

# The Role of Housing Collateral in an Estimated Two-Sector Model of the U.S. Economy

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## Abstract

We investigate the ability of a two-sector model to quantify the role of the housing market in business fluctuations. We use US data to estimate the structural parameters of the model via maximum likelihood methods. We find robust empirical support for feedback effects from housing to the rest of the economy, mostly working through the effects on non-durable consumption that spill over - through borrowing - from shocks in the housing sector.

We use the estimated model to address three questions: (1) What has been the contribution of the housing boom in the post 9/11 recovery; (2) What would have happened had the Fed tried to stabilize house prices? (3) How have financing frictions evolved over time?

[ VERY PRELIMINARY AND INCOMPLETE ]

## 1. Introduction

The role of the housing market in business fluctuations has gained increased attention among academics and policymakers in recent years. On the one hand, this reflects the observation that, while central bankers have won the battle for price stability, large fluctuations in asset values are still common and far from understood in many developed economies. On the other, this reflects the fact that developments in the housing market seem to have broader macroeconomic consequences: for instance, the rise in housing valuations in the United States at the turn of the century not only seems to have driven up residential investment, but, through home equity extraction, has been cited as the driving force behind the high consumption growth of the last years.<sup>1</sup>

However, while academic and policy debates often focus on the importance of the housing market, the new generation of small-scale monetary business cycle models with nominal rigidities that has become popular in monetary policy analysis largely abstracts from housing altogether. To

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<sup>1</sup>See for instance a recent quote from the Fed Chairman Greenspan (2005): “[I]t is difficult to dismiss the conclusion that a significant amount of consumption is driven by capital gains on some combination of both stocks and residences, with the latter being financed predominantly by home equity extraction”.

fill this gap, we develop and estimate using a Bayesian likelihood approach a small-scale dynamic stochastic general equilibrium model for the US economy that explicitly models the housing market.<sup>2</sup> We do so with three main goals in mind. First, we want to understand the extent to which a model with nominal and real rigidities and credit frictions can explain the dynamics of residential investment and housing prices that are observed in the data. Second, we want to understand how important are the feedback effects going from the housing market to the rest of the economy. Third, because we rely on a model which is structurally estimated and robust to the Lucas' critique, we can address policy questions, conduct counterfactuals, and make quantitative statements.

In modelling housing, our starting point is a variant of many small-scale monetary business cycle models that have become popular in monetary policy analysis. We depart from this framework in two important and distinct ways. On the supply side, our model features two sectors: one sector, featuring nominal rigidities, produces consumption and business fixed investment; the other sector, featuring flexible prices, produces new homes (residential investment).<sup>3</sup> On the demand side, residential capital enters the utility function and can be used as a collateral for loans by a fraction of households that are subject to borrowing constraints (crucially, we let the data decide how large the fraction of is). Because new housing and consumption goods are produced using different technologies, the model endogenously generates heterogeneous dynamics both in residential vis-a-vis nonresidential investment and in the relative price of housing. Because fluctuations in the price of housing affect the collateral capacity of a fraction of households, it has potential implications for the feedback of housing prices on other forms of consumption expenditure.

Our main results can be summarized as follows: we find robust empirical support for feedback effects from housing to the rest of the economy, mostly working through the effects on non-durable consumption that spillover - through collateral effects - from shocks in the housing sector. We are able to quantify the contribution to consumption of the recent housing boom, and to show what would have happened had the Fed tried to stabilize house prices.

In the next section, we discuss our model. In section three, we discuss the calibration, the data and the prior distribution of the structural parameters of the model and of the shock processes. In section four, we present our estimates. In section five, we use the estimated model to discuss a number of key issues related to the role of the housing market in the business cycle. In section six, we discuss results based on a sticky-wage extension of our model. We wrap up in Section seven.

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<sup>2</sup>Using a simulated method of moments, Iacoviello (2005) estimates a monetary business cycle model with housing, nominal loans and collateral constraints. His main focus is on the effects of collateral price shocks on consumption, but he assumes that the stock of aggregate housing is fixed, thus shutting off the links between aggregate residential investment and economic activity.

<sup>3</sup>Barsky, House and Kimball (2006) note several reasons why housing might 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.

## 2. The model

The model features two production sectors, heterogeneity in discount factors and collateral constraints tied to a fraction of housing values.

On the purchasers side, there are two types of households, patient (savers) and impatient (borrowers). Patient households work, consume and accumulate housing: they own the productive capital of the economy, supply loanable funds to firms on the one hand, and to impatient households (borrowers) on the other. Impatient households work, consume and accumulate housing: because they have a high propensity to dissave, they are up against their maximum borrowing limit in equilibrium.

On the producers side, there are two sectors. The non-housing sector combines nonresidential capital and labor to produce consumption and two types of nonresidential capital. The housing sector produces new homes, combining nonresidential capital with labor and land. Each household allocates hours worked across the two sectors. We allow for (but do not impose) Calvo-style price rigidities in the non-housing sector. Similarly, we allow for the share of impatient households to take on any value on the unit interval: to the extent that the impatient group becomes arbitrarily small, our model becomes de facto a representative agent model.

### 2.1. Households

Patient and impatient households respectively maximize the expected present value of lifetime utility as given by:<sup>4</sup>

$$E_0 \sum_{t=0}^{\infty} (\beta g_C)^t z_t \left( \log(c_t - \varepsilon_{GC} c_{t-1}) + j_t \log h_t - \tau_t (n_{ct}^{1-\nu} + n_{ht}^{1-\nu})^{\frac{1+\eta}{1-\nu}} \right)$$

$$E_0 \sum_{t=0}^{\infty} (\beta' g_C)^t z_t \left( \log(c'_t - \varepsilon'_{GC} c'_{t-1}) + j_t \log h'_t - \tau_t \left( (n'_{ct})^{1-\nu'} + (n_{ht})^{1-\nu'} \right)^{\frac{1+\eta'}{1-\nu'}} \right)$$

where  $c_t$ ,  $h_t$ ,  $n_{ct}$ ,  $n_{ht}$  represent consumption, housing, labor in the consumption sector and labor in the construction sector. Random variations in  $z_t$ ,  $j_t$  and  $\tau_t$  proxy respectively for aggregate demand, housing demand, and labor supply shocks. These shocks are assumed to follow stationary autoregressive processes of the form:

$$\begin{aligned} \ln z_t &= \rho_z \ln z_{t-1} + \varepsilon_{zt}, \quad \varepsilon_{zt} \sim N(0, \sigma_z) \\ \ln j_t &= (1 - \rho_j) \ln \bar{j} + \rho_j \ln j_{t-1} + \varepsilon_{jt}, \quad \varepsilon_{jt} \sim N(0, \sigma_j) \\ \ln \tau_t &= \rho_\tau \ln \tau_{t-1} + \varepsilon_{\tau t}, \quad \varepsilon_{\tau t} \sim N(0, \sigma_\tau) \end{aligned}$$

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<sup>4</sup>We assume a cashless limit in the sense of Woodford (2003), so that the role of money in transactions becomes negligible.

The specification of the disutility of labor follows Horvath (2000), in assuming that the household has a preference for diversity of labor across sectors. This allows to capture through the parameter  $\nu$  some degree of sector specificity, so long as  $\nu$  is smaller than zero.

Variables with a prime denote the borrower ( $'$ ), variables without a prime denote the lender. So long as  $\beta$  is sufficiently higher than  $\beta'$ , borrowers will decumulate wealth quickly enough to some lower bound. For small fluctuations around the steady state, the lower bound is always binding. It then follows that lenders will own and accumulate all the capital in a neighborhood of the steady state, whereas borrowers' only form of wealth will be their home, and they will borrow the maximum possible amount against it.

In real terms, the flow wealth constraint for lenders is:

$$c_t + \frac{k_{ct}}{\tilde{A}_{kt}} + k_{ht} + q_t (h_t - (1 - \delta_h) h_{t-1}) + \phi_t + p_{lt} (l_t - l_{t-1}) = w_{ct} n_{ct} + w_{ht} n_{ht} + \left( R_{ct} + \frac{1 - \delta_k}{\tilde{A}_{kt}} \right) k_{ct-1} + (R_{ht} + 1 - \delta_k) k_{ht-1} + f_t + b_t - \frac{R_{t-1} b_{t-1}}{\pi_t} + R_{lt} l_{t-1} \quad (1)$$

where  $\pi_t = P_t/P_{t-1}$  is the gross inflation rate between period  $t - 1$  and  $t$ ,  $f_t$  denotes profits from ownership of finished good firms, and  $\phi_t$  denotes standard quadratic adjustment costs for capital.<sup>5</sup> Lenders choose plans for consumption  $c_t$ , capital in the consumption-good sector  $k_c$ , capital in the housing sector  $k_h$ , home purchases  $h_t$ , land holdings  $l_t$ , hours in both sectors  $n_{ct}$  and  $n_{ht}$  and loans  $b_t$  to maximize their utility subject to the constraint above. The term  $\tilde{A}_{kt}$  captures investment-specific technological shocks, whose stochastic properties are described below. Loans  $b_t$  are set in nominal terms, and yield a gross nominal return of  $R_t$ .

Borrowers face two constraints. Their flow wealth constraint is analogous to the constraint of the lenders, with the exception that they do not accumulate capital, they do not own finished good firms, they do not own land. In addition, the maximum amount they can borrow is given by the expected present value of their home, times the loan-to-value ratio  $m$ .

$$c'_t + q_t (h'_t - (1 - \delta_h) h'_{t-1}) = w_{ct} n'_{ct} + w_{ht} n'_{ht} + b'_t - \frac{R_{t-1}}{\pi_t} b'_{t-1} \quad (2)$$

$$b'_t \leq m E_t (q_{t+1} h'_t \pi_{t+1} / R_t) \quad (3)$$

The assumption  $\beta' < \beta$  implies that for small shocks the borrowing constraint 3 will hold with equality in a neighborhood of the steady state.

## 2.2. Technology and Intermediate goods firms

A representative firm takes inputs prices and given, hires labor and rents capital to produce new homes  $I_t$  and intermediate goods  $Y_t$  in order to maximize profits:

<sup>5</sup>That is:

$$\phi_t = \frac{\phi_{kc}}{2} \left( \frac{k_{ct} - k_{ct-1}}{k_{ct-1}} \right)^2 k_{ct-1} + \frac{\phi_{kh}}{2} \left( \frac{k_{ht} - k_{ht-1}}{k_{ht-1}} \right)^2 k_{ht-1}$$

$$\max_{k_{ct-1}, k_{ht-1}, n_{ht}, n_{ct}} \frac{Y_t}{X_t} + q_t I_{ht} - (\sum w_{it} n_{it} + R_{ct} k_{ct-1} + R_{ht} k_{ht-1} - R_t l_{t-1})$$

Intermediate goods (nominal price  $P_t^w$ ) are then transformed into final goods (priced at  $P_t$ ) from final goods firms (described below). With this in mind, we define  $X_t = P_t/P_t^w$  as the markup of final over intermediate goods. The production technologies are:

$$Y_t = \left( \tilde{A}_{ct} (n_{ct}^\alpha n_{ct}'^{1-\alpha}) \right)^{1-\mu_c} k_{ct-1}^{\mu_c} \quad (4)$$

$$I_{ht} = \left( \tilde{A}_{ct} \tilde{A}_{ht} (n_{ht}^\alpha n_{ht}'^{1-\alpha}) \right)^{1-\mu_h-\kappa} k_{ht-1}^{\mu_h} l_{t-1}^\kappa \quad (5)$$

Here,  $\tilde{A}_{ct}$  is a measure of aggregate labor productivity, whereas  $\tilde{A}_{ht}$  is a measure of sector-specific productivity in the  $I$ -sector, described below.

The first order conditions are standard. Out of pure convenience, we allow for the hours of the two groups to enter the two production technologies in a Cobb-Douglas fashion: this allows us obtaining closed form solutions for the steady state of the model; in this formulation,  $1 - \alpha$  measures the labor income share of credit-constrained households.<sup>6</sup>

### 2.3. Final good firms and Monetary Policy

We motivate sticky prices in the consumption-business fixed investment sector by assuming monopolistic competition at the “retail” level and implicit costs of adjusting nominal prices following Calvo-style contracts. Retailers buy intermediate goods  $Y_t$  from intermediate firms at the price  $P_t^w$  in a competitive market, differentiate the goods at no cost, and sell them at a markup over the marginal goods. The CES aggregates of these goods are then converted back into homogeneous consumption and investment goods by households. In each period, a fraction  $1 - \theta$  of retailers sets prices optimally; a fraction  $\theta$  cannot reset their prices optimally, and indexes prices to the previous period inflation rate with an elasticity equal to  $\gamma$ , as in Smets and Wouters (2003). The Phillips curve will then be (expressed in log deviations from the zero inflation steady state):

$$\log \pi_t - \gamma \log \pi_{t-1} = \beta g_C (E_t \log \pi_{t+1} - \gamma \log \pi_t) - \frac{(1 - \theta)(1 - \beta\theta)}{\theta(1 + \beta\gamma)} \log \left( \frac{X_t}{X} \right) + \log u_t \quad (6)$$

where, as in Smets and Wouters (2003), we allow for cost-push shocks that affect inflation independently from fluctuations in the real marginal cost. These shocks are assumed to be *iid* with variance  $\sigma_u^2$ .

To complete the model, we assume that the central bank runs monetary policy according to a standard Taylor rule:

$$R_t = (R_{t-1})^{r_R} \left( \pi_t^{r_\pi} \left( \frac{GDP_t/GDP_{t-1}}{GDP} \right)^{r_Y} \frac{1}{\bar{r}} \right)^{1-r_R} e_{Rt}. \quad (7)$$

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<sup>6</sup>We have also experimented with an alternative setup in which the hours of the groups are perfect substitutes in production. The results were similar to those that we report here for our Cobb-Douglas case.

where  $\bar{r}$  is the target, steady state real interest rate (which we assume to be equal to the patient households discount rate), and  $GDP$  sums all the components of aggregate demand, expressed in units of the consumption good.<sup>7</sup>

The terms  $e_{Rt}$  captures a monetary policy shock.

## 2.4. Market clearing

We assume that total land is fixed, and normalize its total supply to unity. The three market clearing conditions are:

$$C_t + IK_t = Y_t - \phi_t \quad (8)$$

$$h_t + h'_t - (1 - \delta_h)(h_{t-1} + h'_{t-1}) = IH_t \quad (9)$$

$$b_t + b'_t = 0 \quad (10)$$

where  $C_t = c_t + c'_t$  is aggregate consumption, and  $IK_t = (k_{ct} - (1 - \delta_k)k_{ct-1})/A_{kt} + k_{ht} - (1 - \delta_k)k_{ht-1}$  is total (nonresidential) business fixed investment.

## 2.5. Trends and balanced growth

We assume deterministic but heterogeneous trends in productivity in the consumption sector, the business fixed investment sector, and the housing sector. To this purpose, we let the processes for sector-specific productivity to follow:

$$\begin{aligned} \ln \tilde{A}_{ct} &= t \ln \gamma_{AC} + \ln A_{ct}, & \ln A_{ct} &= \rho_c \ln Z_{ct-1} + \varepsilon_{ct} \\ \ln \tilde{A}_{ht} &= t \ln \gamma_{AH} + \ln A_{ht}, & \ln A_{ht} &= \rho_h \ln Z_{ht-1} + \varepsilon_{ht} \\ \ln \tilde{A}_{kt} &= t \ln \gamma_{AK} + \ln A_{kt}, & \ln A_{kt} &= \rho_k \ln Z_{kt-1} + \varepsilon_{kt} \end{aligned}$$

where the innovations  $(\varepsilon_{ct}, \varepsilon_{ht}, \varepsilon_{kt})$  are serially uncorrelated with mean zero and standard deviations  $(\sigma_c, \sigma_h, \sigma_k)$ . Given this setup, a balanced growth path exists since preferences and all production functions have a Cobb-Douglas form. In the balanced growth path, the trend growth rates of the

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<sup>7</sup>Our operational definition of GDP growth sums up the growth rates of real consumption, real residential investment and real business fixed investment by their steady state nominal shares. We exclude imputed rents from the GDP that enters the model Taylor rule above. In our model, imputed rents are simply  $v_t h_t + v'_t h'_t$ , where  $v_t$  and  $v'_t$  are the relative price of housing services, obtained dividing the marginal utility of housing by the marginal utility of consumption. We do so because our model implies a close mapping between house prices and rents, something that does not seem to hold in the data. Including rents in model definition of GDP would be too close to including house prices themselves in a Taylor rule.

real variables will be:<sup>8</sup>

$$\begin{aligned}
G_C &= \gamma_{AC} + \frac{\mu_c}{1 - \mu_c} \gamma_{AK} \\
G_{IK} &= \gamma_{AC} + \frac{1}{1 - \mu_c} \gamma_{AK} \\
G_{IH} &= (1 - \mu_h - \kappa) \gamma_{AH} + (1 - \kappa) \gamma_{AC} + \frac{\mu_c \mu_h}{1 - \mu_c} \gamma_{AK} \\
G_Q &= \kappa \gamma_{AC} + \frac{\mu_c (1 - \mu_h)}{1 - \mu_c} \gamma_{AK} - (1 - \mu_h - \kappa) \gamma_{AH}
\end{aligned}$$

We stress some (perhaps) obvious implications for the long-run growth rate of house prices ( $G_Q$ ) as implied by the model's deterministic trends. First, to the extent that the construction sector only uses land as an input, the long-run production possibilities frontier between new homes and other goods is not flat, and the log-log nature of preferences implies that the real price of housing grows over time. Second, if investment-specific technological progress favors the non-housing sector more, house prices should increase along the balanced growth path. Last, technology improvements in the construction sector lower the relative price of housing.

## 2.6. Discussion of the model setup

Our modelling choices reflect the desire to strike a balance between a rich and realistic model, and the need to keep the structure simple: simplicity allows us to get a better sense for the key mechanisms at work in the model, and considerably speeds up computing time, while making the basic logic behind our model more transparent. We briefly explain below some of our modelling choices, and why we adopted them.

1. Our first assumption is that the same technology is used to produce consumption and nonresidential investment, whereas a different technology combines capital produced in the consumption sector with labor and land to produce new homes. We find this approach a somewhat natural way to proceed, since it permits us to allow for different factor intensities in the two sectors, for different rates of technological progress, for different equilibrium prices of consumption and housing.

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<sup>8</sup>Given our assumptions about investment specific technological change in the nonresidential investment sector, actual investment will include two components -  $k_c$  and  $k_h$  - that grow at different rates (in real terms) along the balanced growth path. In the data, we only have a chain-weighted series (non-residential fixed investment) 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 the National Income and Product Accounts. Because both in our model and in the data the capital held by the construction sector is a very small fraction of non-residential capital (we target a ratio of  $k_h / (k_c + k_h)$  around 0.05), we assume that in the data total investment grows at the same rate as capital in the consumption good sector in our model.

2. We do not assume adjustment costs for housing. Obviously, housing investment is lumpy at the individual level, and home purchases are subject to obvious and readily identifiable transaction costs. Yet most of these costs do not seem to be “quadratic” in nature. Transaction cost in the housing market involve a fixed fee and a cost that is proportional to the value of the house.
3. We assume habits in consumption only. We have experimented with habits in housing and leisure, and found no substantial differences in our results.
4. We assume that hours of the two households enter the production functions in a Cobb-Douglas function. The advantage of this formulation is that the “weight” of the constrained households in the production function has the natural interpretation of the share of labor income accruing to constrained agents. Were the production functions linear in the hours of the two types, there would be additional feed-back between hours and consumption stemming from the presence of borrowing constraints, and the solution of the model would be more intricate. We have experimented with such formulation, and in any case the quantitative differences between the framework we prefer and the linear-labor framework were very small.
5. We assume staggered price setting, but allow wages to be perfectly flexible. In Section 6, we sketch an extension of our model with sticky wages. Our findings suggest that sticky wages do not alter the main message of the paper, but they are a successful extension in two dimensions: first, they reduce the amount of nominal price rigidity that is needed to fit the data; second, they can account for a stronger negative response of residential investment to a monetary contraction, along the lines suggested by Barsky, House and Kimball (2006) and Carlstrom and Fuerst (2006).

### **3. Estimation of the model**

Since a closed form solution is not possible, the behavior of the economy is studied by looking at a loglinear approximation to the model equations in the neighborhood of the steady state. In steady state the shocks are set to their mean values, price inflation is set to zero, the risk-free interest rate is equal to the patient agents’ discount rate. The steady state is solved in closed-form.

#### **3.1. The Bayesian estimation**

The estimation procedure consists of various steps: the transformation of the data into a form suitable for the computation of the likelihood function using the stationary state-space representation of the model; the choice of appropriate prior distributions; the estimation of the posterior distribution with Monte Carlo methods. These steps are discussed in turn in this section.



The Bayesian approach starts from the assertion that both the data  $Y$  and of the parameters  $\Theta$  are random variables. Starting from their joint probability distribution  $P(Y, \Theta)$  one can derive the fundamental relationship between their marginal and conditional distributions known as Bayes theorem:

$$P(\Theta|Y) \propto P(Y|\Theta) * P(\Theta)$$

The Bayesian approach reduces to a procedure for combining the *a priori* information we have on the model, as summarized in the prior distributions for the parameters  $P(\Theta)$ , with the information that comes from the data, as summarized in the likelihood function for the observed time series  $P(Y|\Theta)$ . The resulting posterior density of the parameters  $P(\Theta|Y)$  can then be used to draw statistical inference either on the parameters themselves or on any function of them or of the original data.

### 3.2. The data

Estimation is based on eight quarterly macroeconomic variables over the period 1965:1-2005:4: real consumption, the inflation rate, real residential investment, real business investment, real house prices, the 3-month short-term nominal interest rate and total hours worked in the construction and in the non-construction sectors. Our series are plotted in Figure 1. The model has implications for the deviations from steady state growth path of all these variables: in equilibrium, the transformed variables  $\widehat{C}_t = C_t/G_C$ ,  $\widehat{IK}_t = IK_t/G_{IK}$ ,  $\widehat{IH}_t = IH_t/G_H$ ,  $\widehat{q}_t = q_t/G_Q$  all remain stationary.<sup>9</sup> Similarly, given the King-Plosser-Rebelo form of the utility function, total hours in the two sectors  $N_{ct}$  and  $N_{ht}$ <sup>10</sup> remain stationary, as do inflation  $\pi_t$  and the nominal interest rate  $R_t$ .

We linearize our stationary system around the steady state growth path. For given parameter values, the solution to our model takes the form of a state-space econometric model, thus allowing to compute the likelihood function.

See Appendix A for a description of the data and the sources.

### 3.3. Calibrated parameters and Prior Distributions

**Calibration.** We calibrate some of the parameters. The parameters we calibrate include the discount factors:  $\beta, \beta'$ ; the weight on housing in the utility function  $j$ ; the technology parameters:  $\mu_c, \mu_h, \kappa, \delta_h, \delta_{kc}, \delta_{kh}$ ; the steady state gross markup  $X$ . We pick values for these parameters on the

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<sup>9</sup>In steady state, asset (debt) holdings, wages and consumption of each group will all grow at the same rate as aggregate consumption. We scale each variable by its trend growth rate before linearize our model around the steady state.

<sup>10</sup>Consistently with the aggregator we use in the production function, we define our indexes of total hours as  $N_{ct} = n_{ct}^\alpha (n'_{ct})^{1-\alpha}$  and  $N_{ht} = n_{ht}^\alpha (n'_{ht})^{1-\alpha}$ .

basis of the data sample means and other studies because they contain relatively more information on the first moments of the data.<sup>11</sup>

We set  $\beta = 0.992$ , implying a steady state real interest rate of 3 percent on an annual basis. We pick a value for  $\beta' = 0.95$ : see Iacoviello (2005) for a discussion. We fix  $X = 1.15$ , implying a steady state markup of 15% in the consumption-good sector.

The depreciation rates for housing, capital in the consumption good sector and capital in the construction sector are set equal respectively to  $\delta_h = 0.01$ ,  $\delta_{kc} = 0.025$  and  $\delta_{kh} = 0.03$ . The first number pins down the ratio of residential investment to GDP at around 5%, as in the data. The other two numbers - together with the capital shares in the production function - imply a ratio of business fixed investment to GDP around 25 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,<sup>12</sup> which indicate that construction machinery has a lower service lives than other types of nonresidential equipment.

For the capital share in the production function of goods, we choose a standard value of  $\mu_c = 0.35$ . In the production function for new homes, we choose a capital share of  $\mu_h = 0.15$  and a land share of  $\kappa = 0.10$ . The calibration of the last two numbers follows Davis and Heathcote (2005: Table 3 and footnote 19), and implies that the construction sector is relatively more labor intensive.

Finally, the weight on housing in the utility function is set at  $j = 0.12$ . Together with the other technology parameters, these choices imply that the ratio of total net wealth (the sum of fixed capital, land and housing wealth) to total, annualized GDP is around 3, whereas the ratio of housing wealth to GDP is around 1.3.<sup>13</sup>

**Priors** Our priors are in the last three columns of Table 1. We choose a rather loose prior for the standard errors of the innovations. For the persistence of the AR(1) process, we choose a beta-distribution with a prior mean of 0.8 and standard deviation of 0.1. We set the prior mean of the habit parameters in consumption ( $\varepsilon_c$  and  $\varepsilon'_c$ ) at 0.5 (with a standard error of 0.075). For the monetary policy specification, we base our priors on a standard Taylor rule responding (gradually)

<sup>11</sup>Some of the parameters that we estimate (namely, labor income share of unconstrained agents  $\alpha$  and the loan-to-value ratio  $m$ ) also affect some of the steady state ratios that the calibration aims at pinning down (this happens because in steady state the two groups have different marginal propensities to consume and to save). In preliminary estimation attempts, we fine-tuned the calibrated parameters so ensure that our target ratios were roughly as desired given the posterior distribution of the estimated parameters.

<sup>12</sup>See <http://www.bls.gov/mfp/mprcptl.pdf> (Table 1, service lives of private nonresidential equipment).

<sup>13</sup> That is:

$$GDP = \underbrace{c + c'}_{\text{Consumption.}} + \underbrace{IK}_{\text{non-residential fixed investment}} + \underbrace{qIH}_{\text{residential investment}}.$$

whereas steady state net wealth is defined

$$NW = \underbrace{k_h}_{\text{Private } k \text{ in construction sector}} + \underbrace{k_c}_{\text{Other private } k} + \underbrace{q(h + h')}_{\text{Residential housing stock}}$$

to inflation only, so that the prior means of  $r_R, r_\pi$  and  $r_Y$  are respectively 0.75, 1.5 and 0. We set a prior on the capital adjustment costs around 10 with a standard error of 2.5.<sup>14</sup>

Moving to the parameters describing the disutility of working, we center the elasticity of the hours aggregator for each agent around 2 (that is, the prior mean for  $\eta$  and  $\eta'$  is around 0.5). We select values for  $\nu$  and  $\nu'$ , the parameters describing the inverse elasticity of substitution across hours in the two sectors, around  $-2$ : high values for these numbers in absolute terms are needed (and is preferred by the model, as we will see) to generate positive comovement in hours across the two sectors.<sup>15</sup>

We select the prior mean of the Calvo parameter  $\theta$  to be around 0.75, with a standard deviation of 0.05. The prior for the indexation parameter  $\gamma$  is loosely centered around 0.5.

Finally, our prior mean for the loan to value ratio is set around 0.8, with little standard error, based on the assumption that this number is readily identifiable from common practice in the mortgage market. We set the prior mean for the labor income share of unconstrained agents to be 0.65, with a standard error of 0.05. This is a value in between the range of estimates in the literature: for instance, using aggregate data, Campbell and Mankiw (1989) estimate a fraction of rule-of-thumb/constrained consumers around 40 percent. Using the 1983 Survey of Consumer Finances, Jappelli estimates 20 percent of the population to be liquidity constrained.

## 4. Results

### 4.1. Posterior Distributions

We estimate 32 parameters. Of these, 14 pertain to the standard deviation and the autocorrelation of the shocks (we assume eight shocks, but do not allow for autocorrelation in the monetary shock and the inflation shock). Three parameters govern the rate of technological progress, two measure capital adjustment costs, two measure the degree of habit formation, four pertain to the labor supply schedule, two to the Phillips curve, three to the Taylor rule. The remaining two parameters,  $\alpha$  and  $m$ , measure respectively the labor income share of unconstrained households and the average loan-to-value ratio for the credit-constrained agents.

We report the estimated posterior mean, median and confidence intervals for our estimated parameters in Table 1.

Our estimated results can be summarized as follows. The estimate of the Calvo parameter implies that prices are reoptimized very infrequently, once every 3 years. We interpret the result as evidence that prices are not very sensitive to the marginal cost measure implied by our model.

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<sup>14</sup>Given our capital adjustment cost specification, the implied elasticity of investment to its shadow value is given by  $1/\phi\delta$ . Our prior corresponds to an elasticity of investment to its shadow price of around 4, a reasonable value.

<sup>15</sup>Using a similar functional form, and using a reduced form approach, Horvath (2000) estimates a value of  $\nu$  equal to  $-1$ .

Another feature of our model is that capital in the construction sector is less costly to adjust than capital in the consumption sector. Together with the high volatility of the Solow residual in the construction sector, it generates high volatility of residential investment. Both agents exhibit moderate-to-high degree of habit formation in consumption, relatively high labor supply elasticities, and relatively little preference for mobility across sectors.

As expected, we find a faster rate of technological progress in the business fixed investment sector, following by the consumption good sector, and by the housing sector. At the posterior mean, the estimates imply, in particular, that the long-run annualized growth rates of real per worker consumption, real per worker housing investment and real house prices are respectively 1.90 percent, 0.55 percent and 1.35 percent. The slow growth rate of TFP in the construction sector is perhaps not surprising nor new, although it has not been cited often as one of the explanations for the increase in house prices seen in the data: interestingly, Corrado et al. (2006) construct measures of TFP growth for the period 1987-2004 at sectoral level for the US economy and they find that, for the construction sector, measured productivity change is negative, and increases in the contribution of labor and purchased inputs more than account for the real output growth of the sector.

Our key parameters of interest relate to the loan-to-value ratio and to the fraction of credit constrained agents. The estimated value of  $m$  essentially lines up with its prior. As for  $\alpha$ , our model implies a share of labor income of credit constrained agents around 21%. This fraction is enough to generate a positive elasticity of consumption to a housing shock, something that we discuss more in detail in the next section.

Finally, all shocks are estimated to be quite persistent.

## 4.2. Impulse Responses

In Figures 3 to 10 we present the impulse responses of our model. The effects of most shocks are familiar.

[ COMPLETE DISCUSSION ON THE EFFECT OF THE VARIOUS SHOCKS ]

Of particular interest, of course, are the effects of the housing preference shock (a persistent increase in the marginal utility of housing), shown in Figure 3. By causing an increase in house prices, the disturbance produces two effects. On the one hand, it raises the returns to investing in the construction sector, thus causing residential investment to rise. On the other, it increases the collateral capacity of constrained agents, thus causing their consumption to increase. Because they have a high propensity to consume at the margin, the effects on aggregate consumption are positive, even if consumption of the lenders falls. The size of the effect depends on  $\alpha$ , the labor income share of unconstrained people. It is possible to show that, when  $\alpha$  is high, few agents are credit constrained, and most resources are channelled into the construction sector, thus causing a

larger boom in housing investment. When  $\alpha$  is low, many agents are credit constrained, resources are shifted to these agents (and diverted from firms), and aggregate consumption rises. To illustrate the mechanism, Figure 16 plots the short-run elasticities<sup>16</sup> of the three components of aggregate demand ( $C$ ,  $IH$  and  $IK$ ) to house prices, for different values of  $\alpha$ . Our mean estimate of  $\alpha$  (around 21 percent) percent implies a medium-run elasticity of consumption to housing around 0.05, and an elasticity of investment to house price shocks around 0.3. Hence, the presence of credit constrained households shifts the action from investment to consumption.

Figure 6 displays the model responses to an adverse monetary policy shock. Perhaps the most interesting aspect is that the response of residential investment, while negative, is smaller than the response of business fixed investment, and of the same order of magnitude as the response of consumption. The fact that *flexible price* durable goods would tend to move countercyclically in response to monetary shocks has been stressed by Barsky, House and Kimball (2006) and Carlstrom and Fuerst (2006).<sup>17</sup> The mechanism at work in our paper that generates comovement across sectors is the low elasticity of substitution across hours in the two sectors. However, quantitatively the response of residential investment to a monetary shock, while negative, is much smaller than what is typically found in VAR studies (see for instance Erceg and Levin, 2005).

### 4.3. Variance Decompositions and other moments

Table 2 shows that our model accounts well for most moments of the actual time-series.

In Table 3 we present the results from the variance decomposition exercise. Two results immediately stand out. First, a large fraction of volatility (around 68 percent of the asymptotic variance) in residential investment is due to housing investment shocks. Second, around 66 percent of house price volatility can be accounted for by shifts in the marginal rate of substitution between housing and other goods. At first, this might be disappointing. We view in any case as informative that while the usual suspects (technology, money, inflation shocks) can account for a large chunk of economic fluctuations, they fall short of accounting at the same time for the observed volatility of housing prices and investment, so that their “own” innovations, that one can think of as residuals, are forced to explain the residual variance.

Why are measures of technology shocks in the construction sector so much more volatility than in the other sector? Here, we offer some speculative comments. First, the low volatility of the Solow residual in the other sector might reflect aggregation bias. Second, by its own nature, the construction sector is more exposed to seasonal cycles.

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<sup>16</sup>These responses are computed calculating the average deviation from the baseline of each series for the first 4 quarters after a shock.

<sup>17</sup>This result occurs because the reduction in demand in the consumption good sector leads to a decline in the production cost of housing goods, and thus to an expansion in that sector. See also Monacelli (2006) for a further discussion in a new-keynesian model with borrowing constraints.

There are however two important lessons that we learn from the exercise: even with suitably chosen frictions, aggregate technology shocks and monetary shocks cannot fully account for the observed volatility in housing prices and housing investment. Second, because a large part of the house prices fluctuations at medium to high frequency can, to some extent, be viewed as exogenous, it offers us the possibility to ask the counterfactual question: how big has been the contribution of the housing boom to the recent US business cycle? We investigate the question in the next section.

## 5. Applications

### 5.1. The contribution of housing prices to the turn-of-the-century recovery

Greenspan “Nonetheless, it is difficult to dismiss the conclusion that a significant amount of consumption is driven by capital gains on some combination of both stocks and residences, with the latter being financed predominantly by home equity extraction” (Alan Greenspan)<sup>18</sup>

Several commentators, policymakers and central bankers have remarked how the housing boom of the turn of the century has stimulated consumption through home equity withdrawal on the one hand, and employment and production in the construction industry on the other. In this subsection, we try to quantify how large the effects of the housing boom were. We do so by comparing the actual data with the data that obtain shutting off the housing preference shock, beginning in 2002Q1: this is the period when the model identifies the beginning of the housing boom, through a series of above average realizations of  $\varepsilon_{jt}$ , the iid component of the autoregressive preference shock.

A comparison of the actual with the counterfactual data (shown in Figure 11) allows quantifying how the housing boom has contributed to strong consumption and strong residential investment throughout the same period.

### 5.2. What if the Fed had been aggressive against house prices inflation?

“Thus, at this point, a leveling out or a modest softening of housing activity seems more likely than a sharp contraction, although significant uncertainty attends the outlook for home prices and construction. In any case, the Federal Reserve will continue to monitor this sector closely.” (Ben Bernanke)<sup>19</sup>

In Figure 15, we compare actual and counterfactual series under the assumption that the Fed responds to house price inflation beginning in 2001Q4. That is, we simulate the model history until 2001 under the assumption that the Fed does not respond to house prices. At the onset of

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<sup>18</sup><http://www.federalreserve.gov/boardDocs/Speeches/2005/200509262/default.htm>

<sup>19</sup><http://www.federalreserve.gov/boarddocs/hh/2006/february/testimony.htm>

the housing boom, we assume that the Fed changes policy and responds to house price inflation, and agents behave from then on in accordance with the Fed policy. The change is assumed to be unanticipated, permanent, fully credible, and immediately learnable by the agents. We then feed in the model the sequence of our estimated smoothed shocks, and compare the realizations of the model series with the actual data. We find that the US would have experienced high interest rates, only slightly lower house price inflation, and much lower output growth if the Fed had responded to house prices.

### 5.3. Financing constraints and the Great Moderation

**Great Moderation.** A natural question to ask is to what extent financing constraints might have played a role in the Great Moderation. We estimate the model recursively for various subsamples, starting with the period 1965Q1-1984Q4 and moving the estimation window ahead one year at the time, while keeping the size of the sample constant at 20 years. The last subsample is thus 1986Q1-2005Q4, which means that we produce 22 posterior distributions for each of our estimated parameters.<sup>20</sup> We find that, for large part, most of the Great Moderation seems to be accounted by reduced volatility of the underlying macroeconomic shocks. Variation in most of the model structural parameters seem minor in size and temporary in nature. One interesting exception has to do with the parameters of the Taylor rule. In the later part of the sample, it appears that the policy rule has become more aggressive against inflation.

**Evolution of credit constraints over time.** Who are the credit constrained people? In our model, credit constrained agents happen to be constrained because they discount the future heavily, are up against the maximum borrowing limit at the equilibrium rate. A natural question to ask is whether we can map the credit constrained people, that in our model we indirectly infer from the data, to something that can be observed more directly. There are reasons to believe that credit constraints apply more often to young people, who, as remarked by Tobin (1980), are “frequently young families acquiring homes and furnishings before they earn incomes to pay for them outright; given the difficulty of borrowing against future wages, they are liquidity-constrained and have a high marginal propensity to consume”.

In Figure 17, we plots are recursive estimates of  $1 - \alpha$ , the labor share of constrained agents, against the a 20-year moving average of the fraction of US population aged between 25 and 39. Indeed, there is a close positive correlation between the two series (around 60 percent). We view this as prima facie evidence that demographics, by affecting the fraction of agents who are credit constrained, might have interesting implications for business cycle dynamics.

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<sup>20</sup> A similar exercise in the context of a simple dynamic-new-keynesian model is also undertaken by Canova (2005).

## 6. A Sticky-Price, Sticky-Wage Economy

[ VERY PRELIMINARY ]

Barsky, House and Kimball (2006) and Carlstrom and Fuerst (2006) have remarked the importance of sticky wages to account for the large negative elasticity of durable consumption and residential investment following a monetary tightening. They show how sticky non-durable prices and flexible durable prices generate a counterfactual boom in durable expenditure after a negative monetary shock. Our estimated model avoids result this by uncovering a low degree of intersectoral mobility and high rigidity in the sticky price sector. Yet the response of residential investment to a monetary tightening (shown in Figure xxx) is only slightly negative, and of the same order of magnitude of that of consumption.

We can easily adapt our model to account for wage rigidity. We follow Erceg, Henderson and Levin (2000) to allow for monopolistic competition at the wage-setters level and Calvo-style wage adjustment at level of each group of workers for each sector. The labor supply schedules now include a wage markup between the marginal benefit of working and its disutility cost. In addition, wage inflation depends on current and future expected changes in the wage markup. We estimate the same model as before by adding real wages as an additional observable (nine series), and allowing for observation error in the hours in the construction sector (eight shocks plus one source of observation error). Besides the same parameters as before, we now also estimate the probability of not-adjusting wages  $\theta_w$  and the inertia in the wage setting behavior  $\gamma_w$ . We find moderate wage rigidity ( $\theta_w = 0.5$ ); our estimate of the Calvo parameters drops (from 0.9 to 0.8); larger negative effects of monetary shocks on residential investment: in particular, the initial response of residential investment to a monetary shock is similar in size and shape to that of business fixed investment.

## 7. Related Literature

### 7.1. Where does our paper belong?

Our approach is related to several strands of literature.<sup>21</sup> In particular, it combines four main elements: (1) two sectors, one producing consumption and investment goods, the other producing new housing; (2) nominal rigidities; (3) financing frictions in the household sector; (4) a rich set of shocks, which are essential to take the model to the data.

Greenwood and Hercowitz (1991) is perhaps the most well-known paper dealing with (1). In their setup, the “consumption” sector produces consumption goods, nonresidential capital and residential capital, whereas the housing sector uses residential capital to produce housing services. (In our formulation, the non-housing sector produces an intermediate investment good that is then

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<sup>21</sup>For obvious reasons, we refrain from offering a detailed survey of all papers that have dealt with housing and business cycle, and we refer the reader to Leung (2004) for a detailed survey.



combined with labor and land to produce homes). Greenwood and Hercowitz interpret the two capital stocks in the non-housing sector as nonresidential and residential capital, and calibrate their model accordingly; instead, our two types of capital  $k_h$  and  $k_c$  stand for capital in the construction sector (such as cranes, tractors and the like) and all other nonresidential capital, respectively. They assume reversibility between residential and business capital, which implies that the relative price of housing will always be unity. Davis and Heathcote (2003) use a multisector model with intermediate goods production in which construction, manufacturing and services are combined, in different proportions, to produce consumption, business investment, and residential structures. Residential structures are then combined with land to produce new homes. On the supply side, their model setup shares some features with ours. Obviously, because our goal is to take the model to the data and to use it for monetary policy analysis, we allow for a rich set of intertemporal and intratemporal disturbances and stochastic shifts in productivity.

Edge, Kiley and Laforte (2005) integrate (1), (2) and (4). They distinguish between two production sectors, which (as in our paper) differ in their long-run growth rates of technological progress. They also distinguish between several categories of household expenditure, namely consumption of nondurables and services, investment in durables, and investment in residences. In the same vein, Bouakez, Cardia and Ruge-Murcia (2005) estimate a model with heterogenous production sectors, that differ in price stickiness, capital-adjustment costs and production technology, and use output from each other as material and investment inputs following an Input-Output Matrix and Capital Flow Table that represent the U.S. economy. None of these papers deals explicitly with housing prices and housing investment, which are, instead, our main focus of analysis.<sup>22</sup>

Several papers have done a better job than us in developing realistic models of housing investment in models with incomplete markets and financing frictions on the household side, thus combining elements of (3) and (1). Gervais (2002) and Diaz and Luengo-Prado (2005) look at the properties of housing investment in a model in which housing is illiquid and can be used as collateral: however, they care about quantities not prices. Nakajima (2005) looks at the long-run implications for housing prices of earnings uncertainty: in his setup, housing prices move, but the quantity is fixed. Lustig and Van Nieuwerburgh (2005) study in detail the asset pricing implications of this class of models.<sup>23</sup>

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<sup>22</sup>Monacelli (2006) also attempts at integrating (1), (2) and (3) in a model without capital, but he limits itself to studying how borrowing constraints and nominal debt affect the response of durables to a monetary shock.

<sup>23</sup>Topel and Rosen (1988) build a prototype model of residential investment without nominal rigidities and credit market frictions. In their setup, housing demand is infinitely elastic at the market interest rate, and the housing supply curve is upward sloping, with different short and long run price elasticities. Depending on the specifications, they find a short-run supply elasticity of housing investment around unity: this value is three times larger than our estimate of the response of housing investment to a real house price shock. We feel that some form of misspecification in their model might drive the difference between our and their results. See Davis and Heathcote (2005) for a similar point.

## 7.2. What drives housing prices and housing investment? Some alternative explanations

Our variance decomposition illustrates how the largest bulk of fluctuations in house prices at cyclical frequencies comes from shifts in the marginal utility of housing.

It is instructive to put the result into the context of the large macro (non DSGE) literature which has tried to explain short and long-run fluctuations in the price of housing.

1. Martin (2006) uses a Lucas asset pricing model to quantitatively account for the secular in real house prices, the path of real interest rates, and the timing of low-frequency fluctuations in real house prices over the period 1963-2003. The model predicts that the primary force underlying the evolution of real house prices is the systematic and predictable changes in the working age population driven by the baby boom. In his basic setup, the housing stock is fixed, and changes in the size of the working age population determine the labor input into the production function.
2. Some studies have looked at the link between inflation and asset prices. Here, we mention two:
  1. Brunnermeier and Parker (2006) show that a reduction in inflation can fuel run-ups in housing prices if people suffer from money illusion. When individuals have to decide whether to rent or buy, money illusion from lower inflation tilts preferences from renting towards owning, thus raising house prices when inflation is low, and depressing them when inflation is high. Their mechanism is well suited to explain the recent housing boom, but cannot explain why house prices went up during the high-inflationary episodes of the 1980s.
  2. Piazzesi and Schneider (2006) build an OLG model to show that the Great Inflation led to a portfolio shift by making housing more attractive than equity, thus fueling the housing boom of the 1980s. Their mechanism is well suited to explain the housing boom of the 1980s, but cannot explain why house prices have gone up at the turn of the century.
3. Glaeser, Gyourko, and Saks (2005) cite regulatory obstacles, such as stiffer zoning laws and the ability of existing owners to prevent new construction, as a primary reason why housing prices have risen so much since the 1970s.

These explanations are intriguing, but disagreements among economists clearly shows how any one-size-fits-all explanation of housing boom and busts is hard to test against competing hypotheses, and cannot offer a satisfactory account of trend and cyclical movements at the same time. We

view our structural approach, with multiple shocks competing with each other to explain different properties of various macroeconomic time-series including housing prices and housing investment, as complementary to this studies and definitely more useful if one wants to do policy or welfare analysis.<sup>24</sup>

## 8. Conclusions

In this paper, we have estimated a model of the housing market and the business cycle. From the methodological point of view, our analysis has proceeded in the spirit of Smets and Wouters (2003), by including a relatively large range of shocks and by using Bayesian methods for model estimation and for evaluation of model fit. Our main finding is that the effect of housing market developments on the rest of the economy can be nontrivial, especially in periods of high volatility of the housing market.

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<sup>24</sup>Fisher and Quayyum (2006) use a structural VAR approach to explain the dynamics of residential investment in response to aggregate TFP shocks, monetary shocks and investment-specific shocks. They conclude that high residential investment has been the result of wealth accumulation from previously high rates of technological progress.

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## Appendix A. Data and sources

**Aggregate Consumption** ( $C$ ): Real Personal Consumption Expenditure (seasonally adjusted, Billions of chained (2000) dollars, Table 1.1.5), divided the Civilian Non-institutional Population over 16 (CNP16OV). Source: Bureau of Economic Analysis.

**Business Fixed Investment** ( $IK$ ): Real Private Non Residential Fixed Investment (seasonally adjusted, Billions of chained (2000) dollars, Table 1.1.6.), divided by CNP16OV. Source: Bureau of Economic Analysis.

**Residential Investment** ( $IH$ ): Real Private Residential Fixed Investment (seasonally adjusted, Billions of chained (2000) dollars, Table 1.1.6.), divided by CNP16OV. Source: Bureau of Economic Analysis.

**Inflation** ( $\pi$ ): Quarter on quarter log differences in the Implicit Price Deflator for the Nonfarm Business Sector.

**Nominal Short-Term Interest Rate** ( $R$ ): Nominal 3-Month Treasury Bill rate (Secondary Market Rate). Series ID: H15/H15/RIFSGFSM03\_NM. Source: Board of Governors of the Federal Reserve System.

**Real House prices** ( $q$ ): 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](http://www.census.gov/const/price_sold_cust.xls)

**Hours in Consumption-Good Sector** ( $N_c$ ): Total Nonfarm Payrolls (Series ID: PAYEMS) less All Employees (Series ID: USCONS) in the Construction Sector, times Average weekly hours of production workers (series ID: CES0500000005), divided by CNP16OV. Source: U.S. Department of Labor: Bureau of Labor Statistics.

**Hours in Housing Sector** ( $N_h$ ): All employees in the construction sector (Series ID: USCONS. Source: U.S. Department of Labor: Bureau of Labor Statistics) times Average weekly hours of construction workers (series ID: CES2000000005), divided by CNP16OV.

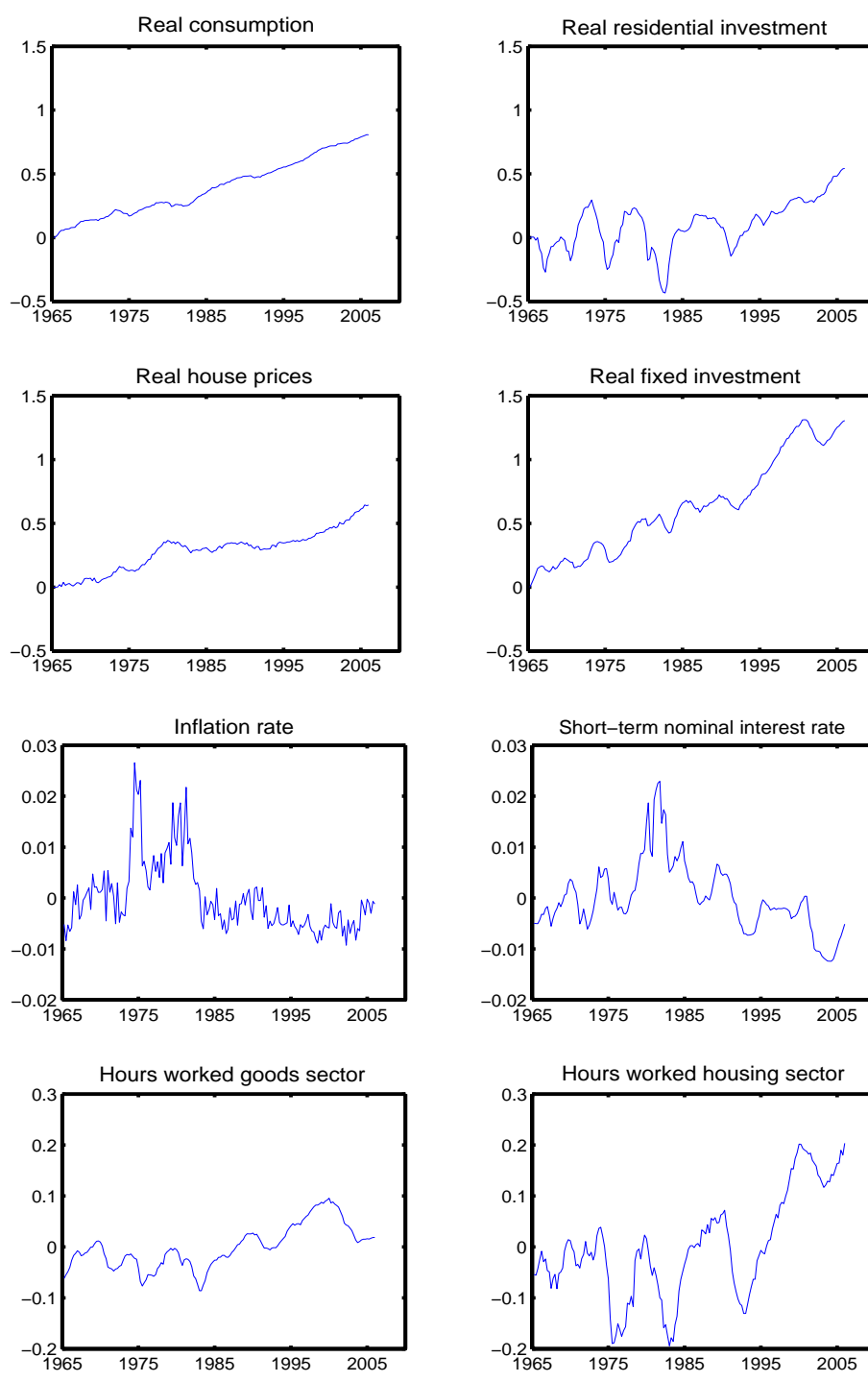


Figure 1 Data

*Note:* Variables in the top panel (with the exception of real house prices) are divided by civilian noninstitutional population age 16 and over, log-transformed. The first observation (1965:1) is normalized to zero. Variables in the bottom panel are de-meant. Hours worked in the two sectors are defined as total hours divided by population.

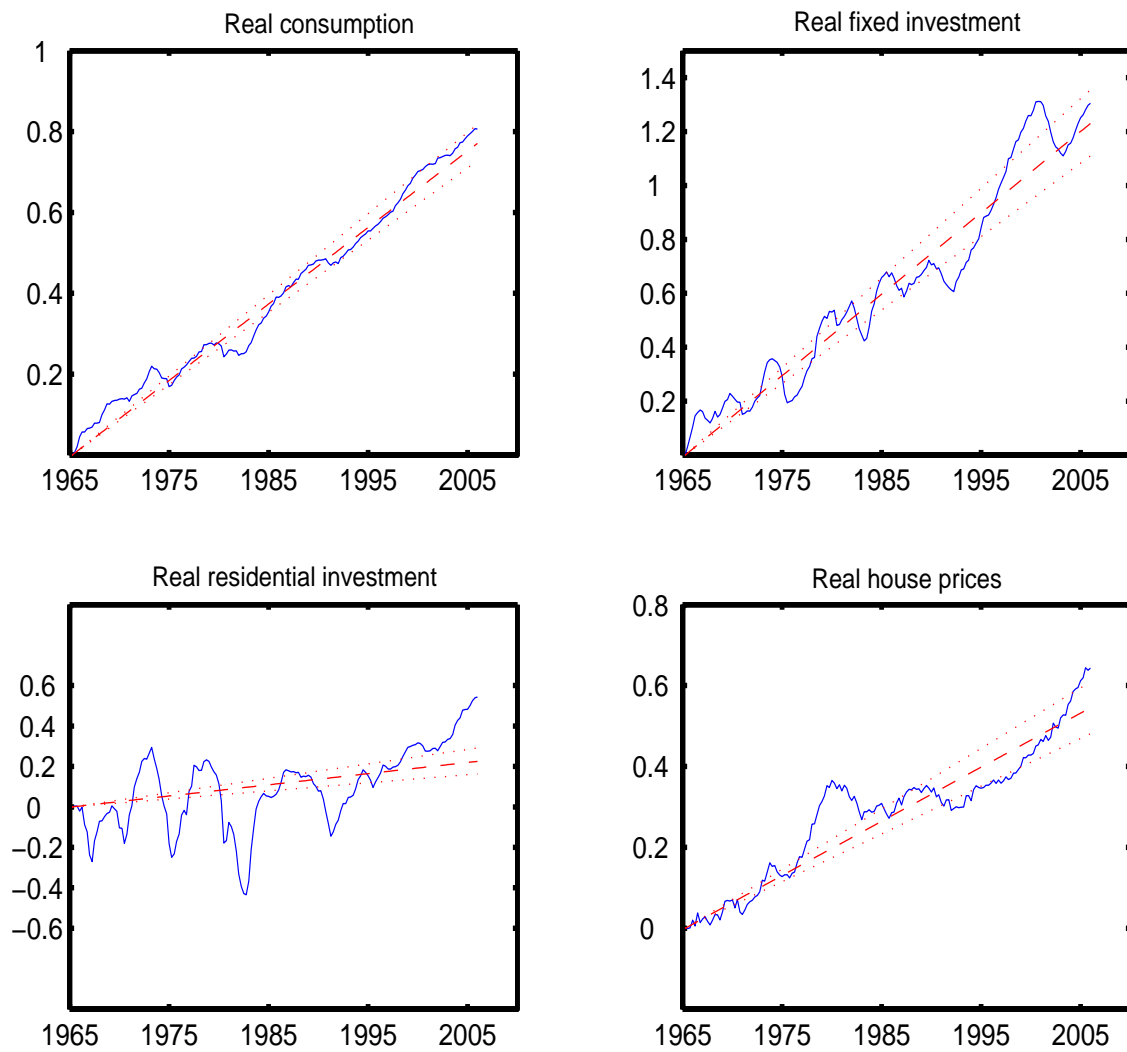


Figure 2 Data and estimated trends

*Note:* Red dashed line corresponds to the median of the posterior distribution of the trend. Red dotted lines corresponds to 5 and 95 percentiles, blue solid line the data.



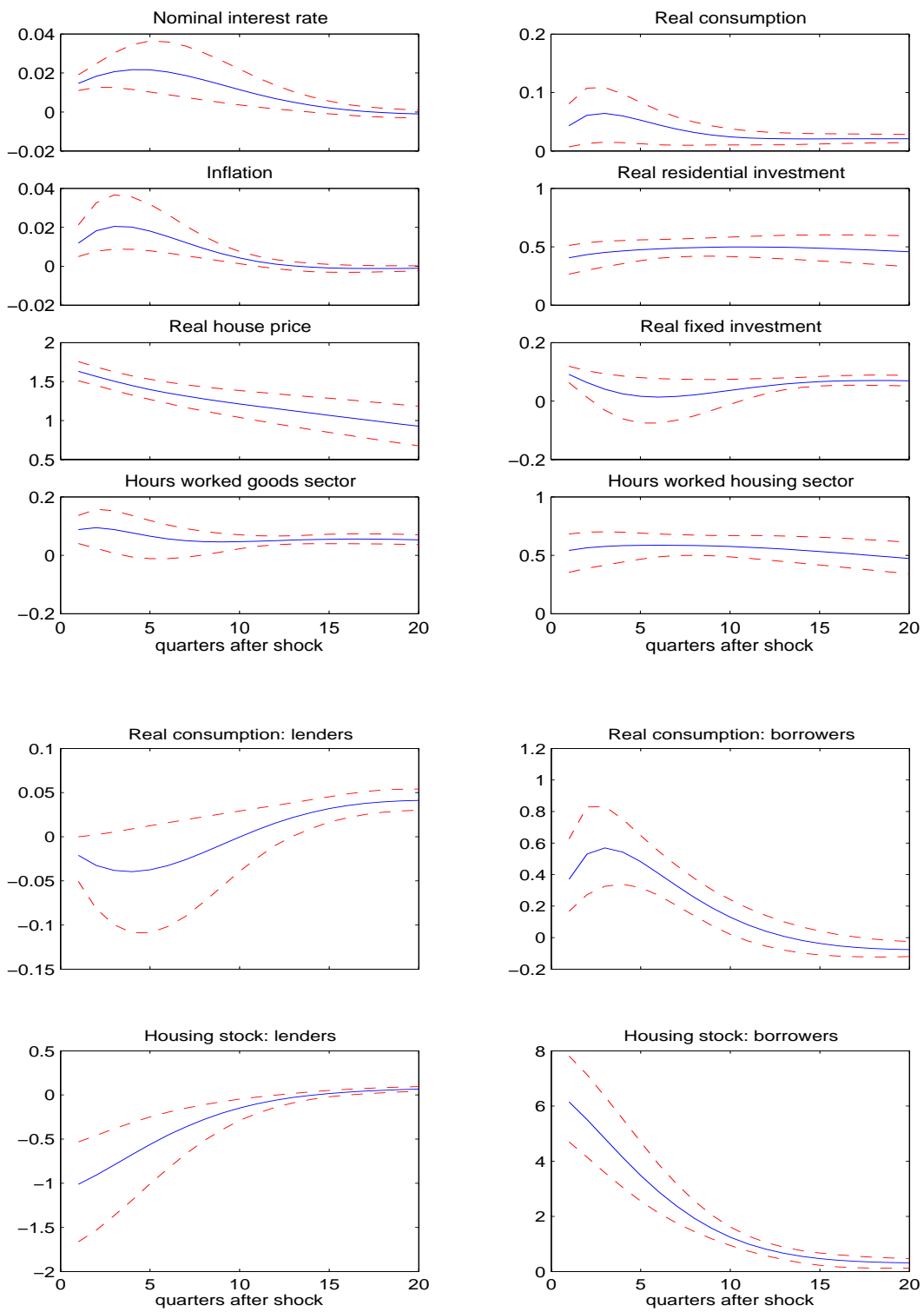


Figure 3 Impulse responses to a positive housing preference shock

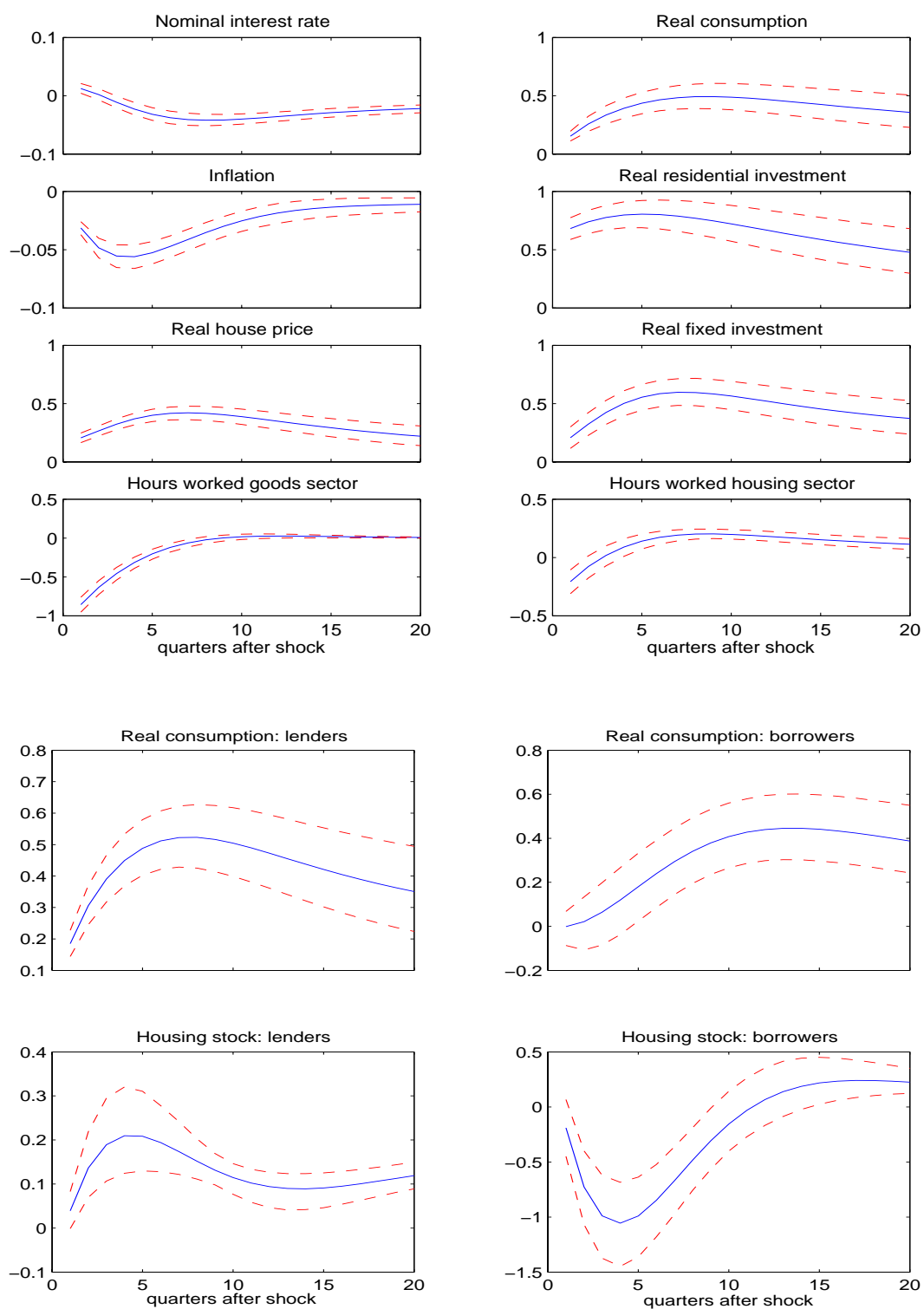


Figure 4 Impulse responses to a positive technology shock in the goods sector

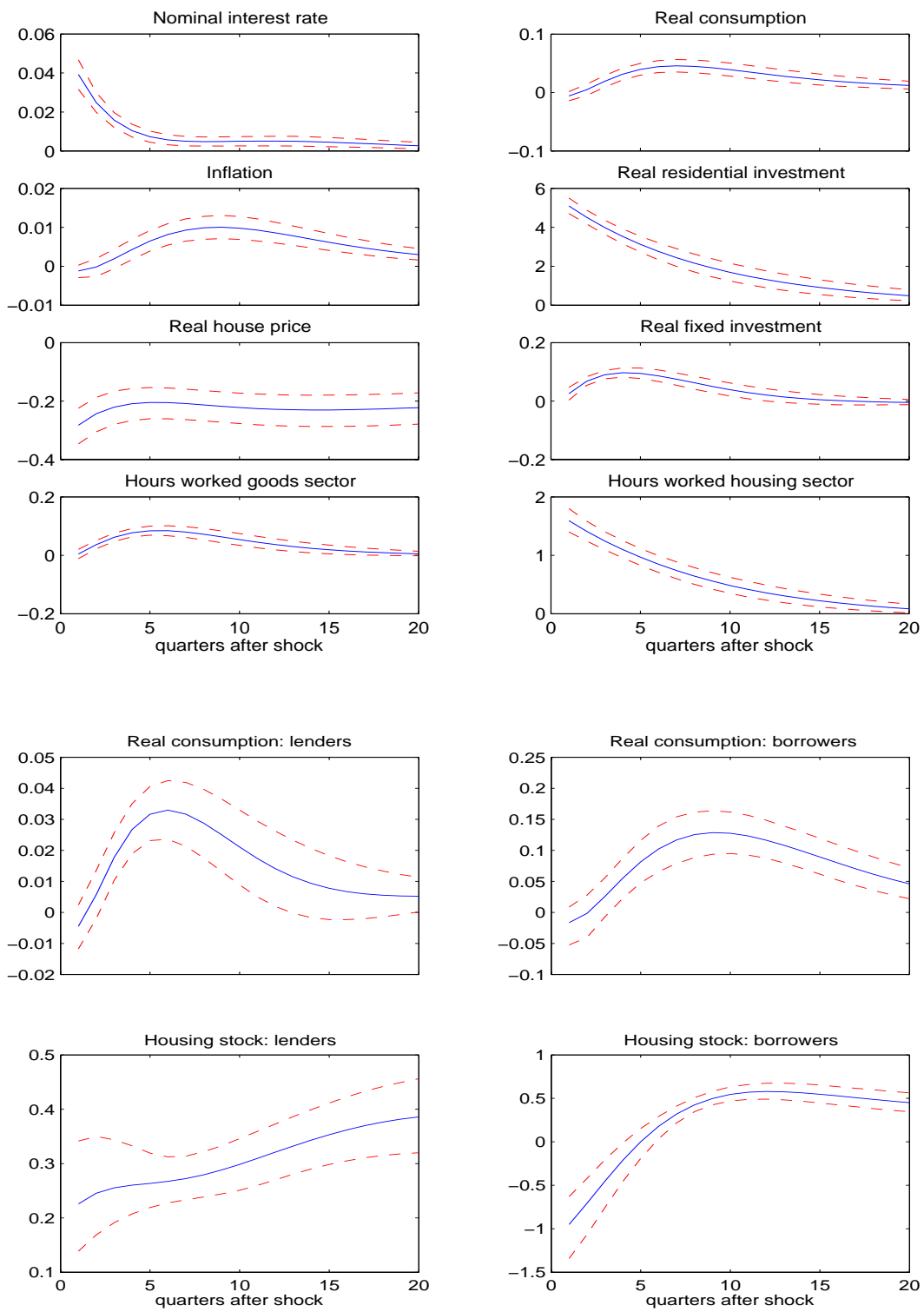


Figure 5 Impulse responses to a positive technology shock in the housing sector

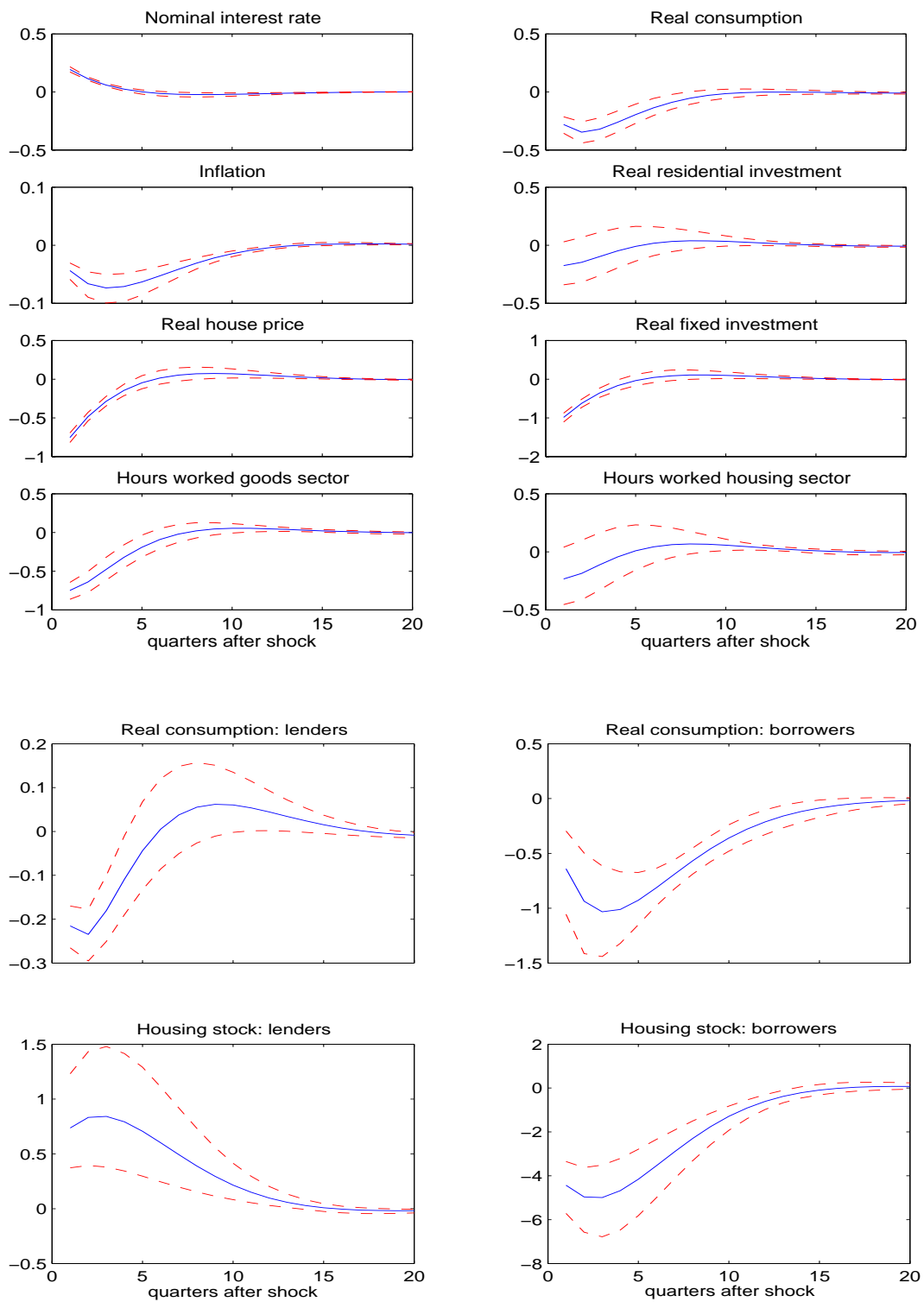


Figure 6 Impulse responses to a negative monetary policy shock

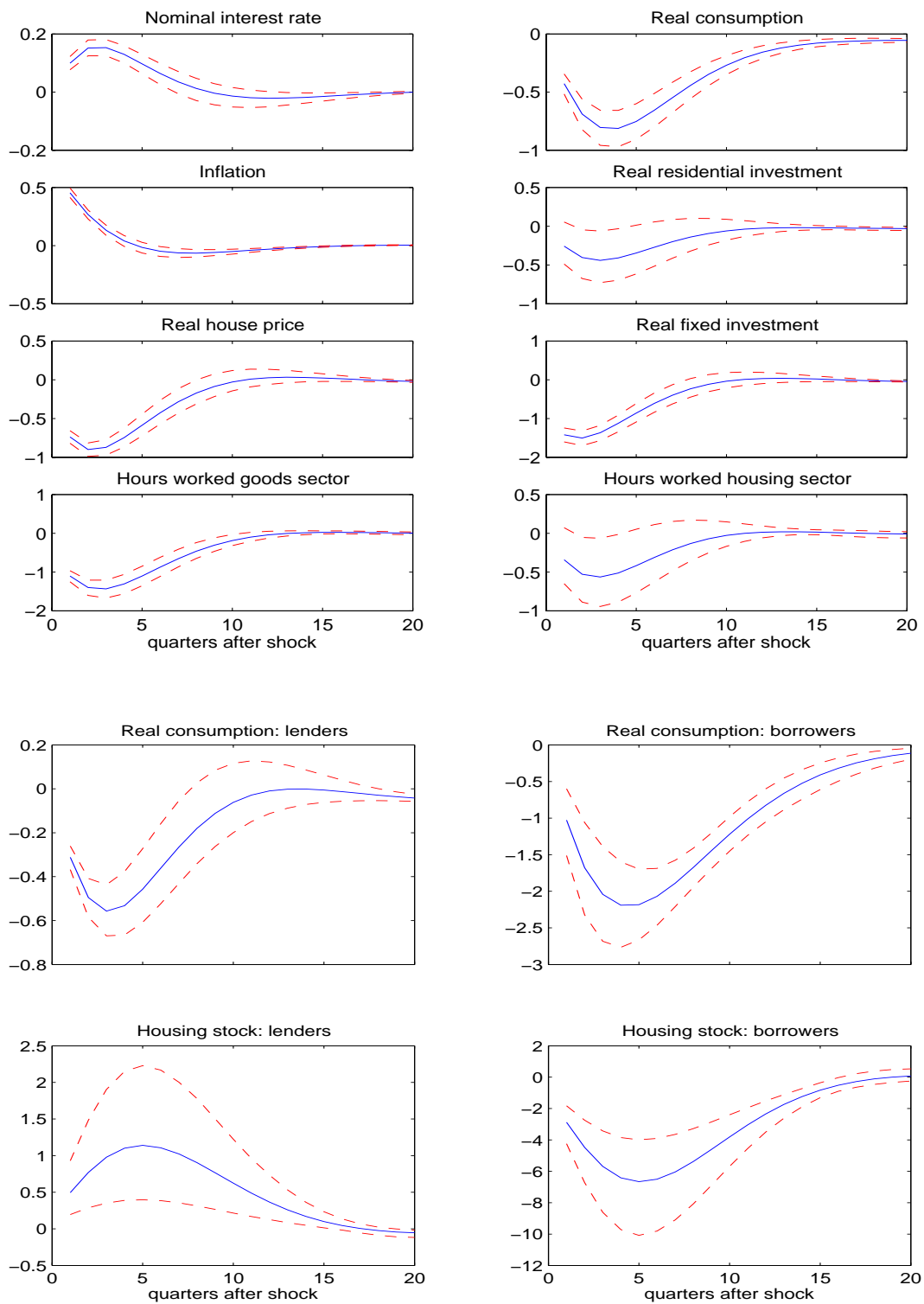


Figure 7 Impulse responses to a negative cost-push shock

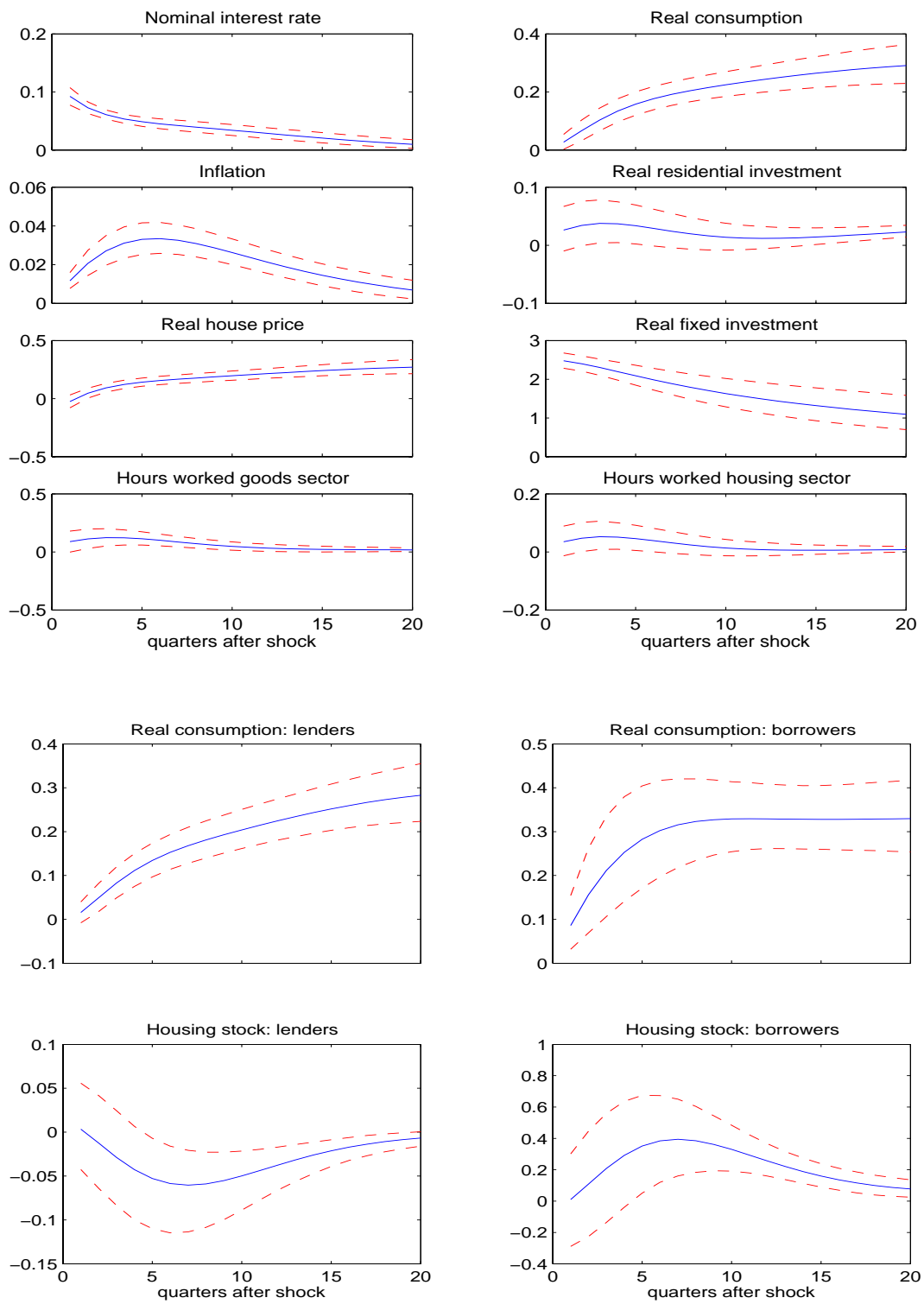


Figure 8 Impulse responses to a positive investment specific technology

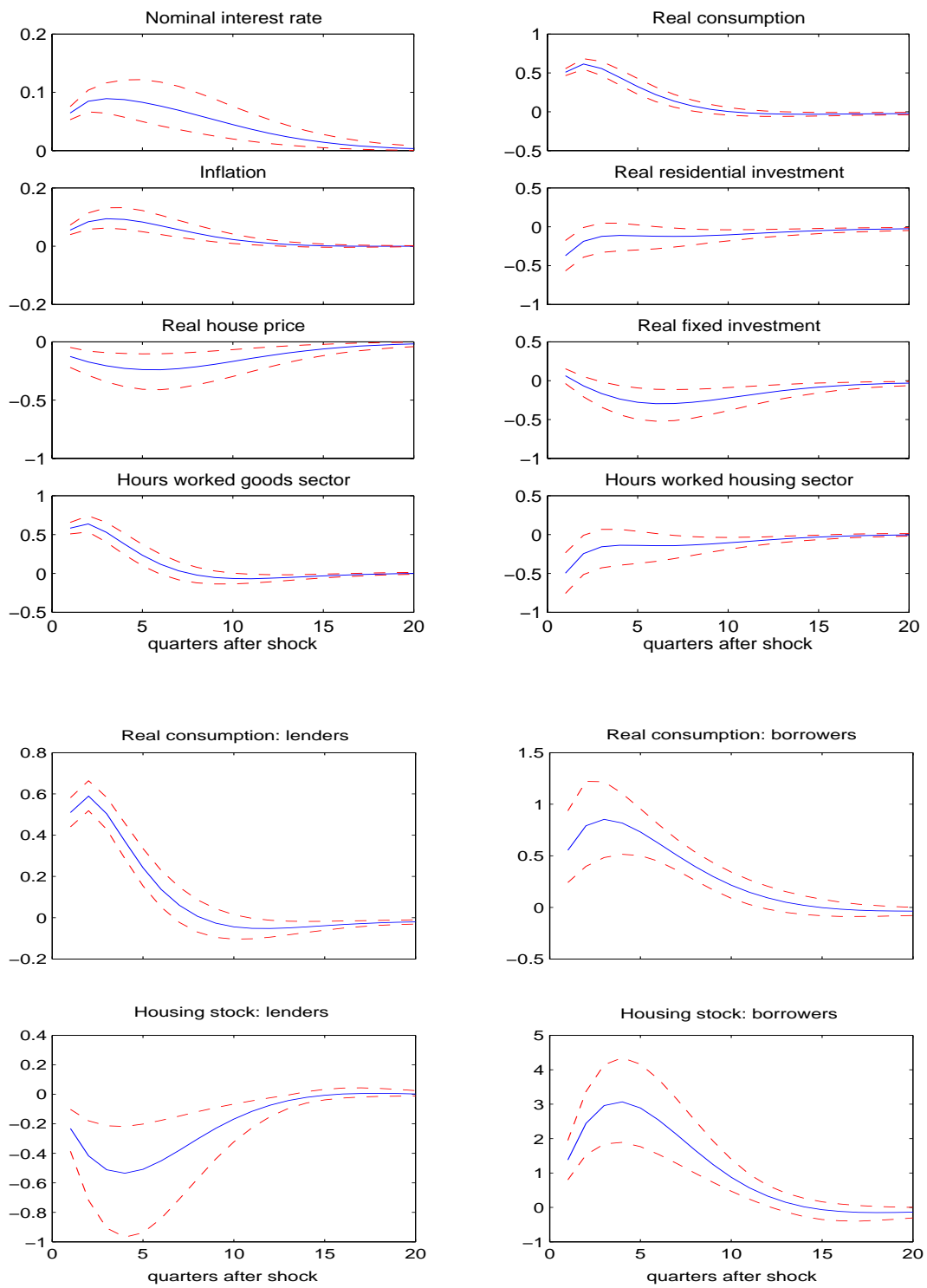


Figure 9 Impulse responses to a positive preference shock

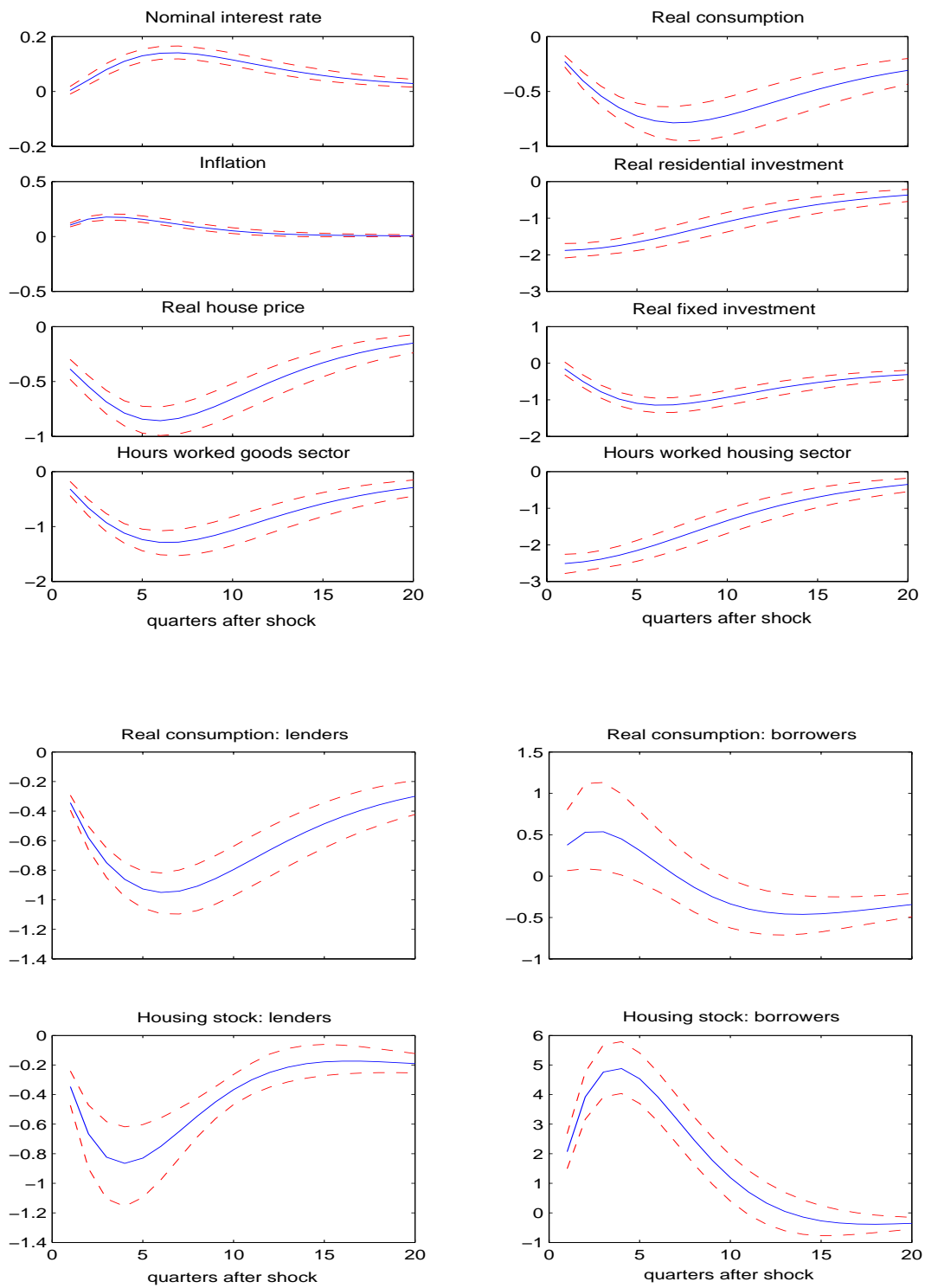


Figure 10 Impulse responses to a negative labor supply shock



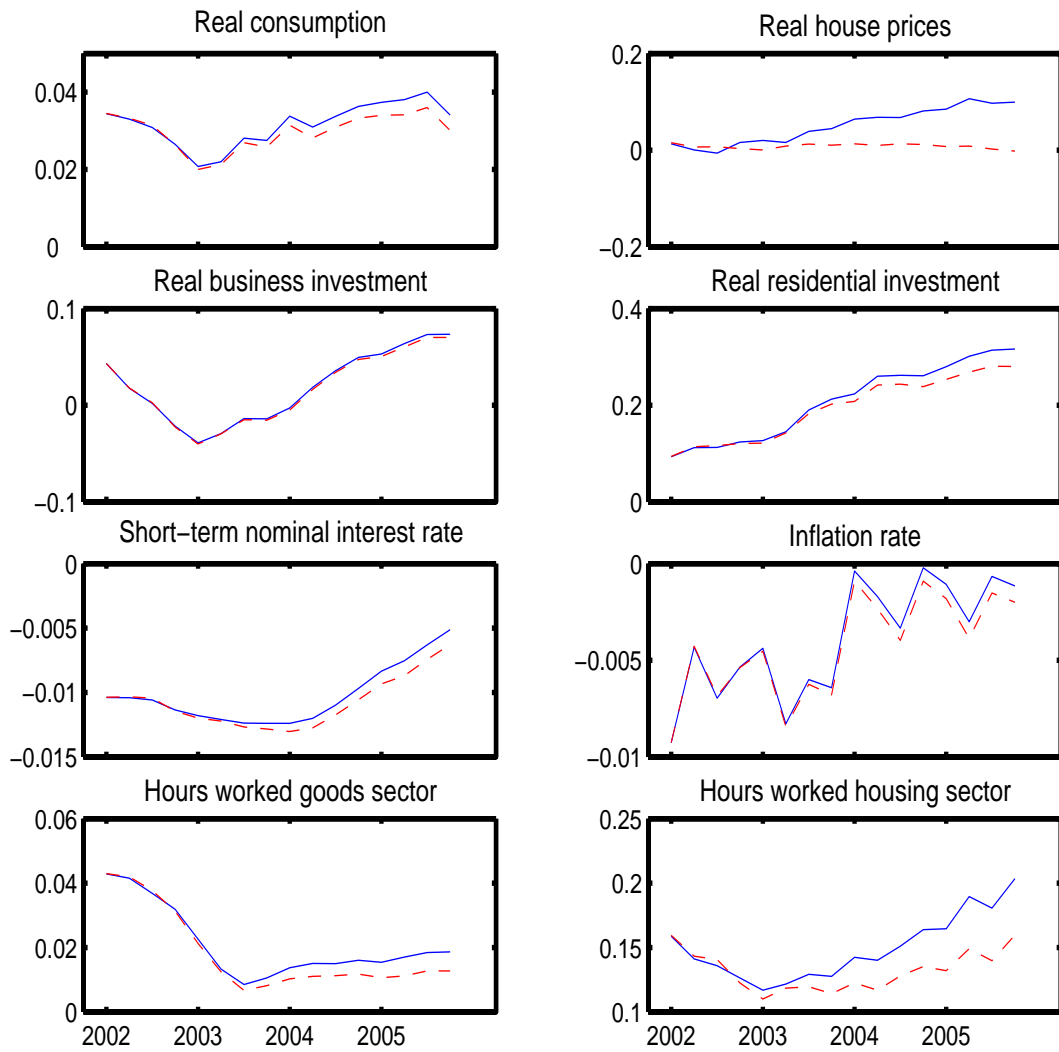


Figure 11 Counterfactual experiment: What if there had been no housing demand shocks from 2002:1 onwards

*Note:* Red dotted lines correspond to the path of the variables in the counterfactual experiment. Blue solid line corresponds to the data. In the simulation the mean of the posterior distribution has been used.

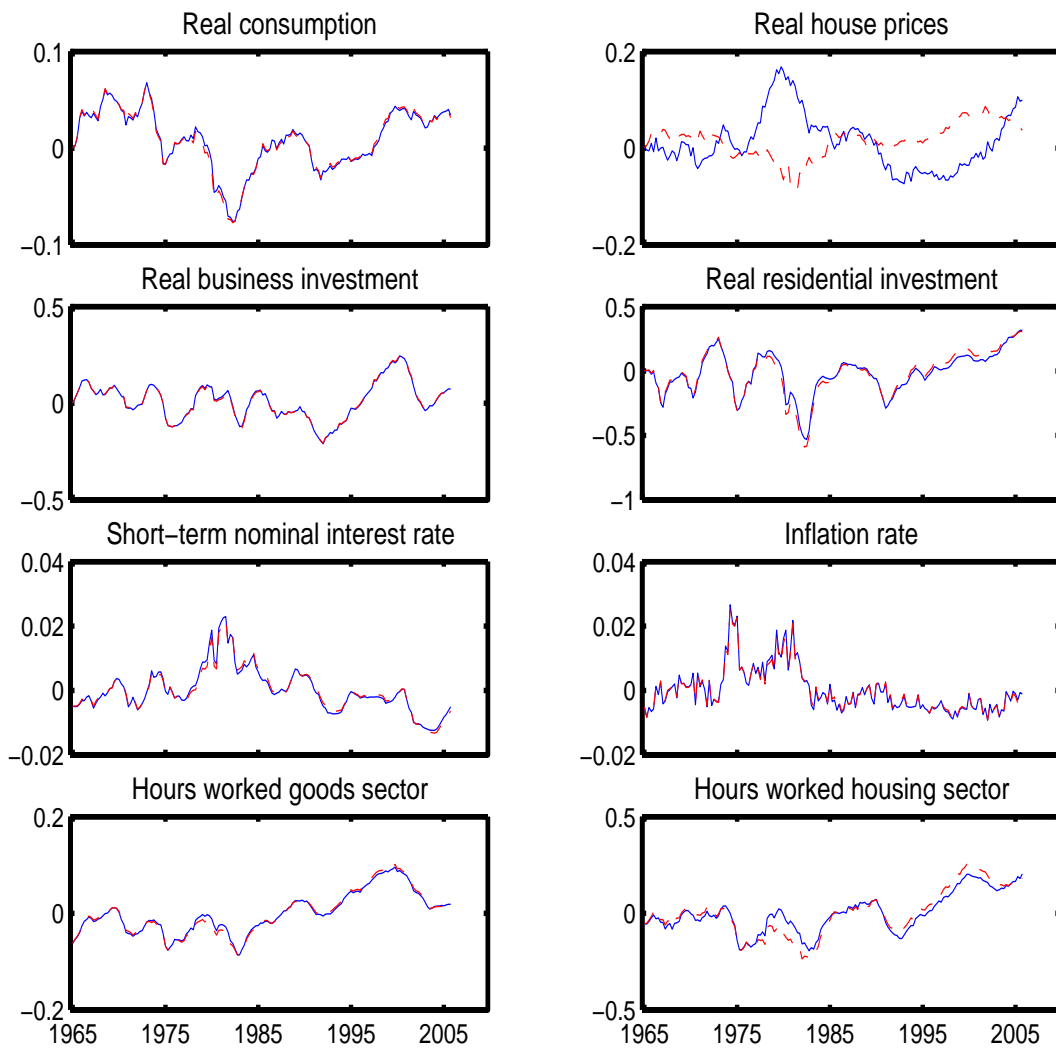


Figure 12 Counterfactual experiment: What if there had been no housing demand shocks from 1965:1 onwards

*Note:* Red dotted lines correspond to the path of the variables in the counterfactual experiment. In the simulation the mean of the posterior distribution has been used.

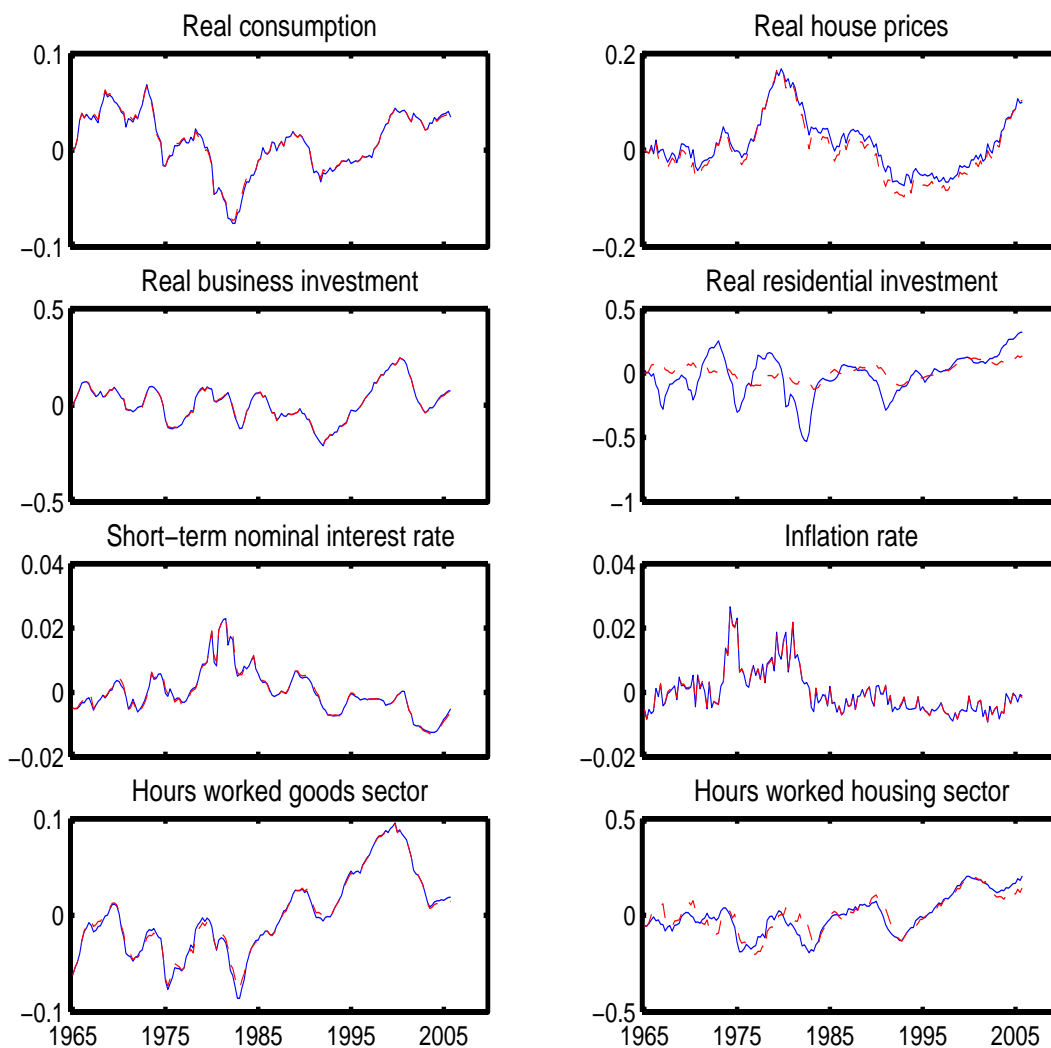


Figure 13 Counterfactual experiment: What if there had been no technology shocks in the housing sector from 1965:1 onwards

*Note:* Red dotted lines correspond to the path of the variables in the counterfactual experiment. In the simulation the mean of the posterior distribution has been used.

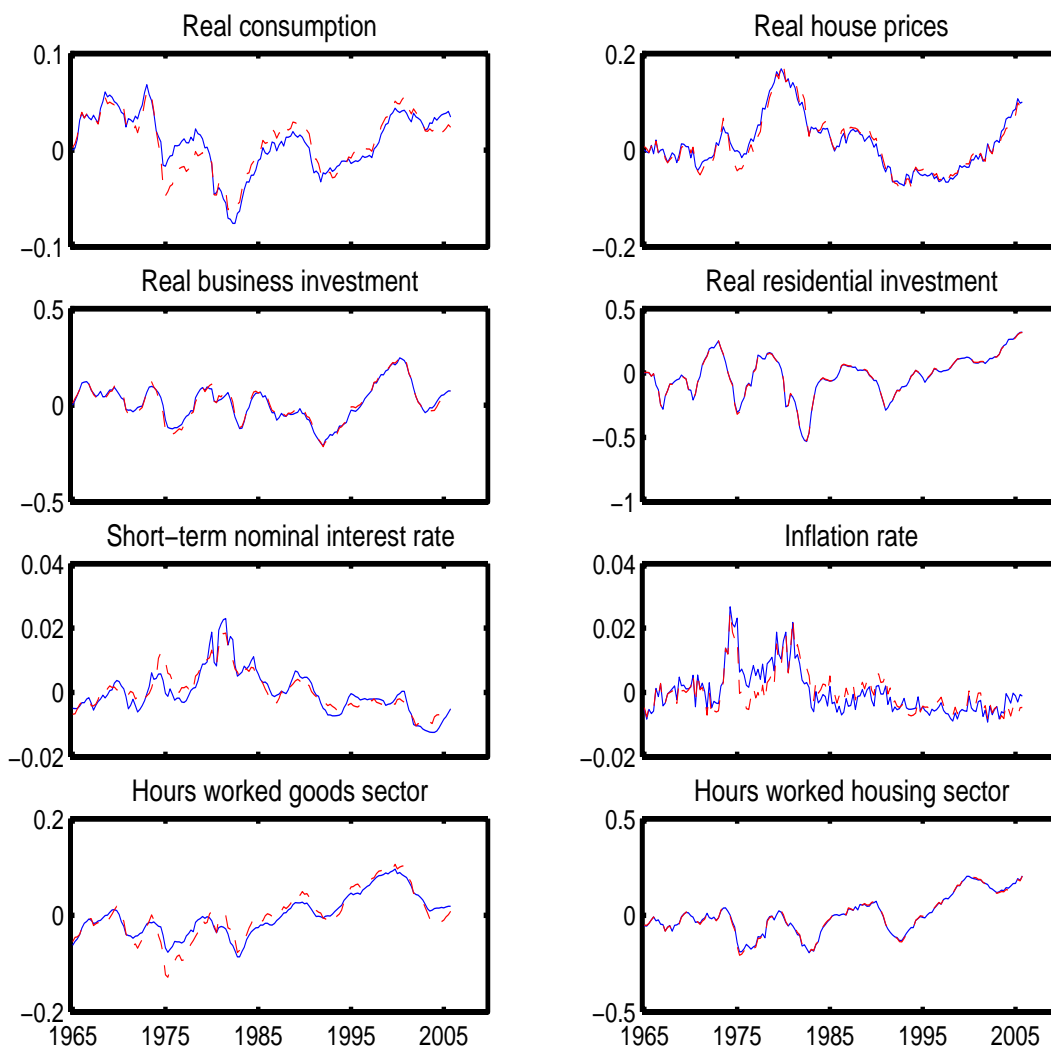


Figure 14 Counterfactual experiment: What if there had been no monetary policy shocks from 1965:1 onwards

*Note:* Red dotted lines correspond to the path of the variables in the counterfactual experiment. In the simulation the mean of the posterior distribution has been used.

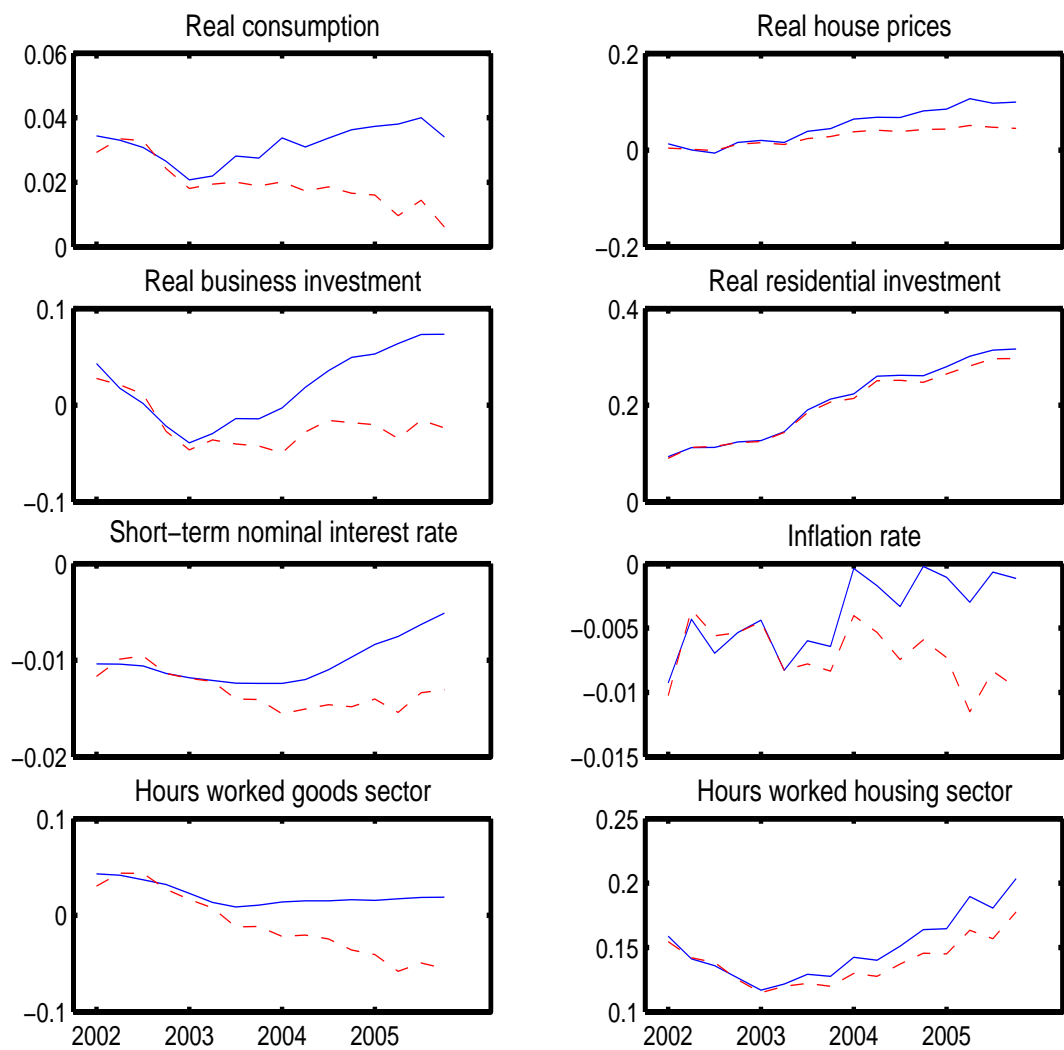


Figure 15 Counterfactual experiment: What if the Federal Reserve had responded to real house prices since 2002:1

*Note:* Red dotted lines correspond to the path of the variables in the counterfactual experiment. In the simulation the mean of the posterior distribution has been used.

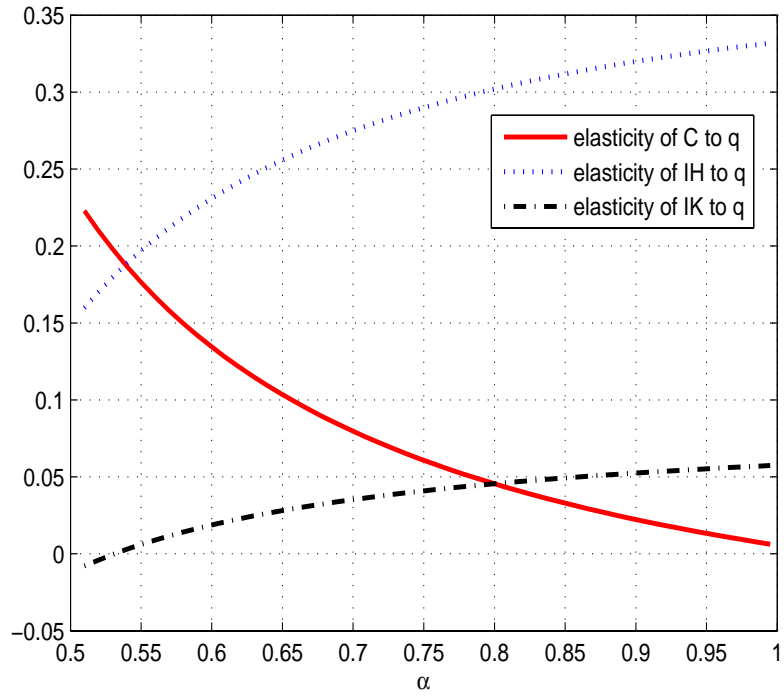


Figure 16 Elasticity of aggregate demand components to real house prices following a housing preference shock: the effect of varying the share of constrained agents

*Note:* The elasticities are computed as ratios of the four quarters averages of the responses. Results based on the output of the Metropolis algorithm.

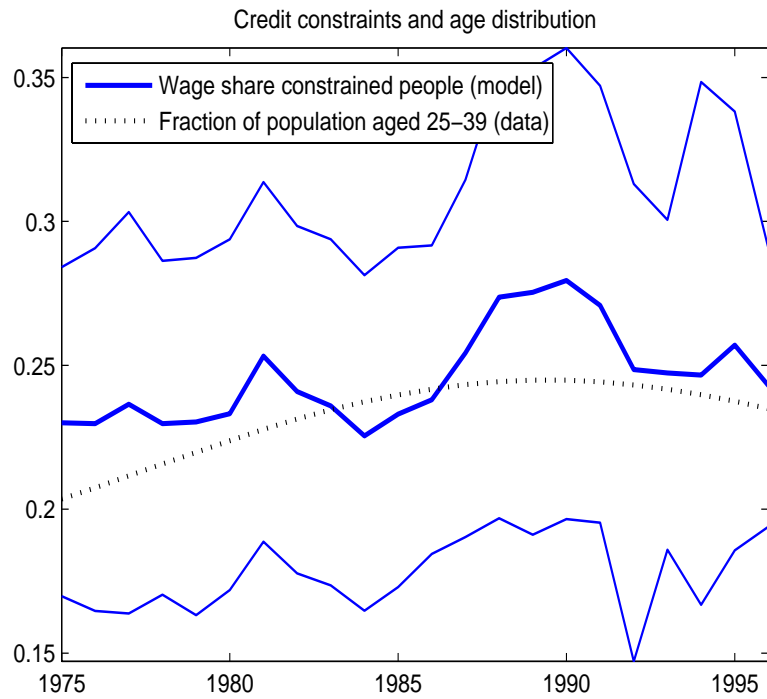


Figure 17 Credit constraints and age distribution of population

*Note:* Black dotted line corresponds to the share of constrained person in the U.S. Blue solid thick line corresponds to the mean recursive estimates of  $(1 - \alpha)$ , while blue solid thin lines denote the 90 percent probability intervals. The model has been estimated recursively over a moving window of 20 years.

**Table 1.** Summary statistics for the posterior distribution of the parameters

parameter	posterior					prior		Type
	2.5	50	97.5	mean	st. dev.	mean	st. dev.	
$\epsilon$	0.423	0.533	0.623	0.530	0.052	0.50	0.075	Beta
$\epsilon'$	0.438	0.732	0.888	0.712	0.132	0.50	0.075	Beta
$\eta$	0.381	0.601	0.876	0.607	0.126	0.25	0.10	Gamma
$\eta'$	0.299	0.456	0.672	0.464	0.094	0.25	0.10	Gamma
$\nu$	-2.894	-2.296	-1.801	-2.306	0.278	-2.0	0.50	Normal
$\nu'$	-3.003	-2.065	-1.177	-2.071	0.468	-2.0	0.50	Normal
$\phi_{k,c}$	20.307	23.436	26.881	23.467	1.704	10.0	2.50	Gamma
$\phi_{k,h}$	9.575	11.832	13.890	11.804	1.103	10.0	2.50	Gamma
$\alpha$	0.679	0.790	0.867	0.784	0.051	0.70	0.05	Beta
$m$	0.734	0.790	0.844	0.789	0.028	0.80	0.025	Beta
$r_R$	0.643	0.689	0.730	0.688	0.022	0.75	0.10	Beta
$r_{\Pi}$	1.186	1.318	1.464	1.319	0.072	1.50	0.10	Normal
$r_Y$	0.277	0.405	0.532	0.406	0.064	0.0	0.10	Normal
$\theta$	0.904	0.922	0.937	0.921	0.009	0.75	0.05	Beta
$\gamma$	0.705	0.848	0.963	0.784	0.051	0.5	0.20	Beta
$g_{a,c}$	0.0030	0.0032	0.0034	0.0032	0.0001	0.005	0.01	Normal
$g_{a,h}$	-0.0029	-0.0023	-0.0017	-0.0023	0.0003	0.005	0.01	Normal
$g_{a,k}$	0.0021	0.0028	0.0035	0.0028	0.0003	0.005	0.01	Normal
$\rho_j$	0.949	0.972	0.991	0.972	0.011	0.80	0.10	Beta
$\rho_{a,c}$	0.912	0.949	0.977	0.947	0.017	0.80	0.10	Beta
$\rho_{a,h}$	0.839	0.883	0.919	0.882	0.021	0.80	0.10	Beta
$\rho_{a,k}$	0.899	0.937	0.974	0.937	0.019	0.80	0.10	Beta
$\rho_z$	0.539	0.717	0.858	0.711	0.083	0.80	0.10	Beta
$\rho_{\tau}$	0.830	0.876	0.915	0.875	0.021	0.80	0.10	Beta
$\sigma_{a,c}$	0.010	0.011	0.013	0.011	0.001	0.005	0.10	Gamma
$\sigma_{a,h}$	0.046	0.052	0.058	0.052	0.003	0.005	0.10	Gamma
$\sigma_{a,k}$	0.021	0.024	0.028	0.024	0.002	0.005	0.10	Gamma
$\sigma_j$	0.029	0.049	0.076	0.050	0.012	0.005	0.10	Gamma
$\sigma_u$	0.005	0.006	0.007	0.006	0.001	0.005	0.10	Gamma
$\sigma_R$	0.002	0.003	0.003	0.003	0.000	0.005	0.10	Gamma
$\sigma_z$	0.013	0.018	0.025	0.018	0.003	0.005	0.10	Gamma
$\sigma_{\tau}$	0.038	0.051	0.064	0.051	0.007	0.005	0.10	Gamma

*Note:* Results based on 500,000 draws from the posterior distribution obtained using the Metropolis algorithm.



**Table 2.** Business cycle properties of the model

	Data	5	50	95
Standard deviation (perc.)				
$C$	1.23	1.39	1.84	2.46
$IH$	10.02	5.84	7.05	8.51
$IK$	4.97	3.57	4.38	5.37
$Q$	1.87	2.39	2.92	3.56
$NC$	1.43	2.47	3.17	4.12
$NH$	4.08	3.50	4.33	5.36
$\pi_c$	0.40	0.51	0.62	0.74
$R$	0.32	0.33	0.42	0.52
$Y$	4.13	3.06	3.84	4.86
Correlations				
$C, Y$	0.86	0.61	0.77	0.87
$IK, Y$	0.75	0.39	0.60	0.75
$IH, Y$	0.85	0.44	0.62	0.76
$Q, Y$	0.57	0.49	0.67	0.79
$Q, C$	0.49	0.31	0.55	0.72
$Q, IH$	0.40	-0.10	0.16	0.41
$Q, IK$	0.59	0.26	0.49	0.67
First order correlation				
$C$	0.87	0.83	0.88	0.91
$IH$	0.90	0.57	0.68	0.77
$IK$	0.91	0.65	0.74	0.81
$Q$	0.78	0.65	0.75	0.82
$NC$	0.91	0.74	0.82	0.87
$NH$	0.89	0.63	0.73	0.81
$\pi_c$	0.47	0.49	0.61	0.71
$R$	0.81	0.65	0.75	0.82
$Y$	0.92	0.72	0.80	0.86
Lead-lag correlations				
$IH(t-1), Y(t)$	0.89	0.24	0.50	0.68
$IH(t), Y(t)$	0.85	0.44	0.62	0.76
$IH(t+1), Y(t)$	0.67	0.29	0.50	0.66

*Note:* Results based on 500,000 draws from the posterior distribution obtained using the Metropolis algorithm.

**Table 3.** Decomposition of the asymptotic variance of the forecast error

	$j$	$a_c$	$a_h$	$\epsilon_R$	$u$	$a_k$	$z$	$\tau$
$C_t$	0.19 [0.1,0.4]	21.58 [10.8,40.6]	0.07 [0.0,0.1]	1.76 [0.9,3.1]	15.65 [9.8,21.9]	18.68 [10.4,35.2]	5.48 [3.5,8.0]	30.76 [19.1,43.3]
$\pi_t$	0.28 [0.1,1.1]	3.84 [2.9,5.3]	0.16 [0.1,0.2]	4.20 [2.1,8.0]	52.56 [45.2,59.1]	1.81 [1.1,3.2]	7.15 [3.0,15.1]	28.00 [20.2,36.1]
$IH_t$	5.00 [2.8,10.8]	6.47 [3.7,11.6]	68.29 [59.6,75.5]	0.08 [0.0,0.2]	0.64 [0.1,1.6]	0.1 [0.0,0.2]	0.2 [0.0,0.6]	17.0 [12.2,23.3]
$Q_t$	66.41 [55.4,78.2]	3.93 [2.1,6.9]	4.00 [2.2,7.1]	1.45 [0.9,2.0]	5.15 [3.2,7.3]	5.35 [2.8,11.8]	0.57 [0.1,2.2]	10.00 [5.9,15.2]
$R_t$	0.66 [0.2,2.1]	5.75 [4.3,7.7]	0.62 [0.0,1.0]	12.66 [9.8,15.8]	20.77 [15.2,26.3]	8.56 [6.0,12.2]	11.78 [5.0,25.7]	36.60 [26.9,45.3]
$IK_t$	0.14 [0.0,0.3]	5.90 [2.8,12.4]	0.05 [0.0,0.1]	1.51 [0.9,2.20]	8.24 [5.0,12.0]	69.70 [57.7,82.1]	0.50 [0.1,2.1]	11.60 [6.2,18.5]
$N_{c,t}$	0.42 [0.2,0.8]	5.02 [3.5,7.2]	0.17 [0.1,0.2]	4.55 [3.2,6.8]	32.00 [25.9,39.4]	0.32 [0.1,0.9]	4.19 [3.0,6.1]	52.3 [41.8,61.7]
$N_{h,t}$	13.15 [8.2,23.4]	0.84 [0.5,1.5]	15.26 [10.6,20.7]	0.36 [0.1,0.9]	2.37 [0.3,5.4]	0.0 [0.0,0.1]	0.58 [0.1,2.5]	65.40 [55.1,73.3]

*Note:* The table reports posterior medians and 90-percent probability intervals (in brackets). Statistics are computed using 500,000 draws obtained from the Metropolis algorithm.