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Housing Market Spillovers: Evidence from an Estimated DSGE Model*

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Abstract

We study sources and consequences of fluctuations in the housing market. The upward trend in real housing prices of the last 40 years can be explained by slow technological progress in the housing sector. Over the business cycle, housing demand and housing technology shocks explain one-quarter each of the volatility of housing investment and housing prices. Monetary factors explain 20 percent, but they played a bigger role in the housing cycle at the turn of the century. We show that the housing market spillovers are non-negligible, concentrated on consumption rather than business investment, and have become more important over time.

KEYWORDS: Housing, Wealth Effects, Bayesian Estimation, Two-sector Models.

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

1. Introduction

The experience of the U.S. housing market at the beginning of the 21st century (fast growth in housing prices and residential investment initially, and a decline thereafter) has led many to raise the specter that the developments in the housing sector are not just a passive reflection of macroeconomic activity but might themselves be one of the driving forces of business cycles. To understand whether such concerns are justified, it is crucial to answer two questions: (1) What is the nature of the shocks hitting the housing market? (2) How big are the spillovers from the housing market to the wider economy?

In this paper, we address these questions using a quantitative approach. We develop and estimate, using Bayesian methods, a dynamic stochastic general equilibrium model of the U.S. economy that explicitly models the price and the quantity side of the housing market. Our goal is twofold. First, we want to study the combination of shocks and frictions that can explain the dynamics of residential investment and housing prices in the data. Second, to the extent that the model can reproduce key features of the data, we want to measure the spillovers from the housing market to the wider economy.

Our starting point is a variant of many dynamic equilibrium models with a neoclassical core and nominal and real rigidities that have become popular in monetary policy analysis (see Christiano, Eichenbaum and Evans, 2005, and Smets and Wouters, 2007). There are at least two reasons why we regard these models (that do not consider housing explicitly) as our starting point. First, because of goal is to study the interactions between housing and the broader economy, it is natural to have as a benchmark a model that fits the US data well on the one hand,[1] and that encompasses most of the views on the sources and propagation mechanism of business cycles on the other. Second, because our housing model (aside from minor differences) encompasses the core of these models as a special case, it can facilitate communication both to policymakers and between researchers.

Two are the features of housing that our model captures. On the supply side, we add sectoral heterogeneity, as in Davis and Heathcote (2005): the non-housing sector produces consumption and business investment using capital and labor; the housing sector produces new homes using capital, labor and land. On the demand side, housing and consumption enter households' utility and housing can be used as collateral for loans, as in Iacoviello (2005). Since housing and consumption goods are produced using different technologies, the model generates endogenous dynamics both in residential vis-à-vis business investment and in the price of housing. At the same time, fluctuations in house prices affect the borrowing capacity of a fraction of households, on the one hand, and the relative profitability of producing new homes, on the other: these mechanisms generate feedback effects for the expenditure of households and firms.

1.1. Findings

We estimate the model using quarterly data over the period 1965:I-2006:IV. The dynamics of the model are driven by productivity, nominal and preference shocks. Our estimated model explains well several features of the data: it can explain both the cyclical properties and the long-run behavior of housing and non-housing variables. It can also match the observation that

[1] See for instance Del Negro, Schorfheide, Smets and Wouters (2007).

both housing prices and housing investment are strongly procyclical, volatile, and very sensitive to monetary shocks.

What Drives the Housing Market? We find that, over long horizons, the model can explain qualitatively and quantitatively the trends in real housing prices and investment of the last four decades. The increase in real housing prices is the consequence of slower technological progress in the housing sector and of the presence of land (a fixed factor) in the production function for new homes. Over the business cycle instead, three main factors drive the housing market. Housing demand and housing supply shocks explain roughly one-quarter each of the cyclical volatility of housing investment and housing prices. Monetary factors explain about 20 percent. We find that, housing demand shocks aside, the housing price boom of the 1970s was mostly the consequence of faster technological progress in the non-housing sector. Instead, the boom in housing prices and residential investment at the turn of the 21st century (and its reversal in 2005 and 2006) was driven in non-negligible part by monetary factors.

How Big are the Spillovers from the Housing Market? From an accounting standpoint, fluctuations in housing investment directly affect output, holding everything else constant. We study the spillovers by considering what our estimated nominal, real and financial frictions add to this mechanism. Nominal rigidities, in particular wage rigidity, increase the sensitivity of output to shifts in aggregate demand, by increasing the sensitivity of housing investment itself to housing demand and monetary shocks. Besides this effect, collateral effects on household borrowing amplify the response of non-housing consumption to given changes in fundamentals, thus altering the propagation mechanism: we quantitatively document these effects in Section 5 by focusing on the effect of fluctuations in housing wealth for consumption dynamics: we show that the estimated collateral effects increase the reduced-form elasticity of aggregate consumption to housing wealth by around 2 basis points, from 0.10 to 0.12. In addition, by estimating the model over two subsamples (before and after the financial liberalization in the mortgage market of the 1980s), we show that fluctuations in the housing market have contributed to 4 percent of the total variance in consumption growth in the early period, and to 12 percent in the late period. Hence, the average spillovers from the housing market to the rest of the economy are non-negligible and have become more important in the last two decades.

1.2. Related Approaches

Our analysis combines four main elements: (1) a multi-sector structure with housing and non-housing goods; (2) nominal rigidities; (3) financing frictions in the household sector and (4) a rich set of shocks, which are essential to take the model to the data.[2]

Greenwood and Hercowitz (1991), Benhabib, Rogerson and Wright (1991), Chang (2000), Davis and Heathcote (2005) and Fisher (2007) are examples of calibrated models dealing with (1), but they consider technology shocks only as sources of business fluctuations. Davis and Heathcote (2005) is perhaps our closest antecedent, since their multi-sector structure endogenizes both housing prices and quantities in an equilibrium framework. They use a model with intermediate goods in which construction, manufacturing and services are used to produce consumption, business investment, and structures. Structures are then combined with land to produce homes. On the supply side, our setup shares some features with theirs. However, since our goal is to take the model to the data, we allow additional real and nominal frictions and a larger set of shocks. There are three advantages in doing so. First, we do not need to commit to a particular view of sources of business cycle fluctuations: indeed our results show that several shocks are needed to explain the patterns of comovement which are observed in the data. Second, we can analyze the monetary transmission mechanism both to housing prices and housing investment. Third, we can do a better job at explaining the interactions between housing and macroeconomy: for instance, Davis and Heathcote (2005) require sectoral technology shocks to explain the high volatility of housing investment; however, these shocks also

[2] Several papers have studied housing in models with incomplete markets and financing frictions by combining elements of (1) and (3); see, for instance, Gervais (2002), Peterson (2004) and Díaz and Luengo-Prado (2005). These papers, however, abstract from aggregate shocks.

yield the counterfactual prediction that housing prices and housing investment are negatively correlated.[3]

2. The Model

The model features two sectors, heterogeneity in households' discount factors and collateral constraints tied to housing values. On the demand side, there are two types of households: patient (lenders) and impatient (borrowers). Patient households work, consume and accumulate housing: they own the productive capital of the economy, and supply funds to firms on the one hand, and to impatient households on the other. Impatient households work, consume and accumulate housing: because of their high impatience, they accumulate only the required net worth to finance the down payment on their home and are up against their housing collateral constraint in equilibrium. On the supply side, the non-housing sector combines capital and labor to produce consumption and business capital for both sectors. The housing sector produces new homes combining business capital with labor and land.

Households. There is a continuum of measure 1 of agents in each of the two groups (patient and impatient). The economic size of each group is measured by its wage share, which is assumed to be constant through a unit elasticity of substitution production function. Within each group, a representative household maximizes:[4]

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

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

[3] Edge, Kiley and Laforte (2005) integrate (1), (2) and (4) by distinguishing between two production sectors and between consumption of nondurables and services, investment in durables and in residences. Bouakez, Cardia and Ruge-Murcia (2005) estimate a model with heterogenous production sectors that differ in price stickiness, capital adjustment costs and production technology. None of these papers deal explicitly with housing prices and housing investment, which are the main focus of our analysis.

[4] We assume a cashless limit in the sense of Woodford (2003).

Variables without (with) a prime refer to patient (impatient) 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' ($\beta' < \beta$). The terms z_t and τ_t capture shocks to intertemporal preferences and to labor supply.

We label movements in j_t as housing preference shocks. There are at least two possible interpretations of this shock. One interpretation is that the shock captures, in a reduced form way, cyclical variations in the availability of resources needed to purchase housing relative to other goods or other social and institutional changes that shift preferences towards housing. Another interpretation is that fluctuations in j_t could proxy for changes in the factor mix required to produce home services. To see why, consider a simplified home technology producing home services through $ss_t = h_t^{\kappa_t}$, where κ_t is a time-varying elasticity of housing services ss_t to the housing stock h_t, holding other inputs constant. This time-varying elasticity could reflect short-run fluctuations in the housing input required to produce a given unit of housing services: if the utility depends on the service flow from housing, the home technology shock looks like a housing preference shock in the reduced-form utility function.[5] The shocks follow:

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

where $u_{z,t}$, $u_{\tau,t}$ and $u_{j,t}$ are i.i.d. processes with variances σ_z^2, σ_τ^2 and σ_j^2. Above, ε measures habits in consumption,[6] and G_C is the growth rate of consumption in the balanced growth path. The scaling factors $\Gamma_c = (G_C - \varepsilon) / (G_C - \beta\varepsilon G_C)$ and $\Gamma_c' = (G_C - \varepsilon') / (G_C - \beta'\varepsilon' G_C)$ ensure that the marginal utilities of consumption are $1/c$ and $1/c'$ in the steady state.

The log-log specification of preferences for consumption and housing reconciles the trend in the relative housing prices and the stable nominal share of expenditures on household investment

[5]This observational equivalence result echoes findings from the household production literature; see for instance Greenwood, Rogerson and Wright (1995). To obtain this result, it is sufficient to note that one could replace the expression $\mathsf{j}_t \ln h_t$ in the utility function with $\varsigma \ln ss_t$, where ς is a constant measuring the weight on housing services in the utility function. The two specifications are equivalent if $ss_t = h_t^{\mathsf{j}_t/\varsigma}$.

[6]The specification we adopt allows for habits in consumption only. In preliminary estimation attempts, we allowed for habits in housing and found no evidence of them.

goods, as in Davis and Heathcote (2005) and Fisher (2007). The specification of the disutility of labor ($\xi, \eta \geq 0$) follows Horvath (2000) and allows for less than perfect labor mobility across sectors. If ξ and ξ' equal zero, hours in the two sectors are perfect substitutes. Positive values of ξ and ξ' (as Horvath found) allow for some degree of sector specificity and imply that relative hours respond less to sectoral wage differentials.

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

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

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.[7] 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

[7] We assume that investment shocks hit only the capital used in the production of consumption goods, k_c, since investment-specific technological progress mostly refers to information technology (IT) and construction is a non-IT-intensive industry.

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. We discuss the properties of ϕ_t, $a(\cdot)$ and Div_t in Appendix B.[8]

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:[9]

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

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

The assumption $\beta' < \beta$ implies that for small shocks the constraint (5) holds with equality near the steady state. When β' is lower than β, impatient agents decumulate wealth quickly enough to some lower bound and, for small shocks, the lower bound is binding.[10] Patient agents own and accumulate all the capital. Impatient agents only accumulate housing and borrow the maximum possible amount against it. Along the equilibrium path, fluctuations in housing values affect through (5) borrowing and spending capacity of constrained households: the effect is larger the larger m, since m measures, ceteris paribus, the liquidity of housing wealth.

[8] We do not allow for a convex adjustment cost of housing demand (in preliminary estimation attempts, we found that the parameter measuring this cost was driven to its lower bound of zero). Home purchases are subject to non-convex adjustment costs (typically, some fixed expenses and an agent fee that is proportional to the value of the house), which cannot be dealt with easily in our model. It is not clear whether these non-convex costs bear important implications for aggregate residential investment. For instance, Thomas (2002) finds that infrequent microeconomic adjustment at the plant level has negligible implications for the behavior of aggregate investment; in addition, a sizable fraction (25 percent) of residential investment in the National Income and Product Accounts consists of home improvements, where transaction costs are less likely to apply.

[9] An analogous constraint might apply to patient households too, but would not bind in equilibrium.

[10] The extent to which the borrowing constraint holds with equality in equilibrium mostly depends on the difference between the discount factors of the two groups and on the variance of the shocks that hit the economy. We have solved simplified, non-linear versions of two-agent models with housing and capital accumulation in the presence of aggregate risk that allow for the borrowing constraint to bind only occasionally. For discount rate differentials of the magnitude assumed here, impatient agents are always arbitrarily close to the borrowing constraint (details are available upon request). For this reason, we solve the model linearizing the equilibrium conditions of the model around a steady state with a binding borrowing constraint.

Technology. To introduce price rigidity in the consumption sector, we differentiate between competitive flexible price/wholesale firms that produce wholesale consumption goods and housing using two 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:

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

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

$$Y_t=\left(\mathsf{A}_{c,t}\left(n_{c,t}^{\alpha}n_{c,t}^{\prime 1-\alpha}\right)\right)^{1-\mu_c}\left(z_{c,t}k_{c,t-1}\right)^{\mu_c}; \tag{6}$$

$$IH_t=\left(\mathsf{A}_{h,t}\left(n_{h,t}^{\alpha}n_{h,t}^{\prime 1-\alpha}\right)\right)^{1-\mu_h-\mu_b-\mu_l}\left(z_{h,t}k_{h,t-1}\right)^{\mu_h}k_{b,t}^{\mu_b}l_{t-1}^{\mu_l}. \tag{7}$$

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.

As shown by (6) and (7), we let hours of the two households enter the two production functions in a Cobb-Douglas fashion. This assumption implies complementarity across the labor skills of the two groups and allows obtaining closed-form solutions for the steady state of the model. With this formulation, the parameter α measures the labor income share of unconstrained households.[11]

Nominal Rigidities and Monetary Policy. We allow for price rigidities in the consumption sector and for wage rigidities in both sectors. We rule out price rigidities in the housing market: according to Barsky, House and Kimball (2007) there are several reasons why housing might

[11] We have experimented with an alternative setup in which hours of the groups are perfect substitutes in production. The results were similar to those reported here. The formulation in which hours are substitutes is analytically less tractable, since it implies that hours worked by one group will affect total wage income received by the other group, thus creating a complex interplay between borrowing constraints and labor supply decisions of both groups.

have flexible prices. First, housing is relatively expensive on a per-unit basis; therefore, if menu costs have important fixed components, there is a large incentive to negotiate on the price of this good. Second, most homes are priced for the first time when they are sold.

We introduce sticky prices in the consumption sector by assuming monopolistic competition at the "retail" level and implicit costs of adjusting nominal prices following Calvo-style contracts. Retailers buy wholesale goods Y_t from wholesale firms at the price P_t^w in a competitive market, differentiate the goods at no cost, and sell them at a markup $X_t = P_t/P_t^w$ over the marginal cost. The CES aggregates of these goods are converted back into homogeneous consumption and investment goods by households. Each period, a fraction $1-\theta_\pi$ of retailers set prices optimally, while a fraction θ_π cannot do so, and index prices to the previous period inflation rate with an elasticity equal to ι_π. These assumptions deliver the following consumption-sector Phillips curve:

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

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.

We model wage setting in a way that is analogous to price setting. 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.[12] 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. These equations are in Appendix B.

To close the model, we assume that the central bank sets the interest rate R_t according to

[12] We assume that there are four unions, one for each sector/household pair. While unions in each sector choose slightly different wage rates, reflecting the different consumption profiles of the two household types, we assume that the probability of changing wages in each sector is common to both patient and impatient households.

a Taylor rule that responds gradually to inflation and GDP growth:[13]

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

Above, $\overline{rr}$ 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 $\rho_s > 0$.

Equilibrium. 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 is aggregate consumption, 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.

Trends and Balanced Growth. We allow for heterogeneous trends in productivity in the consumption, nonresidential and housing sector. These processes follow:

$$\ln \mathsf{A}_{c,t} = t \ln(1 + \gamma_{AC}) + \ln Z_{c,t}, \qquad \ln Z_{c,t} = \rho_{AC} \ln Z_{c,t-1} + u_{C,t};$$

[13] Our definition of GDP sums consumption and investment by their steady-state nominal shares. That is, $GDP_t = C_t + IK_t + \overline{q} IH_t$, where $\overline{q}$ denotes real housing prices along the balanced growth path (following Davis and Heathcote (2005), our GDP definition uses steady-state house prices, so that short-run changes in real house prices do not affect GDP growth). We exclude imputed rents from our definition of GDP because our model implies a tight mapping between house prices and rents at business cycle frequency. Including rents in the model definition of GDP would be too close to including house prices themselves in the Taylor rule and would create a mechanical link between house prices and consumption of housing services.

$$\ln \mathsf{A}_{h,t} = t \ln(1+\gamma_{AH}) + \ln Z_{h,t}, \qquad \ln Z_{h,t} = \rho_{AH} \ln Z_{h,t-1} + u_{H,t};$$

$$\ln \mathsf{A}_{k,t} = t \ln(1+\gamma_{AK}) + \ln Z_{k,t}, \qquad \ln Z_{k,t} = \rho_{AK} \ln Z_{k,t-1} + u_{K,t},$$

where the innovations $u_{C,t}, u_{H,t}, u_{K,t}$ are serially uncorrelated with zero mean and standard deviations $\sigma_{AC}, \sigma_{AH}, \sigma_{AK}$, and the terms $\gamma_{AC}, \gamma_{AH}, \gamma_{AK}$ denote the net growth rates of technology in each sector. Since preferences and production functions have a Cobb-Douglas form, a balanced growth path exists, along which the growth rates of the real variables are:[14]

$$G_C = G_{IK_h} = G_{q\times IH} = 1 + \gamma_{AC} + \frac{\mu_c}{1-\mu_c}\gamma_{AK}; \tag{12}$$

$$G_{IK_c} = 1 + \gamma_{AC} + \frac{1}{1-\mu_c}\gamma_{AK}; \tag{13}$$

$$G_{IH} = 1 + (\mu_h + \mu_b)\gamma_{AC} + \frac{\mu_c(\mu_h+\mu_b)}{1-\mu_c}\gamma_{AK} + (1-\mu_h-\mu_l-\mu_b)\gamma_{AH}; \tag{14}$$

$$G_q = 1 + (1-\mu_h-\mu_b)\gamma_{AC} + \frac{\mu_c(1-\mu_h-\mu_b)}{1-\mu_c}\gamma_{AK} - (1-\mu_h-\mu_l-\mu_b)\gamma_{AH}. \tag{15}$$

As shown above, the trend growth rates of $IK_{h,t}$, $IK_{c,t}/\mathsf{A}_{k,t}$ and $q_t IH_t$ are all equal to G_C, the trend growth rate of real consumption. Second, business investment grows faster than consumption, as long as $\gamma_{AK} > 0$. Third, the trend growth rate in real house prices offsets differences in the productivity growth between the consumption and the housing sector. These differences are due to the heterogeneous rates of technological progress in the two sectors and to the presence of land in the production function for new homes.

[14]Business capital includes two components - capital in the consumption sector k_c and in the construction sector k_h - that grow at different rates (in real terms) along the balanced growth path. The data provide only a chain-weighted series for the aggregate of these two series, since sectoral data on capital held by the construction sector are available only at annual frequency and are not reported in NIPA. Since capital held by the construction sector is a small fraction of non-residential capital (around 5 percent), total investment is assumed to grow at the same rate as the investment in the consumption-good sector.

3. Parameter Estimates

Methods and Data. We linearize the equations describing the equilibrium around the balanced growth path. For given parameter values, the model solution takes the form of a state-space model that is used to compute the likelihood function. The estimation procedure consists of transforming the data into a form suitable for computing the likelihood function; choosing prior distributions for the parameters; and estimating the posterior distribution. Using the joint probability distribution of data and parameters, one can derive the relationship between the prior and posterior distribution of the parameters using Bayes' theorem.

We use ten observables: real consumption,[15] real residential investment, real business investment, real house prices,[16] nominal interest rates, inflation, hours and wage inflation in the consumption sector, hours and wage inflation in the housing sector. We estimate the model from 1965:I to 2006:IV. In Section 5.2, we estimate the model over two subperiods (1965:I to 1982:IV and 1989:I to 2006:IV) in order to investigate the stability of the estimated parameters. Figure 1 plots the series (described in Appendix A). Real house prices have increased in the sample period. Business investment has grown faster than consumption, which has in turn grown faster than residential investment.

We keep the trend and remove the level information from the series that we use in estimation.

[15] Consumption, investment and hours are in per capita terms, inflation and the interest rate are expressed on a quarterly basis. We use total chain-weighted consumption, since our goal is to assess the implications of housing for a broad measure of consumption, and because chained aggregates do not suffer the base-year problem discussed in Whelan (2003). NIPA data do not provide a chained series for consumption excluding housing services and durables, which would correspond to our theoretical definition of consumption.

[16] There is no perfect house price index: several measures are available, and all of them suffer from some problems (see Rappaport, 2007, for a survey). Our measure is the Census Bureau constant quality index for the price of new houses sold. An alternative series is the repeat sales OFHEO Conventional Mortgage House Price Index, which starts in 1970. At low frequencies, the OFHEO series moves together with the Census series (the correlation between their real, year-on-year growth rates is 0.70). In the 1970-2006 period, the OFHEO series has a stronger upward trend: our Census series grows in real terms by an average of 1.7 percent per year, the OFHEO series by 2.4 percent. Being based on repeat sales, the OFHEO series is perhaps a better measure of house price appreciation at short-run frequencies; however, some have argued that the OFHEO series is biased upward (around 0.5 percent per year) because homes that change hands more frequently have greater price appreciation (see Gallin, 2004). In addition, repeat sales indexes do a poor job at controlling for home improvements, which are largely procyclical, thus making the upward bias larger in times when incomes and house prices are rising (see Rappaport, 2007). As a robustness check, we have estimated our model using the OFHEO series as a measure of house prices: our main results were qualitatively and quantititatively unaffected.

We calibrate depreciation rates, capital shares in the production functions and weights in the utility functions in order to match consumption, investment and wealth to output ratios. We fix the discount factor in order to match the real interest rate and demean inflation and the nominal interest rate. In a similar vein, we do not use information on steady-state hours to calibrate the labor supply parameters, since in any multi-sector model the link between value added of the sector, on the one hand, and available measures of total hours worked in the same sector, on the other, is somewhat tenuous. In addition, there are reasons to believe that self-employment in construction varies over the cycle. For this reason, we allow for measurement error in total hours in this sector.[17]

In equilibrium the transformed variables $\mathrm{C}_t = C_t/G_C^t$, $\mathsf{IH}_t = IH_t/G_{IH}^t$, $\mathsf{IK}_t = IK_t/G_{IK}^t$, $\mathsf{q}_t = q_t/G_q^t$ all remain stationary. In addition total hours in the two sectors $N_{c,t}$ and $N_{h,t}$ remain stationary, as do inflation π_t and the nominal interest rate R_t. The model predicts that real wages in the two sectors should grow at the same rate as consumption along the balanced growth path. Available industry wage data (such as those provided by the BLS Current Employment Statistics) show a puzzling divergence between real hourly wages and real consumption over the sample in question, with the latter rising twice as fast as the former between 1965 and 2006. Sullivan (1997) argues that the BLS measures of sectoral wages suffer from potential measurement error. For these two reasons, we use demeaned nominal wage inflation in the estimation and allow for measurement error.[18]

Calibrated Parameters. We calibrate 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

[17] Available measures of hours and employment in construction are based on the Current Employment Statistics (CES) survey. They classify between (1) residential construction workers, (2) nonresidential construction workers and (3) trade contractors, without distinguishing whether trade contractors work in the residential or nonresidential sector. Besides this, the CES survey does not include self-employed and unpaid family workers, who account for about one in three jobs in the construction sector itself, and for much less elsewhere.

[18] We allow for measurement error only on wages in the housing sector. In preliminary estimation attempts, we also allowed for measurement error for wages in the consumption sector. The estimated standard deviation was close to zero, and all other parameters were virtually unchanged.

of the inflation objective shock ρ_s. We fix these parameters because they are either notoriously difficult to estimate (in the case of the markups) or because they are better identified using other information (in the case of the factor shares and the discount factors).

Table 1A summarizes our calibration. Table 1B displays the steady-state moments of the model.[19] We set $\beta = 0.9925$, implying a steady-state annual real interest rate of 3 percent. We fix the discount factor of the impatient households β' at 0.97. This value has a limited effect on the dynamics but guarantees an impatience motive for impatient households large enough that they are arbitrarily close to the borrowing limit, so that the linearization around a steady-state with binding borrowing limit is accurate (see the discussion in Iacoviello, 2005). We fix $X = 1.15$, implying a steady-state markup of 15 percent in the consumption-good sector. Similarly, we set $X_{wc} = X_{wh} = 1.15$. We fix the correlation of the inflation objective shock ρ_s. This parameter was hard to pin down in initial estimation attempts; a value of $\rho_s = 0.975$ implies an annual autocorrelation of trend inflation around 0.9, a reasonable value.

The depreciation rates for housing, capital in the consumption sector and capital in the housing sector are set equal, respectively, to $\delta_h = 0.01$, $\delta_{kc} = 0.025$ and $\delta_{kh} = 0.03$. The first number (together with j, the weight on housing in the utility function) pins down the ratio of residential investment to total output at around 6 percent, as in the data. The other numbers - together with the capital shares in production - imply a ratio of non-residential investment to GDP around 27 percent. We pick a slightly higher value for the depreciation rate of construction capital on the basis of BLS data on service lives of various capital inputs, which indicate that construction machinery (the data counterpart to k_h) has a lower service life than other types of nonresidential equipment (the counterpart to k_c).

For the capital share in the goods production function, we choose $\mu_c = 0.35$. In the housing production function, we choose a capital share of $\mu_h = 0.10$ and a land share of $\mu_l = 0.10$, following Davis and Heathcote (2005). Together with the other estimated parameters, the

[19]Four of the parameters that we estimate (the three trend growth parameters - γ_{AK}, γ_{AC} and γ_{AH} - and the income share of patient agents α) slightly affect the steady-state ratios. The numbers in Table 1.B are based both on the calibrated parameters and on the posterior estimates reported in Table 2.

chosen land share implies that the value of residential land is about 50 percent of annual GDP. This happens because the price of land capitalizes future housing production opportunities.[20]

We set the intermediate goods share at $\mu_b = 0.10$. Input-output tables indicate a share of material costs for most sectors of around 50 percent, which suggests a calibration for μ_b as high as 0.50. We choose to be conservative because our value for μ_b is only meant to capture the extent to which sticky-price intermediate inputs are used in housing production. The weight on housing in the utility function is set at $j = 0.12$. Together with the technology parameters, these choices imply a ratio of business capital to annual GDP of around 2.1 and a ratio of housing wealth to GDP around 1.35.

Next, we set the LTV ratio m. This parameter is difficult to estimate without data on debt and housing holdings of credit-constrained households. Our calibration is meant to measure the typical LTV ratio for homebuyers who are likely to be credit constrained and borrow the maximum possible against their home. Between 1973 and 2006, the average LTV ratio was 0.76.[21] Yet "impatient" households might want to borrow more as a fraction of their home. In 2004, for instance, 27 percent of new homebuyers took LTV ratios in excess of 80 percent, with an average ratio (conditional on borrowing more than 80 percent) of 0.94. We choose to be conservative and set $m = 0.85$. It is conceivable that the assumption of a constant value for m over a 40-year period might be too strong, in light of the observation that the mortgage market has become more liberalized over time. We take these considerations into account when we estimate our model across subsamples, calibrating m differently across subperiods.

Prior Distributions. Our priors are in Tables 2A and 2B. Overall, they are consistent with previous studies or uninformative. We use uniform priors for the standard errors of the shocks. For the persistence, we choose a beta-distribution with a prior mean of 0.8 and standard de-

[20] Simple algebra shows that the steady-state value of land relative to residential investment equals $\frac{p_l}{qIH} = \mu_l \frac{\beta G_C}{1-\beta G_C}$. In practice, ownership of land entitles the household to the present discounted value of future income from renting land to housing production firms, which is proportional to μ_l. For $\mu_l = 0.10$, $\beta = 0.9925$, $qIH/GDP = 0.06$ and our median estimate of $G_C = 1.0047$, this yields the value reported in the main text.

[21] The data are from the Federal Housing Finance Board, summary table 19.

viation of 0.1. We set the prior mean of the habit parameters in consumption (ε and ε') at 0.5. For the monetary policy rule, we base our priors on a Taylor rule responding gradually to inflation only, so that the prior means of r_R, r_π and r_Y are, respectively, 0.75, 1.5 and 0. We set a prior on the capital adjustment costs of around 10.[22] We choose a loose beta prior for the utilization parameter (ζ) between zero (capacity utilization can be varied at no cost) and one (capacity utilization never changes). For the disutility of working, we center the elasticity of the hours aggregator at 2 (the prior mean for η and η' is 0.5). We select values for ξ and ξ', the parameters describing the inverse elasticity of substitution across hours in the two sectors, of around 1, as estimated by Horvath (2000). We select the prior mean of the Calvo price and wage parameter θ_π, θ_{wc} and θ_{wh} at 0.667, with a standard deviation of 0.05, values that are close to the estimates of Christiano, Eichenbaum and Evans (2005). The priors for the indexation parameters ι_π, ι_{wc} and ι_{wh} are loosely centered around 0.5, as in Smets and Wouters (2007).

We set the prior mean for the labor income share of unconstrained agents to be 0.65, with a standard error of 0.05. The mean is in the range of comparable estimates in the literature: for instance, using the 1983 Survey of Consumer Finances, Jappelli (1990) estimates 20 percent of the population to be liquidity constrained; Iacoviello (2005), using a limited information approach, estimates a wage share of collateral-constrained agents of 36 percent.

Posterior Distributions. Table 2 reports the posterior mean, median and 95 probability intervals for the structural parameters, together with the mean and standard deviation of the prior distributions. In addition to the structural parameters, we estimate the standard deviation of the measurement error for hours and wage inflation in the housing sector. Draws from the unknown posterior distribution of the parameters are obtained using the random walk version of the Metropolis algorithm.[23]

[22] Given our adjustment cost specification (see Appendix B), the implied elasticity of investment to its shadow value is $1/(\phi\delta)$. Our prior implies an elasticity of investment to its shadow price of around 4.

[23] Tables and figures are based on a sample of 200,000 draws (estimates based on 5,000,000 draws gave the same results). The jump distribution was chosen to be the normal one with covariance matrix equal to the Hessian of the posterior density evaluated at the maximum. The scale factor was chosen in order to deliver an acceptance rate between 25 and 30 percent, depending on the run of the algorithm. Convergence was assessed

We find a faster rate of technological progress in business investment, followed by consumption and by the housing sector. In the next section, we discuss the implications of these findings for the long-run properties of consumption, housing investment and real house prices.

One key parameter relates to the labor income share of credit-constrained agents. Our median estimate of α is 0.79 . This number implies a share of labor income accruing to credit-constrained agents of 21 percent. This value is lower than our prior mean. However, as we document below, this value is large enough to generate a positive elasticity of consumption to house prices after a housing demand shock. The dynamic effects of this shock are discussed more in detail in the next section.

Both agents exhibit a moderate degree of habit formation in consumption and relatively little preference for mobility across sectors, as shown by the positive values of ξ (0.67) and ξ' (0.99). The degree of habits in consumption is larger for the impatient households ($\varepsilon' = 0.58$, as opposed to $\varepsilon = 0.33$ for the patient ones). One explanation may be that since impatient households do not hold capital and they cannot smooth consumption through saving, a larger degree of habits is needed in order to match the persistence of aggregate consumption in the data. Turning to the labor supply elasticity parameters, the posterior distributions of η and η' (centered around 0.50) show that the data do not convey much information on these parameters. We performed sensitivity analysis with respect to these parameters and found that the main results of the paper are not particularly sensitive for a reasonable range of values of η and η'.

The estimate of θ_π (0.83) implies that prices are reoptimized once every six quarters. However, given the positive indexation coefficient ($\iota_\pi = 0.71$), prices change every period, although not in response to changes in marginal costs. As for wages, we find that stickiness in the housing sector ($\theta_{wh} = 0.91$) is higher than in the consumption sector ($\theta_{wc} = 0.81$), although wage indexation is larger in housing ($\iota_{wh} = 0.42$ and $\iota_{wc} = 0.08$).

Estimates of the monetary policy rule are in line with previous evidence. Two facts are worth mentioning: first, we find a relatively large response to output growth, with $r_Y = 0.51$;

by comparing the moments computed by splitting the draws of the Metropolis into two halves.

second, we tightly identify the response to inflation, with a coefficient of $r_\pi = 1.36$. Finally, all shocks are quite persistent, with autocorrelation coefficients ranging between 0.91 and 0.997.

4. Properties of the Estimated Model

4.1. Impulse Responses

In this subsection, we discuss the main workings of our model, mostly with reference to housing demand shocks and monetary shocks. We single these shocks out not only because of their importance in explaining cyclical movements in housing variables, but also because they nicely illustrate the functioning of our model economy.

Housing Preference Shock. Figure 2 plots impulse responses to the estimated housing preference shock. We also label the shock a housing demand shock, since it raises both house prices and the returns to housing investment, thus causing the latter to rise. The shock also increases the collateral capacity of constrained agents, thus allowing them to increase borrowing and consumption. Since borrowers have a high marginal propensity to consume, the effects on total consumption are positive, even if consumption of the lenders (not plotted) falls.

Figure 2 also displays the responses for three alternative versions of the model in which we set $\theta_p = 0$ (flexible prices), $\theta_{wc} = \theta_{wh} = 0$ (flexible wages) and $\alpha = 1$ (no collateral effects), while holding the remaining parameters at the benchmark values. As the figure illustrates, collateral effects are the key feature of the model that generates a positive and persistent response of consumption following an increase in housing demand. Absent this effect, in fact, an increase in the demand for housing would generate an increase in housing investment and housing prices, but a fall in consumption. Quantitatively, the observed impulse response translates into a first-year elasticity of consumption to housing prices (conditional on the shock) of around 0.07. This result mirrors the findings of several papers that document positive effects on consumption from changes in housing wealth (see, for instance, Case, Quigley and Shiller, 2005, and Campbell and

Cocco, 2007). It is tempting to quantitatively compare our results with theirs. However, our elasticity is conditional to a particular shock, whereas most microeconometric and time-series studies in the literature try to isolate the elasticity of consumption to housing prices through regressions of consumption on housing wealth, both of which are endogenous variables in our model. We return to this issue in the next section.

Next, we consider the response of residential investment. At the baseline estimates, a shift in housing demand that generates an increase in real house prices of around 1 percent (see Figure 2) causes residential investment to rise by around 3.5 percent. As the figure illustrates, sticky wages are crucial here; in particular, the combination of flexible housing prices and sticky wages in construction makes residential investment very sensitive to changes in demand conditions. The numbers here can be related to the findings of Topel and Rosen (1988), who estimate an elastic response of new housing supply to changes in prices. Depending on the specifications, for every 1 percent increase in house prices lasting for two years, they find that new construction rises on impact between 1.5 and 3.15 percent.

Finally, we consider business investment. The impulse response of business investment is the combined effect of two forces: on the one hand, capital in the construction sector k_h rises; on the other, there is slow and persistent decline in capital in the consumption sector k_c, which occurs since resources are shifted away from one sector to the other. Quantitatively, the two effects roughly offset each other, and the overall response of business investment is quantitatively small.[24]

Because the housing preference shock is important in explaining housing prices and housing investment, we conclude this subsection by discussing further what this shock might be capturing. As we argued above, the shock is a catchall for all the unmodeled disturbances that can affect housing demand. We have tested whether some observable indicators of housing demand

[24]The response of business investment to housing shocks appears in line with informal accounts of the recent U.S. business cycle given by policymakers. For instance, in 2006 the Federal Reserve Vice Chairman Kohn has argued that "The production of construction supplies has decelerated, but in general, resources freed up in the residential market appear to have been largely absorbed in nonresidential building or elsewhere."

that are not explicitly included in our model have some explanatory power for our estimated innovations to housing preferences. We have regressed the innovations on current values of demographic factors (the share of population aged between 25 and 39 years and/or the growth rate of new migrants to the United States) and on other variables that potentially affect the cost of purchasing a home, such as a spread between the mortgage contract interest rate and the 10-Year Treasury yield, the initial fees and charges to purchase a home, and the average loan-to-value ratio for all buyers.[25] We have found that only fees and the average loan-to-value ratio have some explanatory power for our innovations, although the degree of fit of the regression is not high.[26] Fees affect the innovations with the expected negative sign; loan-to-value ratios enter significantly with a negative sign: this might be the case if an increase in housing demand from all population leads to more borrowing from agents who are not hitting the borrowing ceiling, and purchase a house with a low downpayment. Obviously, these results are only meant to be suggestive, but they do not go against our idea that the housing preference shock captures times when individuals value housing more relative to other goods.

Monetary Shock. Figure 3 plots an adverse i.i.d. monetary policy shock. Real house prices drop and remain below the baseline for about six quarters. The quantitative effect of the monetary shock on house prices is similar to what is found in VAR-based studies of the impact of monetary shocks on house prices (see, for instance, Iacoviello, 2005). All components of aggregate demand fall, with housing investment showing the largest drop, followed by business investment and consumption. The large drop in housing investment is a well-documented fact

[25] The data on population by age are from Table 94 of the U.S. Census Bureau, International Population Database (the annual data were converted the quarterly frequency using linear interpolation). The data on migration are from the U.S. Department of Homeland Security. The data on mortgage rates, fees and charges and loan-to-value ratios are from the Historical Summary Tables of the Federal Housing Board (Table 23). The 10-Year yield is the 10-Year Treasury Constant Maturity Rate from the Federal Reserve Statistical Release. Because of constraints on data availability, we have run these regressions on the data period 1989-2006 only. We have included one or more lags of GDP growth to the regression to check that our shock is truly exogenous. At the conventional significance levels, the null hypothesis that the coefficients on lagged GDP growth were zero could not be rejected.

[26] This is probably to be expected, since the estimated innovations are i.i.d.. The typical R-squared from these regressions is around 0.2.

in VAR studies (e.g. Bernanke and Gertler, 1995). As the figure shows, both nominal rigidities and collateral effects amplify the response of consumption to monetary shocks. Instead, the responses of both types of investment are only marginally affected by the presence of collateral constraints: the reason for this result is, in our opinion, that the model ignores financing frictions on the side of the firms. In fact, collateral effects slightly reduce the sensitivity of investment to monetary shocks, since unconstrained households shift loanable funds from the constrained households towards firms in order to smooth their consumption. Finally, the negative response of real house prices to monetary shocks instead mainly reflects nominal stickiness.

Quantitatively, the response of residential investment is five times larger than consumption and twice as large as business investment. As Figure 3 shows, wage rigidity plays a crucial role. Housing investment is interest rate sensitive only when wage rigidity is present.[27] In particular, housing investment *falls* because housing prices fall relative to wages; housing investment *falls a lot* because the flow of housing investment is small relative to its stock, so that the drop in investment has to be large to restore the desired stock-flow ratio. Our findings therefore support the models of Barsky, House and Kimball (2007) and Carlstrom and Fuerst (2006), who show how models with rigid non-durable prices and flexible durable prices may generate a puzzling increase in durables following a negative monetary shock, and that sticky wages can eliminate this puzzle.[28]

Other Shocks. Our findings for the responses of aggregate variables to other shocks resemble those reported in estimated DSGE models that do not include a housing sector (e.g. Smets and

[27] In robustness experiments we have found that sectoral wage rigidity (rather than overall wage rigidity) matters for this result. That is, sticky wages in the housing sector and flexible wages in the non-housing sector are already sufficient to generate a large response of residential investment to monetary shocks.

[28] A natural question to ask is the extent to which one can regard construction as a sector featuring strong wage rigidities. Some evidence, besides our econometric findings, seems to point in this direction. First, construction has higher than average unionization rates compared to the private sector in general: 15.4 percent vs. 8.6 percent. Second, several state and federal wage laws in the construction industry work to insulate movements in wages from movements in the marginal cost of working. The Davis-Bacon Act, for instance, is a federal law mandating a prevailing wage standard in publicly funded construction projects; several states have followed with their own wage legislation, and the provisions of the Davis-Bacon Act apply to large firms in the construction sector, even for private projects.

Wouters, 2007, and Justiniano, Primiceri and Tambalotti, 2008).[29]

4.2. Cyclical Properties and Robustness Analysis: What Role do Shocks and Frictions Play?

Our estimated model explains well the behavior of housing and non-housing variables. As Table 3 shows, most of the model's business cycle statistics lie within the 95 percent probability interval computed from the data. The model replicates well the joint behavior of the components of aggregate demand, the cyclicality and volatility of housing prices, and the patterns of comovement between housing and non-housing variables.[30]

The ability of the model to match volatilities and correlations that are found in the data is, of course, the outcome of having several shocks and many frictions. The introduction of a large number of them, while common in the literature on estimated DSGE models, raises the question as to which role each of them plays. Below, we summarize our main findings. We do so by reporting the main properties of our model shutting off once at the time selected shocks or frictions, and holding all other parameters at their estimated value.

1. *Can technology shocks account for the main properties of the data?* A model with technology shocks only - keeping nominal and real rigidities - explains only half of the volatility of housing prices and housing investment. In addition, it generates (contrary to the data) a negative correlation between house prices and housing investment, mostly because housing technology shocks are needed to account for the volatility of housing investment, but these shocks move the price and the quantity of housing in opposite directions.[31]

[29] We find that positive technology shocks in the non-housing sector drive up both housing investment and housing prices, whereas analogous shocks in the housing sector lead to a rise in housing investment and to a drop in housing prices. Temporary cost-push shocks lead to an increase in inflation and a decline in house prices, whereas persistent shifts in the inflation target persistently move up both inflation and housing prices.

[30] In our estimated model, the peak correlation of housing investment with other components of aggregate demand (consumption and business investment) is the contemporaneous one. In the data housing investment comoves with consumption but leads business investment by two quarters. Fisher (2007) develops a model that extends the home production framework to make housing complementary to labor and capital in business production; he shows that in such a model housing investment leads business investment.

[31] The inability of a model with technology shocks only to explain housing prices and housing investment is in line with the findings of Davis and Heathcote (2005). In their model (which is driven technology shocks only),

2. *Are price and wage rigidities needed?* A flexible-wage, flexible-price version (with or without real frictions) can capture the positive effects on consumption of shocks to housing demand (thanks to collateral effects) and can explain the volatility of housing prices. However, this version has trouble in two dimensions. First, it cannot account for the volatility of housing investment. This happens because, compared to our benchmark model, shocks to housing preferences have a much smaller impact on residential investment, and because the absence of nominal rigidities isolates the housing investment sector from monetary and inflation disturbances. Second, it underpredicts the large and positive empirical correlation of housing prices with consumption and housing investment.

3. *Are real rigidities needed?* A version without adjustment costs exacerbates the relative volatility of investment relative to consumption (the volatility of both types of investment is twice as large as in the data). A version with fully mobile labor and no sector-specific capital does not help either: it makes housing investment too volatile and generates a strong negative comovement between housing and business investment. Finally, variable capacity utilization improves the properties of the model by generating larger and more persistent responses of consumption and both types of investment to all shocks: when we do not allow for variable utilization, the standard deviation of these variables drops by about 10 to 15 percent.

4. *What does land do?* A final comment concerns the role of land. In our setup, land works in a way similar to an adjustment cost on housing, since it limits the extent to which the housing stock can be adjusted. In response to shocks, a larger land share reduces the volatility of housing investment and increases the volatility of prices.

the volatility of housing prices is three times smaller than in the data, and the correlation between house prices and housing investment is negative (it is positive in the data and in our estimated model).

5. Sources and Consequences of Housing Market Fluctuations

Having shown that the estimated model fits the data reasonably well, we use it to address the two questions we raised in the introduction. First, what are the main driving forces of fluctuations in the housing market? Second, can how large are the spillovers from the housing market to the broader economy?

5.1. What Drives the Housing Market?

Trend Movements. We find a faster rate of technological progress in business investment, followed by the consumption sector and, last, by the housing sector. At the posterior median, the long-run quarterly growth rates of consumption, housing investment and real house prices (as implied by the values of the γ terms and equations 12 to 15) are respectively 0.47, 0.15 and 0.32 percent. In other words, the trend rise in real house prices observed in the data reflects, according to our estimated model, faster technological progress in the non-housing sector. As shown in Figure 4, our estimated trends fit well the secular behavior of consumption, investment and house prices. According to the model, the slow rate of increase of productivity in construction is behind the secular increase in house prices. Our finding is in line with the results of Corrado et al. (2006), who construct sectoral measures of TFP growth for the U.S.. They also find that the average TFP growth in the construction sector is negative (-0.5 percent, annualized) and that increases in the contribution of labor and purchased inputs more than account for real output growth in the sector.[32]

What about the role of land? At secular frequencies, land is one of the reasons behind the increase in real house prices, since it acts as a limiting factor in the production of new homes. Quantitatively, however, the contribution of land appears small. Given our estimate of γ_{AH} and the land share in new homes of 10 percent, the limiting role of land taken alone can account for about 5 percent of the 93 percent increase in real house prices observed in the data.

[32] Gort, Greenwood and Rupert (1999) find a positive rate of technological progress in structures, but they confine themselves to non-residential structures such as roads, bridges and skyscrapers.

Business Cycle Movements. Table 4 presents results from the variance decomposition. Together, demand (housing preference) and supply (housing technology) shocks in the housing market explain about one-half of the variance in housing investment and housing prices. The monetary component (the sum of i.i.d. monetary shocks and persistent shifts in the inflation target) explains slightly less, around 20 percent. The average variance of the forecast error of exogenous shocks in the housing sector to the other components of aggregate demand (consumption and business investment) is instead small. For instance, housing preference shocks appear to explain less than 1 percent of the variance in consumption and business investment.

A related question is how the different shocks have contributed to the major housing cycles in the United States. Figure 5 provides a visual representation. The solid line displays the detrended historical data, obtained by subtracting from the raw series the deterministic trends plotted in Figure 2. The other lines show the historical contribution of the three factors under our estimated parameters. As Figure 5 shows, the period 1965-2006 has witnessed two major expansions in real housing prices: the first from 1976 to 1980, and the second from 1998 to 2005. In the first cycle, housing prices rose (relative to trend) 17 percent between 1976 and 1980 and dropped 12 percent between 1980 and 1985 (see Table 5). This price cycle was accompanied by large swings in residential investment, with no changes between 1976 and 1980, and a 26 percent rise between 1980 and 1985. Monetary actions did not play an important role here. Instead, the monetary surprises in the 1976-1980 period cooled off the housing price increase, reducing house prices by 3 percent. At the same time, technology shocks accounted for an increase in house prices of around 5 percent.

The recent housing price cycle tells a different story. As shown by Table 5, housing preference shocks played a major role in the 1998-2005 expansion. In addition, monetary conditions explain part of the increase in house prices (around 15 percent of the increase) and about one-half of the increase in housing investment. Monetary conditions are also important in ending the boom in 2005 and 2006. They reduce housing investment and housing prices by 11 and 3 percent, respectively.

5.2. How Big Are the Spillovers from the Housing Market?

We now quantify the spillovers from housing to the broader economy. We do so in two steps. First, we show how our model is consistent with the idea that the conventional wealth effect on consumption is stronger when collateral effects are present and offers an easy way to measure the additional strength that collateral effects provide. Second, we provide an in-sample estimate of the historical role played by collateral effects in affecting U.S. consumption dynamics.

Full Sample Estimates of the Wealth Effect. As we explained above, a large part of the model spillovers occur through the effects that fluctuations in housing prices have on consumption; these effects mostly rely on (and are reinforced by) the degree of financial frictions, as measured by the wage share of credit constrained agents and by the loan-to-value ratio. As a crude way of measuring the spillovers, we run a basic version of the consumption growth regression that, starting from the benchmark random walk model, allows for housing wealth to affect aggregate consumption. In our simulated model output, a basic regression of consumption growth on lagged growth in housing wealth[33] yields (standard errors are in parenthesis):

$$\Delta \ln C_t = \underset{(0.0001)}{0.0041} + \underset{(0.005)}{0.123} \Delta \ln HW_{t-1}.$$

Interestingly, the coefficients of the artificial regression mimic those from the same regression based on actual data, which gives:

$$\Delta \ln C_t = \underset{(0.0006)}{0.0039} + \underset{(0.039)}{0.122} \Delta \ln HW_{t-1}.$$

An advantage of our model is that it allows running counterfactuals. To do so, we run a regression using the simulated model output in the absence of collateral effects (setting $\alpha = 1$). This regression, perhaps not surprisingly, yields a (statistically) smaller coefficient on

[33] The model variables have been generated using the posterior median of the parameters. An artificial sample of 10,000 observations was generated. We experimented with specifications including lagged income, non-housing wealth and interest rates as controls. The coefficients on these variables turned out to be insignificant.

housing wealth, equal to 0.099. The comparison between our data-consistent estimate and the estimate without collateral effects offers a simple way to measure the spillovers from the housing market to consumption. In practice, it suggests that collateral effects increase the elasticity of consumption to housing wealth from about 10 to 12.3 percent.

Another message from this section is that our estimate of α allows capturing well the empirical elasticity of consumption to housing wealth, but it should be remembered that, even without collateral constraints, our model generates a positive correlation between changes in housing wealth and changes in future consumption. This result suggests that caution should be taken in using evidence from reduced-form regressions of consumption on housing wealth in order to assess the importance of collateral effects.

Subsample Estimates: Financial Liberalization and the Historical Contribution of Collateral Effects. In our baseline estimates, we have kept the assumption that the structural parameters were constant throughout the sample. However, several market innovations following the financial reforms of the early 1980s affected the housing market. Campbell and Hercowitz (2005), for instance, argue that mortgage market liberalization drastically reduced the equity requirements associated with collateralized borrowing. More in general, several developments in the credit market might have enhanced the ability to households to borrow, thus reducing the fraction of credit constrained households, as pointed out by Dynan, Elmendorf and Sichel (2006). Motivated by this evidence, we estimate our model across two subperiods, and use our estimates to measure the feedback from housing market fluctuations to consumer spending. Following Campbell and Hercowitz (2005), we set a "low" loan-to-value ratio in the first subperiod and a "high" loan-to-value ratio in the second subperiod in order to model financial liberalization in our setup. Namely, we set $m = 0.775$ in the period 1965:I-1982:IV and $m = 0.925$ in the period 1989:I-2006:IV.[34] As we mentioned earlier, high loan-to-value

[34] The first period ends in 1982:IV, in line with evidence dating the beginning of financial liberalization with the Garn-St.Germain Act of 1982, which deregulated the savings and loan industry. The second period starts in 1989:I; this way, we have two samples of equal length and we allow for a transition phase between regimes.

ratios potentially amplify the response of consumption to given "demand" side disturbances; however, we remain agnostic about the overall importance of collateral effects, by estimating two different values of α (as well as all other parameters) for the two subsamples.

Table 6 compares the model estimates for the two subperiods. The late period captures the high financial liberalization period. Most structural parameters do not differ significantly across subperiods, whereas the volatility of most of the shocks seems to have fallen in the second period. We find a significantly lower value for α in the first subperiod (0.68) compared to the second (0.80). However, the smaller share of credit-constrained agents is more than offset by the larger loan-to-value ratio. As shown by Figure 6, consumption responds more to a given size preference shock in the second period (a similar result holds when comparing monetary shocks). Hence the estimates suggest that financial innovation has reduced the fraction of credit-constrained people but, at the same time, has increased their sensitivity to given changes in economic conditions.

Using the subsample estimates, we calculate the counterfactual consumption path in the absence of collateral constraints ($\alpha = 1$), and subtract it from actual consumption to measure the contribution of collateral constraints to U.S. consumption dynamics. Figure 7 presents our results. In the early period, the contribution of collateral effects to consumption fluctuations accounts for 4 percent of the total variance[35] of year-on-year consumption growth. In the late period, instead, collateral effects account for a larger share, explaining 12 percent of the total variance in consumption growth. This result mirrors the findings of Case, Quigley and Shiller (2005), who show that the reaction of consumption to house prices increased after 1986, when tax law changes began to favor borrowing against home equity and when home equity loans became more widely available.

[35]The variance ratios reported in the text are calculated by dividing, in each sample, the variance of consumption growth in the absence of collateral effects by the total variance of consumption growth.

6. Concluding Remarks

Our estimated model accounts for several features of the data. At cyclical frequencies, it matches the observation that both housing prices and housing investment are strongly procyclical, volatile, and sensitive to monetary shocks. Over longer horizons, the model can explain the prolonged rise in real house prices over the last four decades and views this increase as the consequence of slower technological progress in the housing sector, and the presence of land (a fixed factor) in the production function for new homes. We have used our model to address two important questions. First, what shocks drive the housing market at business cycle frequency? Our answer is that housing demand shocks and housing technology shocks account for roughly one-quarter each of the cyclical volatility of housing investment and housing prices. Monetary factors account for slightly less but have played a larger role in the housing market cycle at the turn of the 21st century. Second, do fluctuations in the housing market propagate to other forms of expenditure? Our answer is that the spillovers from the housing market to the broader economy are non-negligible, concentrated on consumption rather than business investment, and have become more important over time, to the extent that financial innovation has increased the marginal availability of funds for credit-constrained agents.

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Appendix A. Data and Sources

Aggregate Consumption: Real Personal Consumption Expenditure (seasonally adjusted, billions of chained 2000 dollars, Table 1.1.6), divided by the Civilian Noninstitutional Population (CNP16OV). Source: Bureau of Economic Analysis (BEA).

Business Fixed Investment: Real Private Nonresidential Fixed Investment (seasonally adjusted, billions of chained 2000 dollars, Table 1.1.6), divided by CNP16OV. Source: BEA.

Residential Investment: Real Private Residential Fixed Investment (seasonally adjusted, billions of chained 2000 dollars, Table 1.1.6.), divided by CNP16OV, logged. Source: BEA.

Inflation: Quarter on quarter log differences in the implicit price deflator for the nonfarm business sector, demeaned. Source: Bureau of Labor Statistics (BLS).

Nominal Short-term Interest Rate: 3-month Treasury Bill Rate (Secondary Market Rate), expressed in quarterly units, demeaned. (Series ID: H15/H15/RIFSGFSM03_NM). Source: Board of Governors of the Federal Reserve System.

Real House Prices: Census Bureau House Price Index (new one-family houses sold including value of lot) deflated with the implicit price deflator for the nonfarm business sector. Source: Census Bureau, `http://www.census.gov/const/price_sold_cust.xls`. A description of this price index is at `http://www.census.gov/const/www/descpi_sold.pdf`.

Hours in Consumption Sector: Total Nonfarm Payrolls (Series ID: PAYEMS in Saint Louis Fed Fred2) less all employees (Series ID: USCONS) in the construction sector, times Average Weekly Hours of Production Workers (Series ID: CES0500000005), divided by CNP16OV . Demeaned. Source: BLS.

Hours in Housing Sector: All Employees in the Construction Sector (Series ID: USCONS in Saint Louis Fed Fred2), times Average Weekly Hours of Construction Workers (series ID: CES2000000005, source: BLS), divided by CNP16OV. Demeaned.

Wage Inflation in Consumption-good Sector: quarterly changes in Average Hourly Earnings of Production/Nonsupervisory Workers on Private Nonfarm Payrolls, Total Private (Series ID: CES0500000008). Demeaned. Source: BLS.

Wage Inflation in Housing Sector: quarterly changes in Average Hourly Earnings of Production/Nonsupervisory Workers in the Construction Industry (Series ID: CES2000000008). Demeaned. Source: BLS.

Appendix B. The Complete Model

We summarize here the equations describing the equilibrium of the model. Let u_c denote the marginal utility of consumption, u_{nc} (u_{nh}) the marginal disutility of working in the goods (housing) sector, and u_h the marginal utility of housing (with analogous definitions holding for impatient households). We drop the t subscript to denote the steady-state value of a particular variable.

The budget constraint for patient households is:

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

The corresponding first-order conditions for patient households are:

$$u_{c,t} q_t = u_{h,t} + \beta G_C E_t \left(u_{c,t+1} q_{t+1} \left(1 - \delta_h \right) \right) \tag{A.2}$$

$$u_{c,t} = \beta G_C E_t \left(u_{c,t+1} R_t / \pi_{t+1} \right) \tag{A.3}$$

$$u_{c,t} \left(\frac{1}{\mathsf{A}_{k,t}} + \frac{\partial \phi_{c,t}}{\partial k_{c,t}} \right) = \beta G_C E_t \left(u_{c,t+1} \left(R_{c,t+1} z_{c,t+1} - \frac{a\left(z_{c,t+1}\right) + 1 - \delta_{kc}}{\mathsf{A}_{k,t+1}} - \frac{\partial \phi_{c,t+1}}{\partial k_{c,t}} \right) \right) \tag{A.4}$$

$$u_{c,t} \left(1 + \frac{\partial \phi_{h,t}}{\partial k_{h,t}} \right) = \beta G_C E_t \left(u_{c,t+1} \left(R_{h,t+1} z_{h,t+1} - a\left(z_{h,t+1}\right) + 1 - \delta_{kh} - \frac{\partial \phi_{h,t+1}}{\partial k_{h,t}} \right) \right) \tag{A.5}$$

$$u_{c,t} w_{c,t} = u_{nc,t} X_{wc,t} \tag{A.6}$$

$$u_{c,t} w_{h,t} = u_{nh,t} X_{wh,t} \tag{A.7}$$

$$u_{ct} \left(p_{bt} - 1 \right) = 0 \tag{A.8}$$

$$R_{ct} \mathsf{A}_{kt} = a' \left(z_{ct} \right) \tag{A.9}$$

$$R_{ht} = a' \left(z_{ht} \right) \tag{A.10}$$

$$u_{c,t} p_{l,t} = \beta G_C E_t u_{c,t+1} \left(p_{l,t+1} + R_{l,t+1} \right). \tag{A.11}$$

The budget and borrowing constraint for impatient households are:

$$c'_t + q_t h'_t = \frac{w'_{c,t}}{X'_{wc,t}} n'_{c,t} + \frac{w'_{h,t}}{X'_{wh,t}} n'_{h,t} + b'_t - \frac{R_{t-1}}{\pi_t} b'_{t-1} + q_t \left(1 - \delta_h \right) h'_{t-1} + Div'_t \tag{A.12}$$

$$b'_t = m E_t \left(q_{t+1} h'_t \pi_{t+1} / R_t \right) \tag{A.13}$$

and the first-order conditions are:

$$u_{c',t}q_t = u_{h',t} + \beta' G_C E_t \left(u_{c',t+1}\left(q_{t+1}\left(1-\delta_h\right)\right)\right) + E_t\left(\lambda_t \frac{m_t q_{t+1}\pi_{t+1}}{R_t}\right) \tag{A.14}$$

$$u_{c',t} = \beta' G_C E_t\left(u_{c',t+1}\frac{R_t}{\pi_{t+1}}\right) + \lambda_t \tag{A.15}$$

$$u_{c',t}w'_{c,t} = u_{nc',t}X'_{wc,t} \tag{A.16}$$

$$u_{c',t}w'_{h,t} = u_{nh',t}X'_{wh,t} \tag{A.17}$$

where λ_t denotes the multiplier on the borrowing constraint, which is greater than zero in a neighborhood of the equilibrium.

The production technologies are (normalizing land to unity):

$$Y_t = \left(\mathsf{A}_{c,t}\left(n_{c,t}^{\alpha}n_{c,t}'^{1-\alpha}\right)\right)^{1-\mu_c}\left(z_{c,t}k_{c,t-1}\right)^{\mu_c} \tag{A.18}$$

$$IH_t = \left(\mathsf{A}_{h,t}\left(n_{h,t}^{\alpha}n_{h,t}'^{1-\alpha}\right)\right)^{1-\mu_h-\mu_l-\mu_b} k_{b,t}^{\mu_b}\left(z_{h,t}k_{h,t-1}\right)^{\mu_h}. \tag{A.19}$$

The first-order conditions for the wholesale goods firms will be

$$\left(1-\mu_c\right)\alpha Y_t = X_t w_{c,t} n_{c,t} \tag{A.20}$$

$$\left(1-\mu_c\right)\left(1-\alpha\right)Y_t = X_t w'_{c,t} n'_{c,t} \tag{A.21}$$

$$\left(1-\mu_h-\mu_l-\mu_b\right)\alpha q_t IH_t = w_{h,t} n_{h,t} \tag{A.22}$$

$$\left(1-\mu_h-\mu_l-\mu_b\right)\left(1-\alpha\right)q_t IH_t = w'_{h,t} n'_{h,t} \tag{A.23}$$

$$\mu_c Y_t = X_t R_{c,t} z_{c,t} k_{c,t-1} \tag{A.24}$$

$$\mu_h q_t IH_t = R_{h,t} z_{h,t} k_{h,t-1} \tag{A.25}$$

$$\mu_l q_t IH_t = R_{l,t} l_{t-1} \tag{A.26}$$

$$\mu_b q_t IH_t = p_{b,t} k_{b,t}. \tag{A.27}$$

The Phillips curve is:

$$\ln \pi_t - \iota_\pi \ln \pi_{t-1} = \beta G_C\left(E_t \ln \pi_{t+1} - \iota_\pi \ln \pi_t\right) - \varepsilon_\pi \ln\left(X_t/X\right) + u_{p,t}. \tag{A.28}$$

Denote with $\omega_{i,t}$ nominal wage inflation, that is, $\omega_{i,t} = \frac{w_{i,t}\pi_t}{w_{i,t-1}}$ for each sector/household pair. The four wage equations are:

$$\ln \omega_{c,t} - \iota_{wc}\ln \pi_{t-1} = \beta G_C\left(E_t \ln \omega_{c,t+1} - \iota_{wc}\ln \pi_t\right) - \varepsilon_{wc}\ln\left(X_{wc,t}/X_{wc}\right) \tag{A.29}$$

$$\ln \omega'_{c,t} - \iota_{wc}\ln \pi_{t-1} = \beta' G_C\left(E_t \ln \omega'_{c,t+1} - \iota_{wc}\ln \pi_t\right) - \varepsilon'_{wc}\ln\left(X_{wc,t}/X_{wc}\right) \tag{A.30}$$

$$\ln \omega_{h,t} - \iota_{wh}\ln \pi_{t-1} = \beta G_C\left(E_t \ln \omega_{h,t+1} - \iota_{wh}\ln \pi_t\right) - \varepsilon_{wh}\ln\left(X_{wh,t}/X_{wh}\right) \tag{A.31}$$

$$\ln \omega'_{h,t} - \iota_{wh}\ln \pi_{t-1} = \beta' G_C\left(E_t \ln \omega'_{h,t+1} - \iota_{wh}\ln \pi_t\right) - \varepsilon'_{wh}\ln\left(X_{wh,t}/X_{wh}\right) \tag{A.32}$$

where $\varepsilon_{wc} = \left(1-\theta_{wc}\right)\left(1-\beta G_C\theta_{wc}\right)/\theta_{wc}$, $\varepsilon'_{wc} = \left(1-\theta_{wc}\right)\left(1-\beta' G_C\theta_{wc}\right)/\theta_{wc}$
$\varepsilon_{wh} = \left(1-\theta_{wc}\right)\left(1-\beta G_C\theta_{wc}\right)/\theta_{wc}$ and $\varepsilon'_{wh} = \left(1-\theta_{wh}\right)\left(1-\beta' G_C\theta_{wh}\right)/\theta_{wh}$.

The Taylor rule is:

$$R_t = \left(R_{t-1}\right)^{r_R}\pi_t^{r_\pi\left(1-r_R\right)}\left(\frac{GDP_t}{G_C GDP_{t-1}}\right)^{r_Y\left(1-r_R\right)}\overline{rr}^{1-r_R}\frac{u_{R,t}}{\mathsf{s}_t} \tag{A.33}$$

where GDP_t is the sum of the value added of the two sectors, that is $GDP_t = Y_t - k_{b,t} + \overline{q} IH_t$. Two market-clearing conditions are

$$C_t + IK_{c,t}/\mathsf{A}_{k,t} + IK_{h,t} + k_{b,t} = Y_t - \phi_t \tag{A.34}$$

$$h_t + h'_t - (1-\delta_h)\left(h_{t-1} + h'_{t-1}\right) = IH_t. \tag{A.35}$$

By Walras' law, $b_t + b'_t = 0$. Finally, total land is normalized to unity:

$$l_t = 1. \tag{A.36}$$

In equilibrium, dividends paid to households equal respectively:

$$\begin{aligned} Div_t &= \frac{X_t - 1}{X_t} Y_t + \frac{X_{wc,t} - 1}{X_{wc,t}} w_{c,t} n_{c,t} + \frac{X_{wh,t} - 1}{X_{wh,t}} w_{h,t} n_{h,t} \\ Div'_t &= \frac{X'_{wc,t} - 1}{X'_{wc,t}} w'_{c,t} n'_{c,t} + \frac{X'_{wh,t} - 1}{X'_{wh,t}} w'_{h,t} n'_{h,t}. \end{aligned}$$

In addition, we specify the functional forms for the capital adjustment cost and the utilization rate as:

$$\begin{aligned} \phi_t &= \frac{\phi_{kc}}{2G_{IK_c}} \left(\frac{k_{c,t}}{k_{c,t-1}} - G_{IK_c} \right)^2 \frac{k_{c,t-1}}{(1+\gamma_{AK})^t} + \frac{\phi_{kh}}{2G_{IK_h}} \left(\frac{k_{h,t}}{k_{h,t-1}} - G_{IK_h} \right)^2 k_{h,t-1} \\ a(z_{c,t}) &= R_c \left(\varpi z_{c,t}^2/2 + (1-\varpi) z_{c,t} + (\varpi/2 - 1) \right) \\ a(z_{h,t}) &= R_h \left(\varpi z_{h,t}^2/2 + (1-\varpi) z_{h,t} + (\varpi/2 - 1) \right) \end{aligned}$$

where R_c and R_h are the steady-state values of the rental rates of the two types of capital. In the estimation of the model, we specify our prior for the curvature of the capacity utilization function in terms of $\zeta = \varpi/(1+\varpi)$. With this change of variables, ζ is bounded between 0 and 1, since ϖ is positive: values of ζ close to unity imply that the cost of adjusting capacity becomes arbitrarily large.

Equations A.1 to A.36 together with the values for IK_c, IK_h, GDP_t, ϕ_t, $a(z)$, Div_t and Div'_t and the laws of motion for the exogenous shocks (reported in the main text) define a system of 36 equations in the following variables:

Patient households: $c \quad h \quad k_c \quad k_h \quad k_b \quad n_c \quad n_h \quad b \quad l \quad z_c \quad z_h$

Impatient households: $c' \quad h' \quad n'_c \quad n'_h \quad b'$

Firms: $IH \quad Y$

Markets/prices: $q \quad R \quad \pi \quad \lambda \quad X \quad w_c \quad w_h \quad w'_c \quad w'_h \quad X_{wc} \quad X_{wh} \quad X'_{wh} \quad X'_{wh} \quad R_c \quad R_h \quad R_l \quad p_b \quad p_l$.

After detrending the variables by their balanced growth trends, we linearize the resulting system around the non-stochastic steady-state and compute the decision rules using standard methods.

Table 1A. Calibrated Parameters

Parameter	Value
β	0.9925
β'	0.97
j	0.12
μ_c	0.35
μ_h	0.10
μ_l	0.10
μ_b	0.10
δ_h	0.01
δ_{kc}	0.025
δ_{kh}	0.03
X, X_{wc}, X_{wh}	1.15
m	0.85
ρ_s	0.975

Table 1B. Steady-state Targets

Variable	Interpretation	Value
$4 \times R - 1$	Annual Real Interest Rate	3%
C/GDP	Consumption Share	67%
IK/GDP	Business Investment Share	27%
$q \times IH/GDP$	Housing Investment Share	6%
$qH/(4 \times GDP)$	Housing Wealth	1.36
$k_c/(4 \times GDP)$	Business Capital in Non-Housing Sector	2.05
$k_h/(4 \times GDP)$	Business Capital in Housing Sector	0.04
$p_l/(4 \times GDP)$	Value of Land	0.50

Note: Our model definition of GDP and consumption excludes the imputed value of rents from non-durable consumption.

Table 2A. Prior and Posterior Distribution of the Structural Parameters

	Prior Distribution			Posterior Distribution			
Parameter	Distr.	Mean	St.Dev	Mean	2.5 percent	Median	97.5 percent
ε	Beta	0.5	0.075	0.33	0.25	0.33	0.41
ε'	Beta	0.5	0.075	0.58	0.46	0.58	0.69
η	Gamma	0.5	0.1	0.52	0.33	0.52	0.73
η'	Gamma	0.5	0.1	0.51	0.34	0.51	0.70
ξ	Normal	1	0.1	0.66	0.38	0.67	0.91
ξ'	Normal	1	0.1	0.98	0.78	0.99	1.17
$\phi_{k,c}$	Gamma	10	2.5	15.32	12.12	15.27	18.81
$\phi_{k,h}$	Gamma	10	2.5	11.08	6.86	10.88	16.50
α	Beta	0.65	0.05	0.79	0.72	0.79	0.85
r_R	Beta	0.75	0.1	0.61	0.52	0.61	0.67
r_π	Normal	1.5	0.1	1.36	1.23	1.36	1.52
r_Y	Normal	0	0.1	0.51	0.40	0.51	0.63
θ_π	Beta	0.667	0.05	0.83	0.79	0.83	0.87
ι_π	Beta	0.5	0.2	0.72	0.56	0.71	0.89
$\theta_{w,c}$	Beta	0.667	0.05	0.81	0.76	0.81	0.85
$\iota_{w,c}$	Beta	0.5	0.2	0.08	0.02	0.08	0.17
$\theta_{w,h}$	Beta	0.667	0.05	0.91	0.88	0.91	0.93
$\iota_{w,h}$	Beta	0.5	0.2	0.43	0.21	0.42	0.68
ζ	Beta	0.5	0.2	0.72	0.53	0.72	0.88
$100 \times \gamma_{AC}$	Normal	0.5	1	0.32	0.30	0.32	0.35
$100 \times \gamma_{AH}$	Normal	0.5	1	0.10	-0.05	0.10	0.28
$100 \times \gamma_{AK}$	Normal	0.5	1	0.27	0.23	0.27	0.30

Note: Results based on 200,000 draws from the Metropolis algorithm.

Table 2B. Prior and Posterior Distribution of the Shock Processes

	Prior Distribution			Posterior Distribution			
Parameter	Distr.	Mean	St. Dev.	Mean	2.5 percent	median	97.5 percent
ρ_{AC}	Beta	0.8	0.1	0.95	0.92	0.95	0.97
ρ_{AH}	Beta	0.8	0.1	0.997	0.99	0.997	0.999
ρ_{AK}	Beta	0.8	0.1	0.93	0.89	0.93	0.96
ρ_j	Beta	0.8	0.1	0.95	0.91	0.95	0.98
ρ_z	Beta	0.8	0.1	0.98	0.94	0.99	1.00
ρ_τ	Beta	0.8	0.1	0.91	0.86	0.91	0.95
σ_{AC}	Uniform[0,0.2]			0.0101	0.0089	0.0101	0.0115
σ_{AH}	Uniform[0,0.2]			0.0196	0.0175	0.0195	0.0218
σ_{AK}	Uniform[0,0.2]			0.0111	0.0088	0.0110	0.0138
σ_j	Uniform[0,0.2]			0.0462	0.0274	0.0444	0.0771
σ_R	Uniform[0,0.2]			0.0034	0.0028	0.0033	0.0041
σ_z	Uniform[0,0.2]			0.0437	0.0132	0.0447	0.0768
σ_τ	Uniform[0,0.2]			0.0287	0.0200	0.0281	0.0397
σ_p	Uniform[0,0.2]			0.0047	0.0040	0.0047	0.0054
σ_s	Uniform[0,0.2]			0.0003	0.0002	0.0003	0.0004
$\sigma_{n,h}$	Gamma	0.001	0.01	0.1203	0.1078	0.1199	0.1360
$\sigma_{w,h}$	Gamma	0.001	0.01	0.0071	0.0063	0.0071	0.0081

Note: Results based on 200,000 draws from the Metropolis algorithm.

Table 3. Business Cycle Properties of the Model

	Model			Data
	Median	2.5 percent	97.5 percent	
Standard deviation (percent)				
C	1.59	1.21	2.07	1.22
IH	8.50	6.79	10.63	9.97
IK	4.04	3.16	5.18	4.87
q	2.19	1.75	2.73	1.87
π	0.49	0.41	0.60	0.40
R	0.32	0.25	0.41	0.32
GDP	2.22	1.72	2.88	2.17
Correlations				
C, GDP	0.87	0.75	0.93	0.88
IH, GDP	0.64	0.43	0.79	0.78
IK, GDP	0.89	0.80	0.94	0.75
q, GDP	0.67	0.45	0.81	0.58
q, C	0.58	0.31	0.76	0.48
q, IH	0.48	0.20	0.69	0.41

Note: The statistics are computed using a random selection of 1,000 draws from the posterior distribution and, for each of them, 100 artificial time series of the main variables of length equal to that of the data, giving a sample of 100,000 series. The business cycle component of each simulated series is extracted using the HP filter (with smoothing parameter set to 1,600). Summary statistics of the posterior distribution of the moments are computed by pooling together all the simulations. GDP denotes domestic demand excluding government purchases and investment, chained 2000 dollars.

Table 4. Decomposition of the Asymptotic Variance of the Forecast Error

	u_C	u_H	u_K	u_j	u_R	u_z	u_τ	u_p	u_s
C	18.8	1.0	0.9	0.3	18.7	8.9	18.9	22.1	9.3
IH	3.2	29.3	0.6	27.7	15.0	8.9	6.8	3.9	3.9
IK	9.3	0.1	34.4	0.1	14.5	7.5	9.0	17.6	6.7
q	8.6	19.0	0.6	26.3	11.4	10.9	6.0	12.5	3.8
π	4.7	0.1	0.5	0.4	5.2	2.6	2.9	59.4	23.9
R	3.9	0.6	9.3	3.9	19.6	5.3	5.4	17.1	33.4
GDP	15.8	0.9	8.2	2.1	21.5	1.5	19.1	21.9	9.0

Note: The table reports the posterior median value of the variance of the forecast errors at business cycle frequencies (extracted using the HP filter with smoothing parameter equal to 1,600).

Table 5. Contribution to Housing Booms of the Estimated Shocks

Period		% change, q	Contribution to changes of: Technology	Monetary Pol.	Housing Pref.
1976:I	1980:I	16.6	5.3	-3.0	12.4
1980:II	1985:IV	-12.2	-3.1	0.1	-5.7
1998:I	2005:I	14.5	5.9	2.1	8.6
2005:II	2006:IV	-0.3	-0.2	-2.7	0.5
		% change, IH			
1976:I	1980:I	0.7	-28.0	-13.1	34.2
1980:II	1985:IV	26.4	48.3	-2.4	-15.3
1998:I	2005:I	22.0	-4.1	9.8	25.2
2005:II	2006:IV	-15.5	-4.3	-11.4	-3.9

Note: Contribution of Technology Shocks (Non-Housing, Housing and Investment Specific), Monetary Shocks (Interest Rate and Inflation Objective) and Housing Preference Shocks to the housing market cycles reported in the text. Changes in the variables are expressed in deviation from the estimated trends.

Table 6. Subsample Estimates

	Structural Parameters					Shock Processes and Meas. Error			
	1965:I-1982:IV		1989:I-2006:IV			1965:I-1982:IV		1989:I-2006:IV	
	Median	St.Dev	Median	St.Dev		Median	St.Dev	Median	St.Dev
ε	0.39	0.05	0.42	0.05	ρ_{AC}	0.93	0.03	0.90	0.03
ε'	0.50	0.07	0.65	0.06	ρ_{AH}	0.99	0.01	0.995	0.004
η	0.51	0.10	0.49	0.09	ρ_{AK}	0.92	0.04	0.92	0.02
η'	0.49	0.10	0.49	0.10	ρ_j	0.88	0.04	0.94	0.02
ξ	0.86	0.11	0.78	0.12	ρ_z	0.96	0.03	0.89	0.04
ξ'	0.97	0.10	0.97	0.10	ρ_τ	0.83	0.06	0.86	0.06
$\phi_{k,c}$	13.30	1.77	12.30	1.74	σ_{AC}	0.0113	0.0012	0.0083	0.0008
$\phi_{k,h}$	10.24	2.48	9.74	2.45	σ_{AH}	0.0250	0.0024	0.0140	0.0013
α	0.68	0.05	0.80	0.03	σ_{AK}	0.0090	0.0018	0.0109	0.0015
r_R	0.59	0.05	0.74	0.03	σ_j	0.1028	0.0340	0.0561	0.014
r_π	1.49	0.08	1.50	0.09	σ_R	0.0047	0.0006	0.0015	0.0002
r_Y	0.38	0.07	0.34	0.07	σ_z	0.0263	0.0071	0.0112	0.002
θ_π	0.78	0.03	0.81	0.03	σ_τ	0.0327	0.0087	0.0184	0.007
ι_π	0.76	0.10	0.86	0.08	σ_p	0.0065	0.0009	0.0038	0.0005
$\theta_{w,c}$	0.77	0.03	0.85	0.02	σ_s	0.0006	0.0001	4E-5	1E-5
$\iota_{w,c}$	0.12	0.07	0.12	0.05	$\sigma_{n,h}$	0.1485	0.0127	0.0955	0.0084
$\theta_{w,h}$	0.90	0.02	0.91	0.02	$\sigma_{w,h}$	0.0085	0.0009	0.0041	0.0005
$\iota_{w,h}$	0.56	0.15	0.17	0.11					
ζ	0.54	0.13	0.87	0.07					
$100 \times \gamma_{AC}$	0.27	0.04	0.26	0.03					
$100 \times \gamma_{AH}$	-0.12	0.12	0.09	0.10					
$100 \times \gamma_{AK}$	0.28	0.06	0.41	0.04					

Note: Results based on 200,000 draws from the Metropolis algorithm. As explained in the text, the loan-to-value ratio m is set at 0.775 in the first subperiod, at 0.925 in the second subperiod.

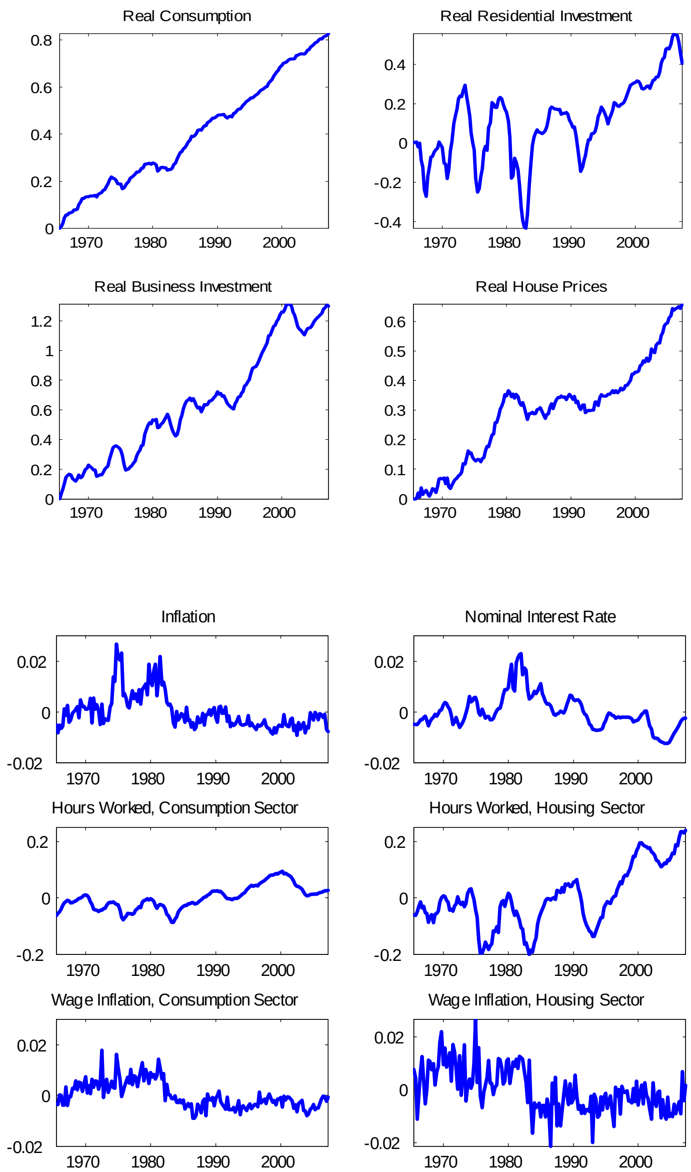

Figure 1: Data

Note: Consumption and investment are divided by population and log-transformed. The first observation (1965:I) is normalized to zero. Variables in the bottom panel are demeaned. Hours worked are divided by population.

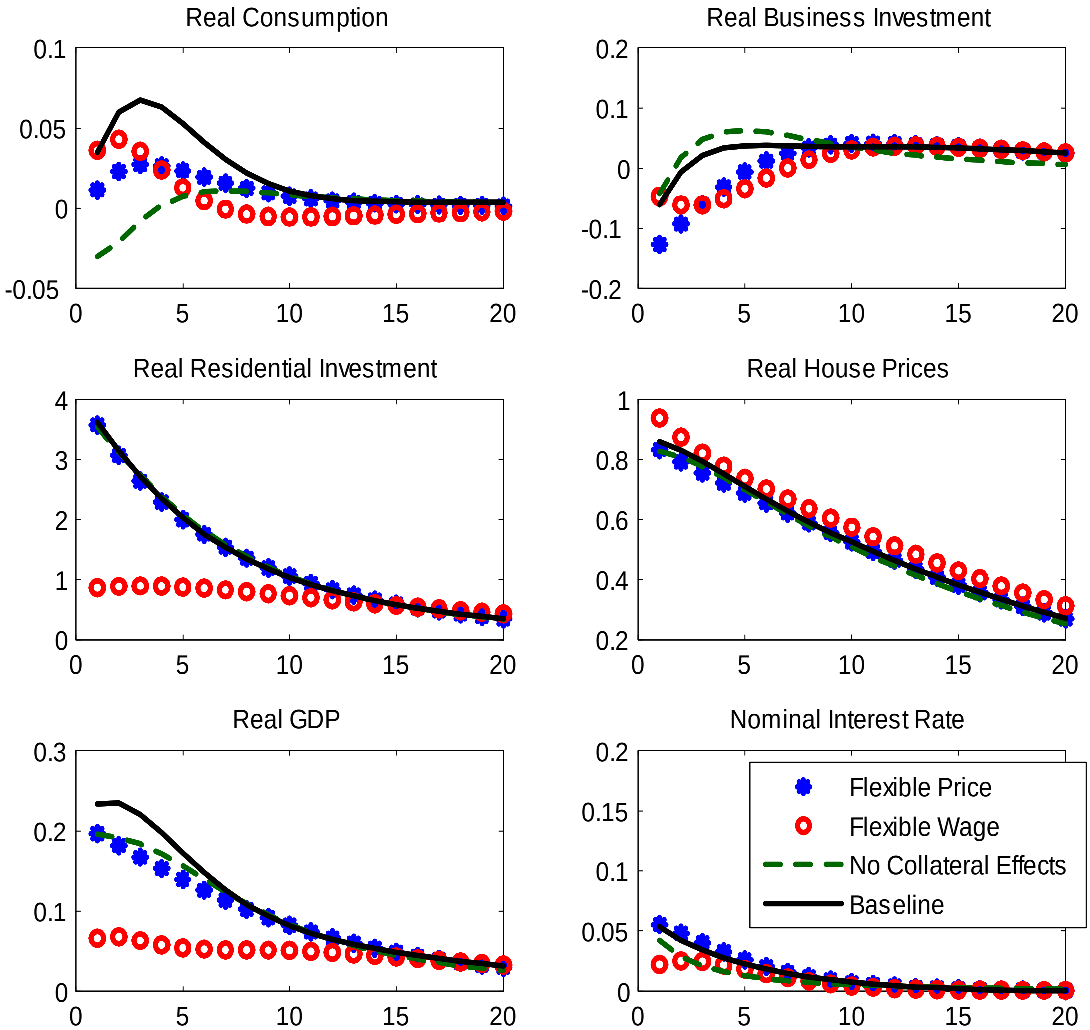

Figure 2: Impulse responses to a housing preference shock: baseline estimates and sensitivity analysis.

Note: The y-axis measures percent deviation from the steady state.

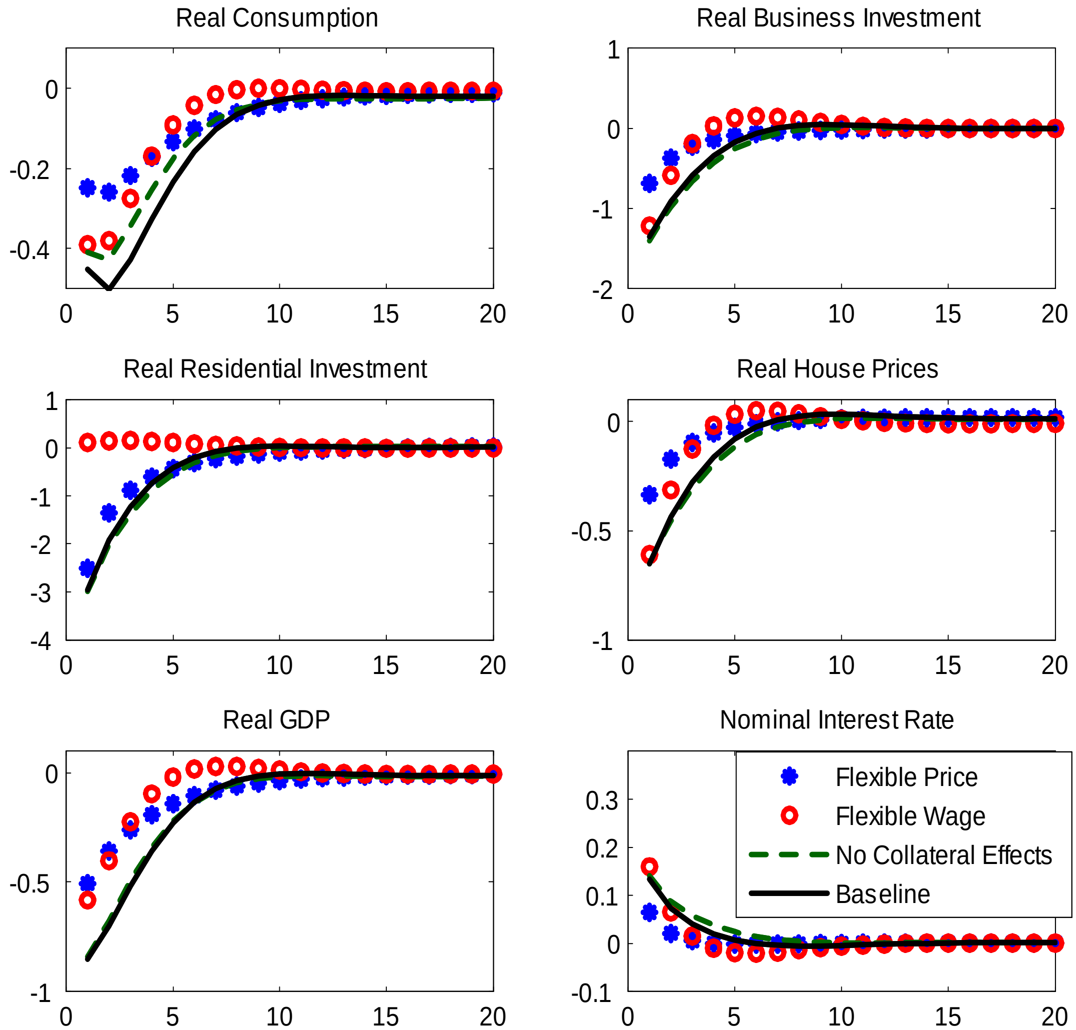

Figure 3: Impulse responses to a monetary policy shock: baseline estimates and sensitivity analysis.

Note: The y-axis measures percent deviation from the steady state.

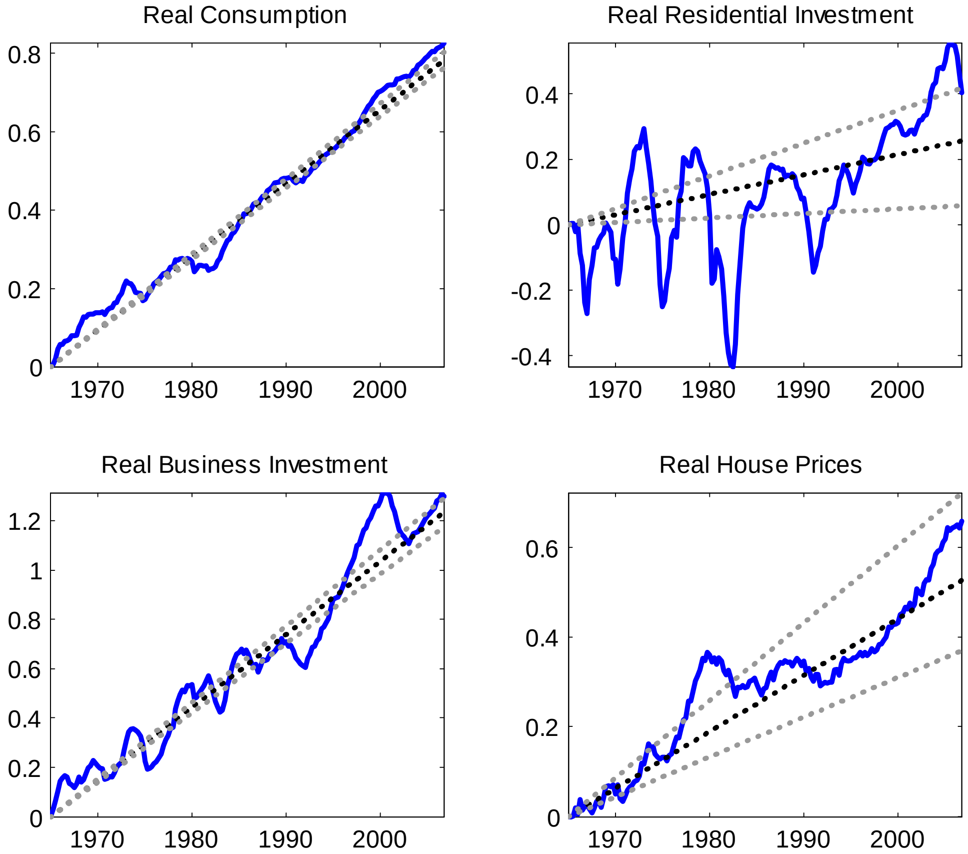

Figure 4: Estimated trends

Note: Dashed lines correspond to the median, 2.5 percentile and 97.5 percentile of the posterior distribution of the trends. Solid line: data.

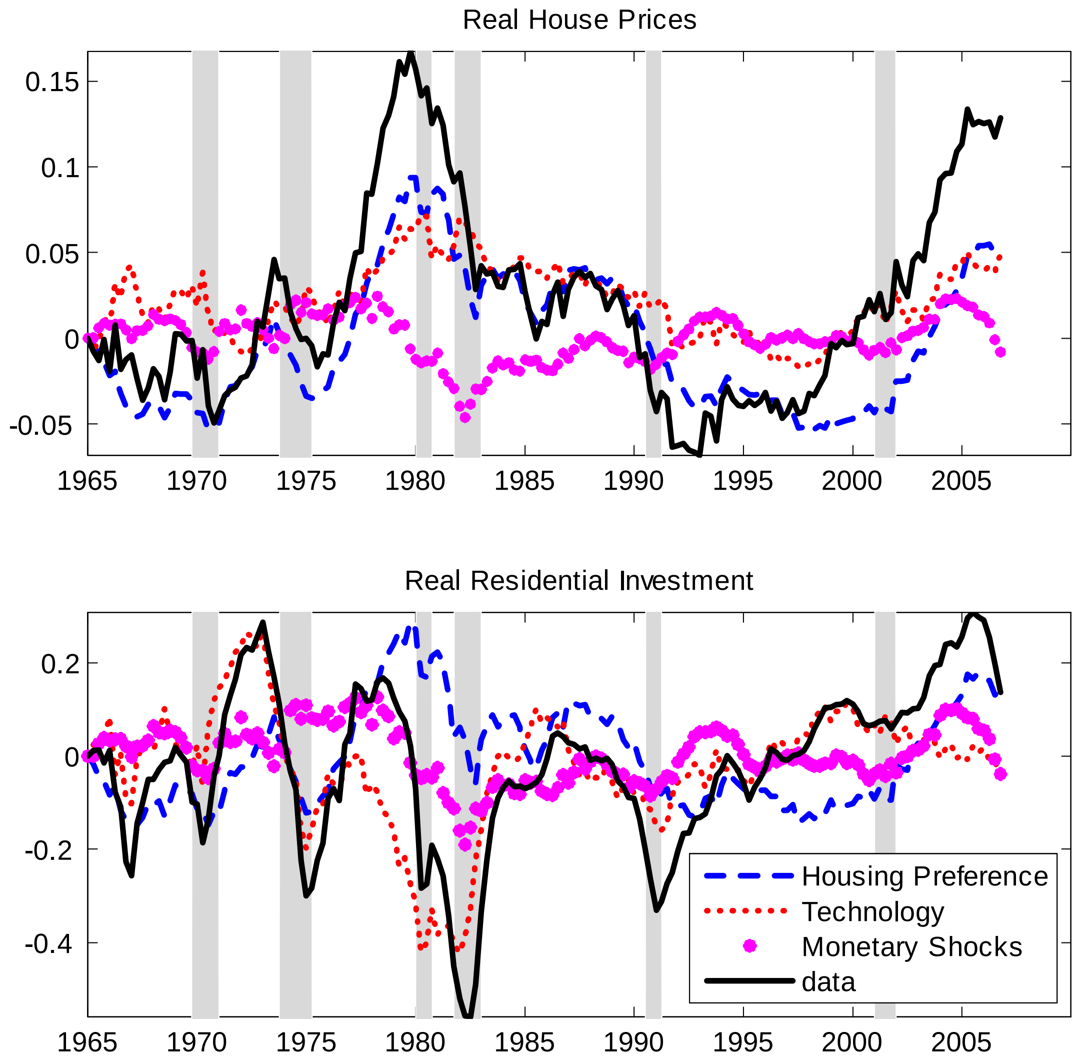

Figure 5: Historical decomposition of real house prices and real residential investment to housing preference shocks, technology shocks and monetary shocks. Monetary shocks include i.i.d. monetary policy shocks and changes in the inflation objective. Technology shocks include housing, non-housing and investment specific technology shocks. All series are in deviation from the estimated trend.

Note: Shaded areas indicate recessions as determined by the NBER.

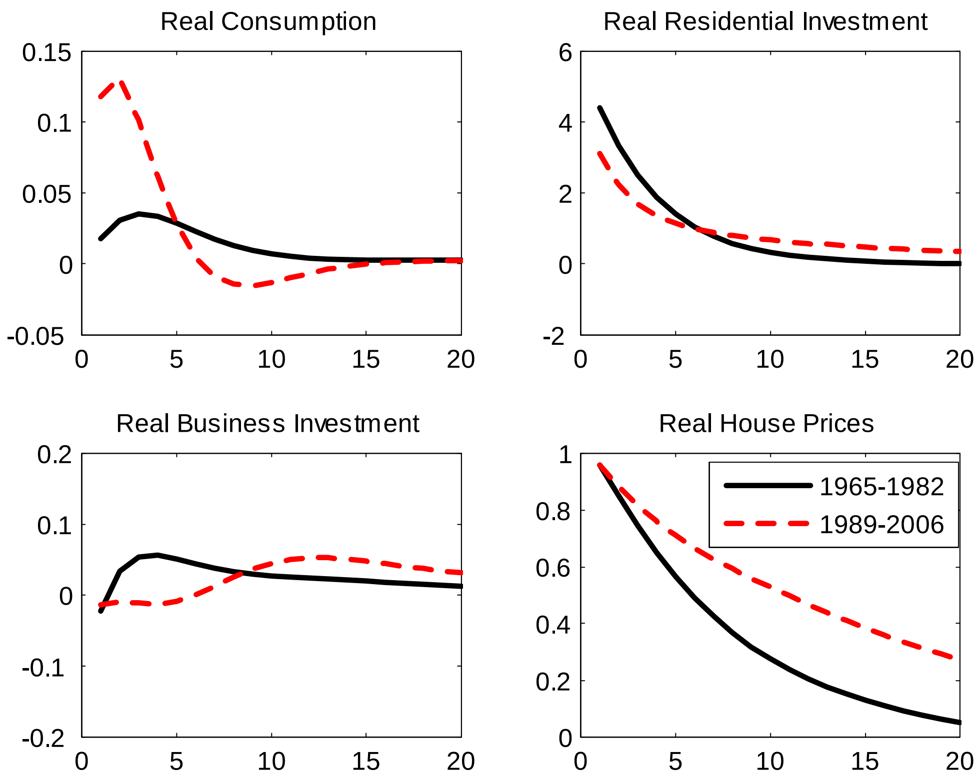

Figure 6: Impulse response functions to an estimated housing preference shock in the two subsamples. The standard error of the preference shock in the second period is normalized so that the shock affect house prices by the same amount in the impact period.

Note: The y-axis measures percent deviation from the steady state.

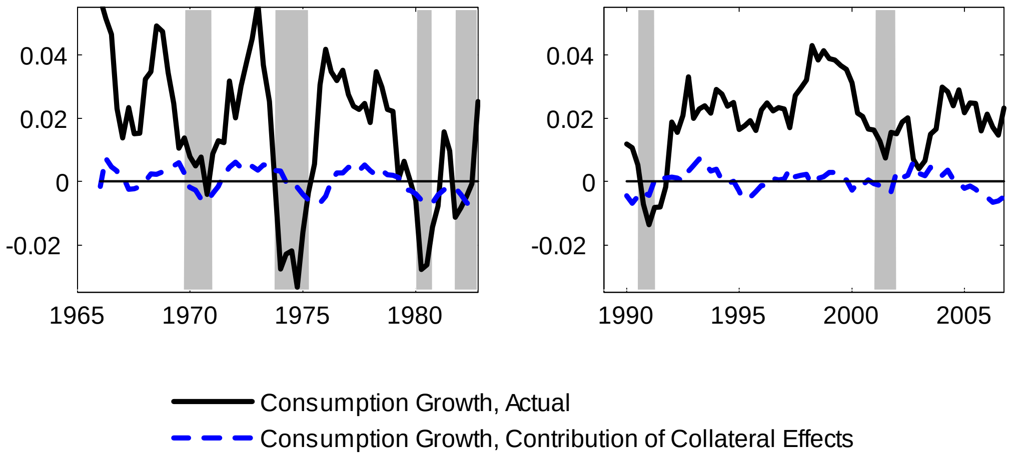

Figure 7: The contribution of collateral effects to fluctuations in year-on-year consumption growth: results based on subsample estimates.

Note: The contribution of collateral effects is calculated subtracting from actual consumption growth the path of simulated consumption growth that obtains when we feed in the model the smoothed estimates of the shocks and shut off collateral effects (setting $\alpha = 1$ and $m = 0$). Shaded areas indicate recessions as determined by the NBER.

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