Collateral Constraints and Macroeconomic Asymmetries*

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Abstract

A simple macroeconomic model with collateral constraints displays strong asymmetric responses to house price increases and declines. House price increases relax collateral constraints, and the response of aggregate consumption, hours and output to a housing wealth shock is positive but small. House price declines tighten collateral constraints, and the response of consumption to a given change in housing values is negative and large. In experiments from the model, we show how the response of consumption to shocks to housing wealth can be much larger when house prices fall than when they rise. In line with the model, a simple non-linear VAR estimated on U.S. national data shows that the response of consumption is less sensitive to housing price increases than to declines. This finding is corroborated using regional (state and MSA level) data. Our results imply that wealth effects computed in normal times might severely underpredict the response of the economy to large house price declines, and that public policies aimed at helping the housing market may be far more effective during protracted housing downturns.

`KEYWORDS`: Housing, Collateral Constraints, Occasionally Binding Constraints.

`JEL CODES`: E32, E44, E47, R21, R31

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*The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Board of Governors of the Federal Reserve System. Replication codes that implement our solution technique for any DSGE model with occasionally binding constraints (irreversible capital, zero bound, occasionally binding borrowing constraints) using an add-on to Dynare are available upon request. Stedman Hood and Walker Ray performed superb research assistance on this project.

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1 Introduction

Accounts of the recent financial crisis attribute a central role to the collapse in housing wealth and to financial frictions in explaining the sharp contraction in consumption and overall economic activity.[1] Prior to the crisis, however, the increase in housing wealth associated with the steady increase in house prices between 2001 and 2006 seems to have had much less influence in boosting consumption. Taken together, these observations suggest an asymmetry in the relationship between housing prices and economic activity. In this paper, we present a model with collateral constraints tied to housing values that has the potential to explain this asymmetry, evaluate its quantitative relevance, and verify its predictions against U.S. data.

Our main story goes as follows. When house prices rise, households can borrow and spend more, but the incentive and need to borrow more becomes proportionally smaller the larger is the increase in house prices. As a consequence, the collateral channel from housing wealth to consumption is positive but not large. Conversely, when house prices fall, collateral constraints are tightened, and borrowing and expenditures co-move with house prices in a more dramatic fashion. As a consequence, the macroeconomic consequences of declines in housing wealth are larger (and more severe) than those of increases in housing wealth of equal magnitude but opposite sign. The empirical analysis overwhelmingly supports the findings from the model that the fallout from a decline in housing prices is much more severe than the boost to activity from an increase.

The model used in this paper is borrowed from Iacoviello and Neri (2010). It is an estimated DSGE model that allows for numerous empirically-realistic nominal and real rigidities as in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). In addition, the model encompasses a housing sector. On the supply side, a separate sector produces new homes using capital, labor, and land. On the demand side, households consume housing services and can use housing as a collateral for loans. In characterizing the properties of the model, we focus on a shock to households preferences for housing. When house prices decline, household wealth is reduced, collateral constraints become binding, and the fraction of total income accounted for by credit-constrained households increases. In contrast, house price increases can relax households' borrowing constraints. Iacoviello and Neri (2010) solve this model using a first-order perturbation method. As a result, the importance of credit-constrained agents remains constant and the effects of shocks that move house prices is symmetric for increases and decreases. We deploy a non-linear solution technique that allows us to capture asymmetric effects of shocks depending on whether the shocks push housing wealth up or down. Under our preferred calibration, we show how the model can generate a response of consumption and hours to house prices that is three times larger when house prices fall than when they rise.

Figure 1 offers a first look at national house prices. It shows the evolution of U.S. house prices over the period 1975-2012. To highlight their correlation properties, the top panel super-

[1] For instance, see Mian and Sufi (2010), Hall (2011).

imposes the time series of U.S. house prices and of U.S. aggregation consumption expenditures. The correlation coefficient is 0.55, a value substantial but not extreme. The bottom panel is a scatterplot of changes in consumption and house prices. It highlights that most of the positive correlation seems to be driven by periods when house prices are below average, both during the 1992-1993 period, and during the 2007-2009 recession. When periods with house price decreases (the solid, magenta line) are included, there is a strong positive correlation between consumption and house prices. However, excluding periods with declines in house prices results in almost no correlation between consumption and house prices.

We test the prediction of the model that house price increases and declines should have asymmetric effects using both national and regional data. We proceed in two steps. First, we estimate a VAR that includes U.S. consumption and house prices. Each equation in the VAR allows for separate house price terms, depending on whether house prices increase or decrease. Population estimates of the VAR parameters based on data generated by the model imply a strong asymmetry in the response of consumption to innovations in house prices, depending on whether the shock to house prices is positive or negative. These population estimates are remarkably consistent with estimates obtained using aggregate U.S. data.

In the second step, we use regional data. The task of isolating the asymmetric effect of changes in house prices using national data only may be fraught with difficulty. Barring the Great Recession, house price declines have been rare at the national level. In addition, knowing what would have happened to economic activity had house prices not changed raises challenging identification issues. Accordingly, we use panel and cross-sectional regressions at the regional level. Regional data exhibit greater variation in house prices. Moreover, at the regional level, we can use instruments that other studies have found useful in isolating exogenous changes in house prices. When we do so, we verify that the asymmetries uncovered using national aggregate data are even more pronounced when we use regional data.

An expanding literature has linked changes in measures of economic activity, such as consumption and employment, to changes in house prices. Recent contributions include Case, Quigley, and Shiller (2005), Campbell and Cocco (2007), Mian and Sufi (2011), Midrigan and Philippon (2011), Mian, Rao, and Sufi (2012) and Abdallah and Lastrapes (2012). The emerging consensus from this literature points towards an important role for housing as collateral for household credit in influencing both consumption and employment. While invoking the collateral constraint channel in explaining the relationship between house prices and economic activity, the empirical literature to date has not recognized that such a channel implies asymmetric relationships for house price increases and declines with other measure of aggregate activity. Explicit modeling of separate terms for house price increase and declines allows us to avoid a downward bias that stems from co-mingling the separate relationships. Furthermore, our uncovering of statistically significant differences for house price increases and declines, as theory predicts, provides more cogent support for the hypothesis that the housing collateral channel has played an important role in linking house price fluctuations to other key measures of economic activity.

The rest of the paper proceeds as follows: Section 2 presents a simple intuition for why collateral constraints imply an asymmetry in the relationship between house prices and consumption using a partial equilibrium model. Section 3 considers an empirically-validated general equilibrium model. Section 4 highlights properties of the general equilibrium model and matches them against an asymmetric VAR estimated on aggregate U.S. data. Section 5 presents additional evidence on asymmetries in the relationship between house prices and other measures of economic activity based on state and MSA-level data. Section 6 considers a policy experiment. Section 7 concludes.

2 Collateral constraints and asymmetries

To fix ideas regarding the fundamental asymmetry introduced by collateral constraints, it is useful to work through a simple partial equilibrium model. Consider the problem of a household that has to choose profiles for goods consumption c_t, housing h_t, and borrowing b_t. Per period utility is given by $u(c_t, h_t)$ and the discount rate is β. The budget and borrowing constraints are:

$$\begin{aligned} c_t + q_t \Delta h_t &= y_t + b_t - R b_{t-1} \\ b_t &\leq m q_t h_t \end{aligned}$$

The price of housing, q_t, is exogenous. Housing is used as collateral for borrowing and $q_t h_t$ is the value of collateral. The parameter m is the loan-to-value ratio. Letting μ_t be the Lagrange multiplier on the borrowing constraint, the consumption Euler equation is:

$$u_{c_t} = \beta R E_t u_{c_{t+1}} + \mu_t$$

In steady state, $\mu > 0$, so long as $\beta R < 1$. Solving this equation forward, one obtains:

$$u_{c_t} = \mu_t + E_t \left(\beta R \mu_{t+1} + \beta^2 R^2 \mu_{t+2} + ... \right)$$

Expressing the Euler equation as above shows plainly that with any utility function concave in consumption, consumption depends negatively on current and future expected borrowing constraints. The Euler equation also implies that small shocks to q_t that keep μ_t positive will have roughly symmetric effects on c_t. However, large enough increases in q_t imply a fundamentally asymmetry. The multiplier μ_t cannot fall below zero. Consequently, large increases in q_t can bring μ_t to its lower bound and will have proportionally smaller effects on c_t than decreases in q_t. Intuitively, an impatient borrower prefers a consumption profile that is declining over time. A large temporary increase in house prices will enable such a profile (high c today, low c tomorrow) without borrowing all the way up to the limit.

3 Model Description

To quantify the importance of the asymmetric relationship between house prices and consumption, we consider an empirically validated general equilibrium model. The model is borrowed from Iacoviello and Neri (2010). It builds on Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007) by allowing for two sectors, a housing sector and non-housing a sector, as well as financial frictions and borrowing collateralized by housing following Iacoviello (2005).

On the supply side, firms in the housing sector produce new homes using capital, labor and land. Firms in the non-housing sector produce intermediate consumption and investment goods using capital and labor. The non-housing sector features nominal price rigidities. Both sectors have nominal wage rigidities and real rigidities in the form of imperfect labor mobility, capital adjustment costs and variable capital utilization.

On the household side, there is a continuum of agents in each of two groups that display different discount factors. Households in the group with the higher discount factor are dubbed "patient," the other "impatient." Patient households accumulate housing and own the productive capital of they economy. They make consumption and investment decisions and supply labor to firms and funds to both firms and impatient households. Impatient households work, consume, and accumulate housing. Their higher impatience pushes them to borrow. In the non-stochastic steady state, their housing collateral constraint is binding.

Below, we sketch the key features of the model. A (not-for-publication) appendix provides the list of all necessary conditions for an equilibrium.

3.1 Households

Within each group of patient and impatient households, a representative household maximizes:

$$E_0 \sum_{t=0}^{\infty} \left(\beta G_C\right)^t \mathsf{z}_t \left(\Gamma_c \ln \left(c_t - \varepsilon c_{t-1}\right) + \mathsf{j}_t \ln h_t - \frac{\tau_t}{1+\eta} \left(n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi}\right)^{\frac{1+\eta}{1+\xi}} \right); \tag{1}$$

$$E_0 \sum_{t=0}^{\infty} \left(\beta' G_C\right)^t \mathsf{z}_t \left(\Gamma_c' \ln \left(c_t' - \varepsilon' c_{t-1}'\right) + \mathsf{j}_t \ln h_t' - \frac{\tau_t}{1+\eta'} \left(\left(n_{c,t}'\right)^{1+\xi'} + \left(n_{h,t}'\right)^{1+\xi'}\right)^{\frac{1+\eta'}{1+\xi'}} \right). \tag{2}$$

Variables accompanied by the prime symbol refer to patient households. c, h, n_c, n_h are consumption, housing, hours in the consumption sector and hours in the housing sector. The discount factors are β and β'. By definition, $\beta' < \beta$. The terms z_t , j_t, and τ_t capture shocks to intertemporal preferences, labor supply, and housing preferences, respectively. The shocks follow:

$$\ln \mathsf{z}_t = \rho_z \ln \mathsf{z}_{t-1} + u_{z,t}, \;\; \ln \mathsf{j}_t = \left(1-\rho_j\right) \ln j + \rho_j \ln \mathsf{j}_{t-1} + u_{j,t}, \;\; \ln \tau_t = \rho_\tau \ln \tau_{t-1} + u_{\tau,t},$$

where $u_{z,t}$, $u_{j,t}$, $u_{\tau,t}$ and are i.i.d. processes with variances σ_z^2, σ_j^2, and σ_τ^2. Above, ε measures habits in consumption and G_C is the growth rate of consumption along the balanced growth path. The scaling factors $\Gamma_c = (G_C - \varepsilon) / (G_C - \beta\varepsilon G_C)$ and $\Gamma'_c = (G_C - \varepsilon') / \left(G_C - \beta'\varepsilon' G_C\right)$ ensure that the marginal utilities of consumption are $1/c$ and $1/c'$ in the non-stochastic steady state.

Patient households accumulate capital and houses and make loans to impatient households. They rent capital to firms, choose the capital utilization rate; in addition, there is joint production of consumption and business investment goods. Patient households maximize their utility subject to:

$$c_t + \frac{k_{c,t}}{\mathsf{A}_{k,t}} + k_{h,t} + k_{b,t} + q_t h_t + p_{l,t} l_t - b_t = \frac{w_{c,t} n_{c,t}}{X_{wc,t}} + \frac{w_{h,t} n_{h,t}}{X_{wh,t}}$$
$$+ \left(R_{c,t} z_{c,t} + \frac{1-\delta_{kc}}{\mathsf{A}_{k,t}} \right) k_{c,t-1} + (R_{h,t} z_{h,t} + 1 - \delta_{kh}) k_{h,t-1} + p_{b,t} k_{b,t} - \frac{R_{t-1} b_{t-1}}{\pi_t}$$
$$+ (p_{l,t} + R_{l,t}) l_{t-1} + q_t (1-\delta_h) h_{t-1} + Div_t - \phi_t - \frac{a(z_{c,t}) k_{c,t-1}}{\mathsf{A}_{k,t}} - a(z_{h,t}) k_{h,t-1}. \quad (3)$$

Patient agents choose consumption c_t, capital in the consumption sector $k_{c,t}$, capital $k_{h,t}$ and intermediate inputs $k_{b,t}$ (priced at $p_{b,t}$) in the housing sector, housing h_t (priced at q_t), land l_t (priced at $p_{l,t}$), hours $n_{c,t}$ and $n_{h,t}$, capital utilization rates $z_{c,t}$ and $z_{h,t}$, and borrowing b_t (loans if b_t is negative) to maximize utility subject to (3). The term $\mathsf{A}_{k,t}$ captures investment-specific technology shocks, thus representing the marginal cost (in terms of consumption) of producing capital used in the non-housing sector. Loans are set in nominal terms and yield a riskless nominal return of R_t. Real wages are denoted by $w_{c,t}$ and $w_{h,t}$, real rental rates by $R_{c,t}$ and $R_{h,t}$, depreciation rates by δ_{kc} and δ_{kh}. The terms $X_{wc,t}$ and $X_{wh,t}$ denote the markup (due to monopolistic competition in the labor market) between the wage paid by the wholesale firm and the wage paid to the households, which accrues to the labor unions (we discuss below the details of nominal rigidities in the labor market). Finally, $\pi_t = P_t/P_{t-1}$ is the money inflation rate in the consumption sector, Div_t are lump-sum profits from final good firms and from labor unions, ϕ_t denotes convex adjustment costs for capital, z is the capital utilization rate that transforms physical capital k into effective capital zk and $a(\cdot)$ is the convex cost of setting the capital utilization rate to z.

Impatient households do not accumulate capital and do not own finished good firms or land (their dividends come only from labor unions). In addition, their maximum borrowing b'_t is given by the expected present value of their home times the loan-to-value (LTV) ratio m_t:

$$c'_t + q_t h'_t - b'_t = w'_{c,t} n'_{c,t} / X'_{wc,t} + \frac{w'_{h,t} n'_{h,t}}{X'_{wh,t}} + q_t (1-\delta_h) h'_{t-1} - \frac{R_{t-1} b'_{t-1}}{\pi_t} + Div'_t; \quad (4)$$

$$b'_t \leq m_t E_t \left(\frac{q_{t+1} h'_t \pi_{t+1}}{R_t} \right). \quad (5)$$

Departing slightly from Iacoviello and Neri (2010), we also allow for shocks to the LTV ratio governed by an auto-regressive process.

3.2 Firms

To allow for nominal price rigidities, the models differentiates between competitive flexible price/wholesale firms that produce wholesale consumption goods and housing using two distinct technologies, and a final good firm (described below) that operates in the consumption sector under monopolistic competition. Wholesale firms hire labor and capital services and purchase intermediate goods to produce wholesale goods Y_t and new houses IH_t. They solve:

$$\max \frac{Y_t}{X_t} + q_t IH_t - \left(\sum_{i=c,h} w_{i,t} n_{i,t} + \sum_{i=c,h} w'_{i,t} n'_{i,t} + \sum_{i=c,h} R_{i,t} z_{i,t} k_{i,t-1} + R_{l,t} l_{t-1} + p_{b,t} k_{b,t} \right).$$

Above, X_t is the markup of final goods over wholesale goods. The production technologies are:

$$Y_t = \left(\mathsf{A}_{c,t} \left(n_{c,t}^{\alpha} n_{c,t}'^{1-\alpha} \right) \right)^{1-\mu_c} \left(z_{c,t} k_{c,t-1} \right)^{\mu_c}; \tag{6}$$

$$IH_t = \left(\mathsf{A}_{h,t} \left(n_{h,t}^{\alpha} n_{h,t}'^{1-\alpha} \right) \right)^{1-\mu_h-\mu_b-\mu_l} \left(z_{h,t} k_{h,t-1} \right)^{\mu_h} k_{b,t}^{\mu_b} l_{t-1}^{\mu_l}. \tag{7}$$

In (6), the non-housing sector produces output with labor and capital. In (7), new homes are produced with labor, capital, land and the intermediate input k_b. The terms $\mathsf{A}_{c,t}$ and $\mathsf{A}_{h,t}$ measure productivity in the non-housing and housing sector, respectively.

3.3 Nominal Rigidities and Monetary Policy

There are Calvo-style price rigidities in the non-housing consumption sector and wage rigidities in both sectors. The resulting consumption-sector Phillips curve is:

$$\ln \pi_t - \iota_\pi \ln \pi_{t-1} = \beta G_C \left(E_t \ln \pi_{t+1} - \iota_\pi \ln \pi_t \right) - \varepsilon_\pi \ln \left(X_t / X \right) + u_{p,t} \tag{8}$$

where $\varepsilon_\pi = \frac{(1-\theta_\pi)(1-\beta G_C \theta_\pi)}{\theta_\pi}$. Above, i.i.d. cost shocks $u_{p,t}$ are allowed to affect inflation independently from changes in the markup. These shocks have zero mean and variance σ_p^2.

Wage setting is modelled in an analogous way. Patient and impatient households supply homogeneous labor services to unions. The unions differentiate labor services as in Smets and Wouters (2007), set wages subject to a Calvo scheme and offer labor services to wholesale labor packers who reassemble these services into the homogeneous labor composites n_c, n_h, n'_c, n'_h. Wholesale firms hire labor from these packers. Under Calvo pricing with partial indexation to past inflation, the pricing rules set by the union imply four wage Phillips curves that are isomorphic to the price Phillips curve.

Monetary policy follows an interest rate rule that responds gradually to inflation and GDP growth:

$$R_t = R_{t-1}^{r_R} \pi_t^{(1-r_R) r_\pi} \left(\frac{GDP_t}{G_C GDP_{t-1}} \right)^{(1-r_R) r_Y} \overline{rr}^{1-r_R} \frac{u_{R,t}}{\mathsf{s}_t}. \tag{9}$$

GDP is the weighted average of output in the two sectors with nominal share weights fixed at their values in the non-stochastic steady state. The term $\overline{rr}$ is the steady-state real interest rate; $u_{R,t}$ is an i.i.d. monetary shock with variance σ_R^2; s_t is a stochastic process with high persistence capturing long-lasting deviations of inflation from its steady-state level, due e.g. to shifts in the central bank's inflation target. That is, $\ln \mathsf{s}_t = \rho_s \ln \mathsf{s}_{t-1} + u_{s,t}$, $u_{s,t} \sim N(0, \sigma_s)$, where $\rho_s > 0$.

3.4 Market Clearing Conditions

The goods market produces consumption, business investment and intermediate inputs. The housing market produces new homes IH_t. The equilibrium conditions are:

$$C_t + IK_{c,t}/\mathsf{A}_{k,t} + IK_{h,t} + k_{b,t} = Y_t - \phi_t; \tag{10}$$

$$H_t - (1 - \delta_h) H_{t-1} = IH_t, \tag{11}$$

together with the loan market equilibrium condition. Above, $C_t = c_t + c_t'$ is aggregate consumption, $H_t = h_t + h_t'$ is the aggregate stock of housing, and $IK_{c,t} = k_{c,t} - (1 - \delta_{kc}) k_{c,t-1}$ and $IK_{h,t} = k_{h,t} - (1 - \delta_{kh}) k_{h,t-1}$ are the two components of business investment. Total land is fixed and normalized to one.

3.5 The Solution Method

We use a piece-wise linear solution approach as is common in the expanding literature on the zero lower bound on nominal interest rates.[2] The economy features two regimes: a regime when collateral constraints bind and a regime in which they do not. With binding collateral constraints, the linearized system of necessary conditions for an equilibrium can be expressed as

$$\mathcal{A}_1 E_t X_{t+1} + \mathcal{A}_0 X_t + \mathcal{A}_{-1} X_{t-1} = 0, \tag{12}$$

where $\mathcal{A}_1$, $\mathcal{A}_0$, and $\mathcal{A}_{-1}$ are square matrices of coefficients, conformable with the vector X. In turn, X is a vector of all the variables in the model expressed in deviation from the steady state for the regime without default. Similarly, when the constraint is not binding, the linearized system can be expressed as

$$\mathcal{A}_1^* E_t X_{t+1} + \mathcal{A}_0^* X_t + \mathcal{A}_{-1}^* X_{t-1} + \mathcal{C}^* = 0, \tag{13}$$

where $\mathcal{C}^*$ is a vector of constants. When the constraint binds, we use standard linear solution methods to express the decision rule for the model as

$$X_t = \mathcal{P} X_{t-1}. \tag{14}$$

When the collateral constraints do not bind, we use a guess-and-verify approach. We shoot back towards the initial conditions, from the first period when the constraints are guessed to

[2] For instance, see Eggertsson and Woodford (2003) and Bodenstein, Guerrieri, and Gust (2010).

bind again. For example, if the constraints do not bind in $t-1$ but are expected to bind the next period, the decision rule between period $t-1$ and t can be expressed as:

$$\begin{aligned} \mathcal{A}_1^*\mathcal{P}X_t + \mathcal{A}_0^*X_t + \mathcal{A}_{-1}^*X_{t-1} + \mathcal{C}^* = 0, \\ X_t = -\left(\mathcal{A}_1^*\mathcal{P} + \mathcal{A}_0^*\right)^{-1}\left(\mathcal{A}_{-1}^*X_{t-1} + \mathcal{C}^*\right). \end{aligned} \tag{15}$$

We proceed in a similar fashion to construct the time-varying decision rules for the case when collateral constraints are guessed not to bind for multiple periods or when they are foreseen to be slack starting in periods beyond t.[3]

It is tedious but straightforward to generalize the solution method described above for multiple occasionally binding constraints. The extension is needed to account for the zero lower bound (ZLB) on policy interest rates as well as the possibility of slack collateral constraints. In that case, there are four possible regimes: 1) collateral constraints bind and policy interest rates are above zero, 2) collateral constraints bind and policy interest rates are at zero, 3) collateral constraints do no bind and policy interest rates are above zero, 4) collateral constraints do not bind and policy interest rates are at zero. Apart from the proliferation of cases, the main ideas outlined above still apply.

3.6 Calibration

Iacoviello and Neri estimate the model with full information Bayesian methods on U.S. data running from 1965:Q1 to 2006:Q4 and including 10 observed series: real consumption, real residential investment, real business investment, real house prices, nominal interest rates, inflation, hours and wage inflation in the consumption sector, hours and wage inflation in the housing sector. We set parameters based on the mean of the posterior distributions estimated by Iacoviello and Neri (2010). For completeness, their estimates of the model behavioral parameters are reported again in the left column of Table 1.[4]

As in Iacoviello and Neri (2010), some parameter choices are based on information complementary to the estimation sample. These parameters are: the discount factors β, β', the weight on housing in the utility function j, the technology parameters μ_c, μ_h, μ_l, μ_b, δ_h, δ_{kc}, δ_{kh}, the steady-state gross price and wage markups X, X_{wc}, X_{wh}, the loan-to-value (LTV) ratio m and the persistence of the inflation objective shock ρ_s. Values for all the calibrated parameters are reported in the right column of Table 1.

[3]For an array of models, Guerrieri and Iacoviello (2012) compare the performance of the piece-wise perturbation solution described above against a dynamic programming solution obtained by discretizing the state space over a fine grid. Their results bolster the reliability of the piece-wise perturbation method.

[4]Iacoviello and Neri (2010) provide an extensive discussion of both the estimation method and results, including the relative importance of different sources of fluctuations. Given our different focus on highlighting asymmetries implied by collateral constraints, we did not reproduce their estimation results concerning the parameters of the model governing the exogenous stochastic processes.

We depart from the estimates in Iacoviello and Neri (2010) for the following parameters. We set m, the steady–state value of the loan-to-value ratio, equal to 0.925, a parameter that more closely aligns with data from the 1980s and onwards. The wage share of credit constrained households, λ, is estimated by Iacoviello and Neri (2010) to be around 20 percent. We set λ at 40 percent in the non-stochastic steady state. When the model is solved with first-order perturbation methods, λ remains constant. With the solution method advocated in this paper, shocks that increase the value of the housing collateral can make the borrowing constraint slack. Hence, λ is time-varying and it only provides an upper bound on the fraction of credit-constrained agents.

A key parameter for the asymmetries we highlight is the discount factor of the impatient agents β'. Very low values of this parameter imply that impatient agents never escape the borrowing constraint. Then, the model has no asymmetries, regardless of the size of the shocks. Conversely, when β' takes on higher values, closer to discount factor of patient agents, smaller increases in house prices suffice to make the borrowing constraint slack (even though the constraint is expected to bind in the long run). Accordingly, the comovement between consumption and house prices is higher the lower the value of β', since low values of β' make the constraint more likely to bind and imply a larger sensitivity of consumption to house price shocks. We set β' equal to 0.988, based on the moment matching exercise described below.

4 Model Results

First, we complete the calibration of the model through a model matching exercise. Second, we use a simple non-linear VAR to investigate the asymmetric relationship between house prices and consumption. The VAR implied by population moments from our model captures asymmetric responses of consumption to house price increases and declines. The VAR estimated on the observed data sample is consistent with its model counterpart.

4.1 A Moment Matching Exercise

We use the model to generate data conditional on two sources of stochastic variation: an AR(1) process that governs the loan-to-value ratio, m_t; and a shock to housing preferences j_t. We single these two shocks out because several studies have suggested that movements in housing demand and credit market shocks may play an important role in driving housing prices and aggregate consumption. Another advantage of these two shocks is that the housing demand shock primarily drives housing prices and, to the extent that there are strong collateral channels, affects consumption as well. The shock to the loan-to-value ratio affects consumption relatively more, since it influences the short-term resources that borrowers use to finance consumption. We choose the standard deviations of the two shocks and the discount factor of the impatient agents in order to optimize the model's ability to account for the volatility of consumption and house prices and their correlation. Importantly, we do not impose any requirements on the model's ability to fit higher moments in the data, such as asymmetries in the responses to shocks. The metric used in our optimization procedure is $\mathcal{L}(ss)$, where ss is the vector including estimates of $\sigma_j, \sigma_m, \beta'$ and $\mathcal{L}(ss)$ is given by

$$\mathcal{L}(ss) = (\widehat{mm} - \mathbf{f}(ss)) \widehat{V}^{-1} (\widehat{mm} - \mathbf{f}(ss))'.$$

Here, $\widehat{mm}$ is a 3×1 vector that includes the sample standard deviation of quarterly consumption growth and quarterly real house price growth, as well as their correlation. The 3×3 matrix $\widehat{V}$ is the identity matrix. Finally, $\mathbf{f}(ss)$ is a 3×1 vector with moments analogous to the ones in $\widehat{mm}$ but implied by the model in population (with all other parameters set as described in the calibration section above). The parameter values that minimize $\mathcal{L}(ss)$ are $\sigma_j = 0.0825$, $\sigma_m = 0.0205$, and $\beta' = 0.988$.

As a cross check, the standard deviations of quarterly consumption growth and house price growth implied by the model in population are 0.66 and 1.71 percent, very close to their observed sample counterparts of 0.63 and 1.77 percent. The correlation of consumption growth and house price growth implied by the model in population is 0.42, also close to its observed sample counterpart of 0.39.

4.2 A Nonlinear VAR

With the estimates above, we use model-generated data on consumption and housing prices to fit a two-variable nonlinear VAR. Each equation in the VAR regresses linearly detrended consumption and house prices on: a constant, the linearly detrended consumption, and distinct terms for positive and negative lagged deviations of housing prices from a linear trend. Innovation to each equation are orthogonalized using a Cholesky scheme: we treat model and data symmetrically, by imposing an ordering scheme such that a "house price shock" affects contemporaneously both house prices and consumption.

Figure 2 shows population estimates from the model (the thin lines) against estimates for U.S. data running from 1975 to 2011 (the thick lines) and 95% bootstrap confidence bands. The top panels focus on innovations to house prices that yield about a 2 standard deviation increase in house prices. The bottom panels show responses to an innovation that brings about a 2 standard deviation decline in house prices. Strikingly, model and data appear in substantial agreement: the response of consumption to a large house price decline is twice as large than that to a large house price increase of equal magnitude, in the model as in the data. Furthermore, for the estimates based on observed data, we compute confidence intervals for the difference between the peak response of the absolute value of consumption to the positive and negative innovations. We confirm that this difference is statistically different from zero at standard significance levels. Accordingly, we fail to reject the null hypothesis of asymmetric responses.

4.3 Responses to positive and negative shocks

To illustrate the fundamental source of the asymmetry in the model, Figure 3 considers the effects of a shock to housing preferences, the process j_t in Equation (3.1), which we interpret as a shock to housing demand. Between periods 1 and 10, a series of innovations to j_t are set to bring about a decline in house prices of 30 percent.[5] Thereafter, the shock follows its autoregressive process. In this case, the decrease in house prices reduces the collateral capacity of constrained households. Accordingly those households can borrow less and are forced to curtail their non-housing consumption even further in order to complete their housing plans. On balance, the decline in aggregate consumption is close to 5 percent. The new-Keynesian channels in the model imply that the large decline in aggregate consumption translate into a large decline in the firms' demand for labor. In equilibrium, the drop in hours worked comes close to reaching 6 percent below the balanced growth path.

Unforseen to the agents in the model, in period 51 a series of innovations for the shock to housing preferences brings about a 30 percent increase in house prices over the next 10 quarters. Recalling the partial equilibrium model described in Section 2, an increase in house prices can relax borrowing constraints. After a short two quarters, the borrowing constraint for the representative impatient household becomes slack. The Lagrange multiplier in the households' utility maximization problem bottoms out at zero. In period 61, the shock to housing preferences starts following its autoregressive process and house prices begin to decline. The borrowing constraint remains slack for another couple of quarters, but even as house prices are well above their balanced growth path, the borrowing constraint starts binding again (and its Lagrange multiplier takes on positive values).

When the constraint becomes slack, the borrowing constraint channel remains operative only in expectation. Thus, impatient households discount that channel more heavily the longer the constraint is expected to remain slack. As a consequence, the response of consumption to the large house price increases considered in the figure is not as dramatic as the reaction to house price declines of an equal magnitude. At peak the increase in consumption and hours worked is about 2 percent, respectively 1/2 and 1/3 of the response to the house price declines.

Figure 4 plots the peak response of consumption to a house demand shock as a function of the change in house prices induced by the same shock. The figure also shows the relationship between the peak elasticity of consumption to housing wealth as a function of the peak impact to housing wealth. Prosaically, the former is defined as the ratio of the peak response of aggregate consumption to the peak response of house wealth, the latter as the peak response of the value of the housing stock. In our model, if borrowing constraints were always binding, this

[5] Iacoviello and Neri (2010) find that house preference shocks are one of the key determinants of house price movements at business cycle frequencies. Similarly, Liu, Wang, and Zha (2011) highlight that a shift in housing demand in a credit-constrained economy can lead to large fluctuations in land prices, an produce a broader impact on hours worked and output.

elasticity would be constant, regardless of the change in house prices. However, because large increases in house prices can make the borrowing constraint slack, they affect consumption less and less. Mechanically, the peak impact on consumption of a housing demand shock continues to decline because our solution algorithm attributes a longer duration to the regime with slack borrowing constraints when the house price increases become larger.

After observing a long string of house price increases, an econometrician running a linear regression would be tempted to conclude that the spillovers from house prices to aggregate consumption are modest. However, the same econometrician would produce quite different estimates after a string of house price declines.

4.4 Sensitivity Analysis

Figure 6 considers again the peak impact of consumption relative to the peak impact on house prices of a housing demand shock. For ease of comparison, the blue solid line reproduces the benchmark results shown in Figure 4. In addition, Figure 6 considers two alternative calibrations. The dashed black line, labelled "High Impatience" focuses on a lower discount factor for impatient agents, setting β' equal to 0.98. Focusing on the bottom panel of the figure, with greater impatience, larger increases in house prices are required to relax the borrowing constraint. Accordingly, the peak elasticity of consumption to housing wealth remains constant for larger increases in housing wealth than under the benchmark calibration. Moreover, even when the borrowing constraint is eventually relaxed by larger underlying housing demand shocks, the constraint is expected to stay slack for a shorter period than under the benchmark. These differences are also reflected in the top panel. The flattening out of the response of consumption to increases in housing wealth becomes less pronounced.

The dot-dashed, red lines in Figure 6 show results for a lower value of the LTV ratio, with m equal to 0.75. When increases in housing wealth make the borrowing constraint slack, there are little differences between the benchmark and the results under this alternative calibration. If anything, for large increases in house prices, the response of consumption is stronger, since the borrowing constraint is likely to be less slack, and the collateral effect stronger, for low values of the LTV ratio. However, when housing wealth declines, the collateral effect is smaller, and the decrease in borrowing is less pronounced. Accordingly, lower values for m also imply al flattening of the response of consumption to increases in housing wealth and a compression of the asymmetry that we have highlighted so far.

Moving in the opposite direction, Figure 5 considers a mechanism that can enhance the asymmetric response of consumption to housing demand shocks. In addition to the baseline model already considered in Figure 4, it considers a variant of the model, labelled "ZLB", that allows for another occasionally binding constraint, namely the zero lower bound on the policy interest rate. In that case, the Monetary policy rule becomes:

$$R_t = \max \left[1, R_{t-1}^{r_R} \pi_t^{(1-r_R)r_\pi} \left(\frac{GDP_t}{G_C GDP_{t-1}} \right)^{(1-r_R)r_Y} \overline{rr}^{1-r_R} \frac{u_{R,t}}{\mathsf{s}_t} \right]. \tag{16}$$

In the ZLB case, sufficiently large price declines can bring the gross policy rate R_t to 1 (equivalently, the net policy rate hits 0). With mechanisms familiar from the literature on the effects of aggregate demand shocks in a liquidity trap, the spillover effects of contractionary house demand shocks onto aggregate consumption become amplified. At the zero lower bound with constant nominal rates, declines in inflation can bring up real interest rates and deepen the contractionary effects of the shock.[6] We pick up this theme again below when discussing our estimates from panel regressions on regional data.

5 Regional Evidence on Asymmetries

The results of our theoretical model and the evidence from the vector autoregressions at the national level motivate additional empirical analysis that we conduct using a panel of data from U.S. states and Metropolitan Statistical Areas (MSA). The obvious advantage of these data is that variation in housing prices and economic activity is greater at the regional than at the aggregate level. The use of regional data allays the concern that little can be learned using national data, given the rarity of declines in house prices at the national level.

Figure 7 shows changes in house prices and changes in employment in the service sector, auto sales, electricity consumption, and mortgage originations in 2005 and 2008 for all the 50 U.S. states and the District of Columbia. For each state there are two dots in each panel: the green dot (concentrated in the north–east region of the graph) shows the lagged percent change in house prices and the percent change in the indicator of economic activity in 2005, at the height of the housing boom.[7] The red dot represents analogous observations for the 2008 period, in the midst of the housing crash. Fitting a piecewise linear regression to these data yields a correlation between house prices and activity that is smaller when house prices are high. This evidence on asymmetry is bolstered by the large cross-sectional variation in house prices across states over the period in question.

5.1 State-Level Evidence

We use annual data from 1990 to 2010 from the 50 U.S. states and the District of Columbia on house prices and measures of economic activity. We choose measure of economic activity

[6]For instance, see Christiano, Eichenbaum, and Rebelo (2011).

[7]An analogous relationship is more tenuous for house prices and employment in the manufacturing goods sector. Most goods are traded and are less sensitive to local house prices than services.

to match our model counterparts for consumption, employment and credit. Our data are described in detail in an Appendix.

Our main specification takes the following form:

$$\Delta \log y_{i,t} = \alpha_i + \gamma_t + \beta_{POS} \mathcal{I}_{i,t} \Delta \log hp_{i,t-1} + \beta_{NEG} \left(1 - \mathcal{I}_{i,t}\right) \Delta \log hp_{i,t-1} + \delta X_{i,t-1} + \varepsilon_{i,t}$$

where $y_{i,t}$ is an index of economic activity and $hp_{i,t}$ is the inflation-adjusted house price index in state i in period t; α_i and γ_t represent state and year fixed effects; and $X_{i,t}$ is a vector of additional controls. We interact changes in house prices with a state-specific indicator variable $\mathcal{I}_{i,t}$ that takes value 1 when house prices are high, and value 0 when house prices are low. We classify house prices as high in a particular state when house prices are above a state-specific linear trend estimated for the 1975-2010 period. Using this approach, the fraction of states with high house prices is about 20 percent in the 1990s, rises gradually to peak at 100 percent in 2005 and 2006, and drops to 27 percent in 2010. Our results were similar using a different definition of $\mathcal{I}_{i,t}$ that takes value 1 when real house price inflation is positive. In our baseline specification, we use one-year lags of house prices and other controls to control for obvious endogeneity concerns. Our results were also little changed when instrumenting current or lagged house prices with one or more lags.

Tables 2 to 5 present our estimates when the indicators of economic activity $y_{i,t}$ are employment in the service sector, automobile sales, electricity usage and mortgage originations respectively.

Table 2 presents the results for our preferred measure of regional economic activity, namely employment in the non-tradeable service sector. We choose this measure (rather than, say, total employment) since U.S. states (and MSAs) heavily trade with each other, so that employment in sectors that mainly produce for the local economy better isolates the local effects of movements in local house prices.[8] The first two columns do not control for time effects. They show that the asymmetry is strong and economically important, and that house prices matter, at statistically conventional levels, both when high and when low. After controlling for time effects in the third column, the coefficient on high house prices is little changed, but the coefficient on low house prices is lower. A large fraction of the decline in house prices in our sample took place against the background of the zero lower bound on policy interest rates.

[8] The BLS collects state-level employment data by sectors broken down according to NAICS (National Industry Classification System) starting from 1990. According to this classification (available at `http://www.bls.gov/ces/cessuper.htm`), the goods-producing sector includes Natural Resources and mining, construction and manufacturing. The service-producing sector includes wholesale trade, retail trade, transportation, information, finance and insurance, professional and business services, education and health services, leisure and hospitality and other services. A residual category includes unclassified sectors and public administration. We exclude from the service sector wholesale trade (which on average accounts for about 6 percent of total service sector employment) since wholesale trade does not necessarily cater to the local economy.

As discussed in the model results, the zero lower bound is a distinct source of asymmetry for the effect of change in house prices. Time fixed effects allow us to parse out the effects of the national monetary policy reaching the zero lower bound and, in line with our theory, they compress the elasticity of employment to low house prices. In the last two columns, after adding additional variables, the only significant coefficient is the one on low house prices. In column five, the coefficient on "high house prices" is positive, although is low and not significantly different from zero. The coefficient on "low house prices," instead, is positive and significantly different from zero. Taken at face value, these results imply that house prices only matter for economic activity when they are low. The difference in the coefficient on low and high house prices is significantly different from zero, with a p-value of 0.014.

Table 3 reports our results when our measure of activity is retail automobile sales. Auto sales are an excellent indicator of local demand, since autos are almost always sold to state residents, and since durable goods are notoriously very sensitive to changes in economic conditions. After adding lagged car sales and personal income as controls, the coefficients on low and high house prices are both positive; the coefficient on low house prices is nearly four times as large, and the p-value of the difference between low and high house prices is 0.11.

Table 4 reports our results using residential electricity usage as a proxy for consumption. Even though electricity usage only accounts for 3 percent of total consumption, we take electricity usage to be a useful proxy for nondurable consumption.[9] Most economic activities involve the use of electricity which cannot be easily stored: moreover, the flow usage of electricity may even provide a better measures of the utility flow derived from a good than the actual purchase of the good. Even in cases when annual changes in weather conditions may affect year-on-year consumption growth, their effect can be easily filtered out using state-level observations on heating and cooling degree days, which are conventional measures of weather-driven electricity demand. We use these weather measures as controls in all specifications reported. As the table shows, in all regressions low house prices affect consumption growth more than high house prices. After time effects, lagged income growth and lagged consumption growth are controlled for (last column), the coefficient on high house prices is 0.11, the coefficient on low house prices is nearly twice as large at 0.18, and their difference is statistically larger than 0 at the 10 percent significance level.

Because the effects of low and high house prices on consumption work in our model through tightening or relaxing borrowing constraints, it is important to check whether measures of leverage also depend asymmetrically on house prices. Table 5 shows how mortgage originations at the state level respond to changes in house prices. We choose mortgage originations because they are available for a long time period, and because they better measure the flow of new credit to households than the stock of existing debt. As the table shows, mortgage originations

[9]Da and Yun (2010) show that using electricity to proxy for consumption produces asset pricing implications that are consistent with consumption-based capital asset pricing models.

depend asymmetrically on house prices too, as in our model where the effect on house prices on consumption and employment works through the asymmetric effect on borrowing that changes in house price produce.

We note here that the aggregated state-level series that we use as proxy for consumption track consumption from the National Income and Product Accounts rather well. Over the sample period, the correlation between NIPA motor vehicle consumption growth (about 1/3 of total durable expenditure) and retail auto sales growth is 0.89; and the correlation between services consumption growth and electricity usage growth is 0.54.

5.2 MSA-Level Evidence

Tables 6 and 7 presents the results of evidence across MSAs. MSAs account for about 80 percent of the population and of employment in the entire United States. In Table 7, the results from the MSA-level regressions are similar qualitatively and quantitatively to those at the state level.

A legitimate concern with the panel and time-series regressions discussed so far is that the correlation between house prices and economic activity could be due to some omitted factor that simultaneously drives both house prices and economic activity. Even if this were the case, our regressions would still be of independent interest, since they would support the idea – even in absence of a causal relationship – that the comovement between housing prices and economic activity is larger when house prices are low, as predicted by the model.

To support claims of causality, one needs to isolate exogenous from endogenous movements in house prices. In Table 7, we follow the methodology and insight of Mian and Sufi (2011) and the data from Saiz (2010) in an attempt to distinguish an independent driver of housing demand. The insight is to use the differential elasticity of housing supply at the MSA level as an instrument for housing prices, so as to disentangle movements in housing prices due to general changes in economic conditions from movements in the housing market that are directly driven by shifts in housing demand in a particular area. Because such elasticity is constant over time, we cannot exploit the panel dimension of our dataset, and instead use the elasticity in two separate periods by running two distinct regressions of car sales on house prices. The first regression is for the 2003-2007 housing boom period, the second for the 2007-2011 housing bust period. In practice, we rely on the following differenced instrumental variable specifications

$$\begin{aligned} \log hp_t - \log hp_s &= \theta + \delta \text{ Elasticity} + \varepsilon \\ \log car_t - \log car_s &= \delta + \beta(\widehat{\log hp_t - \log hp_s}) + u \end{aligned}$$

where $s = 2003$ and $t = 2007$ in the first set of regressions, and $s = 2007$ and $t = 2011$ in the second set.

The first stage regression shows that elasticity is a powerful instrument in driving house prices, with an R^2 from the first stage regression close to 0.15. The second stage regression, when run across the two separate sub-periods, shows how car sales respond to house prices only in the second period. In the 2003-2007 period, the elasticity of car sales to house prices is only 0.04, and is not statistically different from zero. In the 2007-2011 period, in contrast, this elasticity rises to 0.42, and is significantly different from zero.

6 Policy Implications

So far, our theoretical and empirical results show that movements in house prices can produce asymmetries that are economically and statistically important. Next, we consider whether these asymmetries are also important for gauging the effects of policies aimed at the housing market in the context of a deep recession. To illustrate our ideas, we choose a simple example of one such policy, a lump-sum transfer from patient (saver) households to impatient (borrower) households. For instance, this policy could mimic voluntary debt relief from the creditors, or a scheme where interest income is taxed and interest payments are subsized in lump-sum fashion, so that the net effect is a transfer of resources from the savers to the borrowers.

We consider this experiment against two different baselines. In one case, housing prices are assumed to be declining, in the other case, housing prices are assumed to be increasing. The baseline housing price changes are brought about by the same preference shocks considered in Figure 3 and discussed at length above. Accordingly, we do not need to repeat a description of the baseline at this point.

Figure 8 shows the cumulative response of housing prices to the baseline housing preference shocks and to two transfer shocks from saver households to borrower households. Both transfer shocks are unforeseen. They are sized at the same 1 percent of steady state total consumption in both cases. Each transfer is governed by an auto-regressive process of order 1, with coefficient equal to 0.5. The first transfer starts in period 10. A series of unforseen innovations to the shock process phases in the transfer, until it reaches a peak of 1 percent of steady state consumption. Then, the auto-regressive component of the shock quickly reduces the level of the transfer back to 0. The first transfer happens against a background of housing price declines. The second transfer, starting in period 50, mimics the first but happens against a baseline with housing price increases.

The top left panel of figure 8 shows housing prices in deviation from their steady state level. The path shown is almost identical to the one in figure 3 because the transfer shocks only have a negligible effect on housing prices. The transfer payments are timed to coincide with the series of housing preference shocks that reduce housing prices.

The remaining panels in Figure 8 show responses of key variables to the transfer shock in deviation from the baseline path that obtains with the housing preference shock only. Thus, those panels isolate the partial effects of the transfer shocks. The consumption response of borrower households is dramatically different depending on the baseline variation in housing prices. When housing prices decline, the borrowing constraint is tight and the marginal propensity to consume of borrower households is elevated. When housing prices increase, the borrowing constraint becomes slack and the marginal propensity to consume of borrower households drops down closer to that for saver households. In reaction to the lump-sum transfer, consumption of the savers declines less, and less persistently, against a baseline of housing price declines. In that case, there are expansionary spillover effects from the increased consumption of borrowers to aggregate hours worked and output. Taking together the responses of savers and borrowers, the partial effects of the transfer on aggregate consumption are sizable when housing prices are low, and negligible when housing prices are elevated. As a consequence, actions such as mortgage relief can almost pay for themselves through their expansionary effects on aggregate economic activity in a scenario of severely binding borrowing constraints.

7 Conclusions

Our empirical and theoretical results suggest that policy measures aimed at the housing market have the potential of producing outsize spillovers to aggregate consumption in periods when collateral constraints are tight, either because of large declines in house prices or because credit supply standards have been made more stringent. These spillovers are likely to be larger than those that one can estimate in normal times dominated by house price increases, because normal times can severely underpredict the sensitivity of consumption to movements in housing wealth.

Numerous recent papers with an empirical focus have emphasized the importance of household debt and the housing market in understanding the 2007-2009 recession. Our model provides a framework to analyze these results; to make sense of why household debt seems to matter more during severe recessions; and to better assess the costs and benefits of alternative policies aimed at restoring the efficient functioning of the housing market.

References

Abdallah, C. S. and W. D. Lastrapes (2012). Home equity lending and retail spending: Evidence from a natural experiment in texas. *American Economic Journal: Macroeconomics 4*(4), 94–125.

Bodenstein, M., L. Guerrieri, and C. Gust (2010). Oil shocks and the zero bound on nominal interest rates. International Finance Discussion Papers 1009, Board of Governors of the Federal Reserve System (U.S.).

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

Case, K., J. Quigley, and R. Shiller (2005). Comparing wealth effects: The stock market versus the housing market. *Advances in Macroeconomics 5*(1), 1235–1235.

Christiano, L., M. Eichenbaum, and S. Rebelo (2011). When is the government spending multiplier large? *Journal of Political Economy 119*(1), 78 – 121.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1), 1–45.

Da, Z. and H. Yun (2010). Electricity consumption and asset prices. *Available at SSRN 1608382*.

Eggertsson, G. B. and M. Woodford (2003). The zero bound on interest rates and optimal monetary policy. *Brookings Papers on Economic Activity 34*(1), 139–235.

Guerrieri, L. and M. Iacoviello (2012). A toolkit to solve models with occasionally binding constraints easily. Manuscript, Federal Reserve Board.

Hall, R. E. (2011). The long slump. *American Economic Review 101*, 431–469.

Iacoviello, M. (2005). House prices, borrowing constraints, and monetary policy in the business cycle. *American Economic Review 95*(3), 739–764.

Iacoviello, M. and S. Neri (2010). Housing market spillovers: Evidence from an estimated dsge model. *American Economic Journal: Macroeconomics 2*(2), 125–64.

Liu, Z., P. Wang, and T. Zha (2011). Land-price dynamics and macroeconomic fluctuations. NBER Working Papers 17045, National Bureau of Economic Research, Inc.

Mian, A. and A. Sufi (2010). Household leverage and the recession of 2007-2009. *IMF Economic Review 58*, 74–117.

Mian, A. and A. Sufi (2011). House prices, home equity-based borrowing, and the us household leverage crisis. *American Economic Review 101*(5), 2132–56.

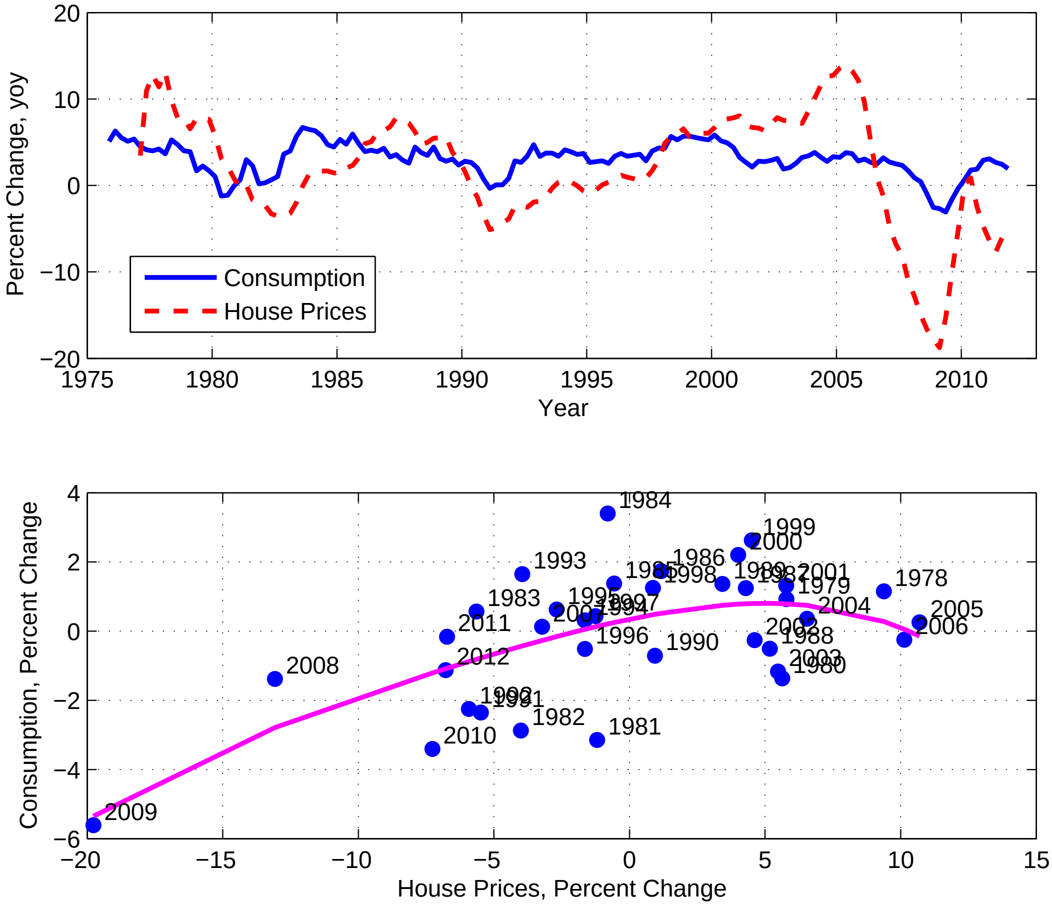
Mian, A. R., K. Rao, and A. Sufi (2012). Household balance sheets, consumption, and the economic slump. Mimeo, Princeton University.

Midrigan, V. and T. Philippon (2011). Household leverage and the recession. NBER working paper no. 16965.

Saiz, A. (2010). The geographic determinants of housing supply. *The Quarterly Journal of Economics 125*(3), 1253–1296.

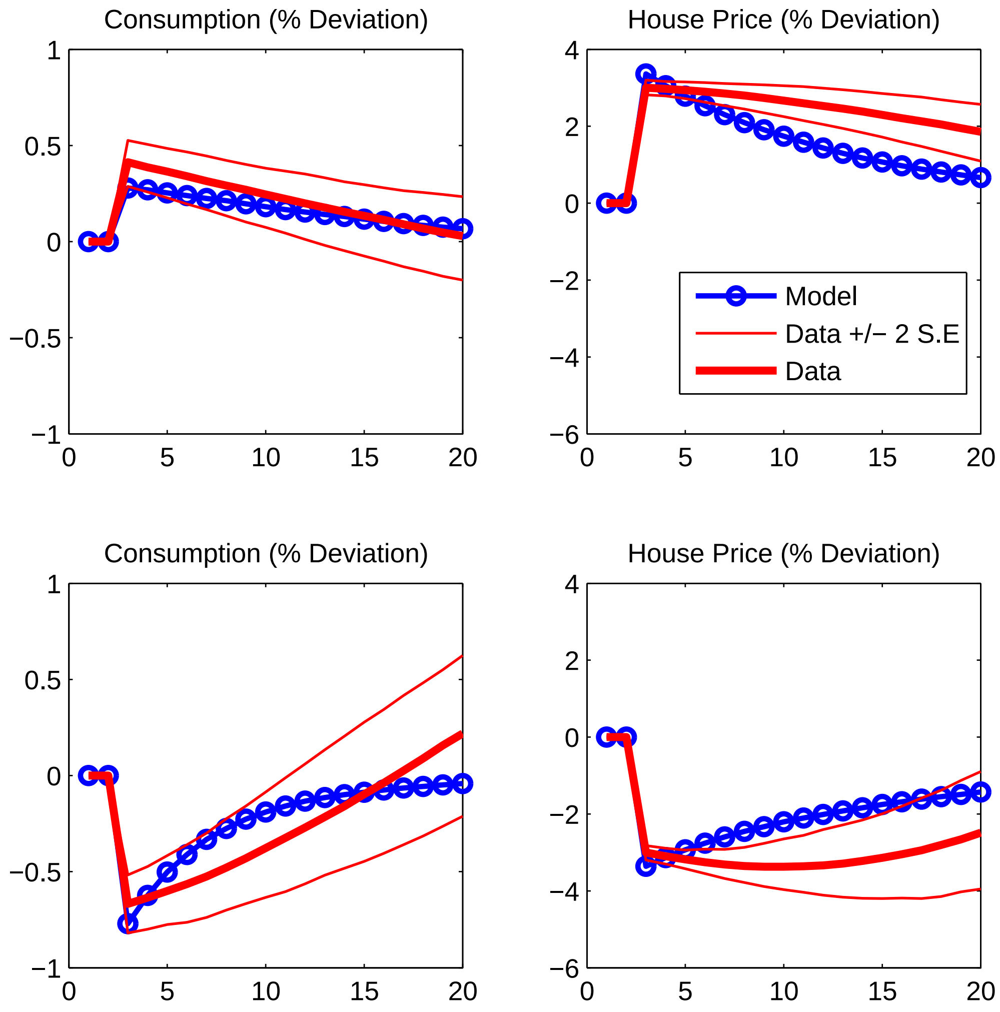
Smets, F. and R. Wouters (2007). Shocks and frictions in us business cycles: A bayesian dsge approach. *American Economic Review 97*(3), 586–606.

Figure 1: Changes in House Prices and Changes in Consumption, U.S. National data*



House Prices: Loan Performance National House Price Index (SA), Haver Analytics, USLPHPIS@USECON, divided by the GDP deflator (DGDP@USECON). Consumption: Real Personal Consumption Expenditures (Haver series: CH@usecon). In the bottom panel, consumption growth and house price growth are expressed in deviation from their sample mean.

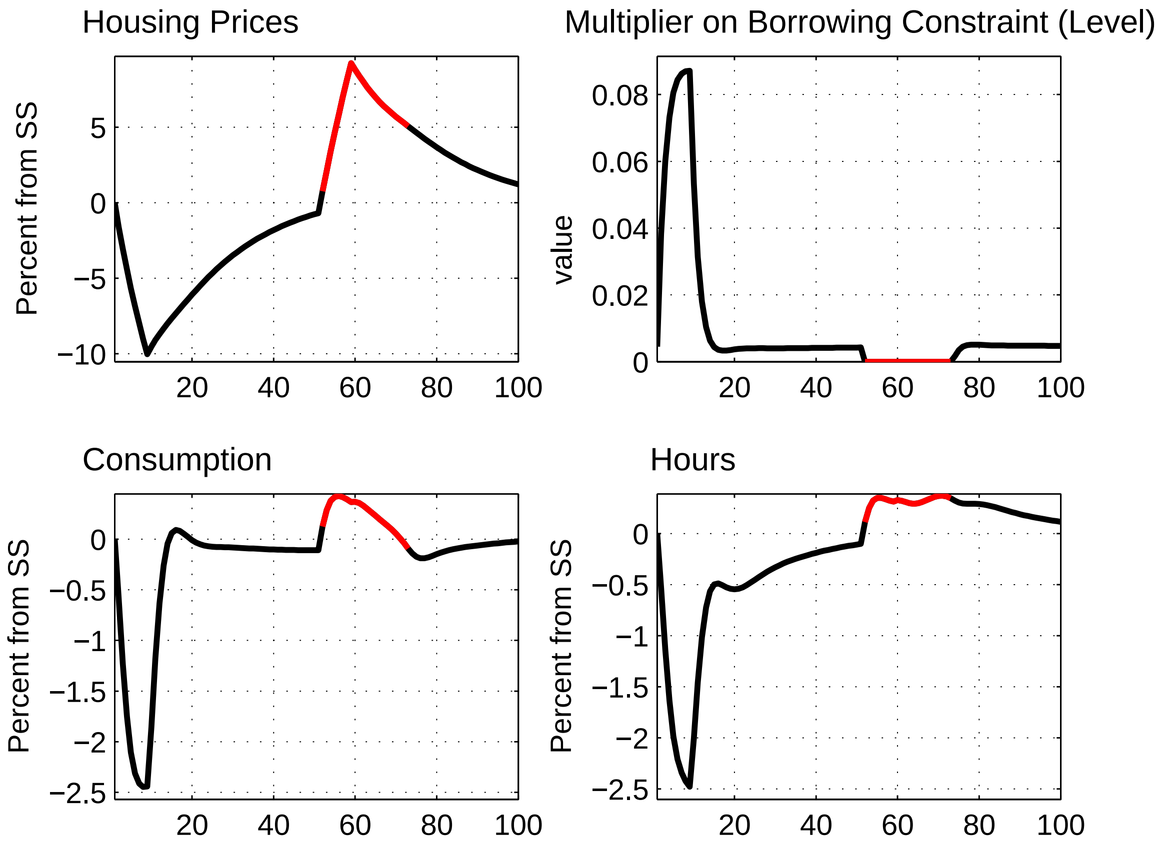
Figure 2: Estimates from asymmetric VAR vs model



Note: Top row: Impulse Responses to a 2 standard error increase in house prices. Bottom row: Impulse Response to a 2 standard error decrease in house prices. Horizontal axis: quarters from the shock; vertical axis: percentage deviation from the unshocked path.

Data VAR run using quarterly data for inflation-adjusted house prices and consumption (linearly detrended) from 1975 to 2011. Model VAR run using observations generated from a model simulation of 500 periods using parameters of Table 1.

Figure 3: Impulse Responses to Positive and Negative House Price Shocks in model with occasionally binding borrowing constraints



Note: The simulation shows the dynamic response of macroeconomic variables to two housing preference shocks. In period 1, a decline in housing demand causes house prices to drop by around 30 percent after 8 quarters. In period 50, an increase in housing demand causes house price to rise by around 30 percent.

Figure 4: Sensitivity of Consumption to Positive and Negative Changes in Housing Prices in the DSGE model

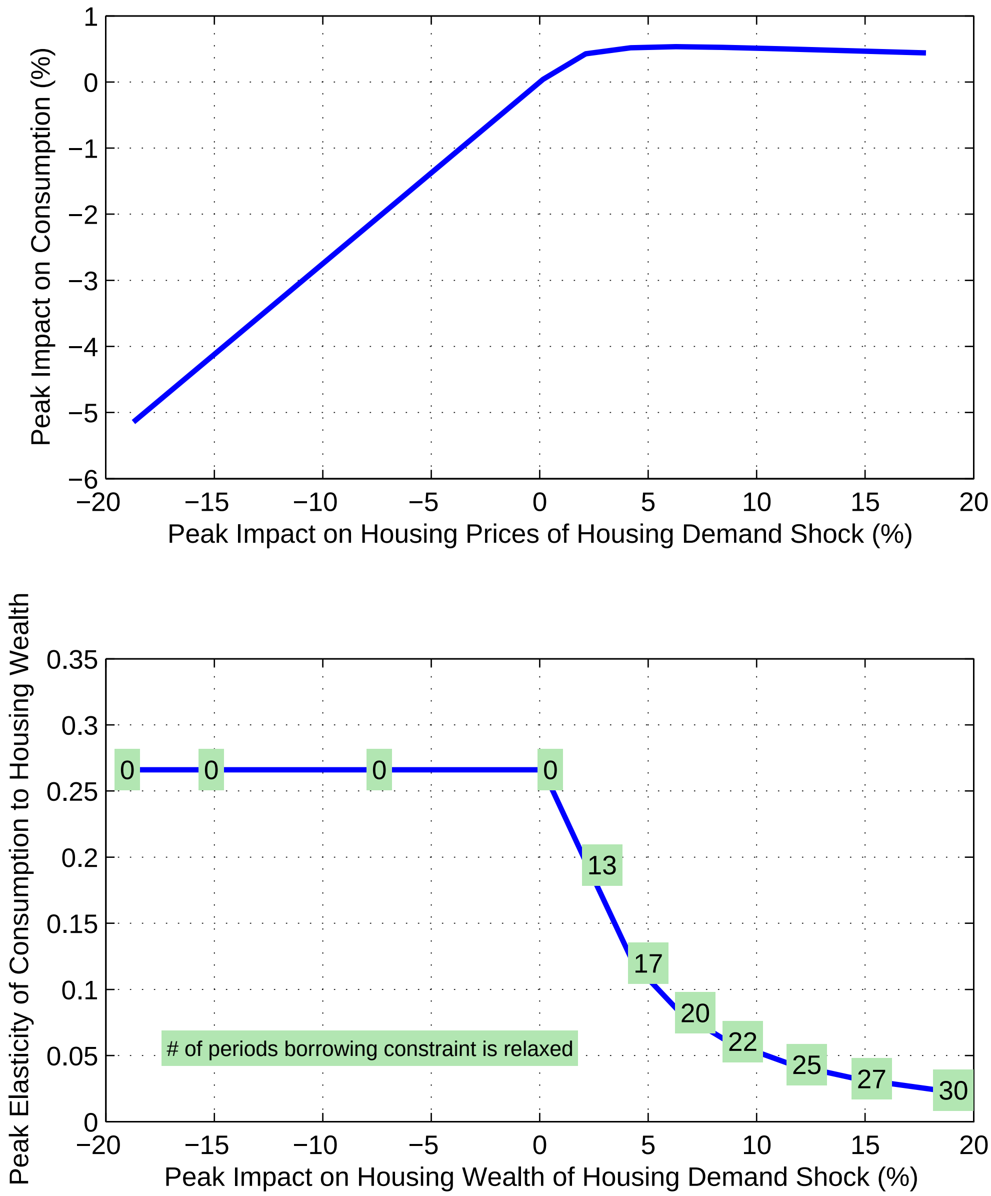


Figure 5: Sensitivity of Consumption to Positive and Negative Changes in Housing Prices in the DSGE model. Allowing for Zero Lower Bound

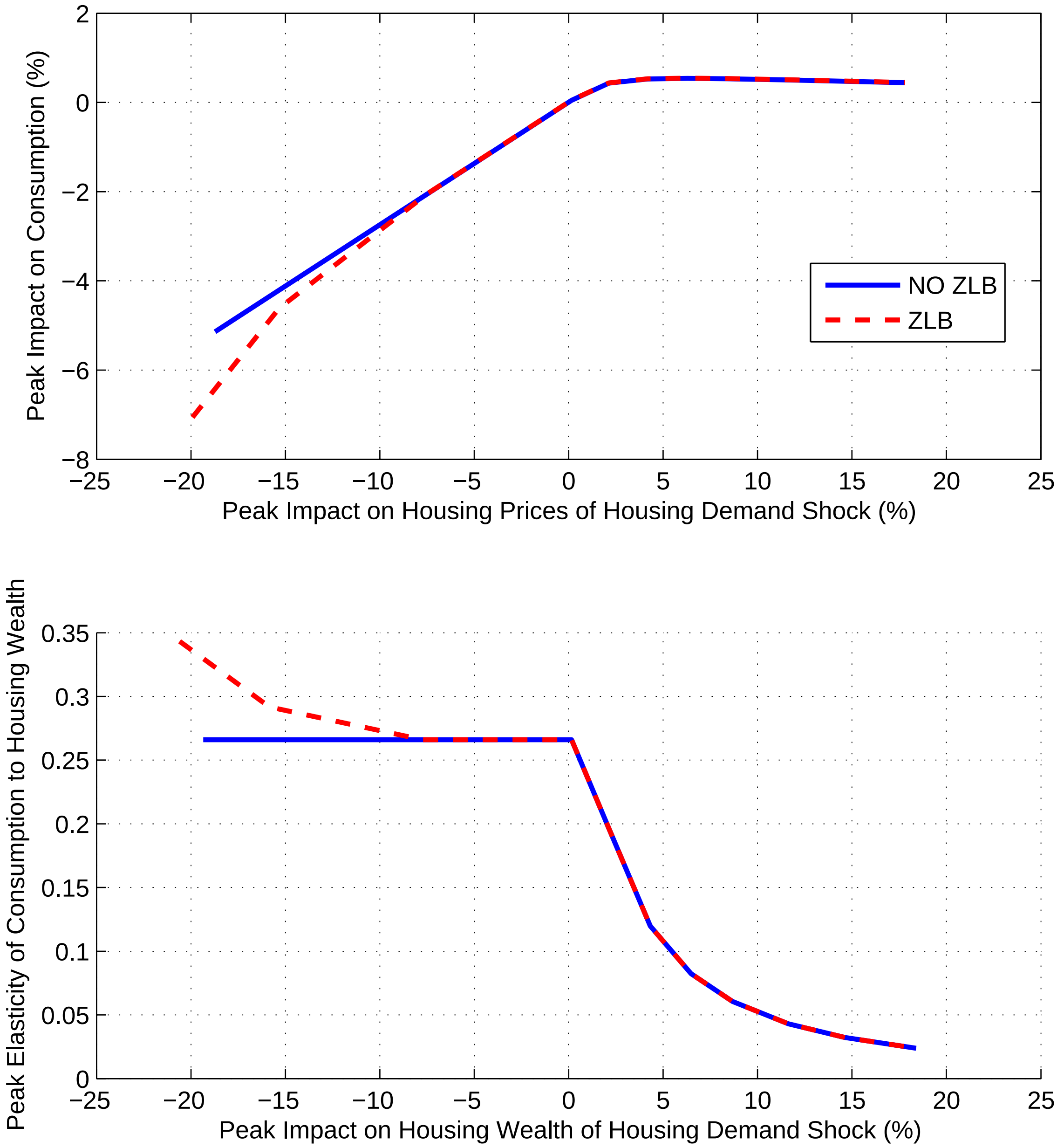
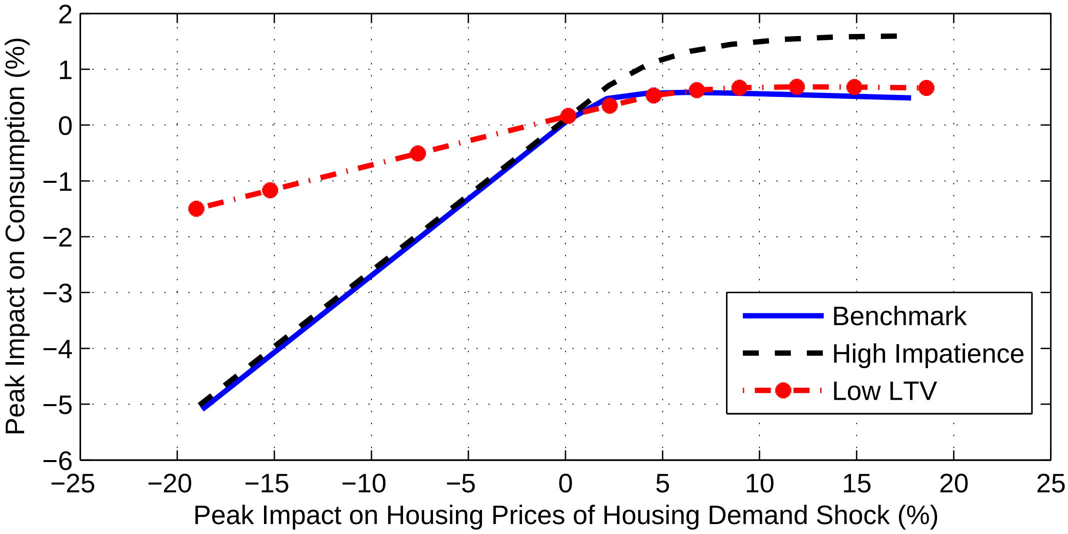


Figure 6: Model sensitivity to different parameters



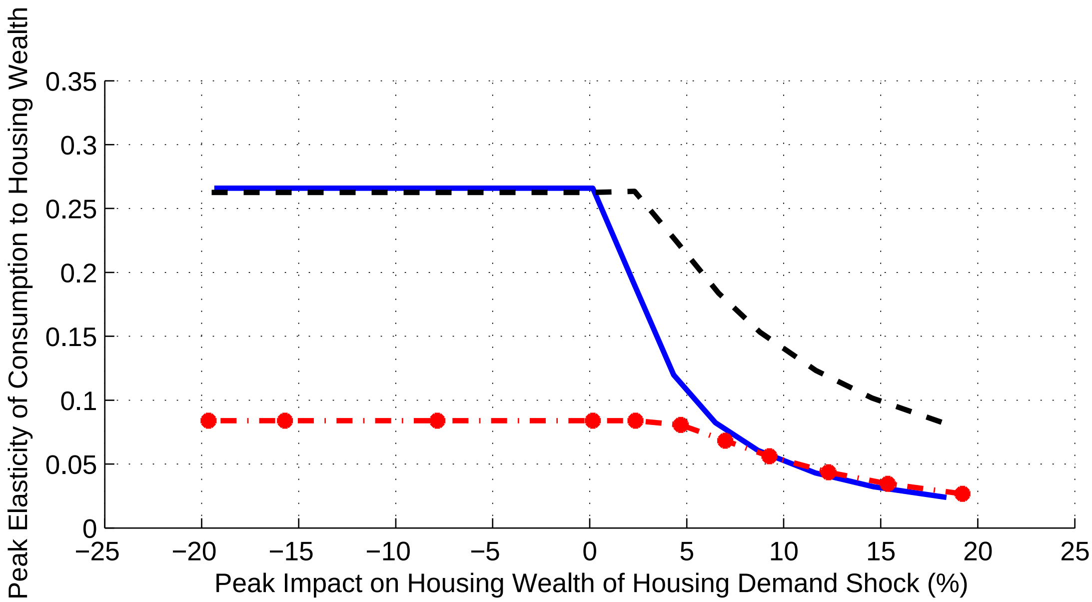
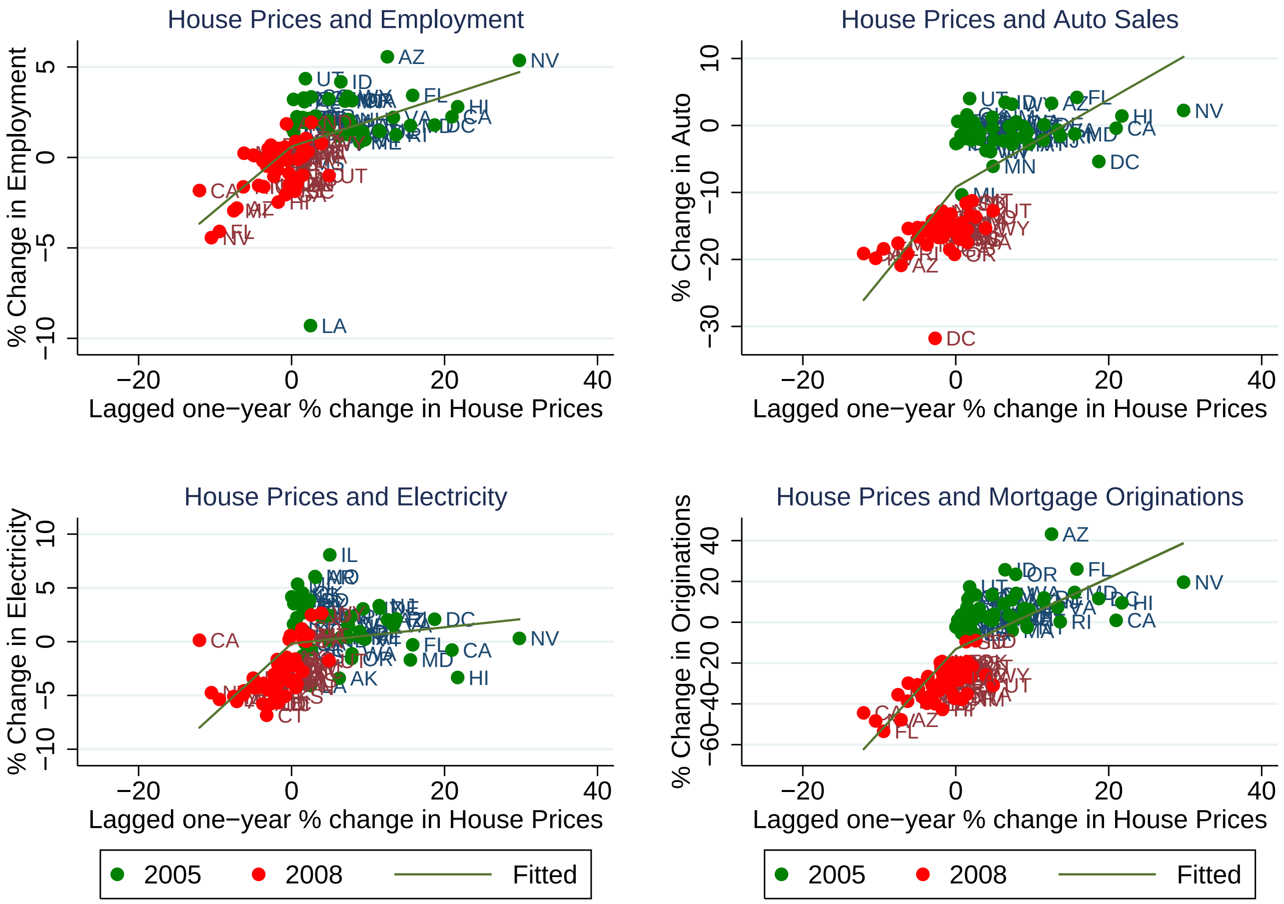
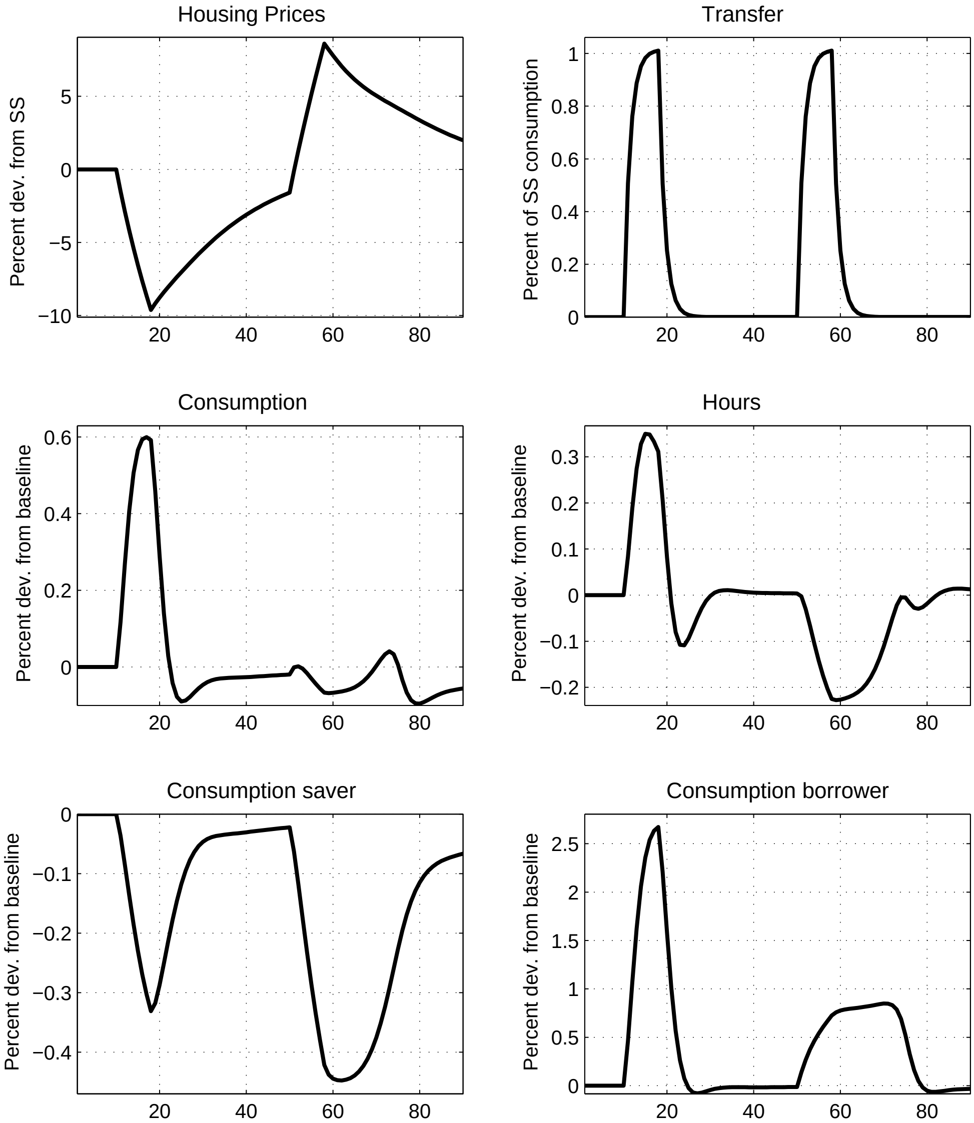


Figure 7: House prices and economic activity by state



Note: Each panel shows house price growth and activity growth across US states in 2005 and 2008. The "fitted" line shows the fitted values of a regression of activity growth on house prices growth broken down into positive and negative changes.

Figure 8: A Transfer from Lenders to Borrowers Against a Background of Housing Price Increases and Declines



Note: The figure shows the effects of two lump-sum transfers from patient (saver) households to impatient (borrower) households each sized at 1 percent of steady state total consumption. The two transfers are unexpected. The first transfer happens against a baseline with a housing price decline. The second transfer happens against a baseline with a housing price increase. Both housing price changes in the baseline stem from a housing preference shock. The responses of consumption, hours, consumption of savers, and consumption of borrowers are shown in deviation from the baseline to isolate the partial effect of the transfer shocks.

Table 1: Parameter Values

	Parameter	Value		Parameter	Value
ε	habit saver	0.32	β	discount saver	0.9925
ε'	habit borrower	0.58	j	housing utility weight	0.12
η	labor disutility saver	0.52	μ_c	capital share, goods	0.35
η'	labor disutility borrower	0.51	μ_h	capital share, houses	0.10
ξ	labor substitutab. saver	0.66	μ_l	land share, houses	0.10
ξ'	labor substitutab. borrower	0.97	μ_b	intermediates share houses	0.10
$\phi_{k,c}$	adj.cost, capital for goods	14.25	δ_h	housing depreciation	0.01
$\phi_{k,h}$	adj.cost, capital for houses	10.90	δ_{kc}	capital depreciation, goods	0.025
ρ_j	AR(1) housing demand shock	0.96	δ_{kh}	capital depreciation, houses	0.03
r_π	inflation response Taylor rule	1.44	X	price markup	1.15
r_Y	output response Taylor rule	0.52	X_{wc}	wage markup, goods	1.15
θ_π	Calvo price stickiness	0.83	X_{wh}	wage markup, houses	1.15
ι_π	Calvo price indexation	0.69			
$\theta_{w,c}$	Calvo wage stickiness goods	0.79	α	savers wage share	0.60**
$\iota_{w,c}$	Calvo wage indexation goods	0.08	m	loan-to-value ratio	0.925**
$\theta_{w,h}$	Calvo wage stickiness houses	0.91	r_R	inertia, Taylor rule	0.70**
$\iota_{w,h}$	Calvo wage indexation houses	0.40	ρ_m	AR(1), LTV shock	0.95*
ζ	Capital Utilization convexity	0.69			
$100\gamma_{AC}$	goods technology trend	0.32	β'	discount borrower	0.988***
$100\gamma_{AH}$	housing technology trend	0.08	σ_j	st.dev housing pref. shock	0.0825***
$100\gamma_{AK}$	investment technology trend	0.27	σ_m	st.dev LTV shock	0.0205***

Note: Parameters denoted with a * were not present in the original model of Iacoviello and Neri (2010). Parameters denoted with ** are calibrated differently. Parameter denoted with *** are estimated in Section 4.

Table 2: State Level: Employment in Non-Tradeable Services and House Prices

	% Change in Employment (Δemp_t)				
Δhp_{t-1}	0.14***				
	(0.01)				
Δhp_high_{t-1}		0.07***	0.08***	0.03*	0.02
		(0.01)	(0.01)	(0.02)	(0.01)
Δhp_low_{t-1}		0.24***	0.12***	0.08***	0.06***
		(0.02)	(0.02)	(0.02)	(0.02)
Δemp_{t-1}				0.25***	0.20**
				(0.09)	(0.09)
$\Delta income_{t-1}$					0.11***
					(0.03)
pval difference		0	0.1053	0.0103	0.0147
Time effects	no	no	yes	yes	yes
Observations	1,020	1,020	1,020	969	969
States	51	51	51	51	51
R-squared	0.12	0.17	0.72	0.75	0.75

Note: Regressions using annual observations from 1990 to 2010 on 51 States. Robust standard errors in parenthesis. ***,**,*: Coefficients statistically different from zero at 1, 5 and 10% confidence level, respectively. pval is the p-value of the test for difference between low-house price and high-house prices coefficient. Data Sources: House Prices are from the FHFA House Price Index (a weighted repeat sales index which includes refinancings), divided by the GDP deflator. Employment is "All Employees" from BLS Current Employment Statistics (Employment, Hours, and Earnings - State and Metro Area). We construct employment in the Non-Tradeable Sector by adding the following sectors: Retail Trade, Transportation and Utilities, Information, Financial Activities, Professional and Business Services, Education and Health Services, Leisure and Hospitality, and Other Services. Income is state-level personal income from the Bureau of Economic Analysis, divided by the GDP deflator.

Table 3: State Level: Auto Sales and House Prices

	% Change in Auto Sales ($\Delta auto_t$)				
Δhp_{t-1}	0.31***				
	(0.04)				
Δhp_high_{t-1}		-0.02	0.15***	0.10***	0.05
		(0.04)	(0.04)	(0.04)	(0.03)
Δhp_low_{t-1}		0.77***	0.34***	0.28**	0.19**
		(0.06)	(0.06)	(0.11)	(0.09)
$\Delta auto_{t-1}$				0.24	0.21
				(0.17)	(0.18)
$\Delta income_{t-1}$					0.40***
					(0.10)
pval difference		0	0.03	0.09	0.11
Time effects	no	no	yes	yes	yes
Observations	918	918	918	867	867
States	51	51	51	51	51
R-squared	0.04	0.10	0.89	0.89	0.90

Note: State–level Regressions using annual observations from 1992 to 2010 on 51 States. Robust standard errors in parenthesis. ***,**,*: Coefficients statistically different from zero at 1, 5 and 10% confidence level, respectively. pval is the p-value of the test for difference between low-house price and high-house prices coefficient. Data source: Auto Sales are "Retail Sales: Motor vehicle and parts dealers" from Moody's Analytics Database. They are divided by the GDP deflator. Auto sales data are constructed with underlying data from the US Census Bureau and employment statistics from the BLS (see empl). The two Census Bureau surveys are the quinquennial Census of Retail Trade, a subset of the Economic Census, and the monthly Advance Montly Retail Trade and Food Services Survey.

Table 4: State Level: Residential Electricity Consumption and House Prices

	% Change in Electricity Consumption ($\Delta elec_t$)				
Δhp_{t-1}	0.08***				
	(0.02)				
Δhp_high_{t-1}		-0.01	0.11***	0.14***	0.115***
		(0.02)	(0.03)	(0.03)	(0.03)
Δhp_low_{t-1}		0.20***	0.17***	0.22***	0.183***
		(0.02)	(0.03)	(0.04)	(0.04)
$\Delta elec_{t-1}$				-0.37***	-0.37***
				(0.03)	(0.03)
$\Delta income_{t-1}$					0.15**
					(0.06)
pval difference		0	0.11	0.07	0.10
Time effects	no	no	yes	yes	yes
Weather Controls*	yes	yes	yes	yes	yes
Observations	1,020	1,020	1,020	969	969
States	51	51	51	51	51
R-squared	0.41	0.43	0.59	0.68	0.68

Note: State–level Regressions using annual observations from 1990 to 2010 on 51 States. Robust standard errors in parenthesis. ***,**,*: Coefficients statistically different from zero at 1, 5 and 10% confidence level, respectively. pval is the p-value of the test for difference between low-house price and high-house prices coefficient. Data source: Electricity Consumption comes from the U.S. Energy Information Administration's (EIA) Electric Power Monthly (EPM) publication. [Electricity Power Annual: Retail Sales - Total Electric Industry - Residential Sales, (NSA, Megawatt-hours)].

* All regressions control separately for number of heating and cooling degree days in each state [source:U.S. National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC)].

Table 5: State Level: Mortgage Originations and House Prices

	% Change in Mortgage Originations ($\Delta mori_t$)				
Δhp_{t-1}	0.22**				
	(0.09)				
Δhp_high_{t-1}		-0.78***	0.45***	0.50***	0.46***
		(0.17)	(0.10)	(0.12)	(0.11)
Δhp_low_{t-1}		1.59***	0.64***	0.84***	0.77***
		(0.24)	(0.13)	(0.11)	(0.12)
$\Delta mori_{t-1}$				-0.02	-0.02
				(0.04)	(0.04)
$\Delta income_{t-1}$					0.28
					(0.23)
pval difference		0	0.29	0.02	0.03
Time effects	no	no	yes	yes	yes
Observations	969	969	969	918	918
States	51	51	51	51	51
R-squared	0.01	0.02	0.91	0.91	0.91

Note: State–level Regressions using annual observations from 1992 to 2010 on 51 States. Robust standard errors in parenthesis. ***,**,*: Coefficients statistically different from zero at 1, 5 and 10% confidence level, respectively. pval is the p-value of the test for difference between low-house price and high-house prices coefficient.

Data Source: Mortgage originations are "Mortgage originations and purchases: Total Number" from the U.S. Federal Financial Institutions Examination Council (FFIEC): Home Mortgage Disclosure Act (HMDA).

Table 6: MSA Level: Employment in Non-Tradeable Services and House Prices

	% Change in Employment (Δemp_t)				
Δhp_{t-1}	0.133***				
	(0.01)				
Δhp_high_{t-1}		0.110***	0.062***	0.049***	0.048***
		(0.01)	(0.01)	(0.01)	(0.01)
Δhp_low_{t-1}		0.177***	0.092***	0.081***	0.081***
		(0.01)	(0.01)	(0.01)	(0.01)
Δemp_{t-1}				0.078***	0.076***
				(0.02)	(0.02)
$\Delta income_{t-1}$					0.022**
					(0.01)
pval difference		0	0.0048	0.0028	0.0012
Time effects	no	no	yes	yes	yes
Observations	5,323	5,323	5,323	5,080	5,339
MSA	260	260	260	259	260
R-squared	0.11	0.11	0.44	0.46	0.45

Note: State–level Regressions using annual observations from 1992 to 2010 on 260 MSAs (104 MSAs were dropped since they had incomplete or missing data on employment by sector). Robust standard errors in parenthesis. ***,**,*: Coefficients statistically different from zero at 1, 5 and 10% confidence level, respectively. pval is the p-value of the test for difference between low-house price and high-house prices coefficient.

Table 7: MSA Level: Car Registrations and House Prices

	Cross-sectional Regressions			
	Δhp 03-07	Δcar 03-07	Δhp 07-11	Δcar 07-11
Elasticity	-5.45***		5.53***	
	(0.76)		(0.68)	
Δhp 03-07		0.05		
		(0.1)		
Δhp 07-11				0.47***
				(0.08)
Method	OLS	IV	OLS	IV
Time effects				
Observations				
MSA	252	252	252	252
R-squared	0.17	0.07	0.21	0.51

Note: Regressions using Housing supply Elasticity at the MSA level as an instrument for housing prices in a regression of MSA car registrations on MSA house prices. The housing supply elasticity measure is taken from Saiz(2010).