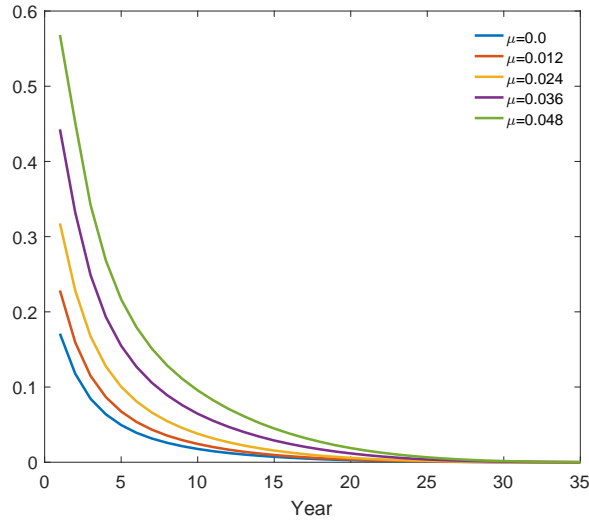
This figure plots the full impulse response function of consumption to a one-time two standard deviation positive house price shock, for various values of average house price growth μ. The vertical units are consumption elasticities showing the percentage change in aggregate consumption in years 1-35 divided by the percentage change in house prices in year 1: $(\%\Delta C_t / \%\Delta P_1)$.

elasticities in the steady-states of economies with permanently different house price growth. This likely overstates the effects of increases in house price growth over shorter horizons, as households take time to shift towards larger housing and additional leverage as house price growth increases. To get some sense of the effects of increasing house price growth over shorter horizons more relevant for typical house price booms, we thus turn to transitional dynamics. In particular, we begin from the steady-state of our baseline economy with annual 1.2% house price growth and then permanently increase house price growth unexpectedly to 4.8%, corresponding to average house price growth in FHFA data over the U.S. housing boom from 2000-2006. For each year in the transition path, we then compute the elasticity of consumption on impact to a two standard deviation house price increase. Figure 12 displays results under two different assumptions for household's expectations of future house price growth. The line in blue shows results when households have rational expectations and realize house price growth has permanently increased from 1.2% to 4.8% while the dashed red line shows results when households do not realize house price growth has increased and so instead continue to expect average house price growth of 1.2%. With unchanged expectations, households interpret the sequence of above average house price growth as a lucky sequence of shocks rather than a new state of the world.

Since the economy is in the old steady-state in year 0 and has reached the new steady-state by year 35, the 0.23 value of the blue line at year 0 corresponds to the aggregate elasticity in our baseline economy while the 0.57 value of the blue line at year 35 corresponds to the first element of the impulse response for the $\mu = 0.048$ economy in Figure 11. Figure 12 illustrates several important points. First, if households expect that house price growth has permanently

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Figure 12: Effects of House Price Boom on Elasticity (Transitional Dynamics)
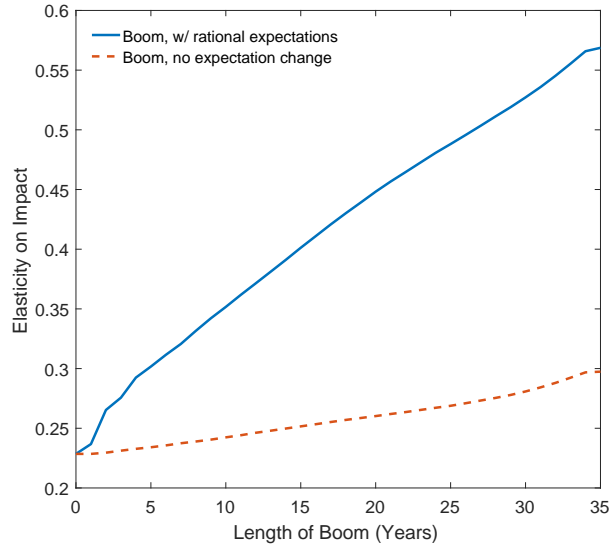
This figure shows transitional dynamics in response to a permanent increase in house price growth from 1.2% to 4.8% when households rationally update expectations (solid line) and when they incorrectly continue to expect the old house price growth of 1.2% (dashed line). House price growth permanently increases in year 1 and the economy reaches the new steady-state in year 35. The vertical axis shows the elasticity on impact to a permanent two standard deviation positive house price shock occurring in a given year in the transition path.
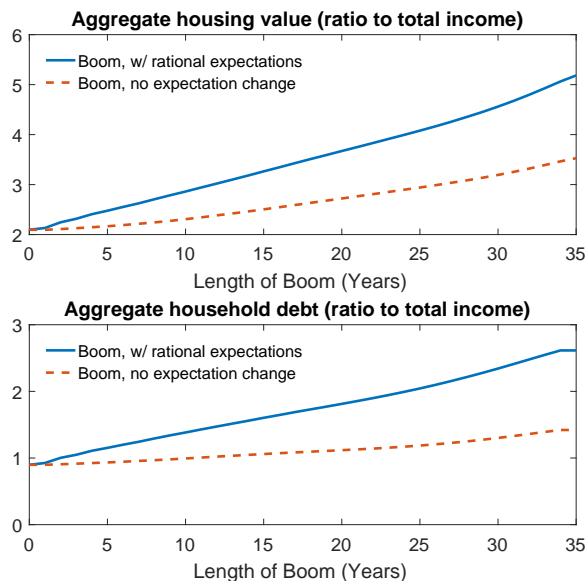
increased, then housing booms of 6-7 years can lead to non-trivial increases in consumption responses to house price shocks. By year 5, the elasticity on impact has increased from 0.23 to a little above 0.3. Second, full transitional dynamics are relatively slow: after 18 years, the sensitivity of the economy to house price shocks has only moved half of the way to its new steady-state. This implies that steady-state comparative statics exercises like those in Figure 11 are likely to overstate the effects of shorter-lived housing booms. Third, expectations matter substantially. Greater house price growth still leads consumption elasticities to rise mildly even if households do not change their expectations, but the effects are very attenuated.

This can be understood by again using our rule-of-thumb formula and looking at housing values and debt over the transition path in Figure 13 under the two assumptions about expectations. In both cases, higher actual house price growth leads to higher housing values, PH. However, if households realize that house price growth has increased, then they also purchase larger houses H since housing has effectively become cheaper, further increasing PH. They do so by taking out substantially more debt, as shown in the bottom panel. This greater debt increases the MPC in the economy and together with the larger value of PH, substantially increases consumption elasticities as shown with our rule-of-thumb formula.

Our final exercise explores the robustness of our conclusions to reducing the persistence of house price shocks. In particular, we assume that instead of following a random walk, house prices follow an AR-process with persistence ρ.[54] Figure 14 shows the impulse response to the

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[54]Like in the CES and non-constant price-rent ratio examples above, this introduces the current house price as

Figure 13: Effects of House Price Boom on Housing and Debt (Transitional Dynamics)

Aggregate housing value (ratio to total income)
— Boom, w/ rational expectations
-- Boom, no expectation change
Length of Boom (Years)

Aggregate household debt (ratio to total income)
— Boom, w/ rational expectations
-- Boom, no expectation change
Length of Boom (Years)

This figure shows transitional dynamics of housing values and debt in response to a permanent increase in house price growth from 1.2% to 4.8% when households rationally update expectations (solid line) and when they incorrectly continue to expect the old house price growth of 1.2% (dashed line). House price growth permanently increases in year 1 and the economy reaches the new steady-state in year 35.

same two standard deviation positive house price shock as we reduce ρ. Reducing ρ from 1 to 0.99 has essentially no effect on results, so it is not particularly important for quantitative results whether shocks are perfectly persistent or only nearly so. As ρ is reduced further, consumption responses on impact *increase* relative to the case with permanent shocks. This is because our experiment is a price shock, not a wealth shock: when prices mean revert, households can respond to a positive house price shock by selling housing today and repurchasing it in the future when houses decline, at an expected profit. This makes consumption on impact more responsive to transitory than permanent price changes.[55]

Of course, the the shock itself also wears off more quickly as ρ declines, as is also apparent in Figure 14. This means that even though consumption effects are stronger on impact, they also die off more quickly. On net, lowering ρ from 1 to 0.95 increases the IRF on impact by 20% and reduces the cumulative impulse response by 7%. Whether one cares more about the impact effect or the cumulative effect will depend on whether one is more interesting in short-term or longer run consumption effects, but either way, our model continues to imply large consumption responses to house price shocks.[56]

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an additional state-variable and complicates model solutions. Eliminating house price growth partially simplifies the analysis, so we assume that $\mu = 0$ and recalibrate our baseline model with $\rho = 1$ to match the same moments. We do not recalibrate the models as we reduce ρ below 1.

[55]This is similar to intuition in King and Rebelo (1999) that intertemporal substitution falls as shock persistence grows.

[56]The empirical value of ρ varies somewhat across data series as well as the associated time-series covered

Figure 14: Impulse Response of Consumption to One-Time-Shock for AR Shocks
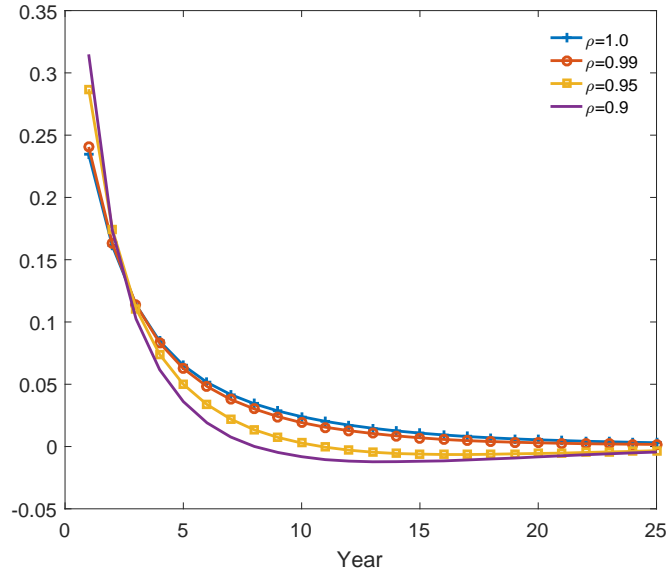
This figure plots the full impulse response function of consumption to a one-time two standard deviation positive house price shock for various values of house price shock persistence, ρ. The vertical units are consumption elasticities showing the percentage change in aggregate consumption in years 1-35 divided by the percentage change in house prices in year 1: $(\%\Delta C_t / \%\Delta P_1)$.

8   Conclusion

In this paper, we explore the implications of consumption theory for understanding housing price effects on consumption. While a large and growing empirical literature documents strong responses of consumption to identified house price movements, a large theoretical literature argues that this response should be small.

We show that a calibrated workhorse incomplete markets model that includes income uncertainty, rental markets, collateralized borrowing and fixed costs of adjusting housing produces large aggregate consumption responses to house price changes, in line with the recent empirical literature and significantly larger than in the standard PIH model. To provide intuition for this result, we derive a new rule of thumb for the individual response of consumption on impact to an unexpected, permanent house price change that contains significant explanatory power even in complicated model environments. In particular, we show that the individual consumption response is equal to the MPC out of transitory income times the individual value of housing. This means the aggregate elasticity is determined by the endogenous joint distribution of MPCs and housing. Using our rule of thumb we see that the reason our baseline model generates large elasticities is that borrowing constraints and the presence of leverage mean that MPCs are large and highly correlated with housing values. In contrast, PIH models generate small elasticities

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but estimates at the high-end are around 1 and estimates at the low-end are around 0.9. The rule-of-thumb formula will progressively lose accuracy for predicting consumption responses on impact as ρ decreases but this increasing bias will progressively push towards understating true responses.

because they produce small MPCs that are uncorrelated with housing.

Our results also imply that the size of housing price effects varies substantially across households. Indeed, we find large variation in elasticities depending on age, leverage, homeownership status and wealth. We also find that responses can change in response to changes in credit supply or in response to house price booms. The quantitative strength of house price booms on the sensitivity of consumption depends crucially on both their length and on households' expectations of future house price growth. The presence of this time-variation and heterogeneity may help reconcile various empirical results and should be accounted for when predicting the aggregate consequences of housing market policies.

References

Abowd, John M. and David Card, "On the Covariance Structure of Earnings and Hours Changes," *Econometrica*, 1989, *57* (2), 411–445.

Aguiar, Mark and Erik Hurst, "Deconstructing Lifecycle Expenditures," *Journal of Political Economy*, 2013, *212* (1).

Attanasio, Orazio and Guglielmo Weber, "The UK consumption boom of the late 1980s: aggregate implications of microeconomic evidence," *The Economic Journal*, 1994.

_ , **Andrew Leicester, and Matthew Wakefield**, "Do House Prices Drive Consumption Growth? The Coincident Cycles of House Prices and Consumption in the UK," *Journal of the European Economic Association*, 2011, *9* (3).

_ , **Laura Blow, Robert Hamilton, and Andrew Leicester**, "Booms and Busts: Consumption, House Prices, and Expectations," *Economica*, 2009, *76* (301), 20–50.

Auclert, Adrien, "Monetary Policy and the Redistribution Channel," 2015. Stanford mimeo.

Beraja, Martin, Andreas Fuster, Erik Hurst, and Joseph Vavra, "Regional Heterogeneity and Monetary Policy," *NBER Working Paper 23270*, 2017.

Berger, David and Joseph Vavra, "Consumption Dynamics During Recessions," *Econometrica*, 2015, *83* (1), 101—154.

Bhutta, Neil and Benjamin J. Keys, "Interest Rates and Equity Extraction During the Housing Boom," *University of Chicago Kreisman Working Papers Series in Housing Law and Policy*, 2014, *3*.

Blundell, Richard, Luigi Pistaferri, and Ian Preston, "Consumption Inequality and Partial Insurance," *American Economic Review*, 2008, *98* (5), 1887—1921.

—, —, and Itay Saporta-Eksten, "Consumption Inequality and Family Labor Supply," *2014 Meeting Papers No. 322 Society for Economic Dynamics*, 2014.

Buiter, Willem H., "Housing Wealth Isn't Wealth," *NBER Working Paper 14204*, 2008.

Caballero, Ricardo and Eduardo M. R. A. Engel, "Explaining Investment Dynamics in U.S. Manufacturing: A Generalized (S,s) Approach," *Econometrica*, 1999, *67* (4), 783—826.

Campbell, John Y. and Joao F. Cocco, "How Do House Prices Affect Consumption?," *Journal of Monetary Economics*, 2007, *54* (3), 591—621.

— and —, "A Model of Mortgage Default," *Journal of Finance (Forthcoming)*, 2015.

Carroll, Chris and Wendy Dunn, "Unemployment Expectations, Jumping (S,s) Triggers, and Household Balance Sheets," *NBER Maroeconomics Annual*, 1998, *12*, 165—230.

Carroll, Christopher D., Misuzu Otsuka, and Jiri Slacalek, "How Large Are Housing and Financial Wealth Effects? A New Approach," *Journal of Money Credit and Banking*, 2011, *1* (43), 55—79.

Case, Karl E., John M. Quigley, and Robert J. Shiller, "Wealth Effects Revisited: 1975-2012," *Critical Finance Review*, 2013, *2* (1), 101—128.

Cerutti, Eugenio, Jihad Dagher, and Mr Giovanni Dell'Ariccia, "Housing Finance and Real-Estate Booms: A Cross-Country Perspective," Staff Discussion Notes, IMF 2015.

Chen, Hui, Michael Michaux, and Nikolai Roussanov, "Houses as ATMs? Mortgage Refinancing and Macroeconomic Uncertainty," Working Paper 19421, National Bureau of Economic Research 2013.

Chetty, Raj, "Sufficient Statistics for Welfare Analysis: A Bridge Between Structural and Reduced-Form Methods," *Annual Review of Economics*, 2009, *1*, 451—488.

Cocco, Joao, "Portfolio Choice in the Presence of Housing," *The Review of Financial Studies*, 2005.

Davila, Eduardo, "Using Elasticities to Derive Optimal Bankruptcy Exemptions," *Mimeo*, 2016.

Davis, Morris A. and François Ortalo-Magné, "Household Expenditures, Wages, Rents," *Review of Economic Dynamics*, 2011, *14*, 248—261.

Díaz, Antonia and María José Luengo-Prado, "The Wealth Distribution with Durable Goods," *International Economic Review*, 2010, *51* (1), 143—170.

Eggertsson, Gauti B and Paul Krugman, "Debt, deleveraging, and the liquidity trap: A fisher-minsky-koo approach*," *The Quarterly Journal of Economics*, 2012.

Favilukis, Jack, Sydney C. Ludvigson, and Stijn Van Nieuwerburgh, "The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk-Sharing in General Equilibrium," Working Paper, NYU 2015.

Floden, Martin and Jesper Lindé, "Idiosyncratic Risk in the United States and Sweden: Is There a Role for Government Insurance," *Review of Economic Dynamics*, 2001, *4* (2).

Fuster, Andreas, Benedict Guttman-Kenney, and Andrew Haughwout, "Tracking and Stress-Testing U.S. Household Leverage," Staff Report 787, Federal Reserve Bank of New York 2016.

Ganong, Peter and Pascal Noel, "The Effect of Debt on Default and Consumption: Evidence from Housing Policy in the Great Recession," 2016.

Glaeser, Edward L., "Real Estate and The Macroeconomy: Discussion," *Brookings Papers on Economic Activity*, 2000.

Gorea, Denis and Virgiliu Midrigan, "Liquidity Constraints in the U.S. Housing Market," 2017.

Greenwald, Daniel L., "The Mortgage Credit Channel of Macroeconomic Transmission," Working Paper, MIT Sloan 2016.

Guerrieri, Luca and Matteo Iacoviello, "Collateral Constraints and Macroeconomic Asymmetries," *Manuscript, Federal Reserve Board*, 2014.

Guerrieri, Veronica and Guido Lorenzoni, "Credit Crises, Precautionary Savings, and the Liquidity Trap," Working Paper, National Bureau of Economic Research 2011.

Guiso, Luigi, Monica Paiella, and Ignazio Visco, "Do capital gains affect consumption? Estimates of wealth effects from italian households' behavior," Temi di discussione 555, Bank of Italy 2005.

Guvenen, Fatih and Anthony A. Smith, "Inferring Labor Income Risk and Partial Insurance from Economic Choices," *Econometrica*, 2014, *82* (6), 2085—2129.

Hall, Robert E, "The Long Slump," *American Economic Review*, 2011, *101* (2), 431–69.

Huo, Zhen and José-Víctor Ríos-Rull, "Balance sheet recessions," Technical Report, Working Paper, Federal Reserve Bank of Minneapolis 2013.

Johnson, David S., Jonathan A. Parker, and Nicholas S. Souleles, "Household Expenditure and the Income Tax Rebates of 2001," *American Economic Review*, 2006, *96* (5).

Justiniano, Alejandro, Giorgio E Primiceri, and Andrea Tambalotti, "Household leveraging and deleveraging," *Review of Economic Dynamics*, 2015, *18* (1), 3–20.

Kaplan, Greg and Gianluca Violante, "How Much Consumption Insurance Beyond Self-Insurance," *American Economic Journals: Macroeconomics*, 2010, *2* (4), 53—87.

_ **and** _ , "A Model of the Consumption Response to Fiscal Stimulus Payments," *Econometrica*, 2014, *82* (4), 1199—1239.

_ , **Giovanni L. Violante, and Justin Weidner**, "The Wealthy Hand-To-Mouth," *NBER Working Paper 20073*, 2014.

_ , **Kurt Mitman, and Gianluca Violante**, "Consumption and House Prices in The Great Recession," 2016.

King, Robert and Sergio Rebelo, "Resuscitating real business cycles," in J. B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics*, 1 ed., Vol. 1, Part B 1999, chapter 14.

Mian, Atif, Kamalesh Rao, and Amir Sufi, "Household Balance Sheets, Consumption, and the Economic Slump," *The Quarterly Journal of Economics*, 2013, *128* (4), 1687—1726.

Midrigan, Virgiliu and Thomas Philippon, "Household Leverage and the Recession," Technical Report 16965, NBER 2011.

Piazzesi, Monika, Martin Schneider, and Selale Tuzel, "Housing, Consumption and Asset Pricing," *Journal of Financial Economics*, 2007, *83*, 531—569.

Saiz, Albert, "The Geographic Determinants of Housing Supply," *The Quarterly Journal of Economics*, 2010, *125* (3), 1253—1296.

Sinai, Todd and Nicholas S Souleles, "Owner-Occupied Housing as a Hedge against Rent Risk," *The Quarterly Journal of Economics*, 2005, pp. 763–789.

Stroebel, Johannes and Joseph Vavra, "House Prices, Local Demand, and Retail Prices," 2016.

Tauchen, George, "Finite State Markov-Chain Approximations to Univariate and Vector Autoregressions," *Economics Letters*, 1986, *20* (2), 177—181.

Vavra, Joseph, "Inflation Dynamics and Time-Varying Volatility: New Evidence and an Ss Interpretation," *The Quarterly Journal of Economics*, 2014, *129* (1), 215—258.

Winberry, Thomas, "Lumpy Investment, Business Cycles, and Stimulus Policy," 2015.

Wong, Arlene, "Population Aging and the Transmission of Monetary Policy to Consumption," Working Paper, Northwestern University 2016.

Yao, Rui and Harold H. Zhang, "Optimal Consumption and Portfolio Choices with Risky Housing and Borrowing Constraints," *The Review of Financial Studies*, 2005.

Appendix

A.1   The Permanent-Income Case

We describe here a special case of our model that can be solved analytically and gives us a reference permanent-income-hypothesis (PIH) result, with small house price effects on consumption.

Consider the case of a deterministic income process ($\sigma_\varepsilon = 0$), no borrowing constraints, and constant house prices $P_t = P$. Assume $(1+r)\beta = 1$ and $\Psi = (1-\beta)^{-\sigma}$. Under these assumptions, there is perfect consumption smoothing: non-durable consumption and housing are constant over the lifetime. Moreover, non-durable consumption is equal to a fixed fraction $\alpha(1-\beta)$ of total wealth, which includes human wealth, housing wealth, and financial wealth:[57]

$$C_{it} = \alpha(1-\beta) \left[\sum_{\tau=t}^{t+J-j} (1+r)^{-\tau} Y_{it+\tau} + (1-\delta) PH_{it-1} + (1+r) A_{it-1} \right].$$

Now consider the effect of an unexpected, permanent shock to the house price P. The elasticity of consumption to this shock is equal to the share of housing in total wealth:

$$\frac{dC_{it}/C_{it}}{dP/P} = \frac{(1-\delta)PH_{it-1}}{\sum_{\tau=t}^{t+J-j}(1+r)^{-\tau}Y_{it+\tau} + (1-\delta)PH_{it-1} + (1+r)A_{it-1}}. \tag{A1}$$

What are the quantitative implications of this case? To assess this, note that equation (A1) also holds in the aggregate, so each quantity on the right-hand side can be measured directly using aggregate data. For consistency with the rest of the paper we use aggregates from the 2001 Survey of Consumer Finances (SCF) and focus on households ages 25-59. We then get $(1-\delta)PH = 2.04Y$ and $A = -.47Y$, where PH is the average value of housing, A is average liquid wealth net of debt, Y is average earnings and we set $\delta = 0.022$ as in our baseline model. Using an interest rate of $r = 2.4\%$ and an infinite horizon approximation, human wealth is equal to $Y/r = 41.66Y$. The aggregate elasticity of non-durable consumption implied by the model is then 0.047, a small number relative to empirical housing price effects. It is also insensitive to the level of household debt. For example, a large increase in household debt of $0.5Y$ so that $A = -0.97Y$ yields a nearly identical and still small elasticity of 0.048.

What drives the consumption response to house prices in the PIH model? The response can be decomposed into three effects: a substitution effect, an income effect, and an endowment effect.[58] It is then possible to interpret equation (A1) in two ways.

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[57]For simplicity, we set the human wealth of offspring to zero.

[58]A permanent increase in P increases the service cost of housing in all future periods. The substitution effect is the shift from housing services in all future periods towards current consumption, keeping the present value of future expenditures constant. The income effect is the change in current consumption due to a reduction in the

First, due to the Cobb-Douglas assumption, the income and substitution effects exactly cancel out. Since only the endowment effect remains, this implies that the change in consumption in (A1) can be interpreted as a pure endowment effect.

However, an alternative interpretation is possible. In this model consumption of housing services is constant over time. Hence, at any point after the first period of life, an increase in the price of housing raises the value of an agent's housing endowment, but at the same time it raises the net present value of the future implicit rental cost on housing services by roughly the same amount.[59] The detailed derivations behind these statements are in Appendix A.2. Therefore, the effect in (A1) can also be interpreted as an (almost) pure substitution effect, with the income and endowment effects canceling out. This interpretation is consistent with the view discussed in the introduction that housing price effects must be small, because of the increase in future implicit rental costs. It is important to note that both interpretations of (A1) are correct. However, the first interpretation will be especially useful in what follows as it survives in richer versions of the model.

A.2 Decomposition

In this section we derive decompositions of the total house price effect into income, substitution, collateral and endowment effects and discuss their interpretation both for the simple PIH model of Subsection A.1 and for the general baseline model treated in the rest of Section 2.

A.2.1 PIH Model

For simplicity, we focus on the infinite-horizon version of the model and drop the individual subscript i. The household's utility function is $\sum_{t=0}^{\infty} \beta^t U(C_t, H_t)$. The per-period budget constraints, with a no Ponzi condition, can be aggregated into the intertemporal budget constraint at date 0:

$$\sum_{t=0}^{\infty} q^t \left[C_t + [P_t - q(1-\delta)P_{t+1}] H_t - Y_t \right] = (1+r)A_{-1} + (1-\delta)P_0 H_{-1},$$

where $q \equiv 1/(1+r)$. Define the implicit rental rate $R_t \equiv P_t - q(1-\delta)P_{t+1}$. Suppose that the house price is initially constant at P so that the implicit rental rate is then $R = (1 - q(1-\delta))P$. We then want to decompose the response of C_0 to a permanent change in P. Define the Marshallian demand $C_0 = C_{0,m}(R, I)$, which comes from maximizing $\sum \beta^t U(C_t, H_t)$ subject to

[59]The effects are not exactly equal due to depreciation δ. When $\delta = 0$ they are exactly equal.

$\sum q^t [C_t + RH_t] = I$. Similarly, define the Hicksian demand $C_0 = C_{0,h}(R, U)$, which comes from minimizing $\sum q^t [C_t + RH_t]$ subject to $\sum \beta^t U(C_t, H_t) \geq U$. The effect of a permanent change dR is equivalent to summing the effects of identical changes in the price of housing services dR_t. So the standard decomposition result also applies and implies that the total response of consumption to a change in P satisfies

$$\frac{dC_0}{dP} = [1 - q(1 - \delta)] \frac{\partial C_{0,h}(R, U)}{\partial R} - [1 - q(1 - \delta)] \frac{\partial C_{0,m}(R, I)}{\partial I} \sum q^t H_t + \frac{\partial C_{0,m}(R, I)}{\partial I} (1 - \delta) H_{-1}.$$

The first term is the substitution effect, the second the income effect, the third the endowment effect.

Under the assumption of Cobb-Douglas preferences and $q = \beta$, the solution to the household problem gives a constant level of housing $H_t = H_0$ and of consumption $C_t = C_0$ with

$$C_0 = \alpha \frac{r}{1+r} \left[(1+r) A_{-1} + (1 - \delta) P_0 H_{-1} + \sum q^t Y_t \right].$$

Now consider a household that starts at $H_{-1} = H_0$ (which applies for small changes in R, for a household that started life at any time $t < 0$). Then the sum of the income and endowment effects is

$$\frac{\partial C_{0,m}(R, I)}{\partial I} \left\{ -[1 - q(1 - \delta)] \sum q^t + (1 - \delta) \right\} H = -\frac{\delta}{1 - q} \frac{\partial C_{0,m}(R, I)}{\partial I} H < 0.$$

The net effect is small if δ is small, and exactly zero if $\delta = 0$. This capture the Sinai and Souleles (2005) intuition that when the price of houses increases, and the net present value of implicit rental cost increases by the same amount, then there are small wealth effects. That the net effect is actually negative reflects the fact that the consumer is a net buyer of housing since he needs to replace the depreciated fraction of housing in all periods.

At the same time, we know that

$$\frac{dC_0}{dP} = \alpha \frac{r}{1+r} (1 - \delta) H_{-1} = \frac{\partial C_{0,m}(R, I)}{\partial I} (1 - \delta) H_{-1} > 0.$$

This implies that the total effect can be interpreted in two ways: 1) a substitution effect that more than compensates for the negative net of income and endowment effects derived above 2) a pure endowment effect, with the substitution and income effects canceling each other.

## A.2.2 General Model with no Adjustment Costs

Given the household's optimization problem on page 13, with $P_t = P$ for all t, let $C(W, s; P, \theta)$ denote the optimal consumption policy. Consider the effects of an unexpected, permanent

change in price from P_0 to P_1. Let (H_-, A_-) denote the household initial holdings of housing and of the risk-free asset. Household net wealth is then $W_0 = P_0 (1 - \delta) H_- + (1 + r) A_-$ before the shock, and $W_1 = P_1 (1 - \delta) H_- + (1 + r) A_-$ after the shock. The total consumption change is $\Delta C \equiv C(W_1, s; P_1, \theta) - C(W_0, s; P_0, \theta)$. To compute the collateral effect choose $\hat{\theta}$ such that $(1 - \theta) P_1 = \left(1 - \hat{\theta}\right) P_0$. That is, consider a change in the collateral requirement that exactly offsets the change in price. The collateral effect is then defined as $CE \equiv C\left(W_0, s; P_0, \hat{\theta}\right) - C(W_0, s; P_0, \theta)$.

Next, find the value of initial wealth $\hat{W}$ such that $V\left(\hat{W}, s; P_1, \theta\right) = V\left(W_0, s; P_0, \hat{\theta}\right)$. That is, we find the wealth that keeps utility unchanged after a change in the price of housing. Here, we are adapting the logic of Hicksian compensation to our dynamic, incomplete-markets problem. We define the substitution effect as $SE \equiv C\left(\hat{W}, s; P_1, \theta\right) - C\left(W_0, s; P_0, \hat{\theta}\right)$, where the change in θ is introduced to mute the collateral effect and the change in W is introduced to mute the income effect.

The income effect is given by $IE \equiv C\left(W_0, s; P_1, \theta\right) - C\left(\hat{W}, s; P_1, \theta\right)$. Finally, the endowment effect is just given by $EE \equiv C\left(W_1, s; P_1, \theta\right) - C\left(W_0, s; P_1, \theta\right)$, and elementary algebra gives $\Delta C = SE + IE + CE + EE$. Since $C(W, s; P, \theta)$ is independent of P, as shown in Proposition 1, we have $\Delta C = EE$. Notice that the exact result of the decomposition, for discrete changes in P, depends on the ordering (e.g., here we started from the collateral effect). Figure A-1 shows this decomposition for the baseline calibration of the model.

Figure A-1: Decomposition of House Price Effects
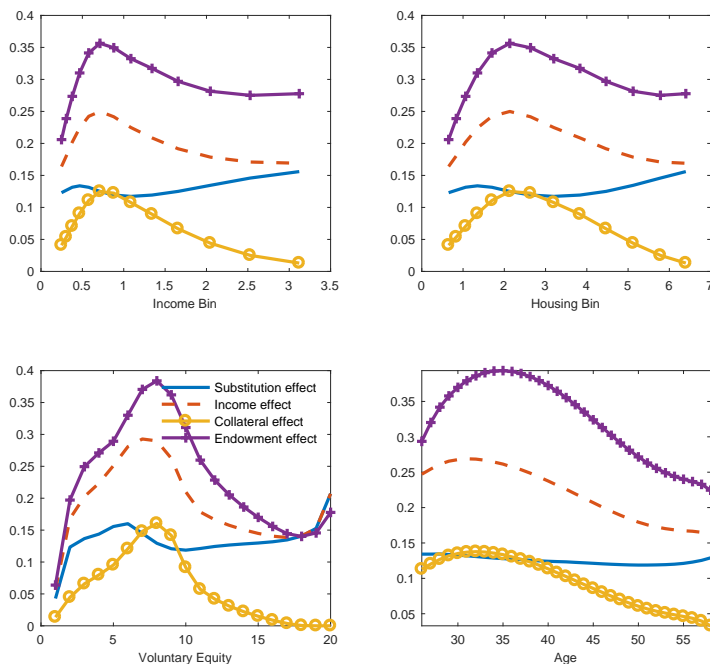
Note: Figures plot the absolute effect rather than the elasticity so that the sum of the income, substitution and collateral effects exactly equal the endowment effect. The income effect is negative, so we plot its absolute value.

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A.3   Robustness Results and Calibration Details

Figure A-2: Accuracy for Individual Points in State-Space (Larger HP Shocks)
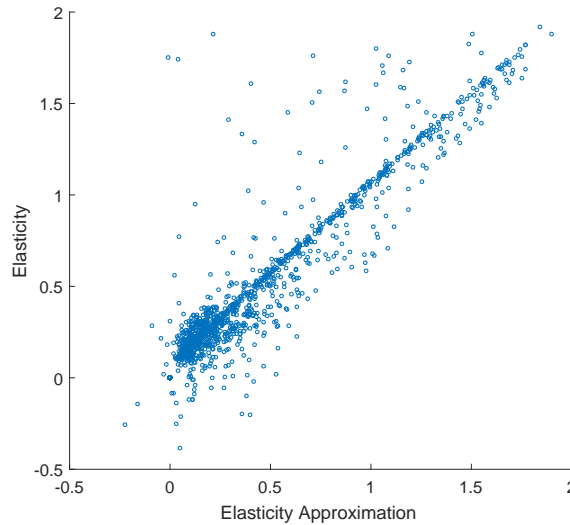
This figure shows how the true elasticity and the approximation vary over the entire endogenous joint-distribution of the state-space in the model with long-term debt but recalibrated with $\sigma_p = 0.08$ to match the volatility of house prices at very disaggregated census tracts rather than our baseline $\sigma_p = 0.0459$ calibrated to match the volatility of national house prices. Each point represents a particular combination of all the endogenous household states and shows the true elasticity for that household state compared to that implied by the rule-of-thumb formula. The R^2 for a simple linear regression is 0.90.

Figure A-3: How Does Accuracy Vary with Leverage? (Larger HP Shocks)
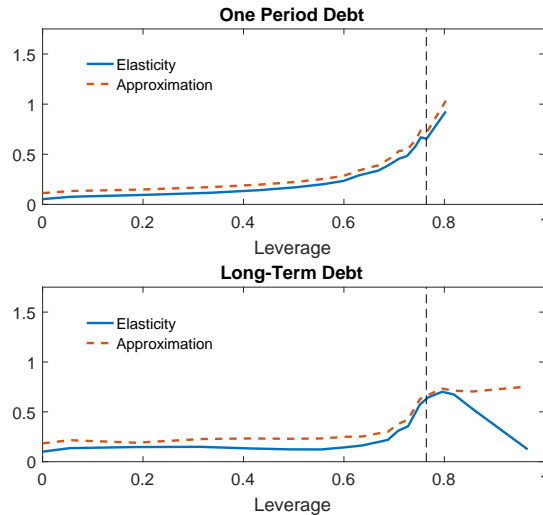
This figure shows how the true elasticity (solid line) and the approximation (dashed line) vary with leverage for larger $\sigma_p = 0.08$ in our baseline model (top panel) and in our extended model with long-term debt (bottom panel). The maximum LTV at origination is shown as the vertical dashed line.

Figure A-4: Impulse Response of Consumption to One-Time-Shock (Model with Long-term Debt)
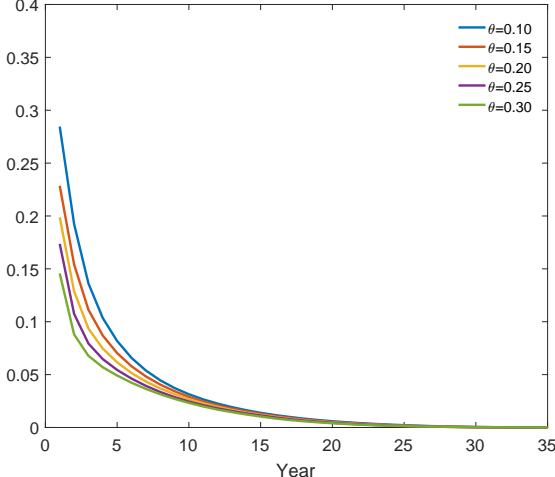
This figure plots the full impulse response function of consumption to a one-time two standard deviation positive house price shock in the model with long-term debt, for various values of the required downpayment θ. The vertical units are consumption elasticities showing the percentage change in aggregate consumption in years 1-35 divided by the percentage change in house prices in year 1: $(\%\Delta C_t / \%\Delta P_1)$.

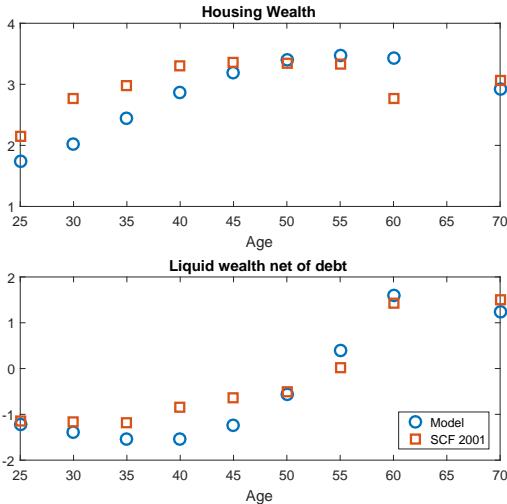Figure A-5: Life-cycle Calibration: Model W/ Fixed Cost But No Rental Option vs. Data

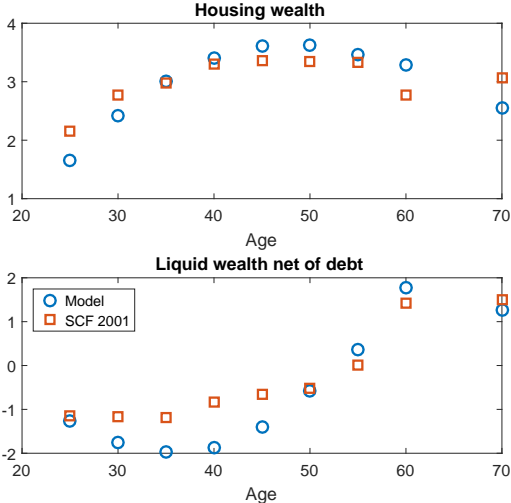Figure A-6: Life-cycle Calibration: Model with no Rental Option and no Fixed Costs vs. Data

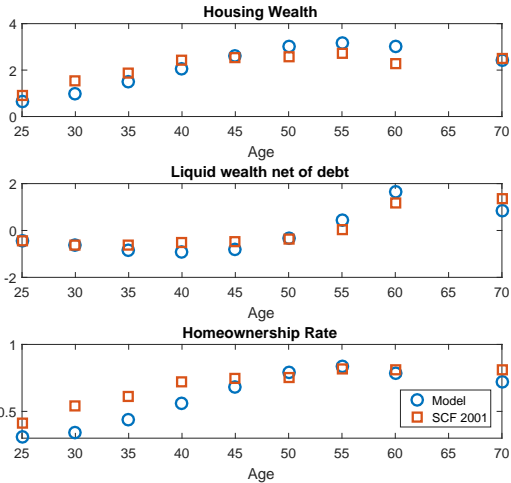Figure A-7: Life-cycle Calibration: Model with Long-term Debt vs. Data

Table A-1: *Parameter Values - Model W/ Fixed Cost But No Rental Option*

Calibrated to External Evidence:	σ	r	μ	σ_P	δ	θ	F	ρ_z	σ_z
	2	2.4%	1.2%	4.59%	2.2%	0.20	0.05	0.91	0.21

Chosen to Hit Life-Cycle:	α	β	Ψ	Ξ
	0.868	0.9161	3,690	1.45

Table A-2: *Parameter Values - Model with no Rental Option and no Fixed Costs*

Calibrated to External Evidence:	σ	r	μ	σ_P	δ	θ	F	ρ_z	σ_z
	2	2.4%	1.2%	4.59%	2.2%	0.20	0.0	0.91	0.21

Chosen to Hit Life-Cycle:	α	β	Ψ	Ξ
	0.88	0.9278	1,915	2.517

Table A-3: *Parameter Values - Model with Long-term Debt*

Calibrated to External Evidence:	σ	r	μ	σ_P	δ	θ	F	ρ_z	σ_z
	2	2.4%	1.2%	4.59%	2.2%	0.20	0.05	0.91	0.21

Chosen to Hit Life-Cycle and Equity Extraction:	α	β	Ψ	Ξ	ϕ	$\hat{\phi}$	F^{refi}
	0.855	0.918	2,200	1.65	0.063	0.0445	0.012

Table A-4: Untargeted Moments, Selected Characteristics of Wealth Distribution in Model with Long-Term Debt

	Data	Model		Data	Model
Housing Values/Mean Income; Homeowners			LTV Ratio; Borrowers		
10th percentile	0.80	1.89	10th percentile	0	0
25th percentile	1.42	2.48	25th percentile	0.17	0.39
50th percentile	2.34	3.32	50th percentile	0.53	0.64
75th percentile	3.71	4.39	75th percentile	0.75	0.72
90th percentile	5.50	5.47	90th percentile	0.89	0.76
Liquid Assets net of mortgage debt/Mean Income; Homeowners			Liquid Assets/Mean Income; Renters		
10th percentile	-2.74	-2.54	10th percentile	-0.058	0
25th percentile	-1.80	-2.02	25th percentile	0	0
50th percentile	-0.92	-1.54	50th percentile	0.005	0.009
75th percentile	-0.07	-0.81	75th percentile	0.049	0.03
90th percentile	0.22	1.03	90th percentile	0.226	0.13
Net Worth/Mean Income; Homeowners			Net Worth/Mean Income; Renters		
10th percentile	0.21	0.49	10th percentile	-0.033	0
25th percentile	0.56	0.75	25th percentile	0	0
50th percentile	1.44	1.42	50th percentile	0.011	0.009
75th percentile	2.92	3.19	75th percentile	0.121	0.03
90th percentile	4.67	6.04	90th percentile	0.566	0.13
Liquid Assets/Mean Income; Homeowners			Mortgage Debt/Mean Income; Homeowners		
10th percentile	-0.06	0	10th percentile	0	0
25th percentile	0.006	0	25th percentile	0.31	0.81
50th percentile	0.085	0	50th percentile	1.16	1.54
60th percentile	0.14	0	60th percentile	1.89	1.72
70th percentile	0.27	0	70th percentile	2.04	1.90
80th percentile	0.52	0	80th percentile	2.31	2.15
85th percentile	0.75	0.26	85th percentile	2.61	2.31
90th percentile	1.08	1.04	90th percentile	3.06	2.54

See footnote 27 for the definitions of liquid assets and housing values. Liquid assets are net of non-mortgage debt. The LTV ratio is computed as the value of mortgage debt divided by housing values. Net worth is the sum of liquid assets (net of all debt) plus housing values. Retirement accounts are also included for households older than 60. However, following most of our analysis, statistics in this table are restricted to working age households ages 25-59. Following Kaplan et al. (2014) and Gorea and Midrigan (2017), we trim the upper tail of the income distribution in the SCF. Kaplan et al. (2014) trim the top 5% while Gorea and Midrigan (2017) trim the top 20%. We use an intermediate value of 10%, but results are similar when using alternative thresholds.

ONLINE APPENDIX

A.4 Description of Computational Procedures

In this appendix, we describe the solution to the baseline model and its extensions. The household state vector is $\mathbf{s} \equiv (A, H, z, P, j)$, and the model is solved by backward induction from the final period of life. When working, households solve:

$$V(\mathbf{s}) = \max \left\{ V^{adjust}(\mathbf{s}), V^{noadjust}(\mathbf{s}), V^{rent}(\mathbf{s}) \right\}.$$

The three value functions, for adjusters, non-adjusters, and renters, are given by

$$V^{adjust}(\mathbf{s}) = \max_{C, A', H'} U(C, H') + \beta E[V(\mathbf{s}')|z]$$

$$s.t. \quad A' + PH' + C = (1 + r)A + Y(z) + (1 - F)(1 - \delta)PH,$$

$$A' \geq -(1 - \theta)\frac{1 - \delta}{1 + r}PH', \quad \mathbf{s}' = (A', H', z', P', j + 1),$$

$$V^{noadjust}(\mathbf{s}) = \max_{C, A'} U(C, H) + \beta E[V(\mathbf{s}')|z]$$

$$s.t. \quad A' + C = (1 + r)A + Y(z) - \delta PH,$$

$$A' \geq -(1 - \theta)\frac{1 - \delta}{1 + r}PH, \quad \mathbf{s}' = (A', H, z', P', j + 1),$$

$$V^{rent}(\mathbf{s}) = \max_{C, A', \tilde{H}} U\left(C, \tilde{H}\right) + \beta E[V(\mathbf{s}')|z]$$

$$s.t. \quad A' + C + \phi P\tilde{H} = (1 + r)A + Y(z) + (1 - F)(1 - \delta)PH,$$

$$A' \geq 0, \quad \mathbf{s}' = (A', 0, z', P', j + 1).$$

The problem for a retired household is identical except that social security benefits replace labor earnings. At the age of retirement households also receive an additional lump sump transfer to match the level of retirement wealth which is now liquid, as described in the text. At the time of death households' continuation value is given by the bequest motive in the text.

To solve the model numerically, we proceed as follows. First, note that the presence of random walk house prices with i.i.d. changes x_t, CRRA preferences and a constant price-rent ratio allows us to combine the separate states P and H into a single state $\hat{H} \equiv PH$ and instead solve the equivalent recursive problem:

$$V^{adjust}(\mathbf{s}) = \max_{C,A',\hat{H}'} U\left(C,\hat{H}'\right) + \beta E\left[x'^{-(1-\sigma)(1-\alpha)}V(\mathbf{s}')|z\right]$$

$$s.t. \quad A' + \hat{H}' + C = (1+r)A + Y(z) + (1-F)(1-\delta)\hat{H},$$

$$A' \geq -(1-\theta)\frac{1-\delta}{1+r}\hat{H}', \quad \mathbf{s}' = (A',\hat{H}',z',j+1),$$

$$V^{noadjust}(\mathbf{s}) = \max_{C,A'} U\left(C,\hat{H}\right) + \beta E\left[x'^{-(1-\sigma)(1-\alpha)}V(\mathbf{s}')|z\right]$$

$$s.t. \quad A' + C = (1+r)A + Y(z) - \delta\hat{H},$$

$$A' \geq -(1-\theta)\frac{1-\delta}{1+r}\hat{H}, \quad \mathbf{s}' = (A',\hat{H},z',j+1),$$

$$V^{rent}(\mathbf{s}) = \max_{C,A',\tilde{H}} U\left(C,\tilde{H}\right) + \beta E\left[x'^{-(1-\sigma)(1-\alpha)}V(\mathbf{s}')|z\right]$$

$$s.t. \quad A' + C + \phi\tilde{H} = (1+r)A + Y(z) + (1-F)(1-\delta)\hat{H},$$

$$A' \geq 0, \quad \mathbf{s}' = (A',0,z',j+1).$$

Note that $P' = x'P$ so that the x' in the expectation integrates over the possible realizations of house price growth from today to tomorrow. Given the above assumptions, this enters the household problem equivalently to i.i.d. discount rate shocks and enters the problem only in its role in evaluating expected continuation values. It does not enter as a current state since shocks are i.i.d. and previous values of the shock are fully reflected in the state $\hat{H}$.

In order to rectangularize the choice set and simplify the computational problems imposed by the endogenous liquidity constraint, we follow Díaz and Luengo-Prado (2010) and reformulate our problem in terms of voluntary equity, defined as

$$Q \equiv A + (1-\theta)\frac{1-\delta}{1+r}\hat{H}.$$

After substituting the budget constraint into the utility function to eliminate C as a choice variable, the value function can then be rewritten in terms of the two non-negative state variables Q and $\hat{H}$. Note that A' and H' are chosen prior to next period shocks to house prices. Thus shocks to house prices imply that realized Q' and $\hat{H}'$ will become stochastic variables which differ from the value chosen by households today. Namely, given a chosen pair $Q', \hat{H}'$, the realized value of $\hat{H}$ next period will be $x'\hat{H}$ and the realized value of Q next period will be $Q' + (1-\theta)\frac{1-\delta}{1+r}(x'-1)\hat{H}'$, where ΔP is the house price shock. This implies that although households in our baseline model are constrained to always choose $Q' \geq 0$, realized voluntary

equity can be negative, for a large enough negative house price shock. To account for this, we solve the model for states that include negative voluntary equity even though households are constrained to choose non-negative values for this variable.[60]

We discretize the problem so it can be solved on the computer by first discretizing z and x' using the algorithm of Tauchen (1986). We use 13 grid points for z and 5 grid points for x'. We then approximate the functions V_j^{adjust}, $V_j^{noadjust}$, and V_j^{rent} as multilinear functions in the endogenous states. In our benchmark calculation, we use 120 knot points for Q (we space these points more closely together near the constraint) and 40 knot points for $\hat{H}$. The presence of fixed adjustment costs on housing together with the borrowing constraint make the household policy function highly non-linear. For this reason, we follow Berger and Vavra (2015) and compute optimal policies for a given state-vector using a Nelder-Meade algorithm initialized from 3 different starting values, to reduce the problem of finding local maxima. The value of adjusting, not adjusting and renting are then compared to generate the overall policy function. We proceed via backward induction from the final period of life.

To simulate the model, we initialize cohorts to match the values of the SCF for age 22-27 year old households. First, we randomly split the sample into two groups to match the fraction of homeowners and renters. Then within each group, we split the sample into 4 income bins and assign the median value of housing and liquid assets from the SCF in that same income bin. (By definition, the value of housing for the renter groups is always zero). The model is simulated with 100,000 households and house price impulse responses are computed for each cohort.

In section 5.1 we introduce long-term debt. In this version of the model, non-adjusting households can increase voluntary equity with no cost, as in the baseline model, but households who want to decrease voluntary equity when $a < 0$ must pay a fixed cost proportional to the value of their house to do so. We also assume that when households neither refinance or move, they need not satisfy the collateral constraint on new debt, but they must pay off some fraction of their existing debt: In particular, when refinancing, households face the constraint:

$$-A' \leq (1 - \theta)\frac{1 - \delta}{1 + r}PH',$$

but when not adjusting, they instead face the constraint:

$$A' \geq \begin{cases} \chi A, & \text{if } A < 0 \\ 0, & \text{if } A \geq 0 \end{cases}$$

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[60]Shocks to house prices in the model are not large enough to ever reach a situation where realized Q is so negative that households would be unable to choose $Q' \geq 0$ without having negative consumption.

Given this constraint, we then solve $V(\mathbf{s}) = \max \left\{ V^{adjust}(\mathbf{s}), V^{noadjust}(\mathbf{s}), V^{refi}(\mathbf{s}), V^{rent}(\mathbf{s}) \right\}$ where $V^{noadjust}(\mathbf{s})$ now includes the above constraint, and $V^{refi}(\mathbf{s})$ is identical to $V^{noadjust}(\mathbf{s})$ in the baseline problem but with budget constraint $A' + C = (1 + r)A + Y(z) - \delta PH - F^{refi}PH$, where F^{refi} is calibrated to match targets described in the text.

We also explore three extensions which do not allow us to solve the problem using $\hat{H}$ instead of separate states P and H. In particular, moving from Cobb-Douglas to CES preferences, eliminating the constant price-rent ratio, or eliminating the random walk and working with AR shocks no longer allows us to make this substitution. In this case, we now include P explicitly as a state variable, which we allow to take on 25 evenly spaced valued from -25 σ_P to 25 σ_P. That is, each node in the price grid is two standard deviations apart, and the overall price grid is wide enough that no households hit the boundary during their finite life. Re-solving the model with a finer grid delivers similar results but substantially slows computations. In order to avoid interpolating between price grid points, we set $\mu = 0$ in these extensions but recalibrate our baseline model to match the same moments with $\mu = 0$. Since adding an additional state-variable substantially slows the problem, we reduce the grid for Q to 110 points and the grid for H to 36 points. Solving the problem with this additional state nevertheless is substantially slower, so we do not recalibrate the model in these extensions. However, these models still hit the original targets reasonably well.

A.5 Extension: CES Preferences

In this section, we extend the analytical analysis of the frictionless model in 3 to CES preferences for consumption and housing. This complements the numerical analysis in 5.3, which explores the effects of CES preferences in our baseline model.

In the body of the paper, we assume Cobb-Douglas utility—i.e., elasticity of substitution equal to 1—and use that assumption to derive Proposition 1. Here we show that the proposition can be extended to the case of CES preferences if we make the additional assumption of $\theta = 0$, that is, if we consider a very loose collateral requirement. In that case, our sufficient statistic formula extends naturally by adding a new term that is positive in the case of elasticity of substitution bigger than 1 and negative in the opposite case. Under plausible parametrizations the magnitude of the elasticity remains large and the Cobb-Douglas based formula implies results similar to the exact CES formula.

Let the utility function be:

$$U(C_{it}, H_{it}) = \frac{1}{1 - \sigma} \left(\alpha C_{it}^{\frac{\epsilon - 1}{\epsilon}} + (1 - \alpha) H_{it}^{\frac{\epsilon - 1}{\epsilon}} \right)^{\frac{\epsilon(1 - \sigma)}{\epsilon - 1}}$$

where ϵ is the intra-temporal elasticity of substitution between non-durable consumption and

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housing services. For simplicity we focus an environment with constant house prices and analyze the response to a permanent, unexpected price change, but results extend naturally to the stochastic case.

Proposition 2 *Consider the model with CES preferences, liquid housing wealth, and $\theta = 0$. The individual response of non-durable consumption to an unexpected, permanent, proportional change in house prices dP/P is*

$$(\epsilon - 1) \frac{\frac{r+\delta}{1+r} PH_{it}}{C_{it} + \frac{r+\delta}{1+r} PH_{it}} C_{it} + MPC_{it} \cdot (1 - \delta) PH_{it-1}.$$

Proof. With constant prices, the user cost of housing (or implicit rental rate) is $\frac{r+\delta}{1+r} P$. So we can define total spending on non-durables and housing services

$$X_{it} \equiv C_{it} + \frac{r + \delta}{1 + r} PH_{it},$$

and the price index

$$P^X \equiv \left[\alpha^\epsilon + (1 - \alpha)^\epsilon \left(\frac{r + \delta}{1 + r} P \right)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}.$$

The household's optimization problem can then be decomposed into an intertemporal optimization problem, characterized by the Bellman equation

$$V(W, s) = \max \frac{1}{1 - \sigma} \left(\frac{X}{P^X} \right)^{1-\sigma} + \beta E\left[V(W', s') \right],$$

subject to

$$W' = (1 + r)\left[W + Y(s) - X \right] \geq 0,$$

and an intratemporal utility maximization problem. The solution to the intertemporal problem is independent of P^X as it only appears as a multiplicative constant in the objective function. So the policy $X(W, s)$ is independent of P. The solution to the intratemporal problem gives

$$C = \frac{\alpha^\epsilon}{\alpha^\epsilon + (1 - \alpha)^\epsilon (\frac{r+\delta}{1+r} P)^{1-\epsilon}} X, \quad H = \frac{(1 - \alpha)^\epsilon (\frac{r+\delta}{1+r} P)^{-\epsilon}}{\alpha^\epsilon + (1 - \alpha)^\epsilon (\frac{r+\delta}{1+r} P)^{1-\epsilon}} X.$$

The response of C to P conditional on X is then

$$\frac{\partial C}{\partial P} = (\epsilon - 1) \frac{r + \delta}{1 + r} \frac{H}{X} C.$$

Combining this effect with the effect on X through W, yields the desired result. ∎

An elasticity of substitution different from one implies that there is an additional term,

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proportional to the implicit share of housing services in the total consumption basket. In the model, this share is tightly linked to the ratio of house values to consumption. For example, take an agent with housing-to-consumption ratio 3.5—which is the roughly the average for agents in the 40s bin. With $r = 2.4\%$ and $\delta = 2.2\%$ this implies a share of housing services to total spending equal to 0.13. For such an agent if $\epsilon = 1.1$, the additional term is equal to $0.1 \times 0.13 = 0.013$. If the same agent has an MPC of 0.1 the magnitude of the baseline sufficient statistic is $0.1 \times 3.5 = 0.35$, so the additional term plays a minor role quantitatively.