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House Prices and Consumer Spending

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ABSTRACT

Recent empirical work shows large consumption responses to house price movements. Can consumption theory explain these responses? We consider a variety of consumption models with uninsurable income risk and show that consumption responses to permanent house price shocks can be approximated by a simple "sufficient-statistic" formula: the marginal propensity to consume out of temporary income times the value of housing. Calibrated versions of the models generate house price effects that are both large and sensitive to the level of household debt in the economy. We apply our formula to micro data to provide new measures of house price effects.

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1 Introduction

The last recession in the US was characterized by a large and persistent decline in consumer spending.¹ Many observers have pointed to the evolution of house prices and household debt as important factors in explaining consumption dynamics before and during the recession. More broadly, there is a widespread policy concern that boom-busts cycles in housing and consumer debt can end with large contractions in consumer spending.² A growing empirical literature argues that consumption responds strongly to house price movements, thus suggesting an important role for housing wealth in consumption dynamics. However, the theoretical rationale for these house price effects on consumption is less clear. In particular, it is a commonly held view that house price effects on consumption should be small, because for most households an increase in the price of their house is associated with an equivalent increase in expected future implicit rental costs.³ What models can deliver the large effects found in the empirical literature and what are the mechanisms at work? Are house price effects larger when the household sector is more levered? Is it important that housing can be used as collateral? Can house price movements independently lead to large consumption swings or do they require correlated movements in common factors such as income or financial conditions?

In this paper, we study these questions in the context of a fairly standard class of incomplete market models with income uncertainty and housing that serves as collateral. Our main quantitative conclusions are: (i) Reasonable calibrations of this class of models can produce large consumption responses to exogenous house price changes, in line with the recent empirical literature; (ii) The size of these responses depends crucially on initial conditions in the economy, namely, on the initial joint distribution of housing and debt.

In the process of delivering these quantitative conclusions, we develop a new theoretical result which sheds light on the mechanism behind these findings. We show that in our baseline model, the individual response of consumption to an unexpected, permanent house price change is given by a simple “sufficient-statistic” formula: the individual marginal propensity to consume out of temporary income shocks (MPC) times individual housing holdings. The aggregate response is then determined by the endogenous joint distribution of the MPC and housing. This formula helps explain why different versions of our model, which produce different joint distributions, generate different average responses. It also explains why, following different histories of past shocks, which produce different initial conditions, an economy displays different aggregate responses to current shocks.

Our formula implies that the total consumption response to a change in house prices

¹See Petev et al. (2012).

²See Cerutti et al. (2015).

³See the literature discussed below.

can be interpreted as a pure “endowment effect” driven by the change in value of initial housing endowments. However, this result should be interpreted with care, as it does not imply that other effects are not at work. Higher house prices increase the value of housing endowments, but also induce income and substitution effects as the relative price of housing services increases, and they relax borrowing constraints through a collateral channel. We analyze these effects and show that each one is large when viewed in isolation. However, if one is interested in understanding the total effect, these four channels are tightly linked together: in our baseline model the income, substitution and collateral effects cancel out, so that only the endowment effect remains.

Our baseline is a partial equilibrium model calibrated to life-cycle wealth data from the Survey of Consumer Finances. We show that this model delivers an average elasticity of consumption to house price shocks over working life of 0.47. Two model features explain this relatively large elasticity. First, with income uncertainty and precautionary savings, the consumption function is concave in net-worth so that low net-worth agents have large MPCs. Second, housing services enter the utility function, which implies that housing wealth is not proportional to total net-worth. In particular, low net-worth agents choose to borrow and thus hold housing that is a multiple of net worth. Therefore, the model generates a joint distribution with a sizable mass of households at high housing levels and, at the same time, low net worth and high MPC. Using our formula, this implies that the aggregate consumption response to house price shocks is large. Thus, relatively standard models imply large responses of consumption to pure changes in house prices and do not require additional features such as house price movements which are correlated with future income in order to generate these effects.

The baseline model features no transaction costs in housing and no rental option. Therefore, it produces unrealistic levels of house trading and cannot match the large fraction of renters in the population, so we next extend the model to allow for illiquid housing and rentals and re-calibrate it to match the levels of housing adjustment and ownership rates in the data. In the extended model, our sufficient-statistic formula no longer holds exactly, but we show that for realistic parameter choices it still provides a good approximation. Somewhat surprisingly, the presence of housing adjustment costs has only minor quantitative implications for the effect of house prices on consumption. The main quantitative difference between the baseline and extended model comes from the presence of renters. In the model with renters the average response over working life is smaller and equal to 0.24. This is due not only to the fact that some agents do not own a house, and thus have a zero endowment effect, but also to the fact that agents who choose to rent are precisely the low net-worth, high-MPC agents who would display the biggest responses if they owned.

After showing that the sufficient-statistic approximation is robust to various model specifications, we take our formula directly to consumption data. Estimating the distribution of

$MPC \times H$ in the data provides an alternative sufficient-statistic-based measure of housing price effects and can also be interpreted as a test of our structural consumption model. The main challenge is to estimate MPCs conditional on housing holdings, which we address by extending the approach of Blundell, Pistaferri and Preston (2008) to recent PSID data. We find that the micro patterns of $MPC \times H$ are similar to those implied by our simulations and that our sufficient-statistic-based measure of housing price effects is in line with existing estimates such as those in Mian et al. (2013).

The majority of our paper focuses on the consumption response to one-time, permanent house price shocks. In the final section of the paper we extend the analysis of dynamics, focusing on a boom-bust housing cycle. A typical feature of housing cycles is that residential investment first increases and then decreases, along with house prices, suggesting an important role for shifts in housing demand. In order to generate such shifts, we introduce changes in expected *future* house price growth. We show that these changes in expected growth allow us to match the cyclical behavior of residential investment. At the same time, changes in expected growth have only mild direct effects on consumption, so consumption is primarily driven by the house price effect investigated in the rest of the paper.⁴ However, this does not imply that shifts in housing demand are irrelevant for consumption dynamics. The important channel here is that past shifts in housing demand affect the joint distribution of housing and debt, and thus determine the magnitude of the house price effect. In particular, in our simulations, the increase in housing demand during the boom leads to increased leverage, and this contributes substantially to the consumption contraction caused in the bust.

The boom-bust simulations show that the distribution of housing and debt matters for the strength of house price effects. This observation is important when 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 depending on the distribution of states 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.⁵

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 large effects.⁶

⁴These results also show that our quantitative conclusions are robust to relaxing the assumption of permanent shocks.

⁵See 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.

⁶While there are different ways of measuring housing price effects, for consistency we will focus the dis-

We contribute to this debate both by showing that theory is consistent with large causal effects and by constructing a new sufficient-statistic based measure of housing price effects.

In two influential studies using aggregate data, 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 around 0.20.⁷ There are also a number of studies that exploit household level micro data, which allows for substantially more variation in consumption and house prices and for alternative sources of identification. Such studies have led to a wide range of estimates. For example, Campbell and Cocco (2007) find an average elasticity of non-durable consumption to house prices of about 1.2 with larger results for old homeowners than for young homeowners. In contrast, Attanasio et al. (2009) find that the average non-durable consumption elasticity is 0.15 and that that consumption response of young homeowners is much stronger than it is for old homeowners.

The greatest challenge for these studies is that it is hard to find exogenous variation in house prices which can be used to separate direct house price effects from the effects of common factors. In particular, an important concern is that expectations about future income growth may drive both house prices and consumption.⁸ Mian et al. (2013) make progress on this front by using high quality credit card data together with the Saiz (2010) housing supply instrument to isolate the effects of exogenous changes in house prices on highly localized measures of spending. Their baseline estimates of the non-durable consumption elasticity are between 0.13 and 0.26.⁹ 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. Despite this caveat, we nevertheless view the elasticities from Mian et al. (2013) 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. (2015) and Stroebel and Vavra (2015) also arrive at similar numbers using new scanner spending data and additional identification strategies.

cussion 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.

⁷They 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 \$28,369 billion and personal consumption expenditures from the BEA were \$9,750.5 billion. This delivers the reported elasticities.

⁸See Attanasio and Weber (1994).

⁹They 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.

Throughout the paper, we refer to a commonly held view that house price effects should be small in standard consumption models. One of the clearest formulations of this view is in Sinai and Souleles (2005) (p. 773), who argue that “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.”¹⁰ To clarify the connection with this line of argument, we begin our analysis from a special case with no income risk where the permanent income hypothesis (PIH) holds. In that special case, the argument of Sinai and Souleles (2005) applies and indeed house price effects are small.¹¹ However, once we move away from that special case, the argument no longer holds and house price effects become large.¹² In Section 2.6, we highlight two reasons for this difference. First, in an incomplete markets model, the timing of house price effects rather than just their present value become relevant. A permanent increase in house prices immediately increases current resources, while higher implicit rental costs occur in the future. Borrowing constraints imply that the current resource effect is dominant for current consumption choices.¹³ Second, the fact that houses serve as collateral means that an increase in house prices relaxes borrowing constraints.

Our paper is part of a large and growing literature that studies the theoretical response of consumption to house prices in quantitative models with heterogeneous agents. A number of papers have calibrated and simulated increasingly rich models with housing and debt, using them both to address aggregate questions and to draw cross sectional predictions, e.g., Carroll and Dunn (1998), Campbell and Cocco (2007), and Attanasio et al. (2011). More recently, models with these features have been embedded into a general equilibrium framework, 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 Huo and Ríos-Rull (2013) and Kaplan et al. (2015) are two recent papers that study heterogeneous agents general equilibrium models where house prices, consumption and income are endogenously determined. Gorea and Midrigan (2015) also go in a similar direction, although they take output as given and focus on the behavior of the saving rate. We see our partial equilibrium analysis as highly complementary to this line of work, as our sufficient-statistic formula and our decompositions help to identify the channels at play and show the crucial role of the endogenous distribution of housing and

¹⁰Other papers that refer to this argument include Buiter (2008) and Campbell and Cocco (2007).

¹¹They are not zero, due to the presence of depreciation and substitution effects in our model.

¹²In fact, Sinai and Souleles (2005) were careful to acknowledge the potential role of borrowing constraints and substitution effects in undermining their result.

¹³In the language used throughout our paper, the endowment effect dominates the income effect.

¹⁴Early work in this direction—that does not model housing—includes Hall (2011), Guerrieri and Lorenzoni (2011), Eggertsson and Krugman (2012).

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

debt for the size of house price effects.

Our emphasis on 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)). In macro, the idea is to use this approach to express some aggregate response, which may be hard to measure, in terms of individual responses, which may be easier to identify in micro data. Of course, some further steps may be necessary to translate these aggregate 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.

Heterogeneous agent, life-cycle models have also been used to study housing markets along other dimensions. For example, Favilukis et al. (2015) use this type of model to ask whether financial innovation and the relaxation of financial constraints were at the roots of the recent US housing boom-bust cycle. Campbell and Cocco (2015) and Corbae and Quintin (2015) study how the boom and bust affected default risk and the incentives of the financial system. Our paper focuses on consumption theory and its predictions for the relationship between house prices and consumption, so we leave aside these important related issues.

The remainder of the paper proceeds as follows: In Section 2 we present the baseline model, derive our sufficient-statistic formula, and show baseline results. In Section 3 we show that our sufficient-statistic remains accurate for the extended model that includes adjustment costs, renters and more realistic mortgages and discuss the effects of these features on the size of housing price effects. In Section 4 we take it directly to micro data to construct a new empirical measure of housing price effects. Finally, in Section 5 we simulate a housing boom-bust episode and show that it leads to substantial time-variation in the strength of house price effects.

2 Model

We consider a dynamic, incomplete markets model of household consumption. Households have a finite life cycle and face uninsurable idiosyncratic income risk. The main distinguishing feature of the model is that households trade houses, which provide housing services that enter the utility function, and can borrow against the value of their houses.

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 . The housing stock yields housing services one-for-one, depreciates at rate δ , and trades at an exogenous price P_t .

Households born at time t maximize the expected utility function

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

where C_{it} denotes consumption of non-durable goods and \tilde{W}_{it+J+1} is a measure of offspring's real wealth, given by

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

In the last expression, Γ_{it+J+1} captures the human wealth of offspring and will be specified shortly, $P_{t+J+1}(1 - \delta)H_{it+J} + (1 + r)A_{it+J}$ is bequeathed wealth, and P_{Xt+J+1} is a price index that adjusts for changes in the future cost of housing, given by equation (3) below.

The per-period utility function and the bequest function are specified as follows:

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

The assumption of Cobb-Douglas preferences for non-durable consumption and housing services plays an important role in our baseline 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 of substitution close to unity (Piazzesi et al. (2007), Davis and Ortalo-Magné (2011), and Aguiar and Hurst (2013)). Furthermore, in Appendix 2 we show that our results are robust to using CES preferences with elasticity of substitution in a reasonable range.

Households face an exogenous income process. When the household works, income is given by

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

where $\chi(j)$ 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 as in Guvenen and Smith (2014).

The per-period budget constraint is

$$C_{it} + P_t (H_{it} - (1 - \delta)H_{it-1}) + A_{it} = Y_{it} + (1 + r)A_{it-1}.$$

Households can borrow, but they have to satisfy the borrowing constraint

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

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

2.2 The Permanent-Income Case

Consider first a special case with deterministic income ($\sigma_\varepsilon = 0$) and no borrowing constraint, which can be solved analytically. This case will give us a reference permanent-income-hypothesis (PIH) model in which housing price effects are small and insensitive to household debt.

Suppose house prices are constant at $P_t = P$. Also, assume:

$$(1 + r)\beta = 1, \quad \Psi = (1 - \beta)^{-\sigma}.$$

Under these assumptions, there is perfect consumption smoothing: consumption of non-durable goods 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:¹⁶

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

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

$$\frac{dC_{it}/C_{it}}{dP/P} = \frac{(1 - \delta)PH_{it-1}}{\sum_{\tau=t}^{t+J-j} (1 + r)^{-\tau} Y_{it+\tau} + (1 - \delta) P_t H_{it-1} + (1 + r) A_{it-1}}. \quad (2)$$

What are the quantitative implications of this baseline case? To assess this, note that Equation 2 also holds in the aggregate and thus each quantity on the right-hand side can be measured directly using aggregate data. For consistency with the rest of the paper let us use aggregates from the 2001 Survey of Consumer Finances (SCF). We then get $(1 - \delta)PH = 2.15Y$ and $A = -.32Y$, where H is average housing, A is average liquid wealth net of debt,

¹⁶For simplicity, we set the human wealth of offspring to zero.

and Y is average earnings. Using an interest rate of $r = 2.5\%$ and an infinite horizon approximation, human wealth is equal to $Y/r = 40Y$. The aggregate elasticity of non-durable consumption implied by the model is then 0.0514, a small number relative to empirical housing price effects. Moreover, this elasticity is insensitive to the level of indebtedness of the household sector. For example, suppose that household debt goes up by $0.5Y$ so that $A = -0.82Y$, holding all else equal. This is a very large increase in debt but yields a nearly identical and still small elasticity of 0.0520. Finally, this simple model implies that elasticities will be higher for older households, since they have a smaller fraction of human wealth to total wealth.

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.¹⁷ It is then possible to interpret equation (2) in two ways.

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 (2) 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.¹⁸ The detailed derivations behind these statements are in Appendix 1. Therefore, the effect in (2) 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 (2) are correct. However, the first interpretation will be especially useful in what follows as it survives in richer versions of the model.

2.3 Sufficient-Statistic Formula

We now return to the general model with income uncertainty and borrowing constraints. In this setup, we derive our main analytical result: the individual consumption response to a permanent house price change is given by a simple formula, the product of the individual

¹⁷A 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 present value of expenditures arising from the increased cost of housing in all future periods. The endowment effect is the change in current consumption due to an increase in the present value of expenditures arising from the increase in the value of the initial housing stock.

¹⁸The effects are not exactly equal due to depreciation δ . When $\delta = 0$ they are exactly equal.

marginal propensity to consume out of temporary income shocks and the beginning-of-period housing stock.

To set the stage for the result, we first represent the household problem recursively. In order to do so, it is useful to recognize that the only individual state variables for household i at time t are total wealth $W_{it} \equiv (1 - \delta)P_{t+1}H_{it-1} + (1 + r)A_{it-1}$, the idiosyncratic income variable z_{it} , and age j_{it} . In recursive notation, the household Bellman equation is then

$$V_t(W, s) = \max_{C, H, A, W'} U(C, H) + \beta E[V_{t+1}(W', s')]$$

subject to

$$C + P_t H + A = Y(s) + W,$$

$$W' = (1 - \delta) P_{t+1} H + (1 + r) A,$$

$$(1 - \theta)(1 - \delta) P_{t+1} H + (1 + r) A \geq 0,$$

where $s = (z, j)$, $Y(s) = \exp\{\chi(j) + z\}$, $z' = \rho z + \varepsilon'$ and $j' = j + 1$. To complete the description of the problem, the bequest motive gives us the terminal condition:

$$V_t(W, s) = \frac{\Psi}{1 - \sigma} \left(\frac{\Gamma(s) + W}{P_{Xt}} \right)^{1-\sigma},$$

for all $s = (j, z)$ with $j = J + 1$.

In a model with constant house prices, the user cost of housing services (i.e., the implicit rental rate) is also constant and equal to $P(r + \delta)/(1 + r)$. Since the non-durable good is the numeraire, the price index is then

$$P_X = \alpha^{-\alpha} (1 - \alpha)^{-(1-\alpha)} \left(P \frac{r + \delta}{1 + r} \right)^{1-\alpha}. \quad (3)$$

We are now ready to prove our main analytical result.

Proposition 1 *The individual response of non-durable consumption to an unexpected, permanent change in house prices is*

$$MPC_{it} \cdot (1 - \delta) H_{it-1}, \quad (4)$$

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

Proof. With constant prices $P_t = PH$ and with Cobb-Douglas/CRRA preferences the Bellman equation can be rewritten in terms of the value of housing $\tilde{H} = PH$ as

$$V(W, s) = \max_{C, \tilde{H}, A, W'} P^{-(1-\sigma)(1-\alpha)} U(C, \tilde{H}) + \beta E[V(W', s')],$$

$$\begin{aligned}
C + \tilde{H} + A &= Y(s) + W, \\
W' &= (1 - \delta) \tilde{H} + (1 + r) A, \\
(1 - \theta) (1 - \delta) \tilde{H} + (1 + r) A &\geq 0.
\end{aligned}$$

Notice that the expression $P^{-(1-\sigma)(1-\alpha)}$ is a constant that multiplies the utility function in each period. It also appears in the same form in the bequest function, through the CPI term P_X , as shown above. We conclude that the policy function $C(W, s)$ for the problem above is independent of the level of P . Therefore, the response of consumption of household i to a permanent shock to P at t is

$$\frac{\partial C(W_{it}, s_{it})}{\partial W} (1 - \delta) H_{it-1}.$$

To complete the argument notice that $\partial C(W_{it}, s_{it}) / \partial W$ is equal to MPC_{it} . ■

The result can be restated in terms of the individual elasticity of non-durable consumption to house prices η_{it} as follows

$$\eta_{it} = MPC_{it} \cdot \frac{(1 - \delta) P_t H_{it-1}}{C_{it}}.$$

Proposition 1 shows that the individual consumption response to a permanent house price change can be represented by a simple formula.¹⁹ Notice that both objects in the formula are endogenous, so the proposition does not give closed form solutions. However, the formula is useful for understanding how endogenous forces determine the sensitivity of an economy to house price shocks. In particular, house price shocks will have bigger effects when there is a stronger correlation between MPCs and housing values in the economy.

In Section 3, we show that the formula continues to hold approximately in richer versions of the model with adjustment costs, more realistic mortgages and the option to rent. Hence, it can provide intuition in substantially more complicated environments. Furthermore, given empirical estimates of MPCs conditional on housing wealth, the formula can be used as a sufficient statistic for the model-implied response of consumption to house price shocks, without the need to structurally estimate the full model. We explore this approach in Section 4.

At first sight, formula (4) may appear tautological. The non-obvious content arises from the fact that the MPC is the marginal propensity to consume out of temporary income shocks, not out of housing wealth. To better understand the result it is useful to think about the underlying forces at work. When house prices increase, there are four effects: (1) a substitution effect that makes households substitute away from housing—which is now more

¹⁹Real house prices exhibit values of annual persistence around .94 in Case-Shiller and OFHEO house price data from 1960-2014, and a random walk cannot be rejected. In Section 5 we discuss the effect of less persistent shocks.

expensive—towards non-durable consumption; (2) an income effect, which makes households poorer overall because the implicit rental cost of housing is higher today and in all future dates; (3) a collateral effect, arising from the fact that higher collateral values allow households to increase borrowing, today and in the future; (4) an endowment effect, which comes directly from the increase in the value of the house owned when the shock hits.²⁰ Formula (4) tells us that the first three effects exactly cancel out, so the total effect is equal to the endowment effect. We will return to this decomposition in Subsection 2.6, after calibrating and simulating our model, to look at the relative magnitude of these four effects.

The Cobb-Douglas assumption on preferences clearly plays an important role in the proof of Proposition 1. However, in Appendix 2, we examine the case of general CES preferences and show that our main quantitative conclusions survive as long as the elasticity of substitution between consumption and housing is not too far from one.

Throughout the paper we focus on models where idiosyncratic risk is the only source of uncertainty. However, it is useful to notice that Proposition 1 extends to the case of stochastic house prices that follow a random walk with drift, and to the case in which additional risky assets are traded, as long as their rates of returns are independent of the house price level.

2.4 Calibration

We now explain the calibration of the baseline model parameters, shown in Table 1.

Table 1: *Parameter Values*

Parameter	σ	r	δ	θ	ρ_z	σ_z	α	β	Ψ	Ξ
Value	2	2.4%	2.2%	0.25	0.91	0.21	0.854	0.9331	1,353	3.4137

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 an intertemporal elasticity of substitution σ equal to 2.²³ 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 conservative value

²⁰To formally define income and substitution effects requires extending these notions to the dynamic, incomplete markets environment analyzed here. The details are presented in Appendix 1.

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

²²We 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 .

²³Using log utility or other values of σ does not substantively change our conclusions on the effect of a price level shock. In Section 5 we discuss how σ affects the model response to anticipated price changes.

of 0.25.²⁴

The income process during working age has a life-cycle component 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 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 the same statistics in PSID earnings (after taking out life-cycle components). In retirement, households receive a social security income payment which is modeled as in Guvenen and Smith (2014).

The three remaining parameters to calibrate are: the coefficient α on housing services, the discount factor β , and the bequest parameter Ψ . We choose these parameters jointly to match life-cycle profiles of housing and non-housing wealth 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). Our model is very stylized for retired agents since they face no sources of risk. Therefore, we prefer to focus our calibration and predictions on working-age agents. Our notion of liquid wealth net of debt includes all assets in SCF excluding retirement accounts for agents before retirement, but including retirement accounts 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 agents of age 25 holdings of housing and liquid assets and income to match the distribution of age 23-27 households in the 2001 SCF.²⁵ We then choose the parameters α, β, Ψ and Ξ to minimize the quadratic distance between the sequences of housing and liquid wealth by age bin in the data and the corresponding sequences 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 penalties for accessing 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.²⁶

Figure 1 shows the fit of the calibrated model in terms of average housing wealth (top panel) and average liquid wealth net of debt (bottom panel), by age bin.²⁷ The blue circles

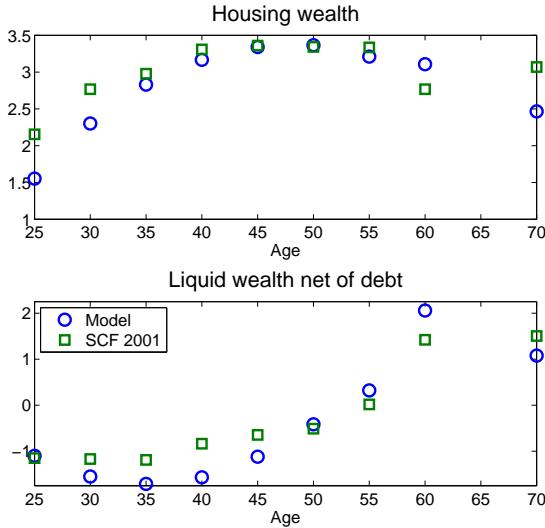
²⁴Lowering θ amplifies the size of consumption responses.

²⁵Using only age 25 households would give us a small sample and introduce large measurement error.

²⁶Nevertheless, targeting total wealth rather than liquid wealth still produces large elasticities.

²⁷The point for the age bin 65 and over is plotted at age 70.

Figure 1: Housing and Net Liquid Wealth over the Life Cycle: Data vs Model



are the model predictions and the green squares are from the 2001 SCF. Despite its simplicity the model delivers a reasonable fit, the main discrepancy being too little housing in the early periods and too much debt in the mid 30s and 40s.

2.5 The effects of a permanent house price shock

We now turn to the model predictions for a simple house prices comparative static exercise. Namely, we look at the instantaneous response of non-durable consumption to a negative, unexpected, permanent 1% reduction in house prices.²⁸

The average elasticity of consumption over working life is 0.47. Figure 2 reports elasticities for different ages, with values as high as 0.6 for agents in their late 20s. Elasticities are higher for younger agents and decline steadily after 30. The main takeaway is that magnitudes are much larger than in the PIH model and are declining rather than increasing with age. In fact, the elasticities obtained here are considerably larger than empirical estimates in the literature. In the following section, we show that adding more realistic features to the model, and in particular adding the option to rent, yields elasticities more in line with empirical estimates.

We can use our formula (4) to interpret this result. In Figure 3 we separately plot the two elements of the formula: the MPC and housing holdings, averaged by age. The high elasticities of young agents are driven by the fact that they have a high MPC and, at the same time, hold substantial amounts of housing. In a precautionary saving model the MPC

²⁸Results are very similar for larger house price declines as well as house price increases.

Figure 2: Elasticities over the Life Cycle: Frictionless Model

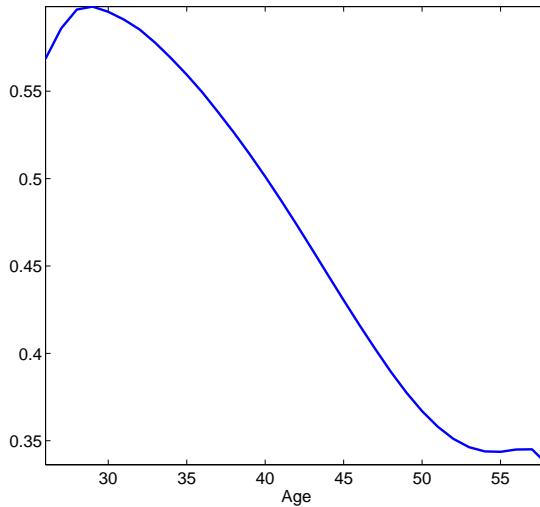
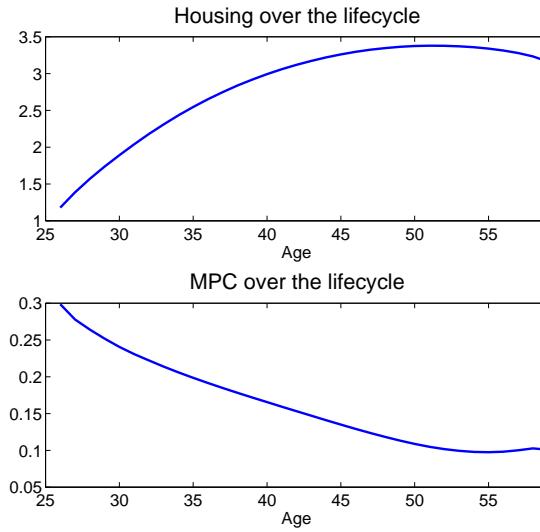


Figure 3: Understanding the Life Cycle: Frictionless Model

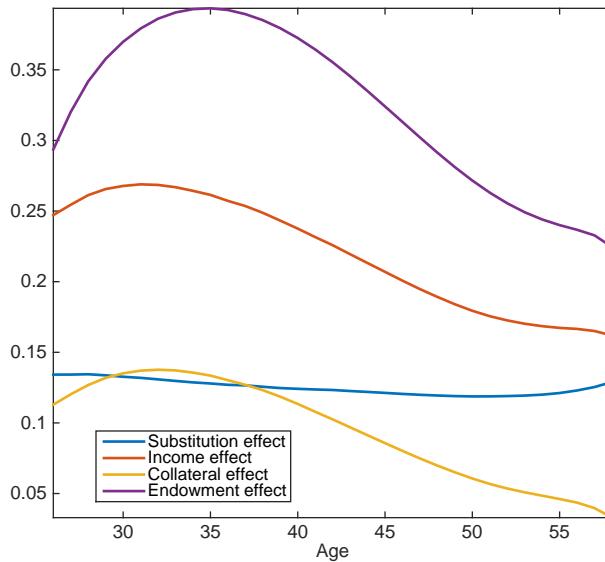


depends on total net worth W and is decreasing in W due to concavity of the consumption function. Young agents own houses but finance them with debt, so they have low net worth despite having relatively high levels of housing. This explains the joint presence of high MPCs and high levels of housing. Interestingly, our finding that young homeowners, who are more levered, exhibit larger responses to house prices than old homeowners, who are less levered, is exactly the empirical finding in Attanasio et al. (2009).

2.6 Decomposing The House Price Effect

To conclude this section, we return to the decomposition of the consumption response introduced in Subsection 2.3 and discuss its connection with the existing literature. The response can be decomposed into four effects: substitution, income, collateral, and endowment. Proposition 1 shows that the first three exactly cancel and the response of consumption to a house price shock can be interpreted as purely driven by an endowment effect. However, this does not imply that each of the other effects is individually small in absolute value. The four effects, in absolute value, are reported by age in Figure 4.²⁹ Notice that it is more convenient here to report the response of the consumption level to a 1% change in house prices, rather than report elasticities, simply because the decomposition is additive and so aggregates easily across agents.

Figure 4: Decomposition of The House Price Effect



One can see from Figure 4 that the income effect cancels with the sum of the substitution and collateral effects. This implies that, as shown by our sufficient-statistic formula, the total consumption response can be interpreted as a pure endowment effect. However, an alternative interpretation of the same figure is that the total consumption response reflects the sum of three effects which are each important and similar in magnitude: the net wealth effect, which is given by the endowment effect minus the income effect, the substitution effect, and the collateral effect.

Both interpretations are correct and useful for different reasons: The latter interpreta-

²⁹The only effect with a negative sign is the income effect.

tion shows that many competing effects are at work, and each is relevant on its own for determining the total consumption response. The former interpretation shows that these effects are tightly linked together through optimizing behavior and that the net effect can be summarized by the product of two easily interpretable empirical objects: the MPC and the housing stock.

To illustrate the usefulness of both interpretations, consider the large consumption response in our model relative to the PIH model. Part of the large response in our model directly reflects the addition of the collateral channel. In addition, unlike in the PIH model, the endowment effect no longer approximately cancels with the income effect. Instead, the net wealth effect of a house price increase is positive and sizable. The intuition for this result is that a permanent increase in house prices leads to an immediate positive endowment effect while the increase in rental costs occurs mostly in the future. Even though house price movements remain roughly neutral for a household's lifetime budget constraint, borrowing constraints mean that consumption responds more to current than future income, so the endowment effect dominates. Thus, the greater consumption response in our model relative to the PIH model can be interpreted as an increase in the net wealth effect, with an additional collateral channel. Alternatively, using our sufficient-statistic interpretation, it is immediate to see that the small consumption response in the PIH model simply reflects the fact that this model implies a very small MPC.

The fact that borrowing constraints change the strength of the net wealth effect is also important when using PIH intuition to empirically identify house price shocks on consumption. For example, Attanasio et al. (2009) find that consumption of the young is more correlated with house prices than that of the old and interpret this as evidence against housing wealth shocks, since in a PIH framework, older households should respond more strongly to changes in wealth due to their shorter planning horizon. Attanasio et al. (2011) validate this prediction in a sophisticated quantitative model which relaxes the stylized PIH assumptions, but our results show that this theoretical relationship does not hold in general and can be somewhat sensitive to particular modeling choices. In our baseline results, the young respond much more strongly to house price shocks. In the following section, we allow for rental markets and find that consumption responses become largely independent of age. Our theoretical results show that the age-profile of consumption responses will be determined by the age-profile of $MPC \times H$, which our quantitative results show is theoretically ambiguous.³⁰ Ultimately, this age-profile is an empirical question, which we address in Section 4.

Our theoretical decomposition of housing price effects also helps reconcile our large elasticities with the intuition of the “small house-price-effects” view mentioned in the in-

³⁰This theoretical ambiguity might also help explain why some other studies such as Kaplan et al. (2015) and Campbell and Cocco (2007) find stronger effects for the old.

tradition. This view builds on the PIH model by arguing that, since changes in housing asset values are offset by future changes in the user-cost of housing, "housing wealth is not real wealth" and should have little effect on consumption. For example, Sinai and Souleles (2005) argue that this should be true when house price movements are perfectly correlated since everyone must live somewhere. However, in their model there is no precautionary motive, which implies that income and endowment effects exactly cancel; there are no substitution effects, as housing holdings are fixed; and there are no collateral effects. Therefore, the three channels identified above are absent.

Finally, our results have implications for the empirical literature measuring the strength of the various channels through which house prices affect consumption. Each channel in our model is large in isolation, so our model is quite consistent with the conclusions in DeFusco (2015) and Mian et al. (2013) that there is a significant consumption response to housing collateral changes and that the poorest and most indebted households respond most significantly to house price movements through this channel. In particular, the collateral channel in our model implies a marginal propensity to borrow of just over 10 cents, which is in line with the evidence in DeFusco (2015). Nevertheless, it is important to note that the collateral effect in our model is tightly linked to the other three effects, and that their sum eventually boils down to the endowment effect alone, so the interpretation of the collateral effect in isolation must be done with care.

3 Extended Model

In this section, we extend the model by relaxing various simplifying assumptions in order to get a better quantitative assessment of housing price effects. In particular, we progressively enrich the model by introducing adjustment costs to housing, the option to rent, and more realistic mortgage contracts.

In terms of our sufficient-statistic approach, our main conclusion is that the formula derived in Proposition 1 provides a good approximation for all realistic calibrations explored in this section. This does not mean that the quantitative implications are insensitive to the different specifications analyzed, since different specifications have different implications for the joint distribution of housing wealth and MPCs. It just means that we can use the formula to interpret the results obtained under all of our calibrations.

In terms of magnitudes, we still find fairly large elasticities under all the calibrations explored. The fully enriched model produces elasticities that are roughly half of what we found in the baseline, and is thus closer to the empirical estimates. This is mostly due to the introduction of the rental option, as we explain shortly.

3.1 Housing Transaction Costs

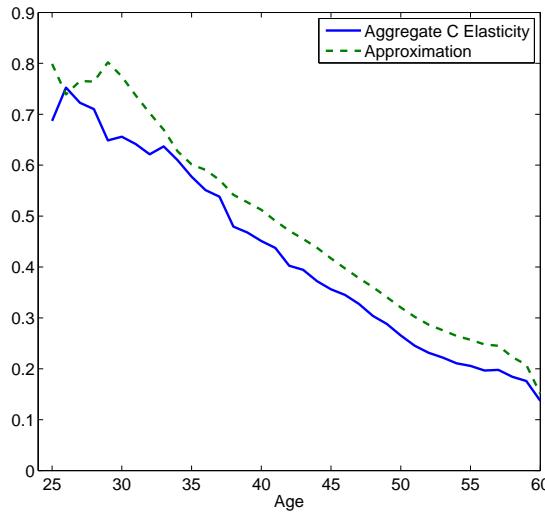
The assumption that housing can be traded frictionlessly is clearly counterfactual: search costs and brokers' fees make it costly to sell and buy houses, and indeed households trade houses only infrequently.³¹ We model adjustment costs as a fixed cost, incurred whenever the household changes its stock 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 iff $H_{it} \neq H_{it-1}$ and where we 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 presence of fixed adjustment costs substantially complicates the household optimization problem, as households' policy functions are now highly non-linear and characterized by (S,s) style inaction regions. In Appendix 3, we provide a detailed description of the numerical solution method. We follow the same calibration strategy as in the baseline and report the parameters in Appendix 4.

Figure 5: Elasticities over the Life Cycle: Model with Adjustment Costs



Once we introduce transaction costs, Proposition 1 no longer holds. In Figure 5 the solid

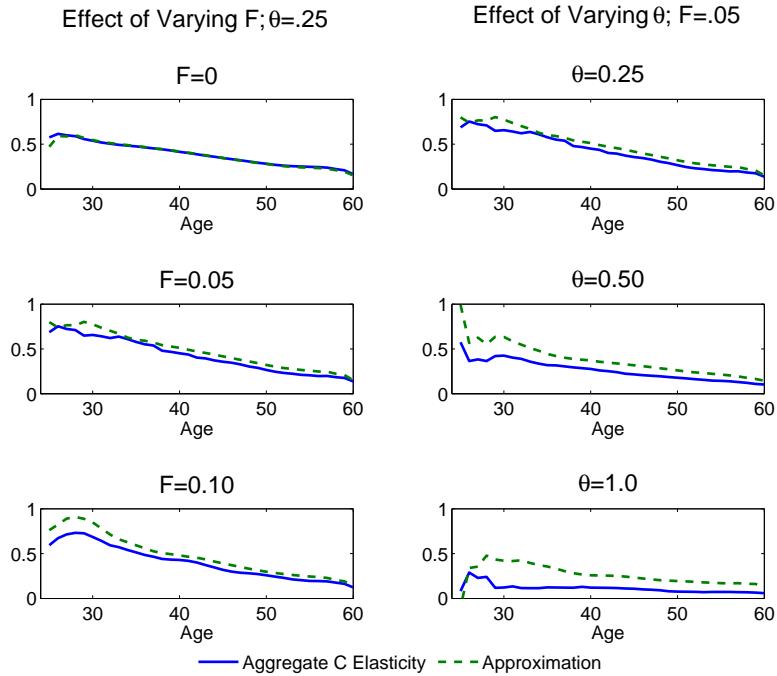
³¹Berger and Vavra (2015) show that the average annual frequency of housing adjustment in the PSID is 4.3% in data from 1968-1996 and 5.8% in data from 1999-2011.

blue line shows the computed average elasticity of non-durable consumption as a function of age and the dashed green line shows the sufficient-statistic-implied elasticity from Proposition 1. The figure shows that even though the formula does not give the exact elasticity anymore, it remains a quite accurate approximation.

The shape of the average elasticity over the life cycle is similar to the one in the baseline model: it is high for the young agents who have high MPCs as well as substantial housing and falls as households age and accumulate assets. Households can borrow to finance houses early in life, so the life-cycle profile of housing is flatter than that of the MPC. The presence of housing transaction costs further amplifies the incentive to purchase a large house when young, using leverage, rather than slowly accumulating housing. This explains why the elasticities for young households are larger in Figure 5 than in Figure 2.

How robust is the accuracy of the approximation formula in Proposition 1 to alternative environments? Figure 6 compares the computed average elasticity with the sufficient-statistic-implied elasticity for different values of the fixed cost F and of the downpayment parameter θ . The panels on the left keep θ at its baseline value and change F , the panels on the right keep F at its baseline value and change θ .

Figure 6: Robustness to Different Fixed Costs and Downpayment Parameters



The figure shows that the formula of Proposition 1 is an accurate approximation for a range of values of F and θ . In particular, increasing F barely affects the accuracy of the approximation as long as θ remains low. The intuition is that, as long as households can borrow

against their house values, consumption can respond even if transaction costs substantially reduce house trading. The consumption response becomes much more muted than what is implied by the $MPC \times H$ formula only when unrealistically high values of F and θ are combined, so that households can no longer respond to the increased house price by either selling or borrowing.

3.2 Rental Markets

Roughly one third of US households rent rather than owning, and their wealth is not affected by changes in house prices. Therefore, it is important to introduce a rental option. To do so, 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, $R_t = \phi P_t$, so that house price movements are passed proportionally into rental costs.³²

Households face a trade-off when choosing between renting and owning. The advantage of renting is that it allows the household to keep its savings in the form of liquid assets, thus providing a better buffer against income shocks. The disadvantage is that renting is costlier, as we assume $\phi > (r + \delta)/(1 + r)$,³³ and rental housing cannot be used as collateral.³⁴ Young households who are more financially constrained are the ones who benefit more from the flexibility of renting and so will disproportionately choose to rent.

The rental-to-price ratio ϕ is an additional parameter of the model. We follow the previous calibration strategy for all other parameters and choose ϕ to target the life-cycle profile of homeownership rates. The parameters are reported in Appendix 4.³⁵ Figure 7 shows that we are still able to match the life-cycle profile of housing and liquid wealth reasonably well. In addition, the model can fairly well match the upward slope and subsequent flattening of homeownership rates over the life cycle.

How does the addition of the rental option affect the size of consumption responses to house prices and the accuracy of our approximation? Figure 8 shows the actual average elasticity over the life cycle for the model with and without the rental option (solid blue

³²Using less than perfect passthrough amplifies elasticities.

³³Notice that $(r + \delta)/(1 + r)P$ is the user cost of housing services for a homeowner facing a constant house price P .

³⁴The latter advantage is not enough, on its own, to induce households to own, because renting reduces the need for borrowing more than it reduces the availability of collateral, since $\theta \leq 1$.

³⁵At 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 $\hat{\phi} < \phi$. 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. At any rate, since we concentrate on results for working-age households, the choice of $\hat{\phi}$ has little effect on any of our results.

Figure 7: Life-Cycle Moments: Data vs Model

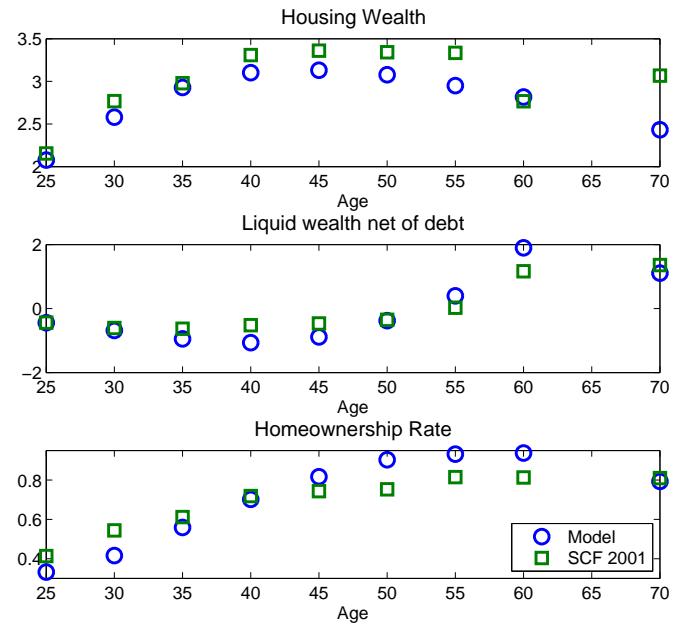
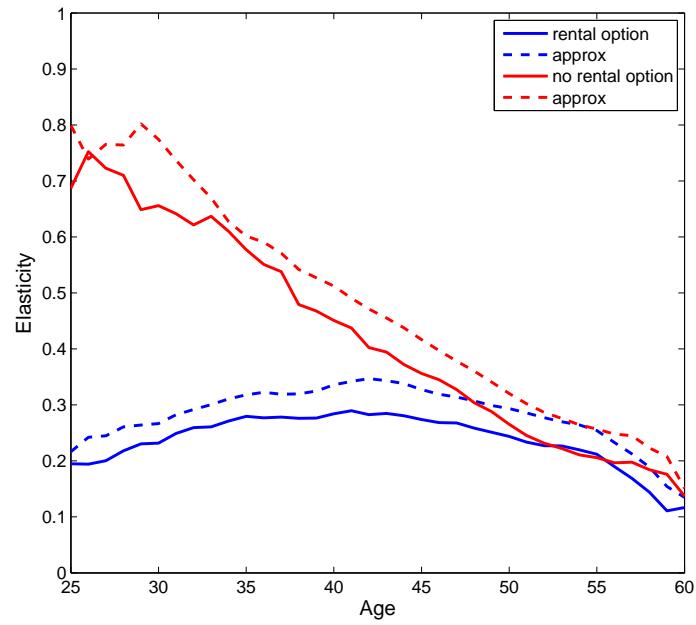
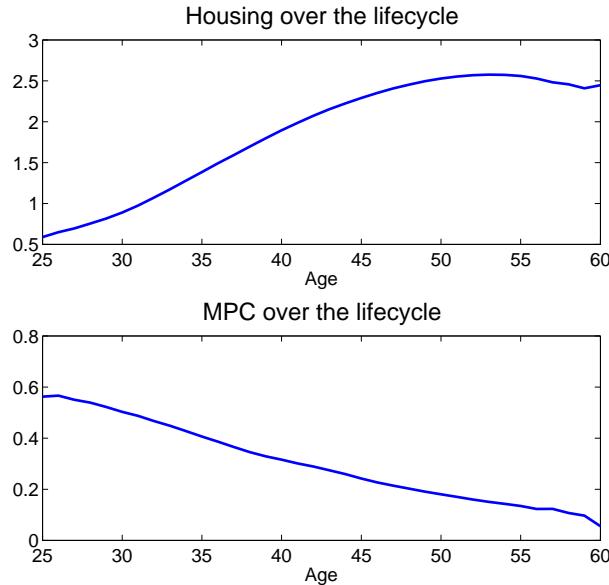


Figure 8: Elasticities over the Life Cycle



line and solid red line). The figure also shows the sufficient-statistic approximation for both models (dashed blue line and dashed red line). There are two takeaways from this figure. The first is that even with the rental option, the sufficient-statistic formula of Proposition 1 remains a good approximation of the true model elasticity. The second is that the addition of a rental option substantially lowers the response of consumption to house prices, especially for the young households. The average elasticity over working life goes from 0.43 in the model without the rental option to 0.24 in the model with rentals.³⁶ Therefore, the introduction of rentals brings us closer to the estimates from the empirical literature discussed in the introduction.

Figure 9: Understanding the Life Cycle



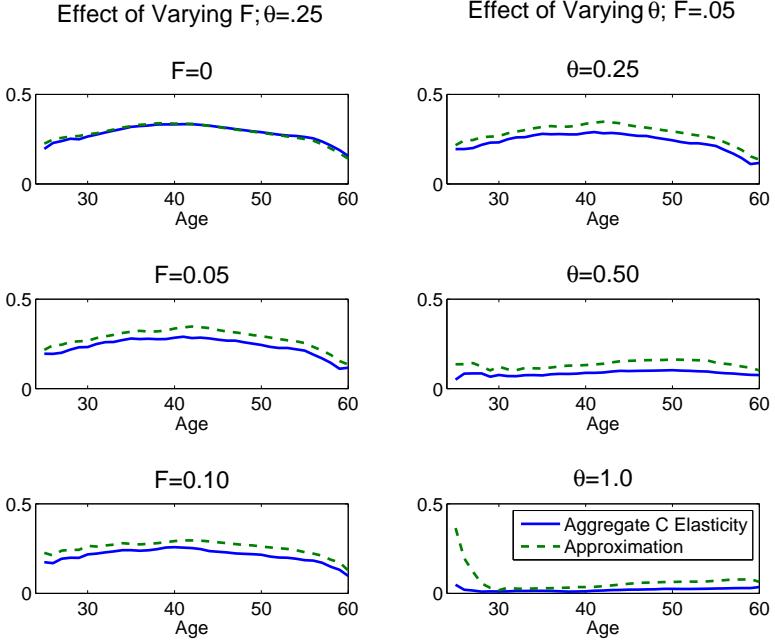
Our $MPC \times H$ formula helps to provide intuition for why this elasticity falls when households have the option to rent. First, since renters do not own a house, their consumption does not respond to house price movements. Hence, if we match the homeownership rate in our dataset of roughly 70%, the average elasticity of consumption to house prices will mechanically fall, even if all households are otherwise identical. However, not all households are identical and home ownership is not randomly distributed in the population. Figure 9 shows the life-cycle profile of housing and MPCs in the model with the option to rent. Notice that the young households with high MPCs are the ones who choose to rent and thus have low levels of housing.³⁷ This in turn lowers their consumption elasticity.

³⁶If we include retired households average elasticities fall from 0.40 to 0.21 when introducing rental markets.

³⁷Indeed, in both the model and the data, the life-cycle profile of homeownership is steeply upward sloping. By age 45 the models with and without rental markets are nearly identical.

Furthermore, within every age group, 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. Thus, our model rationalizes 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.

Figure 10: Robustness to Different Downpayments and Fixed Costs



Finally, Figure 10 assesses the accuracy of the sufficient-statistic formula under a range of alternative parameter values. As in the model with no rental option, the accuracy of the approximation is little affected by changes in the size of housing adjustment costs. It is again somewhat more sensitive to changes in the amount of housing which can be collateralized, but is still quite accurate for reasonable values of this parameter. In particular, as θ rises, the elasticity falls. This is now the combination of two factors. First, household leverage falls, which reduces MPCs for a given housing value. More importantly, in these comparative statics exercises we do not recalibrate the model. Thus, as we raise the required down payment while keeping ϕ constant, home ownership becomes less and less attractive. In our baseline results with $F = 0.05$ and $\theta = 0.25$, we match the average homeownership rate in the data of 70%, but as we raise θ to 1, the homeownership rate in the model falls to 23%. Therefore, most of the decline in the elasticity as θ increases occurs because the homeownership rate is driven to counterfactually low levels.

3.3 More realistic mortgages

So far we have modeled borrowing as one-period loans subject to a collateral constraint. We now briefly discuss extensions that more realistically capture how households borrow against their houses' value. While we do not attempt to model the details of fixed-rate mortgages and home-equity loans, we can easily increase the model's realism by introducing costly equity extraction together with asymmetric adjustments to the borrowing limit.

We have so far assumed that households can costlessly increase borrowing as long as they meet the collateral constraint. In reality, there are costs associated with extracting housing equity by refinancing. This means that even in the model with transaction costs on housing adjustment, our model probably overstates the liquidity of housing wealth. We now assess the robustness of our results to introducing a cost of "cash-out refinancing". In particular, we extend the model by making the following assumption: if a household chooses positive holdings of the risk-free asset A_t or if it 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.

Since the majority of refinancing costs do not depend on loan size, we model this cost as a fixed numeraire amount, in contrast to the housing transaction cost which is proportional to the size of the house.³⁸ We pick this cost of refinancing to match the fraction of refinancing observed in Bhutta and Keys (2014), which implies a fixed cost of 0.005.³⁹ In the model with no refinancing cost, 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. However, the top panel of Figure 11, compared to Figure 7, shows that this modification has negligible effects on the size of elasticities.⁴¹ The top panel of Figure 11 also shows our sufficient-statistic approximation remains accurate in this extension.

Mortgages are long-term loans. This introduces an asymmetry in the response of the borrowing limit to house price shocks. When house prices rise and households gain equity, households have the option to extract this equity and borrow more. In contrast, when

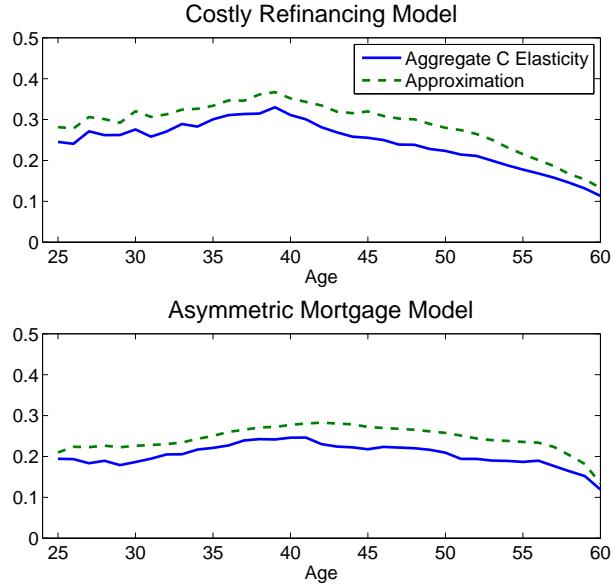
³⁸We have also solved versions of the model with refinancing costs proportional to the size of the house and results were extremely similar.

³⁹Since income is normalized to 1, this refinancing cost is 0.5% of average annual income, but even using much larger values produces similar results. For example, we have solved a version of the model where equity can only be extracted by buying/selling one's house. Even in this extreme case, results are quite similar to Figure 11.

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

⁴¹This is due to extensive margin effects which arise in environments with fixed adjustment costs. Adjustment costs reduce cash-out refinancing substantially, but this reduction is concentrated amongst households who would have only extracted small amounts of equity with small resulting effects on consumption. Any household who needs to extract substantial housing equity in order to increase consumption will still choose to do so even in the presence of adjustment costs.

Figure 11: Elasticities over the Life Cycle: More Realistic Mortgage Models



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.⁴² To capture this asymmetry, we consider a variant of the model in which instead of (1) we have the collateral constraint:

$$-A_{it} \leq \max\{-A_{it-1}, (1-\theta)\frac{1-\delta}{1+r}P_{t+1}H_{it}\}.$$

The bottom panel of Figure 11 shows the elasticity to a 1% decline in house prices under this specification and shows that this has small effects on elasticities, again compared to the model in Figure 7. Once more, the sufficient-statistic approximation remains valid.⁴³

4 Sufficient Statistic: Empirical Evidence

The previous sections show that a simple sufficient-statistic formula provides a good approximation for the consumption response to a permanent house price shock for a wide class of life-cycle models with uninsurable idiosyncratic income risk and borrowing constraints. In this section, we attempt to directly estimate the sufficient-statistic formula using micro data. This provides a new measure of housing price effects that does not rely on the

⁴²In our model, given constant house prices, the maximum loan-to-value ratio is $(1-\theta)(1-\delta)/(1+r)$.

⁴³We have also experimented with a larger price drop of 10% and the effect of the modified constraint is still small.

specific parameters used to calibrate the model, but only on the general structure of this class of models. We then show that our estimate is not far from existing measures obtained with very different approaches.

4.1 BPP approach

Estimating our sufficient statistic requires data on both the MPC out of a transitory income shock 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 $\Delta y_{it} = \eta_{it} + \Delta \varepsilon_{it}$.⁴⁴ Given this income process, the true MPC (in logs) out of a transitory shock is equal to

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

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

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

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} .⁴⁵ Since this requires individual level panel data on income and consumption, we use data from the Panel Study of Income Dynamics (PSID).⁴⁶

4.2 PSID data

Implementing our sufficient statistic empirically requires a longitudinal dataset 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

⁴⁴Abowd and Card (1989) show that this parsimonious specification fits income data well.

⁴⁵We then convert this MPC in logs to the MPC in levels relevant for our theory by multiplying by C/Y.

⁴⁶An 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 much 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 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 closely 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 also drop households that appear in the sample fewer than three consecutive times, because identification of the coefficients of interest requires a minimum of three periods. In our baseline calculations, we keep households where the head is 25-75 years old. Our final sample has 39,722 observations over the pooled years 1999-2011 (seven sample years).

We use the same consumption definition as Blundell et al. (2014), which covers approximately 70% of NIPA consumption. 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.

4.3 Results

Since our formula is equal to the product of the MPC and the value of housing, we first examine how the MPC varies with the value of housing. To do this, we estimate the MPC using the BPP methodology separately in 6 housing bins. The first bin includes only renters—that is, households who own zero housing. The other five bins are constructed as the quintiles of the home value distribution and so are of equal size by construction. In total, in our database we have approximately 15,000 renters and 25,000 home owners.

Figure 12 shows the relationship between the MPC and home values. Overall the relationship between home values and the MPC is flat or slightly declining (though this decline is not statistically significant). Therefore, housing-rich households in the data still display high MPCs, which will contribute to a large aggregate elasticity. Figure 13 translates these results into elasticities by bins, which are computed by multiplying the MPC by bin in Figure 12 times the ratio of average home values over average consumption in the same bin. Elasticities for homeowners are non-monotone in housing and range between 0.11 and 0.63.

Using these estimates we can compute the aggregate elasticity of non-durable consumption for the whole sample, which is equal to 0.33.⁴⁷ This sufficient-statistic based measure

⁴⁷This value is given by $(\sum_k MPC_k \times PH_k) / C$, where MPC_k is the estimated MPC in bin k , PH_k is the average

Figure 12: MPC and Housing

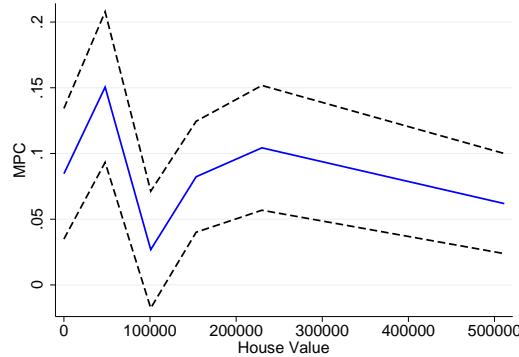
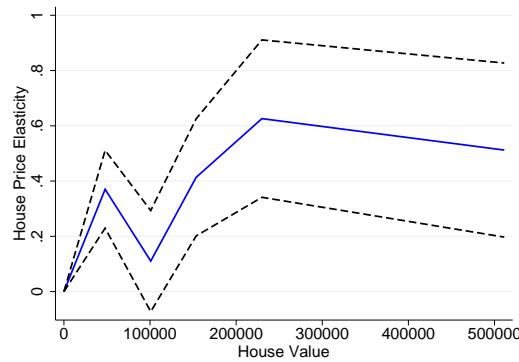


Figure 13: Elasticity and Housing

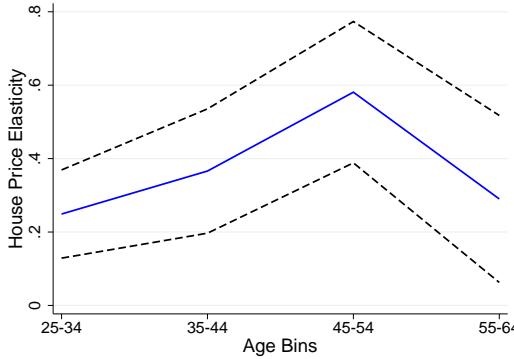


of housing price effects provides an alternative to the standard empirical strategies for estimating such effects. Existing evidence of the importance of house price movements for consumption relies either on strong time-series identification assumptions or on the identification of "exogenous" changes in house prices at the micro level. Amongst the latter style, the series of papers by Mian and Sufi using the elasticity of housing supply to instrument for local house price movements has probably been the most influential in arguing for the importance of housing price effects on aggregate consumption. However, some recent papers such as Davidoff (2013) have questioned the validity of supply elasticity in this context and by extension the evidence for housing price effects. Our sufficient-statistic based measure of housing price effects relies on a completely different source of identification, so it does not require us to take any stance on the validity of this IV strategy. Nevertheless, despite our alternative identification approach, we ultimately find consumption elasticities to house price changes that are large and similar to those in Mian et al. (2013).⁴⁸

home value for bin k , and C is aggregate consumption.

⁴⁸Recall the caveat, from the introduction, that the Mian et al. (2013) measures include local general equilibrium effects. Notice also that our theoretical result validates the housing wealth measure in Mian et al. (2013).

Figure 14: Elasticity and Age



Next, we explore the relationship between the non-durable consumption elasticity and the life cycle. Ideally, we would like to estimate an elasticity for each age. However, due to the limited sample size, we group agents into the following four age bins: 25-34, 35-44, 45-54 and 55-64. The results are reported in Figure 14, which shows a pronounced hump shape in the relation between age and the elasticity of consumption to house prices. This hump shape reflects two separate forces. First, homeownership rates and housing holdings are hump shaped in age. Second, MPCs are slightly hump shaped in age.

Recall, from Figure 8, that the model also displays a hump-shaped relation between elasticity and age. The size of the elasticities produced by the model is fairly close to the data although the hump shape is moderately more pronounced in the data.⁴⁹

5 A Boom-Bust Episode

The results thus far show that the response of consumption to one-time permanent house price shocks is tightly linked to the joint distribution of housing wealth and MPCs. In this section, we move beyond one-time shocks and extend our analysis to dynamic boom-bust cycles. This analysis sheds light on two main points.

First, the joint distribution of housing wealth and MPCs can change over time as a result

In that paper, they measure local changes in housing net worth as $\Delta \log^{H,i}_{06-09} * H^i_{2006} / NW^i_{2006}$, where H^i_{2006} is the value of the housing stock owned by households in zip code i in 2006. That is, their housing net worth shock multiplies the change in house prices by the gross value of housing rather than by housing equity. One might intuitively think that the strength of housing price effects for a given house price change might depend on housing equity rather than gross housing, but our simple formula shows that this intuition is incorrect.

⁴⁹The model does not generate enough middle-aged consumers with high housing values and high MPCs, or, in the parlance of Kaplan and Violante (2014), enough wealthy-hand-to-mouth consumers. This occurs in part because while Kaplan and Violante (2014) rule out borrowing against the illiquid asset, we allow for such borrowing, subject to a refinancing cost calibrated to match cash-out shares in the data. It is an interesting open question how to produce wealthy-hand-to-mouth behavior while allowing for realistic access to home equity financing.

of past shocks. Given the results of the previous sections, this implies that the response of consumption to house price movements is state-dependent. In this section, we show that this state-dependence can be quantitatively significant. In particular, an economy coming out of a housing boom can be especially sensitive to a price correction.

Second, in the model an increase in house prices generates a drop in housing demand and thus in residential investment, which is counterfactual.⁵⁰ A central feature of housing cycles is that residential investment moves in the same direction as house prices. In order to assess the consequences of matching these empirical residential investment patterns, we extend our analysis by introducing time-varying expectations of future house price changes. In particular, we introduce shocks to households' expectation of future house price growth that move in the same direction as current house prices.⁵¹ We show that these shocks can produce a realistic, procyclical pattern for residential investment demand, while having only mild direct effects on non-durable consumption demand.

For our dynamic simulations of boom-bust cycles, we proceed as follows. We start the economy in steady-state with constant house prices and zero expected house price appreciation. We then simulate our baseline model of Section 2.3 for T periods, with a given path of realized prices $\{P_t\}_{t=0}^T$. In each period t , we assume that households observe the price today P_t and have deterministic expectations for the future path of house prices:

$$E_t[P_{t+j}] = P_t e^{g_t \frac{1-\lambda^j}{1-\lambda}} \quad \text{for } j = 1, 2, \dots$$

Households expect prices to grow at the rate g_t in the next period and to keep growing gradually towards the long-run level $P_t e^{g_t/(1-\lambda)}$. The sequence $\{P_t\}_{t=0}^T$ is chosen to match the average US home price series from 2000 to 2013, from Shiller (2015).⁵² The value of λ is set at 0.5. The sequence $\{g_t\}_{t=0}^T$ is chosen to replicate the path of the residential investment rate from NIPA over the same period.⁵³

Figure 15 reports the results of this exercise.⁵⁴ The dashed red lines plot the benchmark

⁵⁰For some highly leveraged households housing demand can increase as a result of a house price increase. However, with any reasonable parametrization of initial conditions aggregate housing demand goes down when P increases.

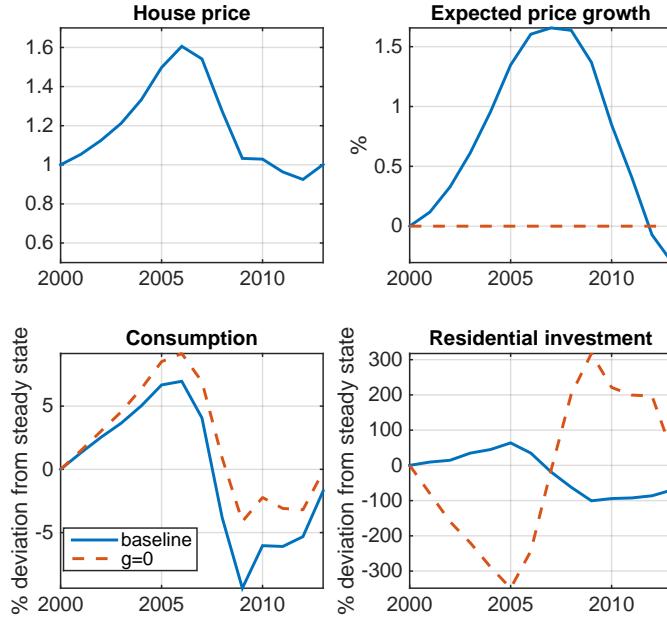
⁵¹Changes in expected house appreciation are consistent with recent empirical work by Case et al. (2012).

⁵²We use the Real Home Price Index from www.econ.yale.edu/shiller/data, file Fig2-1.xls.

⁵³The residential investment rate is measured as residential investment (BEA Fixed Asset Table 1.5 line 8) divided by the stock of private residential capital (BEA Fixed Assets Table 1.1 line 14). Since our model has no long-run growth, the steady-state investment rate is equal to the depreciation rate of 0.022, which is lower than the long-run average investment rate of 0.046 in the data. We adjust for unmodeled growth by subtracting 0.024 from the residential investment rate in the data.

⁵⁴All results in this section use the frictionless calibration from Section 2.4 and report consumption aggregated over all ages. The presence of repeated shocks and growth rate shocks imply that age and time become separate state-variables, substantially increasing the computational burden and limiting the sensitivity analysis that can be performed with the model with transaction costs. Nevertheless, in Appendix 4 we show robustness results for the primary boom-bust exercise in this more complicated model.

Figure 15: Boom-Bust Simulation



case in which consumers receive a sequence of unexpected price shocks that are always perceived as permanent. That is, the case $g_t = 0$ for all t . The first shock, at date 0, has an effect equal to the baseline in Section 2.3.⁵⁵

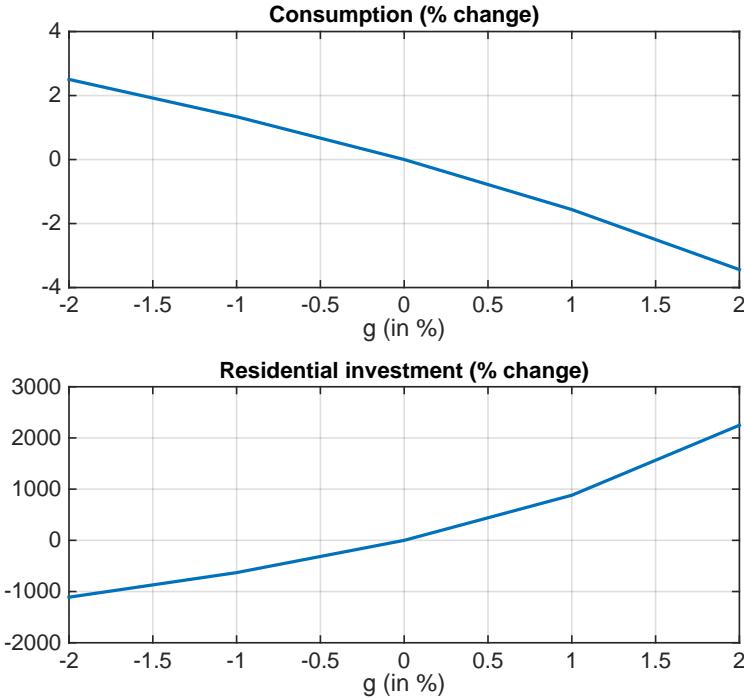
Notice that in the previous sections, we have focused on the impact effect of a house price change on consumption. However, the effect of house price movements on consumption is transitory: following a house price shock, consumption gradually reverts to its steady-state level, which is independent of the level of P . Therefore, when we look at the cumulative effect of a sequence of house price increases, such as the one between 2000 and 2006, the total increase in consumption is not equal to the sum of the impact effects.

In particular, a total price increase of 60% yields a total increase in consumption of about 6%. The drop in consumption after 2006 is much larger than the prior increase. This occurs for three reasons: first, even absent a price reduction, consumption eventually reverts to steady-state; second, the drop in house prices is faster than the increase, so the effects on consumption have less time to dissipate; third, the reduction in housing wealth, for given debt levels, leads to larger MPCs. The third effect is especially interesting and will be investigated in more detail in our full simulations with g_t shocks.

The dashed-red line in the bottom-right panel of Figure 15 shows that when $g_t = 0$ the

⁵⁵The house price increase is 5% and the consumption increase is 1.7. This gives an average elasticity of 0.34 for all households. (In Section 2.3 we reported the average for working age households, 0.34 is the corresponding value for all households).

Figure 16: Effects of Expected House Price Appreciation

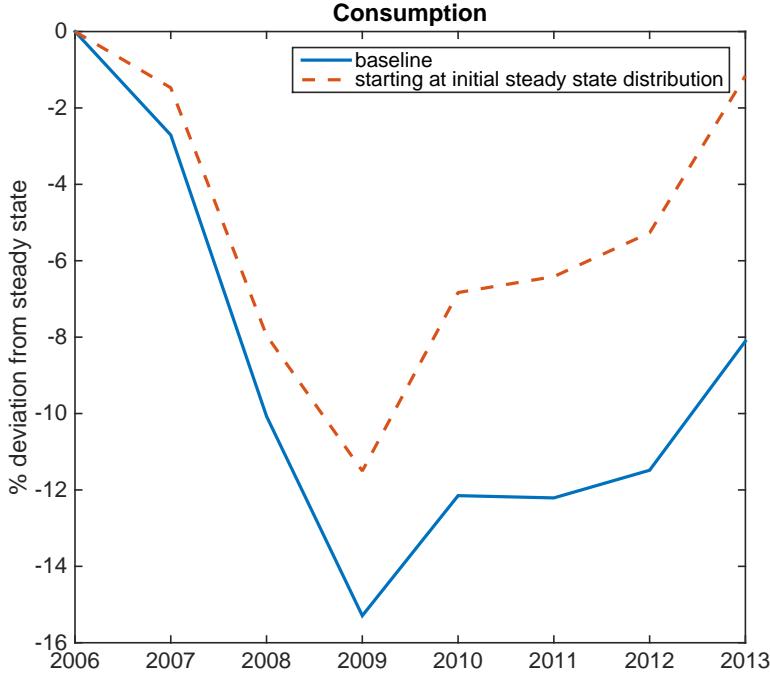


model predictions for housing demand are clearly counterfactual, with residential investment falling in the boom and increasing in the bust. Therefore, let us turn to the blue lines which correspond to our main exercise, where we choose the path of g to match residential investment in the data. The figure shows a large consumption response, a bit smaller than in the $g_t = 0$ case during the boom and a bit larger during the bust. To understand the consumption responses in Figure 15 we need to take into account three forces: first, the direct effect of changes in P ; second, the effect of g on consumption policies; third, the effect of the endogenous change in the distribution of households' net worth. We have examined the first force at length in the previous sections, so we now focus on the latter two forces.

How does a change in g affect consumption policies, holding all else constant? To investigate this effect, Figure 16 shows what happens on impact to an economy in steady-state which is hit by an unexpected, one-time change in g . The top panel shows the response of consumption, the bottom panel shows the response of residential investment. The figure shows that an increase in g tends to mildly reduce consumption for given initial wealth, while it dramatically increases residential investment.⁵⁶ This comparative static exercise

⁵⁶The intuition is as follows. An increase in g implies an expected increase in the cost of housing services in the future and thus an expected increase in the overall CPI. This has both an intertemporal substitution effect, which increases current consumption, and an income effect, which lowers it. When $\sigma > 1$ the income effect

Figure 17: Response to a House Price Drop: The Effect of the Initial Distribution



helps to explain why in Figure 15, by changing the path for g , we are able to obtain large effects on residential investment while only mildly affecting the consumption path, which is still dominated by the house price effect identified in the rest of the paper.

Let us now turn to the endogenous effects of the wealth distribution. Figure 17 compares the consumption response in the bust period in our exercise (blue solid line) to a counterfactual response if we assume that the distribution of households' net worth at the beginning of the bust is unchanged from the initial steady-state (red dashed line).

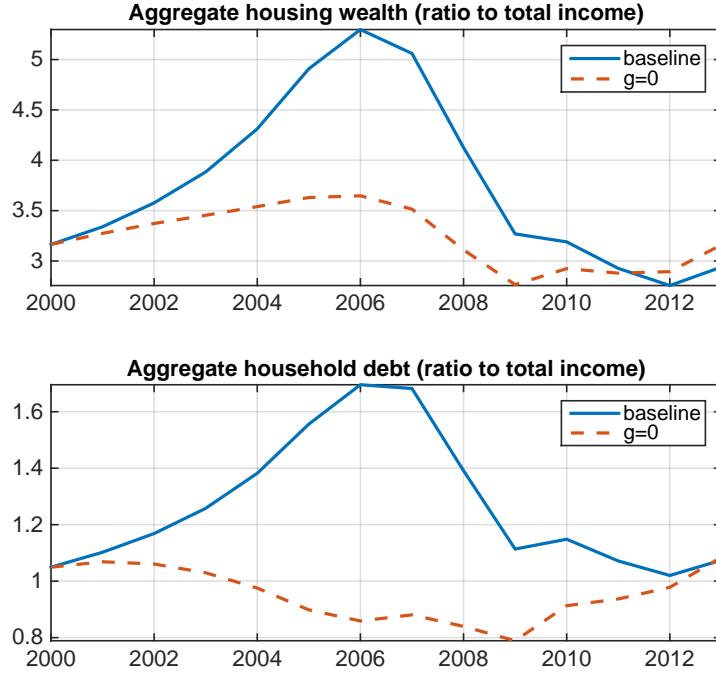
The figure confirms that the endogenous change in the wealth distribution over the boom has a quantitatively important effect in the bust, leading to a deeper and more prolonged contraction in consumption. This occurs because the boom leads to an accumulation of housing wealth and of debt, as shown in Figure 18. This simultaneously increases MPC and H and thus makes household balance sheets more sensitive to a drop in house prices

dominates and consumption falls. However, as long as σ is not too large, the net effect is small. The effect of g on spending on housing services is of the same sign and magnitude as the effect on non-durable consumption, due to Cobb-Douglas preferences. Spending on housing services is, in terms of implicit rental costs,

$$\left[1 - e^g \frac{1 - \delta}{1 + r}\right] PH.$$

So while this expression overall is decreasing slightly, the level of H increases, since the expression in square brackets is strongly decreasing in g .

Figure 18: Boom-Bust Simulation: Housing Wealth and Debt



through the mechanism explored in previous sections. Notice that the presence of g shocks amplifies the importance of these effects, since increases in g lead to greater accumulation of housing and debt in the boom phase.

Thus, an important lesson from this exercise is that endogenous time-variation in the distribution of debt will lead to changes in the strength of house price effects on consumption. This implies that accounting for variation in micro level heterogeneity across time is crucial for making accurate predictions about the aggregate effects of housing market shocks. This can help rationalize why studies using data from different time periods often arrive at substantially different conclusions as to the importance of housing price effects. For example, Case et al. (2013) finds substantially larger housing price effects when using data from 1975-2012 than in their otherwise identical previous study, Case et al. (2005), which only included data through 1999.

The overall take-out from the boom-bust exercise is as follows: Introducing shocks to expected appreciation can deliver a boom-bust in residential investment together with a boom-bust in house prices. The direct effect of shocks to expected appreciation is to mildly dampen the boom-bust in consumption through intertemporal channels. However, the same shocks have a significant indirect effect, which tends to amplify the boom-bust through endogenous changes in the distribution of housing and debt.

The analysis in this section also indirectly sheds light on the effect of transitory shocks to house prices in our model. Transitory shocks can be interpreted as the combination of a one-time increase in P combined with a negative g shock. In our calibration, we just saw that a negative g shock increases current consumption, so a temporary house price shock will have a larger impact effect on consumption than a permanent shock. On the other hand, the effect will go away more quickly, when house prices start to fall in the periods following the impact increase.

In Appendix 4, we report the results of a similar exercise for the extended model with adjustment costs and rentals. Two results are worth mentioning here. First, the consumption boom and bust is roughly half as large, and thus more in line with actual movements in consumption over this time period. The crucial dampening mechanism in the extended model is the presence of the rental market, as in Section 3.2. Second, the values of g needed to fit the same investment sequence are larger than those found here, due to the presence of adjustment costs. Given the small values of g reported in Figure 15, this seems to move us in the direction of realism.

Finally, it is important to recognize that the dynamic analysis in this section is still partial equilibrium in nature, and in particular we do not endogenize the interest rate or the income process faced by households. Therefore, the results obtained should be interpreted as shifts in consumption demand coming from shifts in prices and expectations in the housing market. The model could be embedded in a general equilibrium model with nominal rigidities, which could lead to amplified consumption responses—through the endogenous income channel—or to dampened responses, depending on the strength of the monetary policy response. Still, the magnitude of the initial shifts documented here will be crucial for the equilibrium outcome.

6 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 relatively standard incomplete markets consumption model with idiosyncratic risk actually implies quite large elasticities, and we derive a new sufficient statistic to provide intuition for this large value. This sufficient statistic continues to work well in more realistic models, and we show that these models deliver elasticities closely in line with empirical evidence. We then take our sufficient statistic directly to micro data and show it yields similar conclusions. Not only is our sufficient statistic useful for understanding

why elasticities in our model are large, it also provides good intuition for why some previous models have found small elasticities. These models often either imply counterfactually small MPCs or shut down some of the theoretical channels through which house prices can affect consumption.

Our results also imply that the size of housing price effects may vary substantially across households and time. Indeed, we find large variation over the boom-bust in our model and find that elasticities vary substantially with age and home ownership status. 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.

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Online Appendix

HOUSE PRICES AND CONSUMER SPENDING

D. Berger, V. Guerrieri, G. Lorenzoni, J. Vavra

1 Decompositions

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 Subection 2.2 and for the general baseline model treated in the rest of Section 2.

1.1 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:

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

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 for C_0

$$C_0 = C_{0,m}(R, I),$$

which comes from maximizing $\sum \beta^t U(C_t, H_t)$ subject to $\sum q^t [C_t + RH_t] = I$. 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

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

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

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

The net effect is small if δ is small, and exactly zero if $\delta = 0$. This captures 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:

- a substitution effect that more than compensates for the negative net of income and endowment effects derived above;
- a pure endowment effect, with the substitution and income effects canceling each other.

1.2 General model with no adjustment costs

Given the household's optimization problem on page 10, 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

$$(1 - \theta) P_1 = (1 - \hat{\theta}) P_0,$$

that is consider a change in the collateral requirement that exactly offsets the change in price. The collateral effect is then defined as

$$CE \equiv C(W_0, s; P_0, \hat{\theta}) - C(W_0, s; P_0, \theta).$$

Next, find the value of initial wealth \hat{W} such that $V(\hat{W}, s; P_1, \theta) = V(W_0, s; P_0, \hat{\theta})$. 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

$$SE \equiv C(\hat{W}, s; P_1, \theta) - C(W_0, s; P_0, \hat{\theta}),$$

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

$$IE \equiv C(W_0, s; P_1, \theta) - C(\hat{W}, s; P_1, \theta).$$

Finally, the endowment effect is just given by

$$EE \equiv C(W_1, s; P_1, \theta) - C(W_0, s; P_1, \theta),$$

and elementary algebra gives

$$\Delta C = SE + IE + CE + EE,$$

and 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).

2 Extension: CES Preferences

In this section, we extend the analysis to CES preferences for consumption and housing. 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. We then provide numerical results for the case $\theta > 0$, calibrated as in the main text, and show that, for reasonable values of the elasticity of substitution between consumption and housing, our amended sufficient-statistic formula provides a good approximation and the additional term has small effects if the elasticity of substitution is in the range 0.8 – 1.25. Overall, under plausible parametrizations the magnitude of the elasticity remains large.

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 housing services.

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 change in house prices is*

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

Hence, the individual elasticity of non-durable consumption to housing prices is

$$\eta_{it} = (\epsilon - 1) \frac{\frac{r+\delta}{1+r} P_t H_{it}}{C_{it} + \frac{r+\delta}{1+r} P_t H_{it}} + MPC_{it} \cdot \frac{(1 - \delta) P_t H_{it-1}}{C_{it}}.$$

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

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

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

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

subject to

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

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

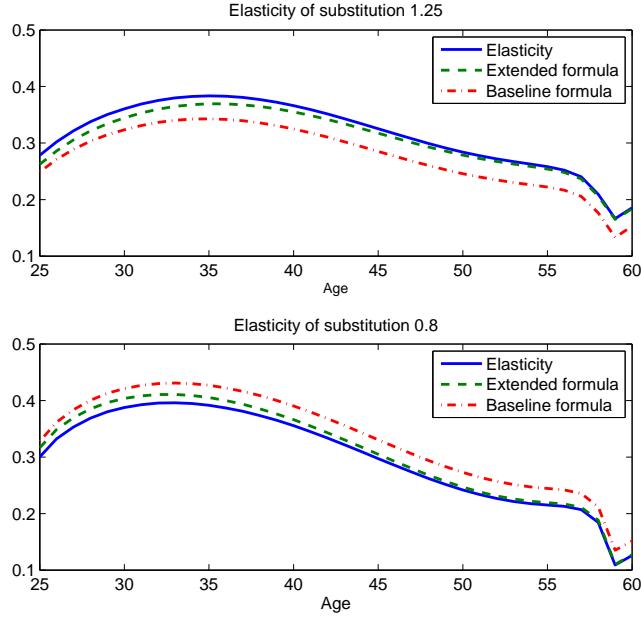
$$\frac{\partial C}{\partial P} = (\epsilon - 1) \frac{r + \delta}{1 + r} \frac{H}{X} C.$$

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, 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.

For the case $\theta > 0$ analytical results are not available and we turn to simulations. Namely, for different values of ϵ we re-calibrate the model to hit the same targets as in the baseline and compute the elasticity of consumption to house prices. In Figure 19 we plot the computed elasticity for different age bins, together with our baseline formula and our amended formula. We present results for the two cases $\epsilon = 0.8$ and $\epsilon = 1.2$. The amended formula provides a good approximation and the baseline still gives magnitudes close to the

Figure 19: CES



true responses.

3 Description of Computational Procedures

In this appendix, we describe the solution to the model with transaction costs and rental described in the body of the text. The household state vector is $\mathbf{s} \equiv (A, H, z, j)$, 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

$$\begin{aligned} V^{adjust}(\mathbf{s}) &= \max_{C, A', H'} U(C, H') + \beta E [V(\mathbf{s}') | z] \\ \text{s.t. } & A' + PH' + C = (1+r)A + Y(z) + (1-F)(1-\delta)PH, \\ & A' \geq - (1-\theta) \frac{1-\delta}{1+r} PH', \quad \mathbf{s}' = (A', H', z', j+1), \end{aligned}$$

$$\begin{aligned}
V^{noadjust}(\mathbf{s}) &= \max_{C, A'} U(C, H) + \beta E [V(\mathbf{s}')|z] \\
\text{s.t. } A' + C &= (1+r)A + Y(z) - \delta PH, \\
A' &\geq -(1-\theta) \frac{1-\delta}{1+r} PH, \quad \mathbf{s}' = (A', H, z', j+1),
\end{aligned}$$

$$\begin{aligned}
V^{rent}(\mathbf{s}) &= \max_{C, A', \tilde{H}} U(C, \tilde{H}) + \beta E [V(\mathbf{s}')|z] \\
\text{s.t. } A' + C + \phi P \tilde{H} &= (1+r)A + Y(z) + (1-F)(1-\delta)PH, \\
A' &\geq 0, \quad \mathbf{s}' = (A', 0, z', j+1).
\end{aligned}$$

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 sum 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, 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

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

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 H' . Note that A' and H' are chosen prior to next period shocks to house prices. Thus, shocks to house prices imply that realized voluntary equity will differ from the value chosen in the previous period. Namely, given a chosen pair Q', H' , the realized value of Q next period will be $Q' + (1-\theta) \frac{1-\delta}{1+r} H' \Delta P$, where ΔP is the house price shock. This implies that although households 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.⁵⁷

We discretize the problem so it can be solved on the computer by first discretizing z using the algorithm of Tauchen (1986). We use 13 grid points for z . We then approximate the functions V_j^{adjust} , $V_j^{noadjust}$, and V_j^{rent} as multilinear functions in the endogenous states.

⁵⁷Shocks 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.

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 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-Mead 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 the boom-bust episode, house price expectations become an additional state-variable, and the model is solved and simulated for the combination of each age-calendar time pair.

4 Additional Quantitative Results and Calibration Details

This section shows a number of numerical results and details which are suppressed from the main text for brevity.

Table 2 shows the best fit parameters for the model with transaction costs but no rental market, and Figure 20 shows the corresponding model fit.

Table 2: *Parameter Values for Model with Fixed Costs and No Rent*

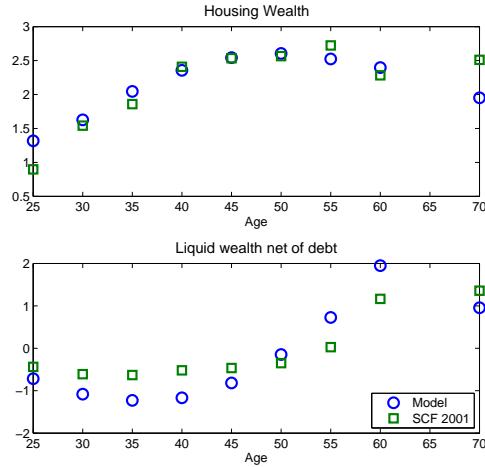
Parameter	σ	r	δ	θ	ρ_z	σ_z	α	β	Ψ	Ξ
Value	2	2.4%	2.2%	0.25	0.91	0.21	0.875	0.922	2,300	1.75

Table 3 shows the best fit parameters for the model with transaction costs and rental markets. See Figure 7 in the main text for corresponding model fit.

Table 3: *Parameter Values for Model with Fixed Costs and Rent*

Parameter	σ	r	δ	θ	ρ_z	σ_z	α	β	Ψ	Ξ	ϕ
Value	2	2.4%	2.2%	0.25	0.91	0.21	0.86	0.922	2,300	2.25	.0605

Figure 20: Housing and Net Liquid Wealth over the Life Cycle: Data vs Model



Finally, Figure 21 shows the boom-bust patterns for the model with rentals and transaction costs. In the body of the text, we concentrate on the frictionless models for computational reasons. The boom-bust exercise is substantially more computationally burdensome, which limits the extent of robustness checks and sensitivity analysis that can be performed. Nevertheless, for our baseline specification, this figure shows that results are qualitatively similar. Overall, the only substantive difference is that residential investment is mildly less sensitive to growth rate shocks, so fitting residential investment in the data requires larger (but still realistic) movements in growth rates.

Figure 21: Boom-Bust in Model with Rentals and Transaction Costs

