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Using a DSGE model to look at the recent boom-bust cycle in the US

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Using a DSGE model to look at the recent Boom-Bust Cycle in the US

by

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Abstract:

This paper presents a DSGE model with residential investment and credit-constrained households estimated with US data over the period 1980Q1-2008Q4. In order to better understand speculative movements of house prices, we model land as an exhaustible resource, implying that house prices have asset market characteristics. We conduct an event study for the US over the period 1999Q1-2008Q4 which has been characterised by a housing boom and bust and examine which shocks have contributed to the evolution of GDP and its components over this period. We devote special attention to the contribution of non-fundamental shocks to asset prices over this episode.

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Introduction

This paper analyses the drivers of the US economy since the collapse of the dot com bubble in 2001 up to the end of 2008, using a DSGE model which allows for frictions in financial markets. It is by now common wisdom that overborrowing of US households, especially to finance residential investment, is one of the major causes for the current financial crisis which started to unfold at the end of 2007 (see, for example, Reinhart and Rogoff (2008) or Hatzius (2008)).

While there is little disagreement about the financial market origins of the current downturn there is still quite some uncertainty about the drivers of the boom in the US economy, since the bursting of the dot.com bubble at the beginning of 2000. Some commentators regard the expansion of sub-prime lending, i.e. a reduction of collateral requirements asked by commercial banks, as the major source of the current problem. Other commentators find that US monetary policy has been too expansionary in recent years. Yet another group attributes major importance to a bubble in the housing market. Finally, some argue the driving force was revisions in medium to long term income growth expectations related to the turnaround in US productivity growth.

Concerning *financial innovation*, the rise in popularity of securitized mortgage loans led to a decline in lending standards, because banks who passed on the risks had little incentives to take particular care in monitoring borrowers. As shown by Mayer et al. (2009), the number of subprime mortgages nearly doubled from 1.1 million in 2003 to 1.9 million in 2005. The share of non prime mortgages rose from about 10% to more than 30% over the same period. The initial easing of credit supply conditions and the tightening of credit associated with rising defaults are generally seen as a major factor behind the residential investment boom and bust in the US housing market. However, increased subprime lending is unlikely to be the only explanation. As emphasised by Shiller (2008), using data on the evolution of house prices in different segments of the US housing market, house prices did not only rise in the low price segment but also in the middle and high price segments. This suggests that other factors than extending loans to low income borrowers must have been at work.

The view that *monetary policy* is to blame is especially argued by Leamer (2007) and Taylor (2007). However, there is no consensus on the impact of monetary policy in the literature. Del Negro and Otrok (2005) and Fisher and Quayyam (2006), using structural VARs, only attribute a small portion of the increase in residential investment and house prices to monetary policy. Iacovello and Neri (2007) consider this issue in an estimated DSGE model. In contrast to the previous studies they find a sizeable monetary policy effect. However Edge *et al.* (2008), also using a DSGE model find that monetary policy only played a minor role, while they identify 'shifts in demand' as primary drivers of residential investment.

Shiller (2007) sees the housing *bubble* as the "major cause, if not the cause of the subprime crisis." He regards the bubble (or misperception) as more important than the subprime explanation because price increases not only occurred in the low price house segments (primarily finance by subprime loans) but in all price tiers (however to a different degree (see 2007, pp. 35-36)). Instead he regards the generalised nature of the boom as a result of "contagion of market psychology". He sees evidence that the recent housing boom was fuelled by overly optimistic expectations about future house price increases, from surveys conducted in 2003 (see Case et al. (2003)). He regards feedback loops between initial price increases and media amplifying the significance of these price increases by producing "new era" stories and thus encouraging beliefs among the public (including banks and rating agencies) in the continuation of the initial price increase. While ex post, with a sharp decline in house prices (of more than 30%), the bubble explanation has some credibility, it must be emphasised that before the bubble burst there was no consensus among housing market experts about the nature of the US housing boom. Even as late as 2006 there were papers written, disputing the bubble nature of the boom (see, for example Hwang Smith et al. (2006)). It shows the difficulties in disentangling fundamental from non fundamental shocks.

Finally, another explanation that might be relevant relates to revisions in medium to long term income growth expectations. The US has experienced a turnaround in its *productivity growth* in the mid-1990s, which even accelerated in the first half of this decade. For many, the technological breakthroughs in IT production and the widespread diffusion of IT technologies, especially in the service sector, signalled a new era of accelerated growth in the US (see Jorgenson and Stiroh (2007) and van Ark *et al.* (2007)). However, starting in 2004 we see a marked decline in productivity growth in the US, which has persisted until today (see Kahn et al. (2007) and Kahn (2009). The question can therefore be asked to what extent a revaluation of future growth projections has contributed to the decline in housing investment, while the boom itself could have been fuelled by a series of correlated positive income/technology shocks.

In this paper we want to shed some light on how strongly the factors discussed above have contributed to US economic developments since 2001 with the help of an estimated open-economy DSGE model. Using a DSGE model we can identify shock processes and associate them with the four hypotheses presented above. Concerning the productivity explanation we identify a TFP growth process (both for final goods and for investment). Regarding bank lending we identify shocks to the collateral constraint. As to monetary policy we use estimated shocks to the Taylor rule in order to measure deviations from systematic behaviour estimated over the whole sample period. Finally we identify a housing bubble as a (negative) risk premium shock to the arbitrage condition for housing investment, a house price bubble as a persistent negative shock to the risk premium of land prices, and we use the arbitrage equation for corporate capital to identify stock market bubbles.

The DSGE model we use in this paper differs from the standard model in two ways. First, unlike in the first generation DSGE models where capital and insurance markets are regarded as being perfect (see Gali et al. (2007)), we allow for financial frictions in the form of collateral constraints on borrowers with high rates of time preference, following Kiyotaki and Moore (1997), Iacoviello (2005) and Monacelli (2007). In addition, we do not require savers and investors/borrowers to satisfy exactly their optimising conditions for savings and investment, i.e. respond to fundamental shocks only, but we allow for bubbles, following Bernanke and Gertler. (1999). We use the term "bubbles" loosely to denote temporary but persistent deviations of asset prices from fundamental values due, for example, to noise traders, herd behaviour or waves of optimism or pessimism. Our strategy for identifying bubbles empirically is similar to the approach taken by Chirinko et al. (2001), using GMM estimation. We regard a DSGE model as a useful shock accounting device for the following reasons:

1) It allows to look at a multiplicity of shocks.
2) DSGE models (unlike error correction models) have a well specified theory about the adjustment dynamics, thus making distinct predictions about the dynamic impacts of particular shocks.

3) As a special case they allow to characterise an efficient financial market benchmark, which can be tested against the time series evidence.

The paper is structured as follows. Section 1 describes the model with a special emphasis on the household sector and housing investment. Section 2 presents estimation results and the fit of the model. In section 3 we show how the US economy is responding to the shocks discussed above. Section 4 presents our 'event study' for the period 1999q1 to 2008q4.

1. The Model

We consider the US as an open economy, which produces goods which are imperfect substitutes to goods produced in the RoW. Households engage in international financial markets and there is near perfect international capital mobility. There are three production sectors, a final goods production sector as well as an investment goods producing sector and a construction sector. We distinguish between Ricardian households which have full access to financial markets, credit constrained households facing a collateral constraint on their borrowing and liquidity constrained households which do not engage in financial markets. And there is a monetary and fiscal authority, both following rules based stabilisation policies. Behavioural and technological relationships can be subject to autocorrelated shocks denoted by U_t^k, where k stands for the type of shock. The logarithm of U_t^k [1] will generally be autocorrelated with autocorrelation coefficient ρ^k and innovation ε_t^k.

1.1 Firms:

1.1.1 Final goods producers

Firms operating in the final goods production sector are indexed by j. Each firm produces a variety of the domestic good which is an imperfect substitute for varieties produced by other firms. Because of imperfect substitutability, firms are monopolistically competitive in the goods market and face a demand function for goods. Domestic firms sell consumption goods and services to private domestic and foreign households and the domestic and foreign government and they sell investment and intermediate goods to other domestic and foreign firms. Output is produced with a Cobb Douglas production function using capital K_t^j and production workers $L_t^j - LO_t^j$ as inputs

$$(1) \qquad Y_t^j = (ucap_t^j K_t^j)^{1-\alpha} (L_t^j - LO_t^j)^{\alpha} U_t^{Y\alpha}, \qquad \text{with } L_t^j = \left[\int_0^1 L_t^{i,j\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}.$$

The term LO_t^j represents overhead labour. Total employment of the firm L_t^j is itself a CES aggregate of labour supplied by individual households *i*. The parameter $\theta > 1$ determines the degree of substitutability among different types of labour. Firms also decide about the degree

[1] Lower cases denote logarithms, i.e. $z_t = log(Z_t)$. Lower cases are also used for ratios and rates. In particular we define $p_t^j = P_t^j / P_t^Y$ as the relative price of good j w. r. t. the GDP deflator

of capacity utilisation ($UCAP_t^j$). There is an economy wide technology shock U_t^Y. The objective of the firm is to maximise profits *Pr*

(2) $$\mathrm{Pr}_t^j = p_t^j Y_t^j - w_t L_t^j - i_t^K p_t^{K,j} K_t^j - (adj^P(P_t^j) + adj^L(L_t^j) + adj^{UCAP}(ucap_t^j)).$$

where i^K denotes the rental rate of capital. Firms also face technological and regulatory constraints which restrict their price setting, employment and capacity utilisation decisions. Price setting rigidities can be the result of the internal organisation of the firm or specific customer-firm relationships associated with certain market structures. Costs of adjusting labour have a strong job specific component (e.g. training costs) but higher employment adjustment costs may also arise in heavily regulated labour markets with search frictions. Costs associated with the utilisation of capital can result from higher maintenance costs associated with a more intensive use of a piece of capital equipment. The following convex functional forms are chosen

(3) $$\begin{aligned} adj^L(L_t^j) &= w_t(L_t^j u_t^L + \frac{\gamma_L}{2}\Delta L_t^{j\,2}) \\ adj^P(P_t^j) &= \frac{\gamma_P}{2}\frac{(P_t^j - P_{t-1}^j)^2}{P_{t-1}^j} \\ adj^{UCAP}(ucap_t^j) &= p_t^I K_t(\gamma_{ucap,1}(ucap_t^j - 1) + \frac{\gamma_{ucap,2}}{2}(ucap_t^j - 1)^2) \end{aligned}$$

The firm determines labour input, capital services and prices optimally in each period given the technological and administrative constraints as well as demand conditions. The first order conditions are given by:

(4a) $$\frac{\partial \mathrm{Pr}_t^j}{\partial L_t^j} \Rightarrow \left(\frac{\partial Y_t^j}{\partial L_t^j}\eta_t^j - w_t u_t^L - w_t\gamma_L \Delta L_t^j + E_t(w_{t+1}\frac{\gamma_L}{(1+r_t)}\Delta L_{t+1}^j)\right) = w_t$$

(4b) $$\frac{\partial \mathrm{Pr}_t^j}{\partial K_t^j} \Rightarrow \left(\frac{\partial Y_t^j}{\partial K_t^j}\eta_t^j\right) = i_t^K p_t^{K,j}$$

(4c) $$\frac{\partial \mathrm{Pr}_t^j}{\partial ucap_t^j} \Rightarrow \left(\frac{\partial Y_t^j}{\partial ucap_t^j}\eta_t^j\right) = \frac{P_t^{K,j}}{P_t^j}K_t^j(\gamma_{ucap,1} + \gamma_{ucap,2}(ucap_t^j - 1))$$

(4d) $$\frac{\partial \mathrm{Pr}_t^j}{\partial O_t^j} \Rightarrow \eta_t^j = 1 - 1/\sigma^d - \gamma_P\left[\frac{1}{(1+r_t)}E_t\pi_{t+1}^j - \pi_t^j\right] \quad \text{with } \pi_t^j = P_t^j / P_{t-1}^j - 1 .$$

Where η_t is the Lagrange multiplier of the technological constraint and r_t is the real interest rate. Firms equate the marginal product of labour, net of marginal adjustment costs, to wage costs. As can be seen from the left hand side of equation (4a), the convex part of the adjustment cost function penalises in cost terms accelerations and decelerations of changes in employment. Equations (4b-c) jointly determine the optimal capital stock and capacity utilisation by equating the marginal value product of capital to the rental price and the marginal product of capital services to the marginal cost of increasing capacity. Equation (4d) defines the mark up factor as a function of the elasticity of substitution and changes in inflation. The average mark up is equal to the inverse of the price elasticity of demand. We follow the empirical literature and allow for additional backward looking elements by assuming that a fraction (*1-sfp*) of firms index price increases to inflation in t-1. Finally we also allow for a mark up shock. This leads to the following specification:

(4d') $$\eta_t^j = 1 - 1/\sigma^d - \gamma_P\left[\beta(sfpE_t\pi_{t+1}^j + (1-sfp)\pi_{t-1}^j) - \pi_t^j\right] - u_t^\eta \quad 0 \le sfp \le 1$$

1.1.2 Residential construction

Firms *h* in the residential construction sector use new land (J_t^{Land}) sold by (Ricardian) households and final goods (J_t^{Constr}) to produce new houses using a CES technology

(5) $$J_t^H = \left(s_L^{\frac{1}{\sigma_L}} J_t^{Land\frac{(\sigma_L - 1)}{\sigma_L}} + (1-s_L)^{\frac{1}{\sigma_L}} J_t^{Constr\frac{(\sigma_L - 1)}{\sigma_L}} \right)^{\frac{\sigma_L}{\sigma_L - 1}}$$

The corresponding aggregator for house prices is given by

(6) $$P_t^H = \left[1 + \gamma_H\left(\beta(sfpE_t\pi_{t+1}^H + (1-sfp)\pi_{t-1}^H) - \pi_t^H\right)\right]\left(s_L P_t^{Land^{1-\sigma_L}} + (1-s_L)\ P_t^{Constr^{1-\sigma_L}}\right)^{\frac{1}{1-\sigma_L}}$$

where we allow for adjustment costs related to changes in house prices.

Firms in the residential construction sector are monopolistically competitive and face price adjustment costs. Thus the mark up is given by

(7) $$\eta_t^{Const} = 1 - 1/\sigma^{Constr} - \gamma_{P,Constr}\left|\beta(sfpE_t\pi_{t+1}^{Constr} + (1-sfp)\pi_{t-1}^{Constr}) - \pi_t^{Constr}\right| - u_t^{Constr} \quad 0 \le sfp \le 1$$

New and existing houses are perfect substitutes. Thus households can make capital gains or suffer capital losses depending on house price fluctuations

1.1.3 Investment goods producers

There is a perfectly competitive investment goods production sector which combines domestic and foreign final goods, using the same CES aggregators as households and governments do to produce investment goods for the domestic economy. Denote the CES aggregate of domestic and foreign inputs used by the investment goods sector with J_t^{inp}, then real output of the investment goods sector is produced by the following linear production function,

(8a) $$J_t = J_t^{inp} U_t^I$$

where U_t^I is a technology shock to the investment good production technology which itself follows a random walk with drift

(8b) $u_t^I = g^{UI} + u_{t-1}^I + \varepsilon_t^{UI}$

Given our assumption concerning the input used in the investment goods production sector, investment goods prices are given by

(9) $P_t^I = P_t^C / U_t^I$.

1.1.4 Financial intermediaries

The economy is inhabited by savers and borrowers. Financial intermediaries use deposits from savers to provide loans to borrowing households. Banks pay a riskless rate on deposit, which is equal to the risk free rate on government bonds. Concerning the lending behaviour of banks we follow the literature on risky debt contracts, which suggest that under conditions of uncertainty it is optimal for the lender to link the supply of loans not only to the refinancing costs but also to the net worth of the borrower. We implement this supply rule by postulating a mark up for the loan interest rate which depends positively on the loan to value ratio (defined as $B_t^c /(p_t^H H_t^c)$) of the borrower.

(10) $$i_t^c = \left(1 + mup^B + \chi\left(\frac{B_t^c}{P_t^H H_t^c} - (\Gamma + u_t^B\right)\right)i_t$$

This specification yields results which are similar to those obtained with an explicit collateral constraint a la Kiyotaki and Moore (1997). Instead of increasing the shadow price of lending as in Kiyotaki et al. here the loan interest rate is increased explicitly if the value of the housing collateral declines. The loan interest rate is set as a variable mark up over the deposit rate.

1.2 Households:

The household sector consists of a continuum of households $h \in [0,1]$. A fraction s^r of all households are Ricardian and indexed by *r* and s^c households are credit constrained and indexed by *c*. The period utility function is identical for each household type and specified as a nested constant elasticity of substitution (CES) aggregate of consumption (C_t^h) and housing services (H_t^h) and separable in leisure ($1 - L_t^h$). We also allow for habit persistence in consumption. Thus temporal utility for consumption is given by

(11) $$U(C_t^h, H_t^h, 1 - L_t^h) = \frac{1}{1-\sigma^C}\left\{\left[s_C^{\frac{1}{\sigma^H}}\left(C_t^h - hC_{t-1}^h\right)^{\frac{\sigma^H - 1}{\sigma^H}} + s_H^{\frac{1}{\sigma^H}} H_t^{h\,\frac{\sigma^H - 1}{\sigma^H}}\right]^{\frac{\sigma^H}{\sigma^H - 1}}\right\}^{1-\sigma^C} + \vartheta\left(1 - L_t^h\right)^{1-\kappa}$$

All three types of households supply differentiated labour services to unions which maximise a joint utility function for each type of labour *i*. It is assumed that types of labour are distributed equally over the three household types. Nominal rigidity in wage setting is introduced by assuming that the household faces adjustment costs for changing wages. These adjustment costs are borne by the household.

1.2.1 Ricardian households

Ricardian households have full access to financial markets. They hold domestic government bonds($B_t^{G\,r}$) and bonds issued by other domestic and foreign households ($B_t^r, B_t^{F,r}$), real capitals (K_t) used in the final goods production sector as well as the stock of land ($Land_t$) which is still available for building new houses. In addition they hold a stock of deposits (D) with a financial intermediary who provides loans to credit constrained households. The household receives income from labour, financial assets, rental income from lending capital to firms, selling land to the residential construction sector plus profit income from firms owned by the household (final goods $\Pr_t^j$, residential construction $\Pr_t^H$ and financial intermediaries $\Pr_t^B$). We assume that all domestic firms are owned by Ricardian households. Income from labour is taxed at rate t^W, consumption at rate t^c. In addition households pay lump-sum taxes T^{LS}. We assume that income from financial wealth is subject to different types of risk. Domestic bonds and interest income from deposits yield risk-free nominal return equal to i_t. Domestic and foreign bonds are subject to (stochastic) risk premia linked to net foreign indebtedness. An equity premium on real assets arises because of uncertainty about the future value of real assets. The Lagrangian of this maximisation problem is given by

(12)

$$Max \quad V_0^r = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^{r\,t} U(C_t^r, 1-L_t^r, H_t^r)$$

$$-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^r \beta^{r\,t} \begin{pmatrix} (1+t_t^c) p_t^C C_t^r + p_t^I I_t + p_t^H (1+t_t^c) I_t^{H,r} + p_t^H (1+t_t^c) I_t^{HLC,r} + (B_t^{G,r} + B_t^r + D_t) + \\ rer_t B_t^{F,r} - (1+r_{t-1})(B_{t-1}^{G,r} + B_{t-1}^r + D_{t-1}) - (1+r_{t-1}^F)(1-risk(.)) rer_t B_{t-1}^{F,r} - \\ ((1-t_t^k) i_{t-1}^K + t_t\, \delta^k) p_{t-1}^I K_{t-1} - (1-t_t^W) w_t L_t^r + \frac{\gamma_W}{2} \frac{\Delta W_t}{W_{t-1}}^2 - p_t^L J_t^{Land} - \\ \sum_{j=1} \Pr_t^j - \Pr_t^H - \Pr_t^B + T_t^{LS,r} \end{pmatrix}$$

$$-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^r \xi_t\, \beta^{r\,t} (K_t - J_t - (1-\delta^K) K_{t-1})$$

$$-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^r \zeta_t^r \beta^{r\,t} \left(H_t^r - J_t^{H,r} - (1-\delta^H) H_{t-1}^{H,r}\right)$$

$$-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^r \xi_t^r \beta^{r\,t} \left(Land_t + J_t^{Land} - (1+g_t^L) Land_{t-1}\right)$$

The investment decisions w. r. t. physical capital and housing are subject to convex adjustment costs, therefore we make a distinction between real investment expenditure

(I_t, I_t^H) and physical investment (J_t, J_t^H). Investment expenditure of households including adjustment costs is given by

$$(13a)\quad I_t = J_t\left(1+\frac{(\gamma_K+u_t^I)}{2}\left(\frac{J_t}{K_t}\right)\right)+\frac{\gamma_I}{2}(\Delta J_t)^2$$

$$(13b)\quad I_t^{H,r} = J_t^{H,r}\left(1+\frac{(\gamma_H+u_t^H)}{2}\left(\frac{J_t^{H,r}}{H_t^r}\right)\right)+\frac{\gamma_{IH}}{2}(\Delta J_t^{H,r})^2$$

The budget constraint is written in real terms with all prices expressed relative to the GDP deflator (*P*). Investment is a composite of domestic and foreign goods. From the first order conditions we can derive the following consumption rule, where the ratio of the marginal utility of consumption in period t and t+1 is equated to the real interest rate adjusted for the rate of time preference

$$(14)\quad \frac{U_{C,t}^r}{U_{C,t+1}^r} = \beta^r(1+i_t-\pi_{t+1}^c-\Delta t_{t+1}^c)$$

From the arbitrage condition of investment we can derive an investment rule which links capital formation to the shadow price of capital $q_t^K = \frac{\xi_t}{p_t^I}$.

$$(15)\quad \left((\gamma_K+u_t)\left(\frac{J_t^K}{K_{t-1}}\right)+\gamma_I\Delta J_t^K\right)-E_t\left(\frac{1}{(1+i_t-\pi_{t+1}^I)}\Delta J_{t+1}^K\right)=\frac{\xi_t}{p_t^I}-1$$

Where the shadow price of capital is given as the present discounted value of the rental income from physical capital

$$(16)\quad \frac{\xi_t}{p_t^I} = \mathrm{E}_t\left(\frac{1}{(1+i_t-\pi_{t+1}^I+u_t^I)}\frac{\xi_{t+1}}{p_{t+1}^I}(1-\delta^K)\right)+((1-t_t^K)i_t^K+t_t^K\delta^K)=0$$

Notice, there is a risk premium attached to the discount factor of the arbitrage equation for physical capital investment. As shown in the appendix u_t^I can be interpreted as a non fundamental shock (bubble) to the arbitrage equation. From the FOC for housing investment we can derive a housing investment rule, which links investment to the shadow price of housing capital

$$(17)\quad \left((\gamma_H+u_t^H)\left(\frac{J_t^{H,r}}{H_{t-1}^r}\right)+\gamma_{IH}\Delta J_t^{H,r}\right)-E_t\left(\frac{1}{(1+i_t-\pi_{t+1}^H-\Delta t_{t+1}^c)}\Delta J_{t+1}^{H,r}\right)=\frac{\zeta_t^r}{p_t^H(1+t_t^c)}-1.$$

The shadow price of housing capital can be represented as the present discounted value of the ratio of the marginal utility of housing services and consumption

(18) $$\frac{\zeta_t^r}{p_t^H(1+t_t^c)} = \frac{U_{H,t}^r}{U_{C,t}^r}\frac{p_t^C}{p_t^H} + \mathrm{E}_t\left(\frac{1}{(1+i_t-\pi_{t+1}^H-\Delta t_{t+1}^c+u_t^H)}\frac{\zeta_{t+1}^r(1-\delta^H)}{p_{t+1}^h(1+t_{t+1}^c)}\right)$$

We have added a non fundamental shock u_t^H to the arbitrage equation for housing capital in order to capture possible bubbles to housing investment. For the price of land we obtain a (quasi) Hotelling rule

(19) $$p_t^{Land} = \mathrm{E}_t\left(\frac{1}{(1+r_t+u_t^{Land})}p_{t+1}^{Land}(1+g_L)\right)$$

The growth rate of the price of land must guarantee a rate of return which can be earned by other assets, i. e. the growth rate of land must be equal to $r_t - g_L$. Bubbles to land prices are captured by the term u_t^{Land}

1.2.2 Credit constrained households

Credit constrained households differ from Ricardian households in two respects. First they have a higher rate of time preference ($\beta^c < \beta^r$) and they face a collateral constraint on their borrowing. They borrow B_t^c exclusively from domestic Ricardian households. Loans are intermediated by a banking sector which charges a mark up over the deposit rate which depends positively on the loan to value ratio (see eq. 10). The Lagrangian of this maximisation problem is given by

(20)
$$Max\;\; V_0^c = \mathrm{E}_0\sum_{t=0}^{\infty}\beta^{ct}U(C_t^c,1-L_t^c,H_t^c)$$
$$-\mathrm{E}_0\sum_{t=0}^{\infty}\lambda_t^c\beta^{ct}\left((1+t_t^c)p_t^C C_t^c + p_t^H(1+t_t^H)I_t^{H,c} - B_t^c + (1+r_{t-1}^c)B_t^c) - (1-t_t^W)w_t L_t^c + \frac{\gamma_W}{2}\frac{\Delta W_t^2}{W_{t-1}} + T_t^{LS,c}\right)$$
$$-\mathrm{E}_0\sum_{t=0}^{\infty}\lambda_t^c\zeta_t^c\beta^{ct}\left(H_t^c - J_t^{H,c} - (1-\delta^H)H_{t-1}^c\right)$$

From the first order conditions we can derive the following decision rules for consumption

(21) $$\frac{U_{C,t}^c}{U_{C,t+1}^c} = \beta^c\left(1+i_t^c-\pi_{t+1}^c-\Delta t_{t+1}^c\right)$$

And housing investment

(22) $$\left((\gamma_H+u_t^H)\left(\frac{J_t^{H,c}}{H_{t-1}^c}\right)+\gamma_{IH}\Delta J_t^{H,c}\right) - E_t\left(\frac{1}{(1+i_t^c-\pi_{t+1}^H-\Delta t_{t+1}^c)}\Delta J_{t+1}^{H,c}\right) = \frac{\zeta_t^c}{p_t^H(1+t_t^c)} - 1$$

where again the shadow price of housing capital is the present discounted value of the ratio of the marginal utility of housing services and consumption

(23) $$\frac{\zeta_t^c}{p_t^H(1+t_t^c)} = \frac{U_{H,t}^c}{U_{C,t}^c}\frac{p_t^C}{p_t^H} + \mathrm{E}_t\left(\frac{1}{(1+i_t^c - \pi_{t+1}^H - \Delta t_{t+1}^c + u_t^H)}\frac{\zeta_{t+1}^c(1-\delta^H)}{p_{t+1}^H(1+t_{t+1}^c)}\right)$$

The major difference between credit constrained and Ricardian households is the interest rate in both the consumption and the investment rule of the former. Credit constrained households face a mark up which depends positively on the loan to value ratio. The non fundamental shock to housing investment is constrained to be equal across household types.

1.2.3 Wage setting

A trade union is maximising a joint utility function for each type of labour *i* where it is assumed that types of labour are distributed equally over constrained and unconstrained households with their respective population weights. The trade union sets wages by maximising a weighted average of the utility functions of these households. The wage rule is obtained by equating a weighted average of the marginal utility of leisure to a weighted average of the marginal utility of consumption times the real wage of these two household types, adjusted for a wage mark up

(25) $$\frac{s^c U_{1-L,t}^c + s^r U_{1-L,t}^r}{s^c U_{c,t}^c + s^r U_{c,t}^r} = \frac{(1-t_t^W)}{(1+t_t^C)}\frac{W_t}{P_t^C}\eta_t^W$$

where η_t^W is the wage mark up factor, with wage mark ups fluctuating around $1/\theta$ which is the inverse of the elasticity of substitution between different varieties of labour services. The trade union sets the consumption wage as a mark up over the reservation wage. The reservation wage is the ratio of the marginal utility of leisure to the marginal utility of consumption. This is a natural measure of the reservation wage. If this ratio is equal to the consumption wage, the household is indifferent between supplying an additional unit of labour and spending the additional income on consumption and not increasing labour supply. Fluctuation in the wage mark up arises because of wage adjustment costs and the fact that a fraction (*1-sfw*) of workers is indexing the growth rate of wages π_t^W to inflation in the previous period.

(26)
$$\eta_t^W = 1 - 1/\theta - \gamma_W/\theta\left[\beta(\pi_{t+1}^W - (1-sfw)\pi_t) - (\pi_t^W - (1-sfw)\pi_{t-1})\right] \quad 0 \le sfw \le 1$$

Combining (17) and (18) one can show that the (semi) elasticity of wage inflation with respect to the employment rate is given by (κ/γ_W), i. e. it is positively related to the inverse of the labour supply elasticity and inversely related to wage adjustment costs.

1.2.4 Aggregation

The aggregate of any household specific variable X_t^h in per capita terms is given by $X_t = \int_0^1 X_t^h dh = s^r X_t^r + s^c X_t^c$ since households within each group are identical. Hence aggregate consumption is given by

(27a) $C_t = s^r C_t^r + s^c C_t^c$

Aggregate housing investment is given by

(27b) $J_t^H = s^r J_t^{H,r} + s^c J_t^{H,c}$

and aggregate employment is given by

(27c) $L_t = s^r L_t^r + s^c L_t^c$ with $L_t^r = L_t^c$.

Credit constrained households only engage in debt contracts with Ricardian households, therefore we have

(28) $B_t^c = \frac{s^r}{s^c} B_t^r$.

1.3 Trade and the current account

So far we have only determined aggregate consumption, investment and government purchases but not the allocation of expenditure over domestic and foreign goods. In order to facilitate aggregation we assume that households, the government and the corporate sector have identical preferences across goods used for private consumption, public expenditure and investment. Let $Z^i \in \{C^i, I^i, C^{G,i}, I^{G,i}\}$ be demand of an individual household, investor or the government, and then their preferences are given by the following utility function

(29a) $$Z^i = \left[(1 - s^M - u_t^M)^{\frac{1}{\sigma^M}} Z^{d\,i\,\frac{\sigma^M - 1}{\sigma^M}} + (s^M + u_t^M)^{\frac{1}{\sigma^M}} Z^{f\,i\,\frac{\sigma^M - 1}{\sigma^M}} \right]^{\frac{\sigma^M}{(\sigma^M - 1)}}$$

where the share parameter s^M can be subject to random shocks and $Z^{d\,i}$ and $Z^{f\,i}$ are indexes of demand across the continuum of differentiated goods produced respectively in the domestic economy and abroad, given by.

(29b) $$Z^{d\,i} = \left[\sum_{h=1}^{n} \left(\frac{1}{n} \right)^{\frac{1}{\sigma^d}} Z_h^{d\,i\,\frac{\sigma^d - 1}{\sigma^d}} \right]^{\frac{\sigma^d}{\sigma^d - 1}} \quad , \quad Z^{f\,i} = \left[\sum_{h=1}^{m} \left(\frac{1}{m} \right)^{\frac{1}{\sigma^f}} Z_h^{f\,i\,\frac{\sigma^f - 1}{\sigma^f}} \right]^{\frac{\sigma^f}{\sigma^f - 1}}$$

The elasticity of substitution between bundles of domestic and foreign goods $Z^{d\,i}$ and $Z^{f\,i}$ is σ^M. Thus aggregate imports are given by

$$(30) \qquad M_t = (s^M + u_t^M)\left[\rho^{PCPM}\frac{P_{t-1}^{\ C}}{P_{t-1}^{\ M}} + (1-\rho^{PCPM})\frac{P_t^C}{P_t^M}\right]^{\sigma^M} (C_t + I_t^{inp} + C_t^G + I_t^G)$$

where P^C and P^M is the (utility based) consumer price deflator and the lag structure captures delivery lags.. We assume similar demand behaviour in the rest of the world, therefore exports can be treated symmetrically and are given by

$$(31) \quad X_t = (s^{M,W} + u_t^X)\left(\rho^{PWPX}\frac{P_{t-1}^{\ C,F}E_{t-1}}{P_{t-1}^{\ X}} + (1-\rho^{PWPX})\frac{P_t^{C,F}E_t}{P_t^X}\right)^{\sigma^X} Y_t^F$$

where P_t^X, $P_t^{C,F}$ and Y_t^F are the export deflator, an index of world consumer prices (in foreign currency) and world demand. Prices for exports and imports are set by domestic and foreign exporters respectively. The exporters in both regions buy goods from their respective domestic producers and sell them in foreign markets. They transform domestic goods into exportables using a linear technology. Exporters act as monopolistic competitors in export markets and charge a mark-up over domestic prices. Thus export prices are given by

$$(32) \qquad \eta_t^X P_t^X = P_t$$

and import prices are given by

$$(33) \qquad \eta_t^M P_t^M = E_t P_t^F$$

Mark-up fluctuations arise because of price adjustment costs. There is also some backward indexation of prices since a fraction of exporters (*1-sfpx*) and (*1-sfpm*) is indexing changes of prices to past inflation. The mark ups for import and export prices is also subject to random shocks

$$(34) \qquad \eta_t^k = 1 - 1/\sigma^k - \gamma_{Pk}\left[\beta(sfp^k \cdot_t \pi_{t+1}^k + (1-sfp^k)\pi_{t-1}^k) - \pi_t^k\right] + u_t^{P,k} \qquad k = \{X, M\}$$

Exports and imports together with interest receipts/payments determine the evolution of net foreign assets denominated in domestic currency.

$$(35) \qquad E_t B_t^F = (1 + i_t^F)E_t B_{t-1}^F + P_t^X X_t - P_t^M M_t$$

1.4 Policy

We assume that fiscal and monetary policy is partly rules based and partly discretionary. Policy responds to an output gap indicator of the business cycle. The output gap is not calculated as the difference between actual and efficient output but we try to use a measure that closely approximates the standard practice of output gap calculation as used for fiscal surveillance and monetary policy (see Denis et al. (2006)). Often a production function framework is used where the output gap is defined as deviation of capital and labour utilisation from their long run trends. Therefore we define the output gap as

$$(36) \quad YGAP_t = \left(\frac{ucap_t}{ucap_t^{ss}}\right)^{(1-\alpha)} \left(\frac{L_t}{L_t^{ss}}\right)^{\alpha}.$$

where L_t^{ss} and $ucap_t^{ss}$ are moving average steady state employment rate and capacity utilisation:

$$(37) \quad ucap_t^{ss} = (1-\rho^{ucap})ucap_{t-1}^{ss} + \rho^{ucap} ucap_t^j$$

$$(38) \quad L_t^{ss} = (1-\rho^{Lss})L_{t-1}^{ss} + \rho^{Lss} L_t$$

which we restrict to move slowly in response to actual values.

Both government expenditure and receipts are responding to business cycle conditions. On the expenditure side we identify the systematic response of government consumption, government transfers and government investment to the business cycle. For government consumption and government investment we specify the following rules

$$(39) \quad \Delta c_t^G = (1-\tau_{Lag}^{CG})\overline{\Delta c^G} + \tau_{Lag}^{CG}\Delta c_{t-1}^G + \tau_{Adj}^{CG}(cgy_{t-1} - \overline{cgy}) + \sum_i \tau_i^{CG} ygap_{t-i} + u_t^{CG}$$

$$(40) \quad \Delta i_t^G = (1-\tau_{Lag}^{IG})\overline{\Delta i^G} + \tau_{Lag}^{IG}\Delta i_{t-1}^G + \tau_{Adj}^{IG}(igy_{t-1} - \overline{igy}) + \sum_i \tau_i^{IG} ygap_{t-i} + u_t^{IG}$$

Government consumption and government investment can temporarily deviate from their long run targets cgy and igy (expressed as ratios to GDP in nominal terms) in response to fluctuations of the output gap. Due to information and implementation lags the response may occur with some delay. This feature is captured by a distributed lag of the output gap in the reaction function.

The transfer system provides income for unemployed and for pensioners and acts as an automatic stabiliser. The generosity of the social benefit system is characterised by three parameters: the fraction of the non-employed which receive unemployment benefits and the level of payments for unemployed and pensioners. In other words the number of non-participants POP^{NPART} is treated as a government decision variable. We assume that unemployment benefits and pensions are indexed to wages with replacement rates b^U and b^R respectively and we formulate the following linear transfer rule

$$(41) \quad TR_t = b^U W_t (POP_t^W - POP_t^{NPART} - L_t) + b^R W_t POP_t^P + u_t^{TR}.$$

Government revenues R_t^G consists of taxes on consumption as well as capital and labour income.

(42) $$R_t^G = t_t^w W_t L_t + t_t^c P_t^c C_t + t_t^K i_t^K P_t^I K_{t-1}$$

We assume consumption and capital income tax to follow a linear scheme, but a progressive labour income tax schedule

(43a) $$t_t^w = \tau_0^w Y_t^{\tau_1^W} U_t^{TW}$$

where τ_0^w measures the average tax rate, and τ_1^w the degree of progressivity. A simple first-order Taylor expansion around a zero output gap yields

(43b) $$t_t^w = \tau_0^w + \tau_0^w \tau_1^w ygap_t$$

Government debt (B_t) evolves according to

(44) $$B_t = (1+i_t)B_{t-1} + P_t^C C_t^G + P_t^C I_t^G + TR_t - R_t^G - T_t^{LS}.$$

There is a lump-sum tax (T_t^{LS}) used for controlling the debt to GDP ratio according to the following rule

(45) $$\Delta T_t^{LS} = \tau^B \left(\frac{B_{t-1}}{Y_{t-1}P_{t-1}} - b^T\right) + \tau^{DEF} \Delta\left(\frac{B_t}{Y_t P_t}\right)$$

where b^T is the government debt target.

Monetary policy is modelled via the following Taylor rule, which allows for some smoothness of the interest rate response to the inflation and output gap

(46)
$$i_t = \tau_{lag}^{INOM} i_{t-1} + (1-\tau_{lag}^{INOM})[r^{EQ} + \pi^T + \tau_\pi^{INOM}(\pi_t^C - \pi^T) + \tau_{y,1}^{INOM} ygap_{t-1}] + \tau_{y,2}^{INOM}({}_t ygap_{t+1} - ygap_t) + u_t^{INOM}$$

The central bank has a constant inflation target π^T and it adjusts interest rates whenever actual consumer price inflation deviates from the target. The central bank also responds to the output gap. There is also some inertia in nominal interest rate setting.

1.5 Equilibrium

Equilibrium in our model economy is an allocation, a price system and monetary and fiscal policies such that both non-constrained and constrained households maximise utility, final goods producing firms, firms in the construction sector and investment goods producer maximise profits and the following market clearing condition for final goods holds:

(47) $Y_t = C_t + J_t^{inp} + J_t^{Constr} + C_t^G + I_t^G + X_t - M_t$

Inputs of final goods are used in the investment goods sector and in residential construction (eq. 5 and 8) and the allocation of aggregate consumption and housing investment over different groups of households is as specified in equations 27.

1.6 Fundamental vs. non-fundamental shocks

In order to fit a DSGE model to the data, either structural shocks or measurement error must be assumed and there must at least be as many shocks as there are observed variables in the model. Since the seminal work of Smets and Wouters (2007) it is common in this literature to try to provide a structural interpretation to shocks and capture variations in technology, preferences, policies and institutions via shocks to TFP, the marginal utility to consumption, monetary and fiscal rules and mark-ups respectively. These shocks can be denoted 'fundamental shocks'. The interpretation of shocks to arbitrage equations which explain business fixed investment, residential investment (Q–equations) and house prices is more ambiguous. A fundamental interpretation can be given to those shocks if one assumes shocks to the adjustment cost technology or to preferences (in the case of residential investment) or the rate in which new land is created in the case of land prices. Alternatively, shocks to arbitrage equations can also be interpreted as non-fundamental or as bubbles. This is the identifying assumption we are making in this paper. In particular we ask ourselves, do the shocks which we identify over the relevant time horizon for the three arbitrage relations resemble movements which look like bubbles? Since we do not want to impose restrictions on a specific type of bubble we do not make strong parametric assumptions about the error process. However, the estimated shocks to the optimality conditions for investment and land prices can nevertheless provide information about the type of shock. For example, a finding of declining risk premia in our Q equations for investment followed by a rapid rise suggests the presence of a bubble.

In implementing a bubble processes we follow Bernanke *et al.* (1999). Consider the following asset market relationship according to which the fundamental value q_t of an asset is equal to the current return div_t plus the expected value in the next period discounted with the expected return *r*

(40) $q_t = (div_t + E_t q_{t+1})/(1 + r_t)$

We assume that besides div_t, there is a non-fundamental shock x_t which also influences the current price. And we assume that x_t follows the "near rational" bubble process[2]

[2] We confine ourselves to near rational bubbles for technical reasons (see next footnote). By deviating from a rational bubble we implicitly allow for the presence of noise trading which is not eliminated by rational speculators.

(41) $$x_{t+1} = \begin{cases} \left(\frac{a}{prob}\right) x_t (1 + r_t) + e_t & \textit{with probability prob} \\ 0 & \textit{with probability} (1 - prob) \end{cases}$$

with $a < 1/(1 + r)$ [3]. The expected value of x_t is

(42) $$E_t x_{t+1} = a x_t (1 + r_t)$$

Now we can define the market price s_t for the respective asset

(43) $$s_t = q_t + x_t,$$

which follows the process

(44) $$((1 + r_t)(1 - (1 - a))\frac{x_t}{s_t})s_t = (div_t + E_t s_{t+1})$$

In the presence of bubbles the expected return of the asset differs from the fundamental return r_t by the presence of a positive or negative premium. The asset price including the bubble obeys the asset price equation with a declining risk premium and the risk premium is defined as

(45) $$rprem_t = -(1 - a)\frac{x_t}{s_t}$$

and x_t rises before the bubble bursts and vanishes afterwards.

We allow for risk premia in the asset price equations for corporate capital, residential housing, land and the exchange rate.

[3] This restriction allows us to introduce a stationary non fundamental shock into the model.

2. Estimation results and model fit

Our assumptions on technology imply that domestic and foreign GDP and its components are stationary in growth rates. Our model implies that various nominal ratios such as the consumption to GDP ratio (*cyn*), the investment to GDP ratio (*iyn*), the housing investment to GDP ratio (*ihyn*), the government consumption to GDP ratio (*cgyn*), the government investment to GDP ratio (*igyn*), the government transfers to wages ratio (*trw*), the trade balance[4] share in GDP (*tbyn*), the wage share (*ws*), the employment rate (*L*) and the real exchange rate (*RER*) are stationary. Concerning nominal variables we assume that the domestic and foreign inflation target is a constant. This implies that domestic wage inflation rate (π^{w}), domestic and foreign price inflation (π, π^{F}) rates and nominal domestic and foreign interest rates (i, i^{F}) are stationary, as well as certain price ratios, in particular the relative consumption (P^C/P), import (P^M/P) and export price (P^X/P) ratios. Housing (P^H/P)and construction prices (P^{Constr}/P) ratios are also stationary. These variables, together with the exogenous technology shock to the investment good production (U^{I}) and an exogenous observed time varying depreciation rate, form our information set. World economy series [i^{F}, π^{F}, Δy^F] are considered as exogenous and are modeled as a VAR(1) process. To assure stationarity of the Y/Y^W ratio, an equilibrium correction term is added to the Δy^F equation. This introduces a small feedback of domestic demand into world demand. The model is estimated on quarterly data for US over the period 1983Q1 to 2008Q4 (for data description see appendix).

Some data transformations are taken:

1. all real quantities are divided by the (*linear*) trend of active population, to obtain per-capita data;
2. relative *linear* trends in price indexes and real quantities have been removed;
3. the linear trend in the series of employment is also removed;
4. the pension component of the transfer rule is removed from the data prior to estimation: this eliminates the trend in the transfer to wage share and only the reaction coefficient b^{U} is estimated.

All the exogenous observed processes (world economy, technology shock to investment good production, time varying depreciation rate) have been estimated separately to the rest of the model parameters.
The parameters listed in Table 1 are calibrated and kept constant over the estimation exercise. Due to a lack of reliable data on tax rates we do not estimate t_1^W which measures the degree of progressivity of wage taxes, but set it corresponding to the OECD estimate of the elasticity of tax revenues with respect to the output gap[5].

TABLE 1 about here

Other parameters are determined according to steady state constraints:

[4] Concerning the import and export shares, we remove shift data so to have zero mean trade balance in the data.
[5] The OECD calculates an elasticity of income tax revenue with respect to the output gap of 1.5 and an elasticity of the wage bill w.r.t. the gap of 0.7. This implies an elasticity of the tax rate w.r.t. to output gap of 0.8.

- $\gamma_{ucap,1} = (1 - \tau) * (1 - \alpha) 1/\text{KSN}$, determined in order to assure the steady state constraint $ucap$ = 1, where $KSN = K / Y * PI / P$ is the nominal capital to GDP share.
- ϑ is determined in order to assure the steady state condition $\overline{L} = 0.7$;
- s_H^c and s_H^r are determined to assure calibrated steady state conditions $\overline{IH} / \overline{C}$ =0.1 and $\overline{IH}^C / \overline{C}^C$ =0.07 based on available information on the housing sector;

For both government consumption and investment, reaction rules have been adopted responding to the output gap plus an error correction to assure stationarity of the nominal shares to GDP. Thus, the estimated government consumption rule takes the form

$$(46) \quad \Delta c_t^G = (1 - \tau_{Lag}^{CG}) \overline{\Delta c^G} + \tau_{Lag}^{CG} \Delta c_{t-1}^G + \tau_{Adj}^{CG} (cgy_{t-1} - \overline{cgy}) + \tau_0^{CG} \Delta ygap_t + \tau_1^{CG} \Delta ygap_{t-1} + u_t^{CG}$$

$$(47) \quad \Delta i_t^G = (1 - \tau_{Lag}^{IG}) \overline{\Delta i^G} + \tau_{Lag}^{IG} \Delta i_{t-1}^G + \tau_{Adj}^{IG} (igy_{t-1} - \overline{igy}) + \tau_0^{IG} \Delta ygap_t + \tau_1^{IG} \Delta ygap_{t-1} + u_t^{IG}$$

The model parameters are estimated applying the Bayesian approach as, e.g., Schorfheide (2000), Smets and Wouters (2003). From the computational point of view, the DYNARE toolbox for MATLAB has been applied (Juillard, 1996-2005).

2.1 Prior distributions

Exogenous AR shocks have beta distributions for auto-correlation coefficients with prior mean at 0.85 except for the monetary and price mark-up shock, where we set prior mean to 0.5 (i.e. we did not have any 'preference' between a persistent shock or a white noise). Standard errors have prior gamma distributions, with prior mean values at

- 0.5% for 'persistent shocks' and for shocks to capital and foreign asset risk premia, government consumption, investment, transfers;
- 1% for housing and land risk premia shocks and χ shock;
- 0.25% for monetary shock and shock to PC equation;
- 5% for technology shock, preference leisure and labour demand shocks;
- 10% for mark-up shocks

For the fiscal parameters, we set a prior around zero for τ^{CG} and τ^{IG}, to let the data drive pro-cyclical or counter-cyclical reaction of government consumption and investment to changes in the output gap. For transfers we set a prior mean of b^U at 0.3 with a quite wide range [0; 0.6]. Persistence in the government spending and investment rule has a prior at 0.5.

For price and wage rigidities we roughly follow Smets and Wouters (2003) with prior mean at 4 (prices) and 12 (wages). Capital and labour adjustment costs have prior mean at 30, while for investment the prior is smaller (15). Prior consumption is set at 0.7. Substitution elasticities between domestic and foreign goods have prior gamma distributions with mean 1.25 and standard deviation 0.5 , while that for housing services is set to 0.5 (mean 0.4) and 0.5 (mean 0.2) for land. The prior mean of the share of Ricardian households ($s^r / (s^r + s^c)$) is set at 0.5. The prior for the intertemporal elasticity of substitution is set to 0.5. Finally, the share of forward looking behaviour in hybrid Phillips curves and the price indexation coefficients have prior mean at 0.7 in the range [0, 1].

2.2 Posterior estimation

Posterior mode estimation has been performed. The shape of the likelihood at the posterior mode and the Hessian condition number have been considered to rule out major identification problems for some parameters. In Table 2.1 we show prior distributions and posterior mode estimations of our structural parameters (see Table A1 in the annex for estimates of standard errors of shocks and AR coefficients of autocorrelated shocks).

TABLE 2.1 about here

The estimated share of credit-constrained consumers is 0.59, which implies 41% of households are fully unconstrained. This relatively low share of 'Ricardian' households cannot directly be compared to estimates derived from other DSGE models which assume liquidity-constrained, or 'rule-of-thumb', households that do not save. These models typically estimate a share of Ricardian households between 0.5 and 0.75. Credit-constrained households intertemporally optimize, like Ricardian households, but do this facing a collateral constraint. Allowing for credit constrained optimizers reduces the estimated share of Ricardian unconstrained consumers. This is in contrast to Iacoviello and Neri (2008), who estimate only 21% of wage income accrues to credit-constrained consumers. Our approach differs as their model contains an explicit collateral constraint which leads to an increase in the shadow price of lending, while we model credit constraints through an explicit increase in the loan interest rate if the value of the housing collateral declines. Note that our estimates also suggest a degree of habit persistence in consumption of 0.65 and an intertemporal elasticity of substitution of around 0.25. The substitution elasticity for housing services is estimated at 0.4.

The estimated persistence in nominal interest rate setting is at 0.93 higher than our prior. The estimated fiscal response parameters are counter-cyclical. For government transfers we find a positive response of transfers to the employment gap (b^U=0.22) and government consumption and investment respond negatively to the current change in the output gap. Estimates for adjustment cost of capital and investment are generally somewhat lower than our priors with the exception of that for housing investment which is higher. The share of forward-looking behaviour in price indexation is high than expected, and ranges between 0.75 and 0.9.

In Figure 1 we show the one step ahead predictions of the model for the growth rates of GDP (g^Y), consumption (g^C), investment (g^I), labour (g^L), government consumption (g^G), government investment (g^{GI}), government transfers (g^{TR}), construction investment (g^{CONSTR}), as well as for inflations ($\pi^{constr}, \pi^{house}, \pi$, π^M, π^X), wage inflation (π^W), growth rate of investment specific technological progress (g^{UI}), nominal interest rates (i, i^F), nominal exchange rate (g^E), world inflation (π^F), world GDP (g^{YW}).
We also show the fit of real ratios to GDP of consumption (*cy*), government consumption (*cgy*), and nominal ratios to GDP of government investment (*igyn*), investment (*iyn*), construction investment (*iconstryn*), trade balance (*tbyn*), transfers to wages ratio (*trw*), the real foreign GDP to domestic GDP ratio (*ywy*) as well as the stationary real exchange rate (*ER*), labour (*L*), wage share (*ws*), house to GDP deflator (*PHOUSE/PY*), construction to

GDP deflator (*PCONSTR/PY*), consumption to GDP deflator (*PC/PY*), import to GDP deflator (*PM/P*), export to GDP deflator (*PX/P*).

Figure 1 about here

2.3 Model comparisons

A quite widely applied method to assess the validity of the estimated DSGE models is to compare them with non-structural linear reduced-form models such as VARs or BVARs (see e.g. Sims, 2003; Schorfheide, 2004; Smets and Wouters, 2003; Juillard *et al.* 2006). In Table 2.2 we compare our base model with BVAR models (lags 1 to 12) using Sims and Zha (1998) priors. The BVAR estimates were obtained following Juillard et al. (2006), combining the Minnesota prior with dummy observations. The prior decay and tightness parameters are set to 0.5 and 3, respectively. As in Juillard et al. (2006), the parameter determining the weight on own-persistence (sum-of-coefficients on own lags) is set at 2 and the parameter determining the degree of co-persistence is set at 5. To obtain priors for error terms we used the residuals from unconstrained AR(1) processes estimated over a sample of observations that was extended back to 1978Q1 (the DSGE model is estimated over a sample starting from 1983Q1). The marginal data density of the DSGE has been obtained by the Laplace approximation formula (Metropolis runs are in progress). Similarly to other estimated DSGE's in the literature, our base model has a comparable marginal likelihood with respect to BVAR's (up to 5 lags). Although the robustness of these kinds of results is sometimes criticized, for the reason that it may depend on different prior assumptions in both the DSGE and the BVAR, BVARs are a potentially useful metric for comparing the out-of-sample performance of DSGE models.

Table 2.2 about here

In Table 2.3 we also report the RSME's of the 1-step and 4-step ahead predictions of the DSGE model and of a VAR(1) that includes error corrections mimicking the long run restrictions implied by the model concerning nominal ratios. In Figure 1 bis we also show the plots of the 1-step ahead fit of the VAR(1). The in-sample RMSE's of the VAR(1) are obviously better than those of the DSGE, and they are useful to have an idea of the 'upper' bound of the in-sample fit. This does not obviously imply a better performance of the VAR out-of-sample (see above discussion on BVAR comparison). It is interesting to note that for most of the observed variables, the DSGE performs better in the 4-step than in the 1-step ahead prediction horizons.

Table 2.3 about here
Figure 1 bis about here

3. Basic model properties

This section discusses basic model properties relating to the shocks we are concentrating on in this paper. Figures 2 to Figure 7 show the impulse response functions to six distinct structural shocks: an interest rate shock, a technology shock, capital, housing and land risk premium shocks and a shock to credit conditions. These shocks reflect the factors that, as highlighted in the introduction, are put forward as explanations for the boom and bust cycle in the US economy. The figures show the impulse responses of the main endogenous model variables to shocks equal to one percent.

First, a temporary 1 percentage point reduction in interest rates (Figure 2) leads to a hump shaped response of output with output peaking in the third quarter. Domestic demand increases with corporate investment rising more strongly than consumption. The increase in consumption of credit-constrained households is stronger than that of Ricardian households and is more persistent. This is related to the time it takes for real wages to adjust. Residential investment of credit-constrained households increases more strongly than that of Ricardian households and is also more persistent. Consumption and residential investment of non-constrained households returns faster to zero and undershoots, due to the overshooting in real interest rates. The exchange rate depreciates and the worsening terms of trade partly offsets the deterioration in the trade balance due to higher imports. The increase in domestic demand is accompanied by a rise in labour demand and higher real wages puts upward pressure on prices. Though inflation is not very persistent in the case of a monetary shock it takes about 5 years before the price level has approximately adjusted to a temporary monetary shock. Consumer price inflation rises more strongly as import prices increase due to the depreciation of the exchange rate.[6]

Figure 2 about here

Figure 3 shows the effects of a permanent increase in the level of TFP by 1%. The decline in marginal costs leads to a sharp fall in inflation and a gradual increase in domestic demand components. The real wage also rises, but there is a rather persistent negative employment effect. This illustrates the demand externality of supply shocks when there are nominal rigidities, as highlighted by Gali (1999). Because firms lower prices insufficiently in response to a cost-reducing shock, there is a lack of aggregate demand which makes it optimal for individual firms to lower employment. The central bank responds to the shock by reducing interest rates to offset the deflationary pressures. The response of credit-constrained households in consumption and residential investment is somewhat stronger than that of Ricardian households reflecting a higher interest rate sensitivity. Because of the permanent increase in residential investment the land price adjusts instantaneously and jumps up. This increase outweighs the decline in construction investment inflation, which moves in line with domestic price inflation, and house price inflation rises. The depreciation of the exchange rate gives a boost to exports but the trade balance falls after an initial improvement as the increase

[6] A fall in interest rates of 100 basispoints on impact raises GDP by almost 0.8 percent at its peak, after 3 quarters. This is a similar impact multiplier as reported in e.g Ratto et al. (2009) and Christoffel et al. (2008). Inflation peaks in the first quarter and we do not see the hump-shaped response in consumer price inflation that is a feature of many estimated VARs. This could be due to our small open economy assumption that we do not allow the exchange rate to affect export prices of the rest of the world. This implies that the depreciation of the dollar is immediately passed on to domestic consumer prices. Experiments show that a hump-shaped inflation response can only be found when the weight on forward-looking price indexation (*sfp* in eq. (4d')) is set to values lower than 0.7 (the estimated value is 0.9).

in imports due to higher domestic demand dominates . The depreciation increases import prices and as a result consumer price inflation falls by less than domestic price inflation.

Figure 3 about here

The most pronounced effect of a risk premium shock (u_t^I in eq. 16) is as could be expected on corporate investment (see Figure 4). Temporarily lower capital costs give rise to a large and persistent increase in physical investment. This in turn gives also rise to a prolonged positive consumption response. Aggregate consumption responds positively in the short run despite a negative initial response of Ricardian consumption, because credit-constrained consumers respond to higher labour income. Aggregate consumption is also persistent because of Ricardian consumers increasing consumption over time due to higher income from capital. A similar pattern can be observed for residential investment with initially a negative response from Ricardian households, followed by a gradual increase, and an increase in credit-constrained residential investment. The shock raises inflationary pressures and monetary policy responds by increasing interest rates.

Figure 4 about here

Temporarily lower capital costs on residential investment (u_t^H in eq. 18 and 23) increases investment of both types of households but leads to a small shift in spending away from consumption (Figure 5) . The substitution effect is stronger for credit-constrained households. Increased residential investment also crowds out corporate investment and the total output effect is small and short-lived. The net effect on GDP is therefore not very large. Land prices increase because of the constraint on the supply of land, and although construction price inflation falls initially, in line with domestic price inflation, house price inflation increases.

Figure 5 about here

A lower discount rate on land (u_t^{Land} in eq. 19) increases land prices initially (Figure 6). However since the shock is perceived to be temporary there is an expectation of a future decline in house prices (which increases capital costs for residential investment). Therefore, a temporary negative risk premium shock lowers residential investment. This leads to a shift in spending from residential investment to consumption, and this substitution is strongest for credit-constrained households. Note that, while this shock has a significant impact on house prices, the effect on GDP is relatively small, as the decline in residential investment is partly offset by an increase in consumption.

Figure 6 about here

Finally, Figure 7 shows the response to a credit relaxation shock (u_t^χ in eq. 21). A temporary relaxation of credit conditions boosts both consumption and investment of credit-constrained households. Higher real interest rates have a small negative impact on Ricardian consumption but consumption of non-constrained households recovers also in later periods. Aggregate consumption rises and the increase in output raises inflationary pressures. Monetary policy responds by raising interest rates.

Figure 7 about here

4. Shocks driving the boom and bust cycle

We now turn to our analysis of the shocks that drove the US economy in the boom and bust cycle starting in 1999Q1 and finishing in 2008Q4. This period covers the final years of a prolonged boom period that started in the 1990s and that led to the first recession in this century, commonly associated with the bursting of the dot com bubble. It also covers the subsequent recovery and build-up of a next boom, in particular in the housing sector, followed by a bust in recent years.

The estimated residuals in a DSGE model can be given a structural interpretation as shocks to technology, preferences, monetary policy or as non-fundamental shocks (bubbles) to asset prices. Given the current policy discussion about the US we concentrate in this paper on five types of shocks which are generally regarded as important drivers of the US economy in the last decade. These are positive shocks to technology, expansionary monetary policy in the Greenspan era, asset price bubbles in stock market and housing market, and excessive bank lending associated with the fast development of the subprime mortgage market. We capture *technology shocks* to final goods and investment goods production via the shock terms u_t^Y and u_t^I which we model as random walk processes. We identify shocks to *monetary policy* u_t^{INOM} as stationary deviations of the nominal interest rate from a standard Taylor rule and we capture shifts in *lending conditions* as shocks to the collateral constraint of households u_t^{χ}. By adding exogenous shocks to the discount factors of the various asset market arbitrage equations we allow for non-fundamental shocks (bubbles) in the model. In particular we identify bubbles in asset price (Q)-equations for corporate investment u_t^K (*stock market* bubble), as well as residential investment u_t^H and land prices u_t^{Land} (*housing bubble*) (see section 1.6 for the bubble interpretation of correlated shocks to asset price equations).

Figure 8 about here

Figure 8 shows the estimated historical evolution of these fundamental and non-fundamental shocks of the model over the 1990s and 2000s. The first chart (TFP) shows a decline in productivity up to 1995, which flattened out in later years and was then followed by a sharp increase in productivity in the first half of this decade which flattened off again in 2004, fell slightly and started rising again at the end of our sample. The lending conditions shock (DEBTCC) shows a tightening in lending conditions in the early years of this decade, but a relaxation since 2004, which was only reversed in 2008. The monetary policy shock shows no clear sign of an overly lax monetary stance during the build-up of the bubble. If anything, the residual of the Taylor rule was positive over much of this time, and only became negative briefly in 2007-8. Note that the last observation shows a large positive residual, suggesting monetary policy became restrictive when the federal funds rate hit the zero lower bound. According to the estimated Taylor rule, interest rates could have been 120bp lower in the last quarter of 2008, The bottom three charts show the evolutions of the three non-fundamental shocks over these two decades. A stock market bubble built up in the second half of the 1990s and burst in 2000-1. In following years a new bubble built up, which burst again in 2007. The risk premium on residential investment shows a gradual decline since 2000, which came to an abrupt halt and sharp reversal in 2005. A similar pattern is visible in the bubble for land prices, with a sharp fall in the risk premium in 2004 and an increase in 2007-8.

Figure 9 now shows the US growth decomposition for our five broad categories of shocks, where we have grouped together the two housing shocks. Interestingly, the 2001 recession does not seem to be associated with a strong and persistent negative technology shock. Quite to the contrary, the period from 2001 onwards is characterised by continued strong TFP growth in the US, which lasts until 2004. Our estimate of the Taylor rule suggest that monetary policy has been slightly expansionary in 2001-2, when measured against the benchmark of a standard (Taylor) rule oriented policy. Monetary policy supported growth in the recession but remained broadly neutral, if not slightly tight (in 2005-6), in the following years. Only in 2008 we can see an expansionary departure from the Taylor rule.
The primary shock responsible for the 2001 recession is the bursting of the stock market bubble u_t^K . We estimate a sharp increase in the risk premium in the Q equation for corporate investment starting in 2001Q1. This coincides with the fall in US stock prices (Dow Jones index) around the third quarter of 2001 and which continued its decline in 2002. The impact of this bursting bubble remained negative in the following years and dragged down GDP growth till mid-2003.

Figure 9 about here

There appears to have been a positive contribution to GDP growth from the housing bubble from 2003 onwards. This continued till 2006 and then turned negative. Similarly, reduced collateral constraints for credit constrained households has supported GDP growth from 2004 to 2005. Figure 9 suggests that the housing boom, fuelled both by a bubble in the housing market and a loosening of collateral constraints has prolonged the growth momentum in the US after the US productivity boom started to fade off in 2004. The year 2008 is characterised by large negative contributions from credit tightening and the bursting of the housing bubble plus a decline in investment. As mentioned before, monetary policy reacts in an unprecedented strong manner to counteract these negative shocks.

Figure 10 shows the contribution of shocks to consumption growth. Initially, productivity growth is a major source of consumption growth. Especially in 2004/5 a loosening of credit constraints replaces TFP as a driver of consumption growth. In 2008 we identify a tightening of credit as a major explanatory factor for the collapse of consumption in the US. The housing bubble only explains a small fraction of movements in consumption. It is also interesting to notice that monetary policy impacted negatively on consumption over the years 2004 to 2006 but supported consumption strongly in 2008.

Figure 10 about here

Unlike GDP and private consumption, the peaks and troughs of residential investment appear to be driven by non-fundamental shocks, i.e. there seems to be excess volatility of residential investment. Figure 11 shows the contribution of shocks to aggregate residential investment growth and Figure 12 focusses on that of credit-constrained households in particular. The figures suggest that the housing bubble was building up since 2001 and started to burst in 2006. From 2003 to 2006, there was also a strong positive contribution of the relaxation of credit constraints to residential investment growth. Starting in 2006 a large reversal of housing investment takes place which we identify as a bursting of a house price bubble.

Figure 11 about here
Figure 12 about here

The housing bubble also drives house prices (Figure 13) especially over the years 2001 to 2005. House price inflation was further boosted by a relaxation of credit conditions in 2003-5. An abrupt reversal of these shocks from 2006 onwards led to a sharp decline in house prices.

Figure 13 about here

5. Conclusion

This paper presents an extension of the QUEST III model that explicitly models housing investment and allows for credit constrained households along the lines suggested by the recent literature on the financial accelerator mechanism. In order to better understand speculative movements of house prices, we model land as an exhaustible resource. This implies that land prices, which are an important component of house prices, have asset market characteristics in our model and can therefore be subject to fundamental shocks and bubbles. We estimate the model over the period 1980Q1 to 2008Q4 and apply it to explain the recent boom-bust cycle in the US. We are in particular interested to assess the relative contribution of technology, monetary policy, financial innovations and non-fundamental shocks to asset prices (bubbles) for an explanation of the US business cycle over the period 1999Q1 to 2008Q4.

Our tentative conclusions are as follows. First, the 2001 recession appears to have been mainly caused by a collapse of the dot com bubble. Second, the 2001 recession did not signal an end to the high productivity growth period. In fact, TFP growth remained positive until 2004. After 2004 we do, however, observe a strong decline in productivity growth. US households and banks may not immediately have been aware of declining productivity trends and continued private consumption and residential investment spending patterns. Some empirical evidence on the late detection of trend productivity reversals is provided by Kahn (2009) who shows that a significant productivity growth regime shift, occurring in 2004 could only have been detected in 2007, using modern statistical techniques. Third, monetary policy reacted timely and countercyclically. This helped avoiding a stronger recession in 2002 and supported GDP in 2008. Fourth, the housing boom which started in 2002 is hard to explain by economic fundamentals. Even in the period of high productivity growth between 2002 and 2004, only about 10% of housing investment is explained by income growth. Fifth, the expansion of mortgages to subprime borrowers has also contributed significantly to the housing boom but also supported private consumption. Finally, the bursting of this housing bubble is an important factor driving the current US recession.

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TABLES

TABLE 1. Calibrated parameters

Structural parameters		Steady states	
α	0.72	$\overline{cgy}$	0.148
α^G	0.9	$\overline{igy}$	0.0307
β^r	0.992	$\overline{g^{UI}}$	0
β^c	0.962	π, π^F	0.005
δ	0.025	$\overline{g^{popW}}$	0.0028214
δ^G	0.0125	$\overline{g^Y}, \overline{g^{YF}}$	0.0045
δ^{house}	0.01	$\overline{g^{UP}}$	0.003875
τ^B	0.0025	$\overline{ucap}$	1
τ^{DEF}	0.075	$\overline{L}$	0.703
b^T	2.4	θ	1.6
σ^d	12.5	$TRWS$	0.195
ρ^{INOM}	0	$\overline{IH} / \overline{C}$	0.1
ρ^{TB}, ρ^{χ}	0.975	$\overline{IH}^C / \overline{C}^C$	0.07
t^K, t^c	[0.2,0.1]	s_L	0.3
τ_0^w, τ_1^w	[0.15, 0.8]		
Risk, premlande	10^{-5}		

TABLE 2.1: Estimation Results for structural parameters

Parameter name		Prior			Posterior	
		distrib	mean	std	mode	std
$\frac{s^r}{(s^c+s^r)}$	SNLC	beta	0.5	0.2	0.4138	0.1036
σ_c	SIGCE	gamma	0.5	0.2	0.2558	0.1043
σ_H	SIGHE	gamma	0.5	0.4	0.3936	0.2366
h	HABE	beta	0.7	0.1	0.6496	0.0498
κ	KAPPAE	gamma	1.25	0.5	0.2496	0.2001
rp	RPREMK	beta	0.02	0.0041	0.0219	0.0028
χ_t^C	RISKCCE	gamma	1	0.5	0.7537	0.2014
$\gamma_{ucap,2}$	GAMUCAP2E	beta	0.05	0.024	0.0351	0.0166
ω^X	SE	beta	0.87	0.04	0.9075	0.0159
σ^X	SIGEXE	gamma	1.25	0.5	0.9377	0.1905
σ^M	SIGIME	gamma	1.25	0.5	0.9632	0.2346
ρ^{PCPM}	RHOPCPME	beta	0.5	0.2	0.7259	0.1477
ρ^{PWPX}	RHOPWPXE	beta	0.5	0.2	0.3108	0.1258
τ_{Lag}^{INOM}	ILAGE	beta	0.85	0.075	0.9391	0.023
τ_{π}^{INOM}	TINFE	beta	2	0.4	2.4609	0.2858
$\tau_{Y,1}^{IINOM}$	TY1E	beta	0.3	0.2	0.3886	0.1125
$\tau_{Y,2}^{INOM}$	TY2E	beta	0.3	0.2	0.1635	0.0454
τ_{Lag}^{CG}	GSLAGE	beta	0	0.4	-0.4646	0.1589
τ_{Adj}^{CG}	GVECM	beta	-0.5	0.2	-0.112	0.062
τ_0^{CG}	G1E	beta	0	0.6	-0.433	0.1646
τ_1^{CG}	G2E	beta	0	0.6	0.3213	0.1677
τ_{Lag}^{IG}	IGSLAGE	beta	0	0.4	-0.1213	0.1345
τ_{Adj}^{IG}	IGVECM	beta	-0.5	0.2	-0.8401	0.1227
τ_0^{IG}	IG1E	beta	0	0.6	-0.466	0.4643
τ_1^{IG}	IG2E	beta	0	0.6	-0.6393	0.4716
b^U	BU	beta	0.3	0.1	0.2228	0.0318
γ_H	GAMHOUSEE	gamma	30	20	8.8246	8.0759
γ_{IH}	GAMHOUSE1E	gamma	30	20	93.037	15.1722
γ_K	GAMKE	gamma	30	20	19.8977	6.3089
γ_I	GAMIE	gamma	15	10	2.2008	2.3444
γ_L	GAMLE	gamma	30	20	2.6081	1.872
γ_P	GAMPE	beta	4	2	9.079	1.0714
$\gamma_{PConstr}$	GAMPCONSTRE	gamma	30	20	15.5934	6.2495
γ_{Phouse}	GAMPHOUSEE	gamma	30	20	10.7024	5.2096
γ_{PM}	GAMPME	gamma	30	20	3.1189	2.9826

γ_{PX}	GAMPXE	gamma	30	20	7.0329	4.2988
γ_{W}	GAMWE	gamma	12	4	10.7332	1.8337
γ_{WR}	WRLAGE	beta	0.5	0.2	0.3816	0.0976
Sfp	SFPE	beta	0.7	0.1	0.8926	0.082
Sfpconstr	SFPCONSTRE	beta	0.7	0.1	0.8929	0.0756
Sfphouse	SFPHOUSEE	beta	0.7	0.1	0.8574	0.0841
Sfpm	SFPME	beta	0.7	0.1	0.8592	0.0886
Sfpx	SFPXE	beta	0.7	0.1	0.7582	0.0983
Sfw	SFWE	beta	0.7	0.1	0.798	0.0998
σ^{L}	SIGLANDE	beta	0.5	0.2	0.4191	0.1614
s^{c}		-	-	-	0.4138	-
s^{r}		-	-	-	0.5862	-
ϑ	OMEGE	-	-	-	0.1647	-
$\gamma_{ucap,1}$	GAMUCAP1E	-	-	-	0.0711	-
$\frac{s_H^c}{s_C^c}$	PREFHOUSECCE	-	-	-	0.6928	-
$\frac{s_H^r}{s_C^r}$	PREFHOUSENLCE	-	-	-	2.3149	-

TABLE 2.2. Comparison of the fit of the base model and of BVAR's.

	Marginal likelihood
BVAR(1)	7902.719
BVAR(2)	7975.419
BVAR(3)	7989.103
BVAR(4)	7992.722
BVAR(5)	7990.816
BVAR(6)	7998.039
BVAR(7)	7999.188
BVAR(8)	8012.401
BVAR(9)	8017.359
BVAR(10)	8019.296
BVAR(11)	8019.332
BVAR(12)	8019.145
DSGE model*	7983.322

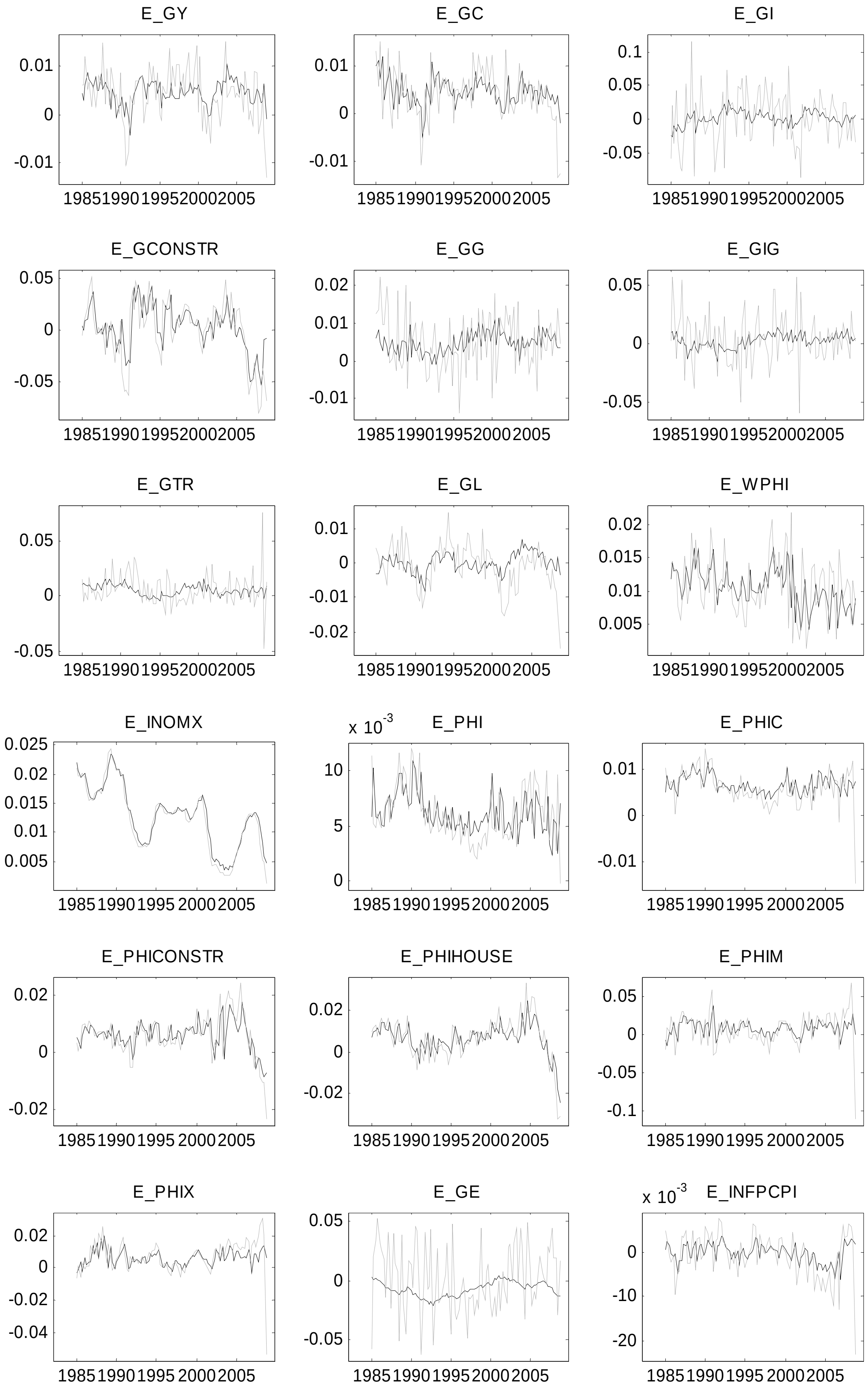
* Laplace approximation

TABLE 2.3. Comparison of the fit of the base model and a VAR(1) with error corrections reproducing long run constraints of the DSGE model. RMSE's are reported for 1-step and 4-step ahead predictions.

	DSGE 1-step	VAR(1) 1-step	DSGE 4-step	VAR(1) 4-step
g_t^Y	0.00499	0.003244	0.005214	0.00483
g_t^C	0.005307	0.002796	0.005479	0.004333
g_t^I	0.038607	0.022173	0.037883	0.034519
$g_t^{IConstr}$	0.021108	0.012431	0.026419	0.016709
g_t^G	0.006953	0.004698	0.006794	0.006416
g_t^{IG}	0.021687	0.014418	0.020789	0.019492
g_t^{TR}	0.014362	0.009066	0.014675	0.01361
g_t^L	0.00614	0.002152	0.00633	0.002776
π_t^W	0.004518	0.003172	0.004767	0.004047
$inom_t$	0.001173	0.000596	0.003484	0.001678
π_t	0.002489	0.001341	0.003188	0.001623
π_t^C	0.003555	0.001999	0.004082	0.002865
π_t^{Constr}	0.005275	0.002907	0.007033	0.003864
π_t^{House}	0.006268	0.004137	0.009279	0.00511
π_t^M	0.020234	0.012571	0.021427	0.018979
π_t^X	0.008748	0.00487	0.011375	0.007741
g_t^E	0.028547	0.020023	0.027447	0.023931

FIGURES

FIGURE 1. In-sample one step ahead predictions of the estimated model. (Data are grey lines; model predictions are black lines)



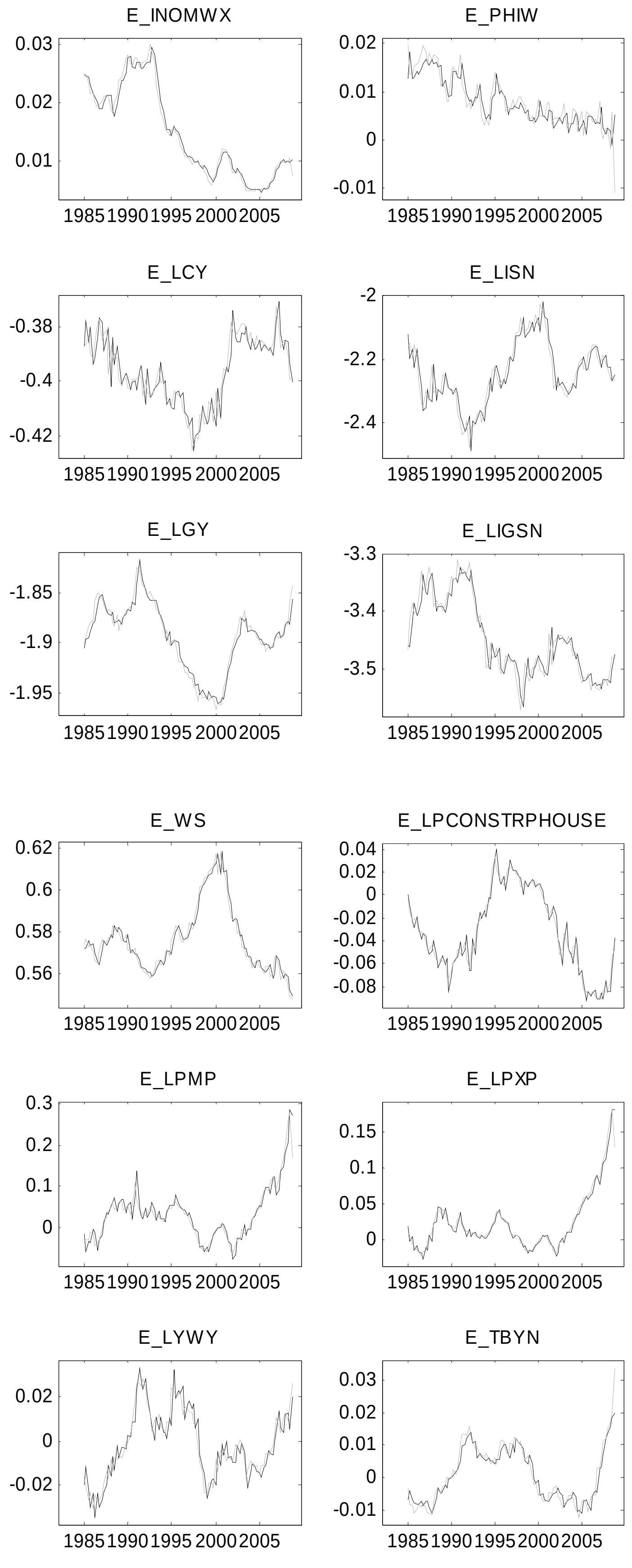
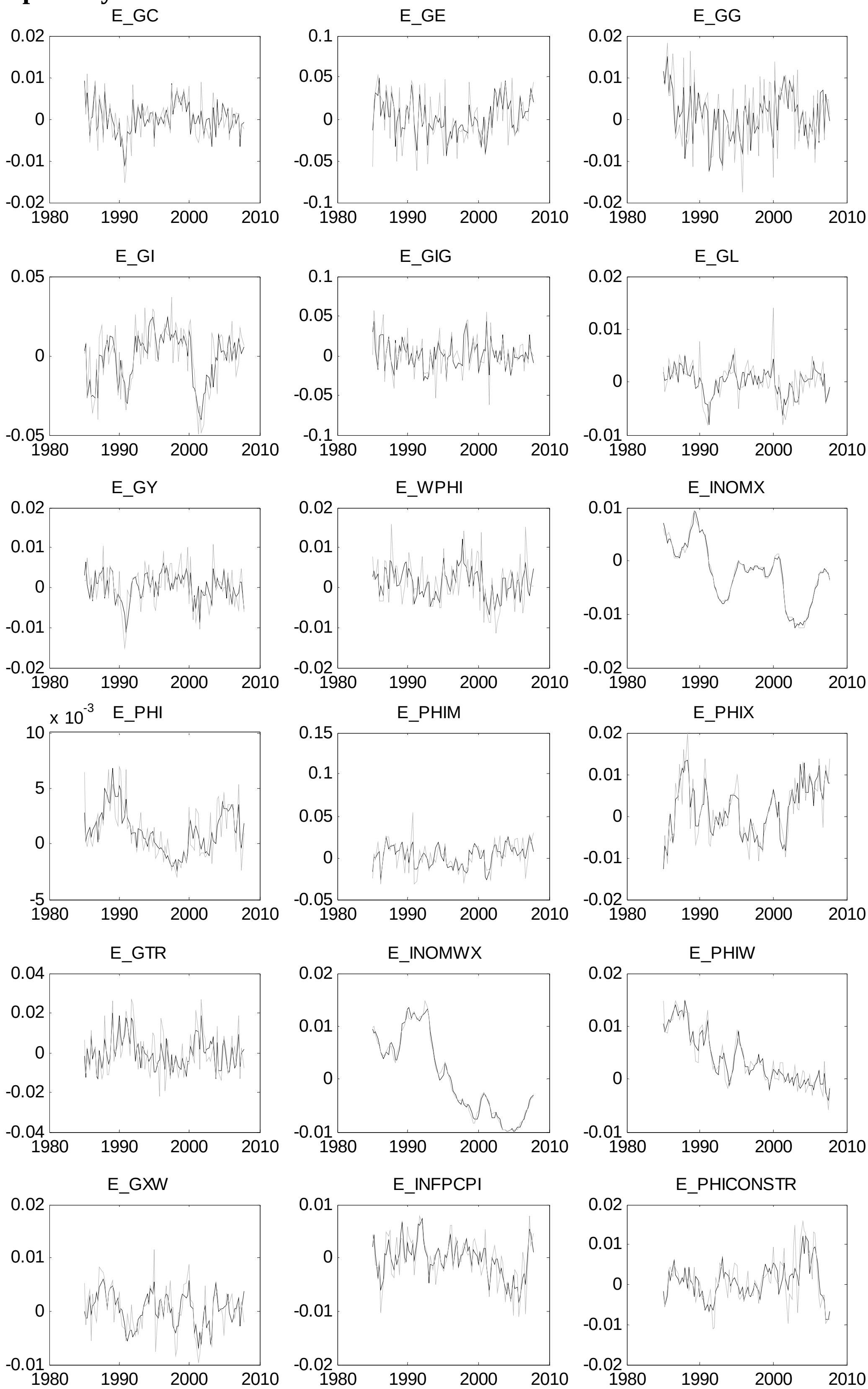
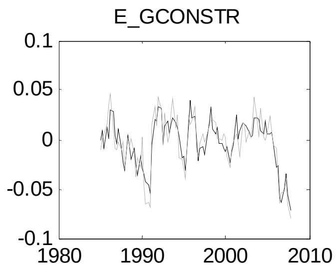

E_INOMWX
0.03
0.02
0.01
E_PHIW
0.02
0.01
0
-0.01
x 10^-3
E_GXW
15
10
5
0
-5
E_LCY
-0.38
-0.4
-0.42
E_LISN
-2
-2.2
-2.4
E_LICONSTRSN
-2.8
-3
-3.2
-3.4
E_LGY
-1.85
-1.9
-1.95
E_LIGSN
-3.3
-3.4
-3.5
E_LL
-0.3
-0.35
-0.4
-0.45
E_WS
0.62
0.6
0.58
0.56
E_LPCONSTRPHOUSE
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
E_LPCP
0.01
0
-0.01
-0.02
-0.03
E_LPMP
0.3
0.2
0.1
0
E_LPXP
0.15
0.1
0.05
0
E_LER
0.2
0
-0.2
E_LYWY
0.02
0
-0.02
E_TBYN
0.03
0.02
0.01
0
-0.01
1985 1990 1995 2000 2005

FIGURE 1 bis: fit of a VAR(1) including VECM corrections matching those implied by the DSGE model.




E_GCONSTR
0.1
0.05
0
-0.05
-0.1
1980
1990
2000
2010

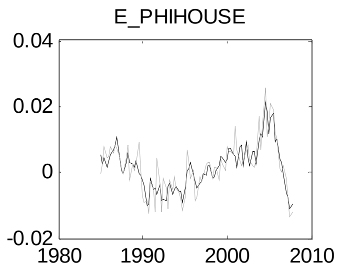
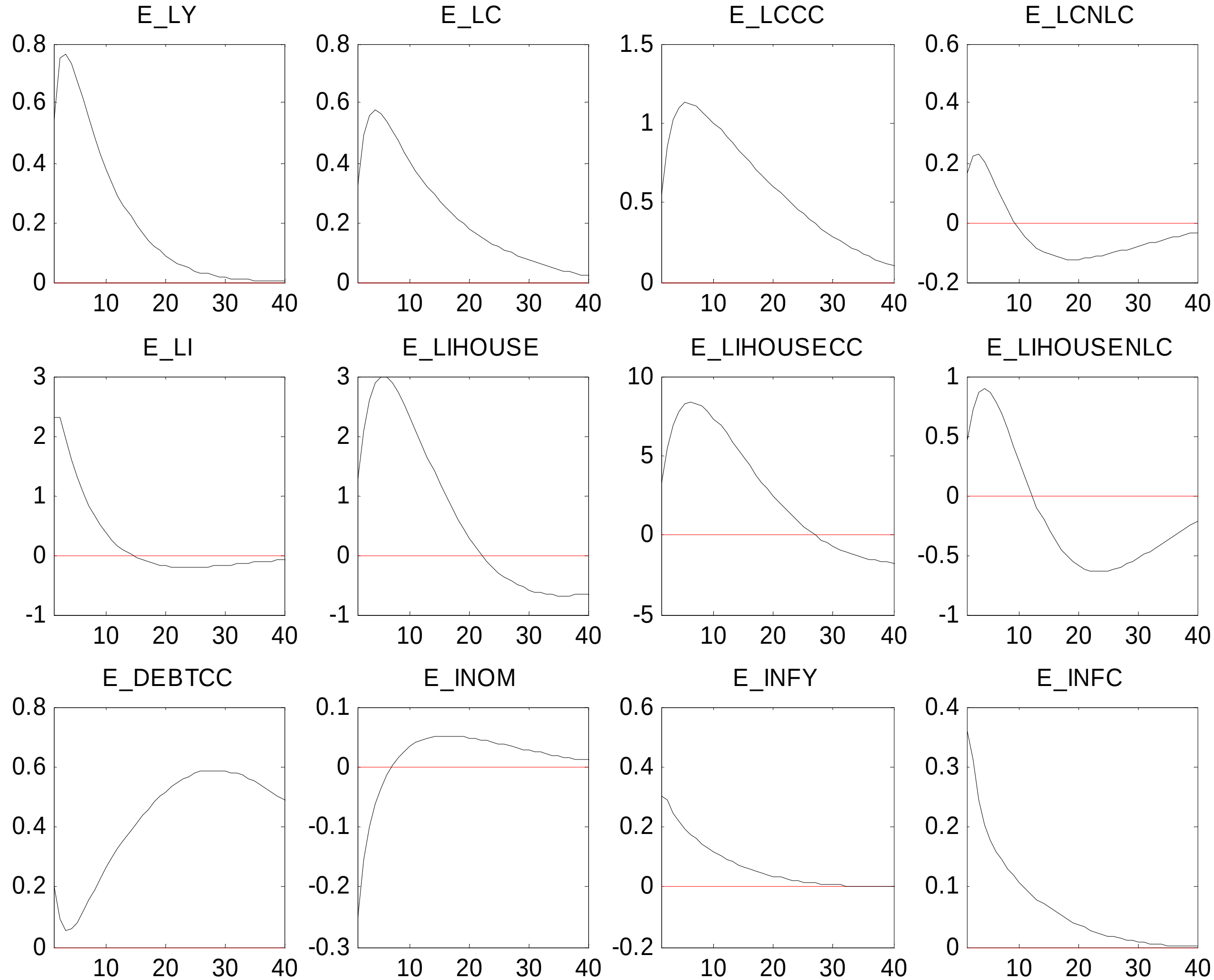
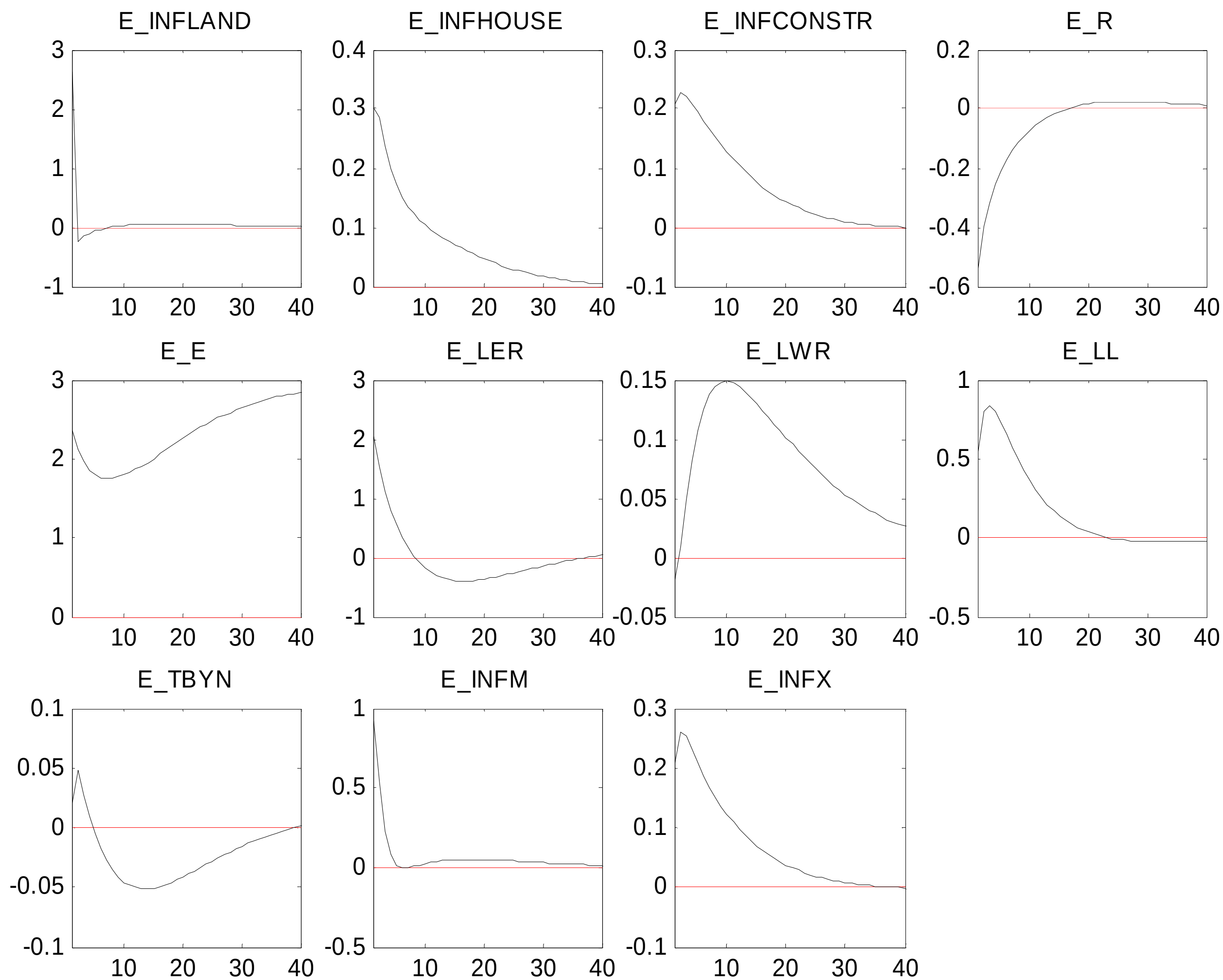

E_PHIHOUSE
0.04
0.02
0
-0.02
1980
1990
2000
2010

FIGURE 2: IRF's to a negative interest rate shock

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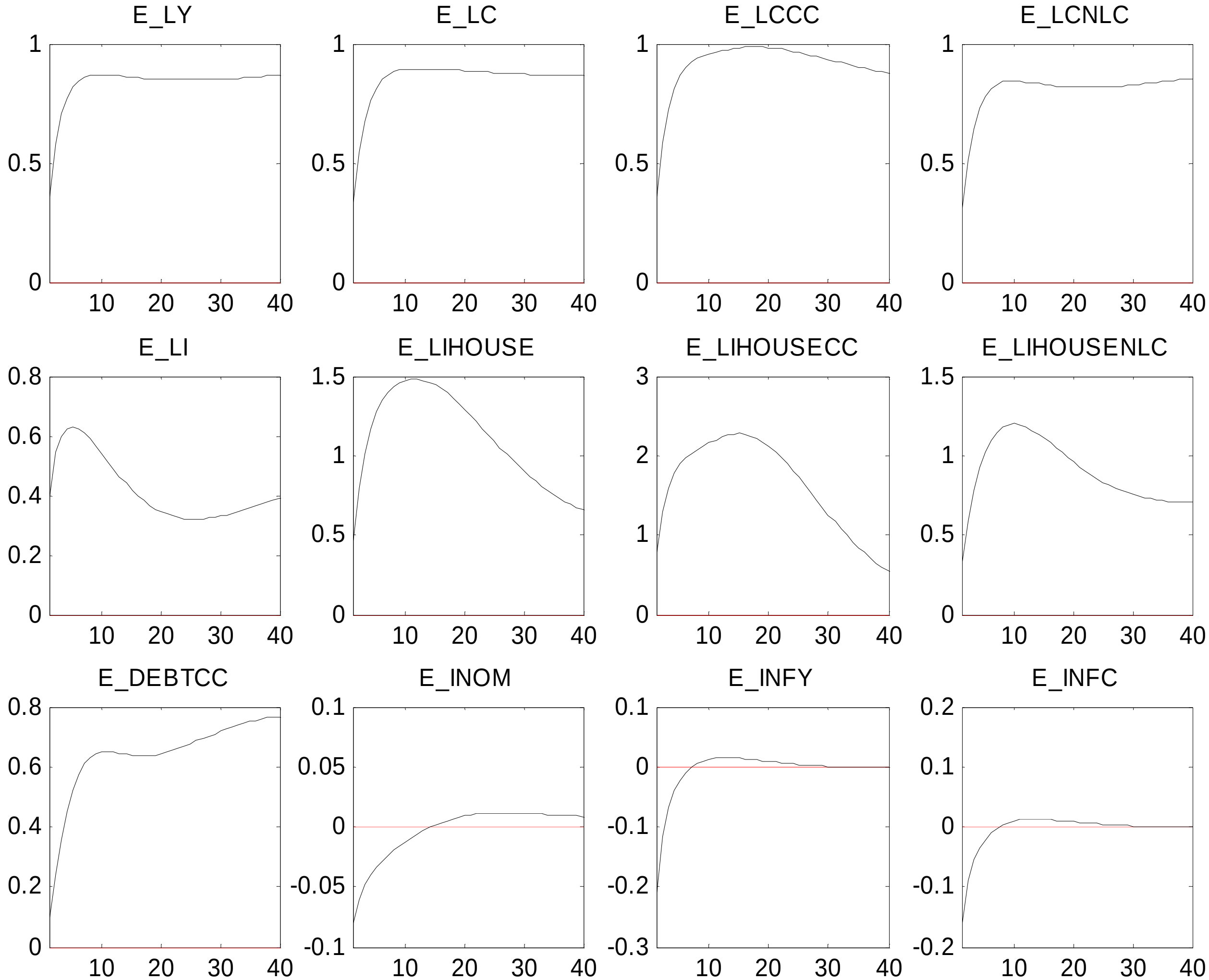
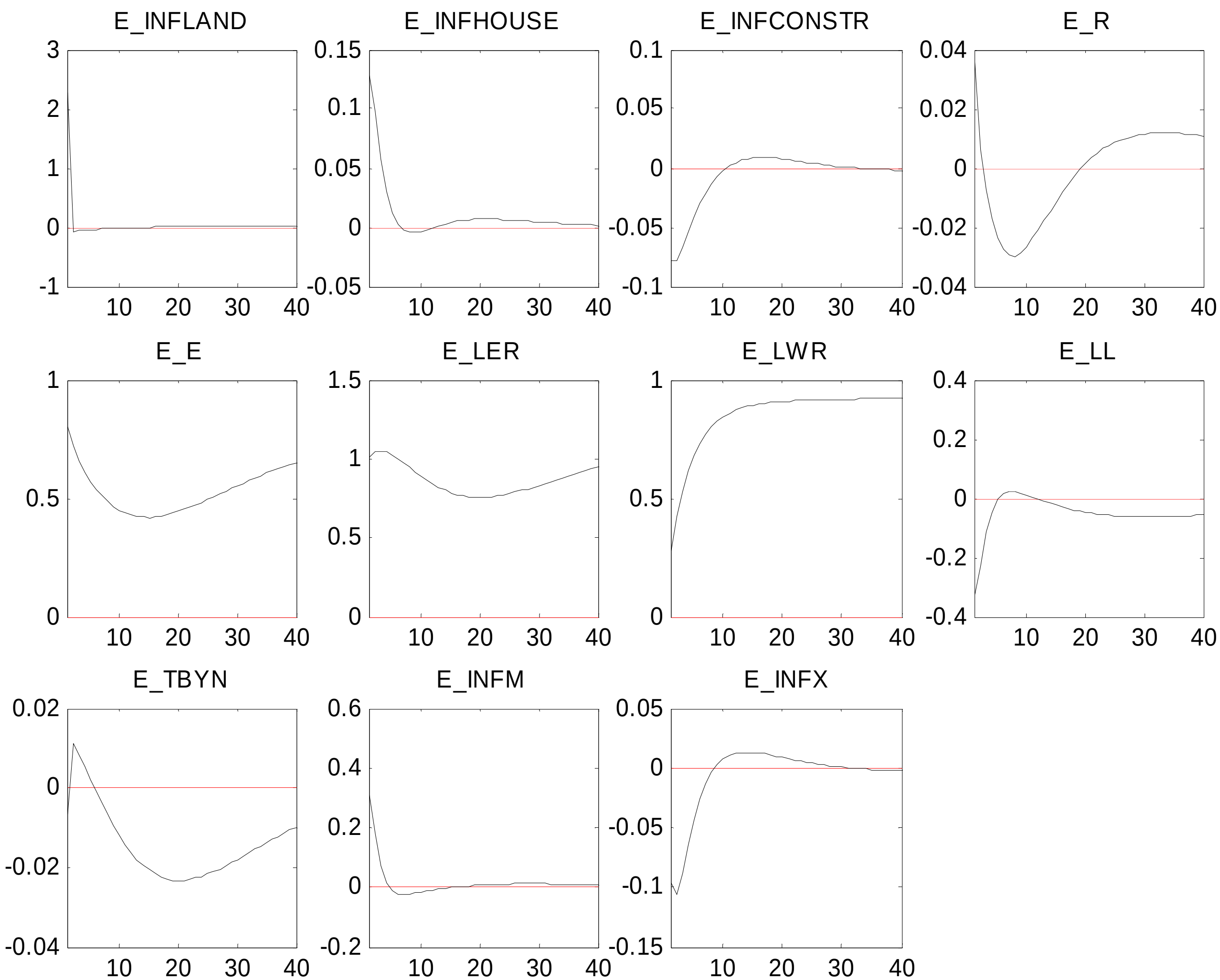
E_INFHOUSE
E_INFCONSTR
E_R
E_E
E_LER
E_LWR
E_LL
E_TBYN
E_INFM
E_INFX

FIGURE 3: IRF's to a positive 1% technology shock

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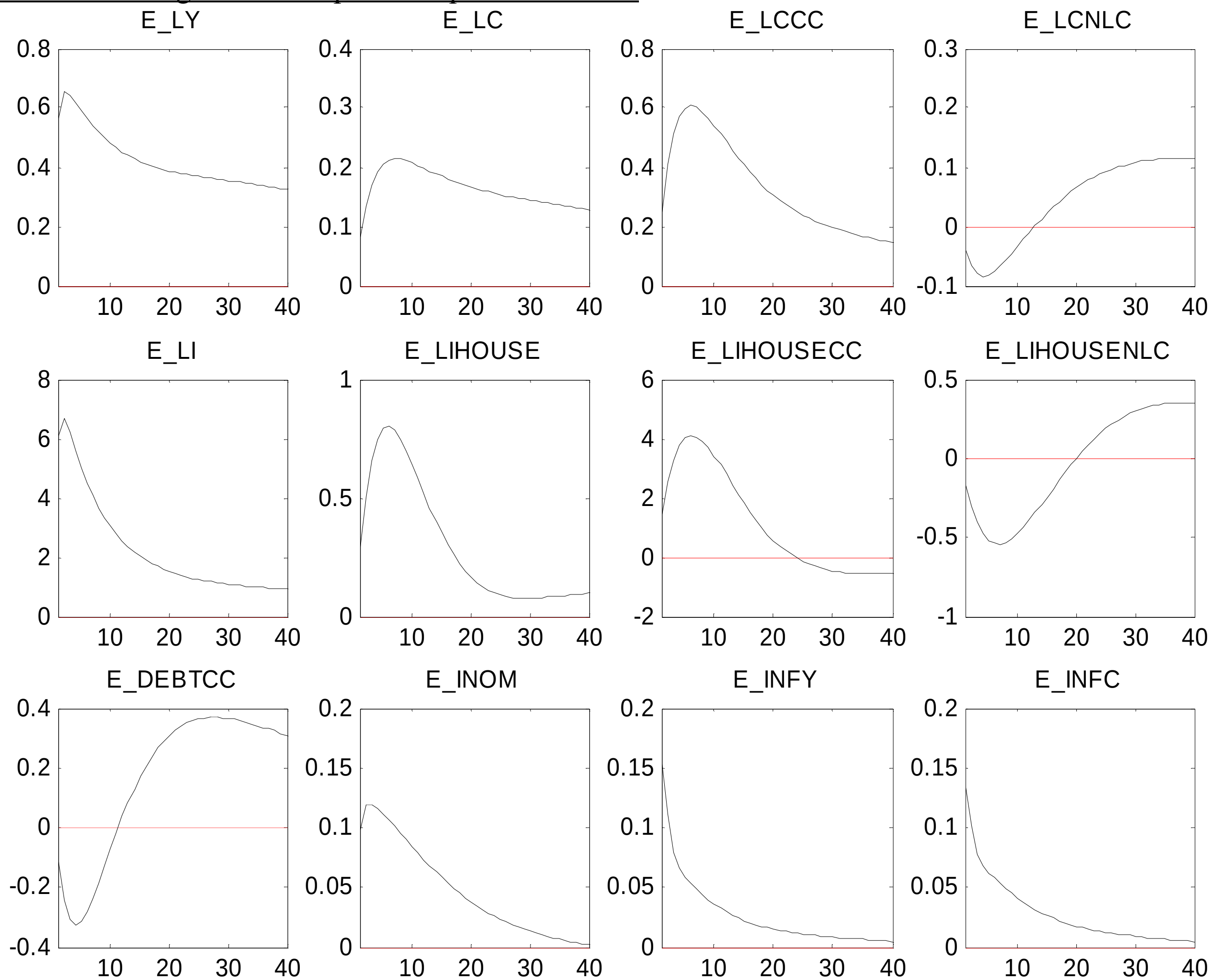
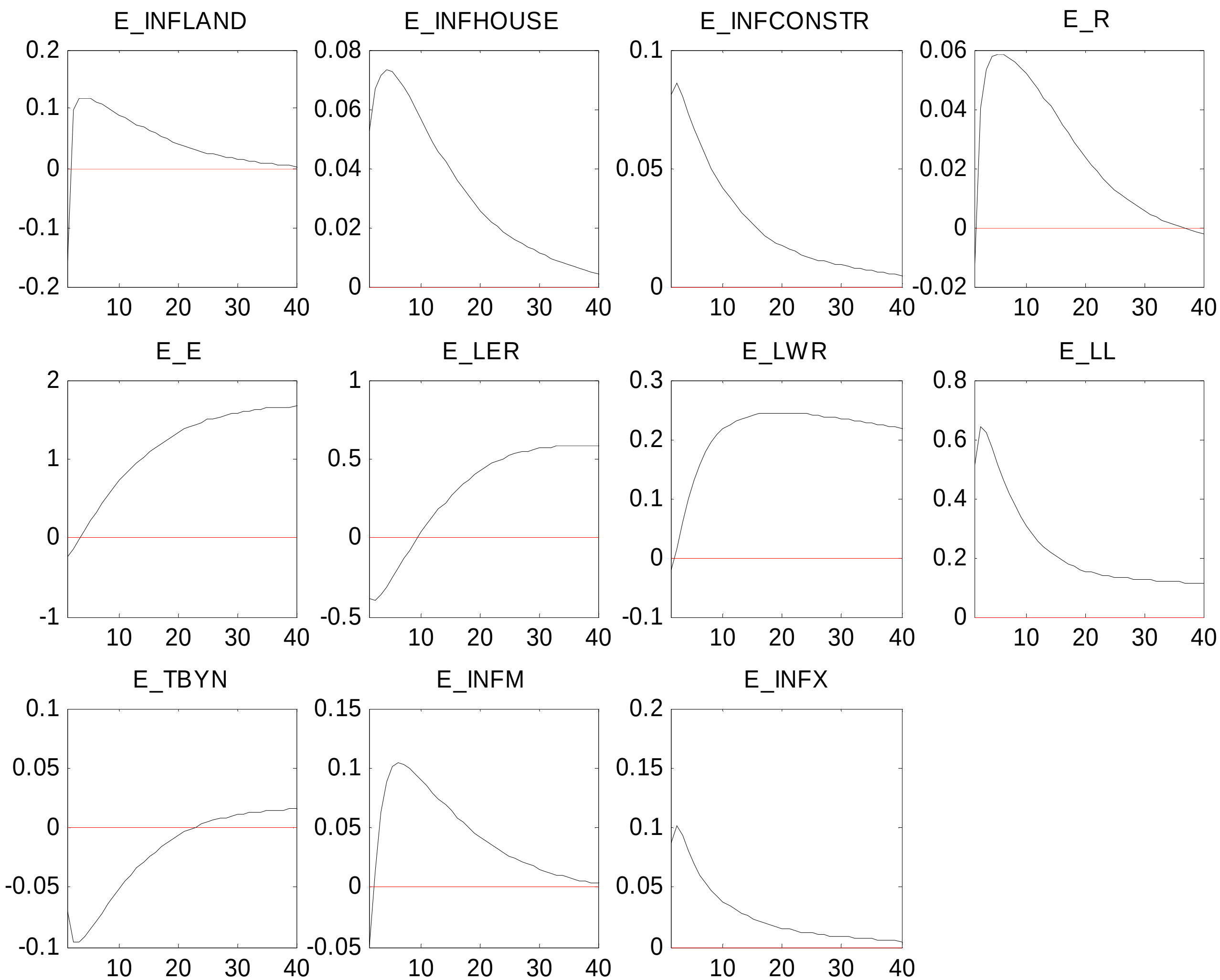
E_INFCONSTR
E_R
E_E
E_LER
E_LWR
E_LL
E_TBYN
E_INFM
E_INFX
10 20 30 40

FIGURE 4: IRF's to a negative 1% capital risk premium shock

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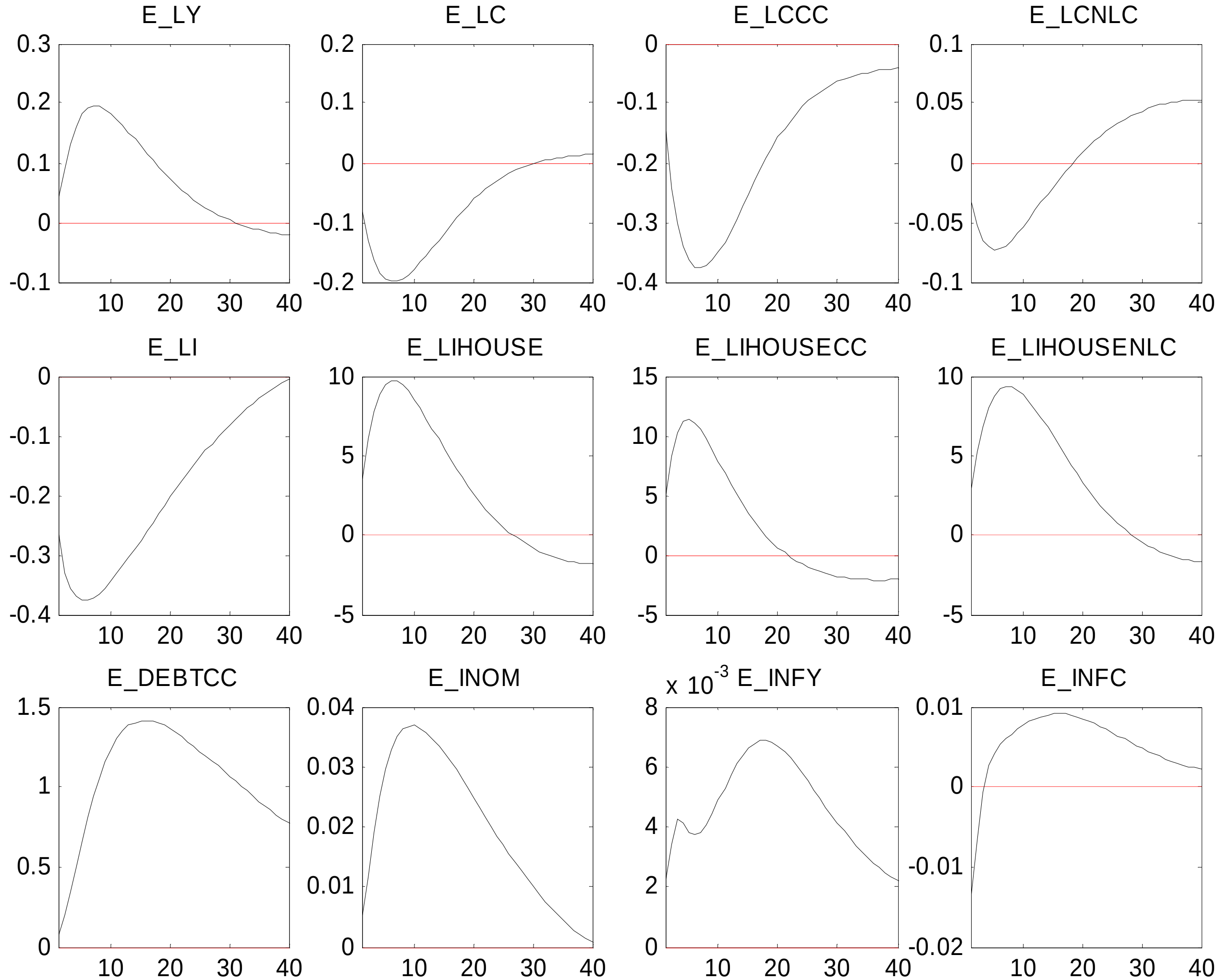
E_INFHOUSE
E_INFCONSTR
E_R
E_E
E_LER
E_LWR
E_LL
E_TBYN
E_INFM
E_INFX

FIGURE 5: IRF's to a negative 1% housing risk premium shock



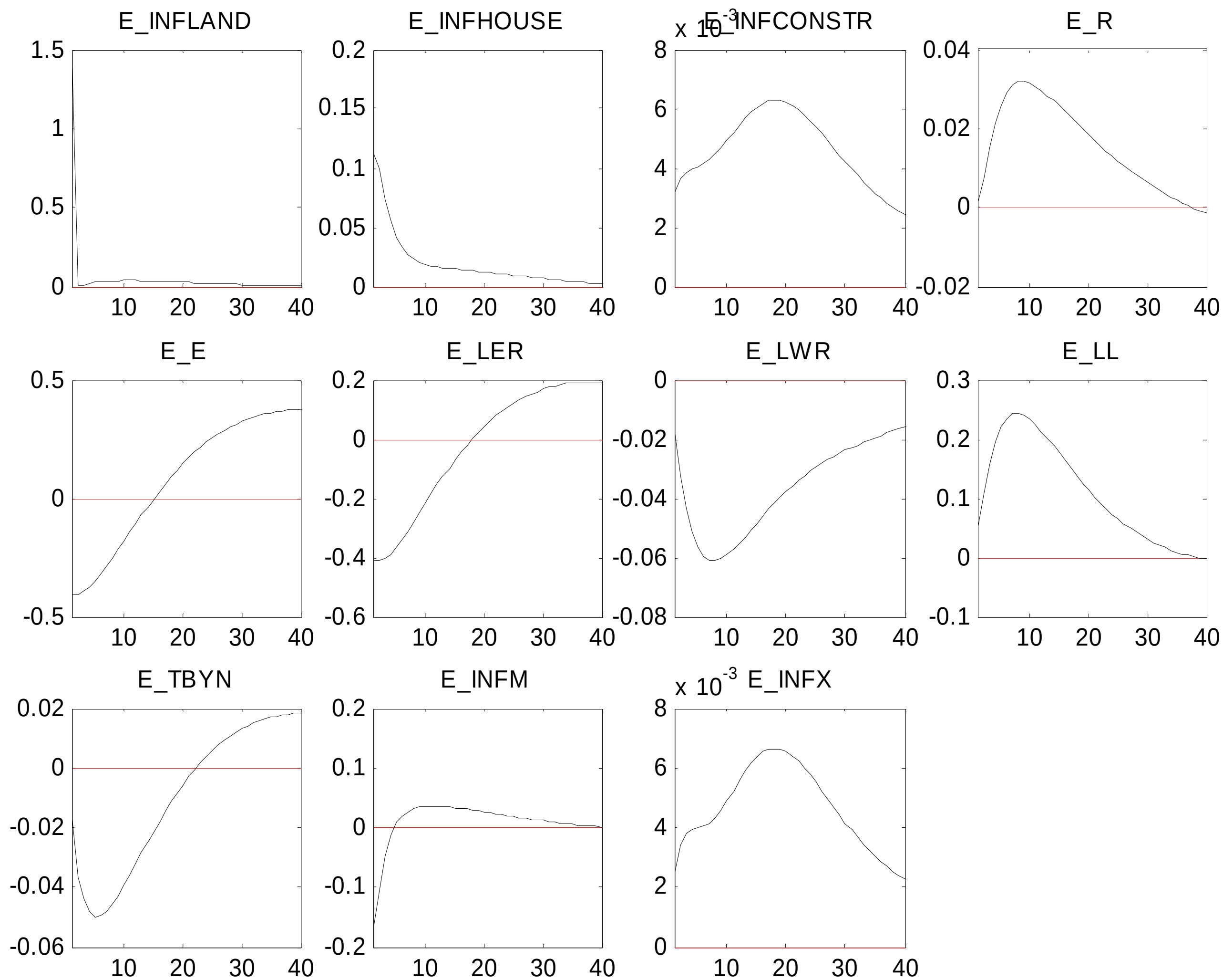
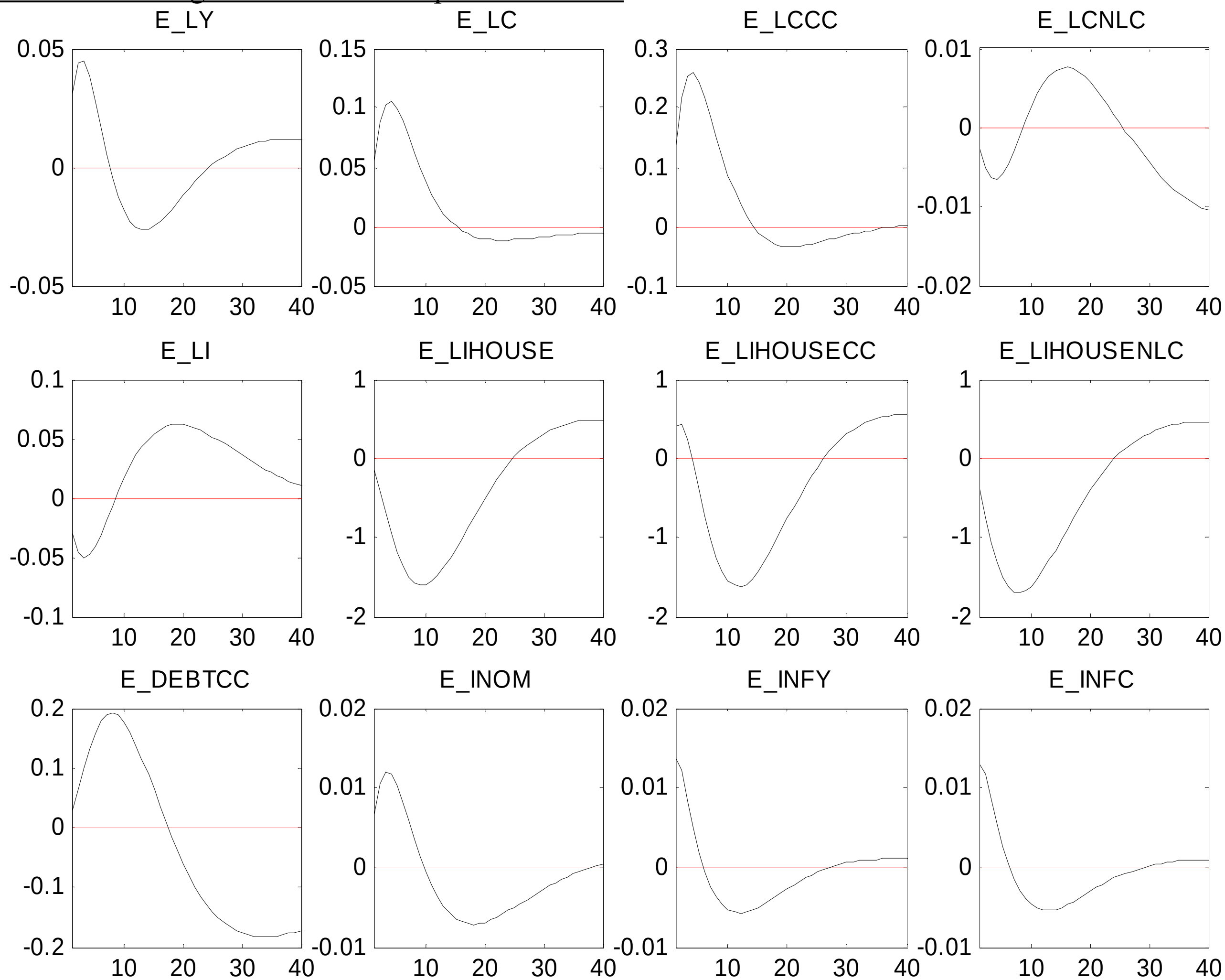
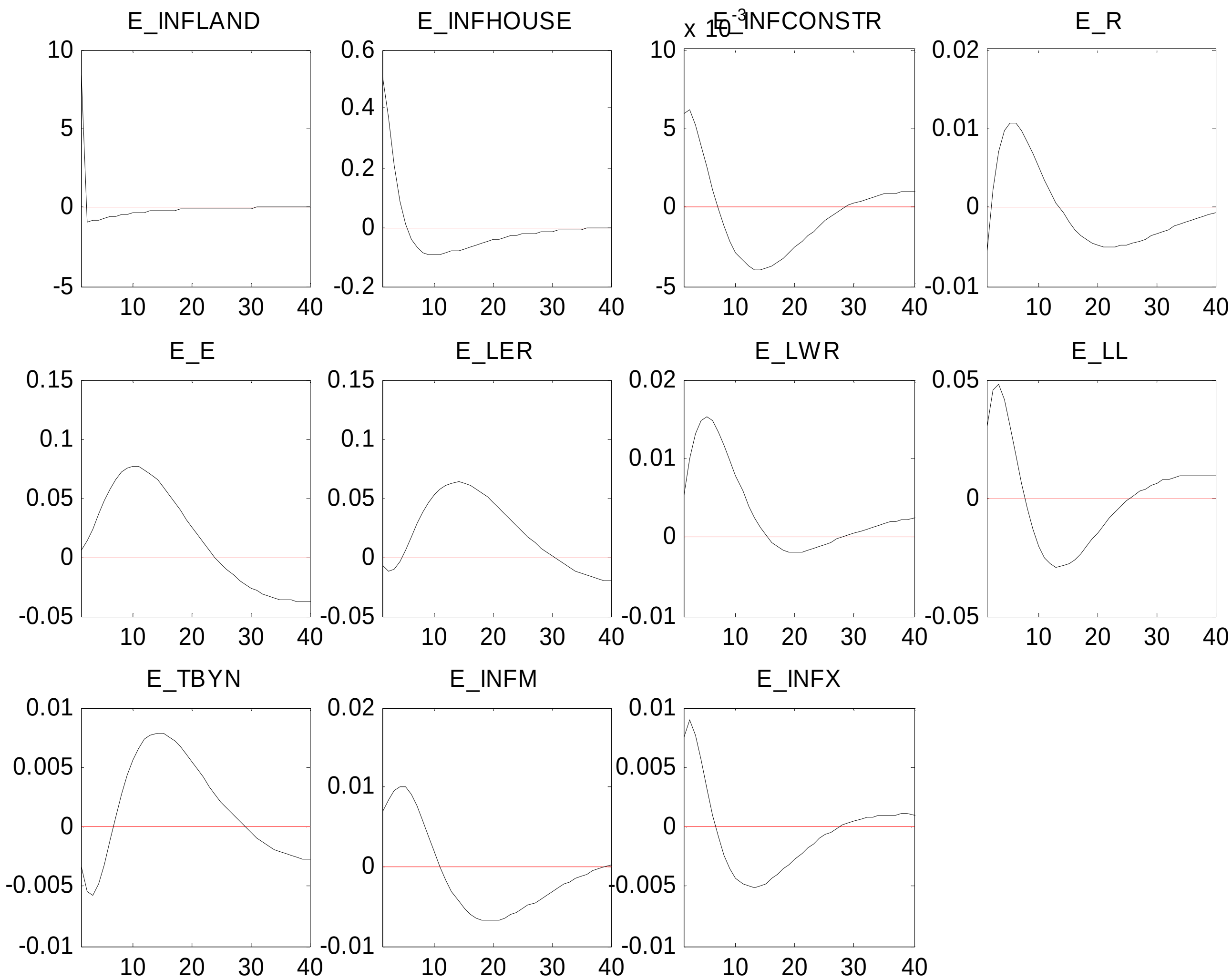

E_INFLAND
E_INFHOUSE
x 10^-3 E_INFCONSTR
E_R
E_E
E_LER
E_LWR
E_LL
E_TBYN
E_INFM
x 10^-3 E_INFX
10 20 30 40

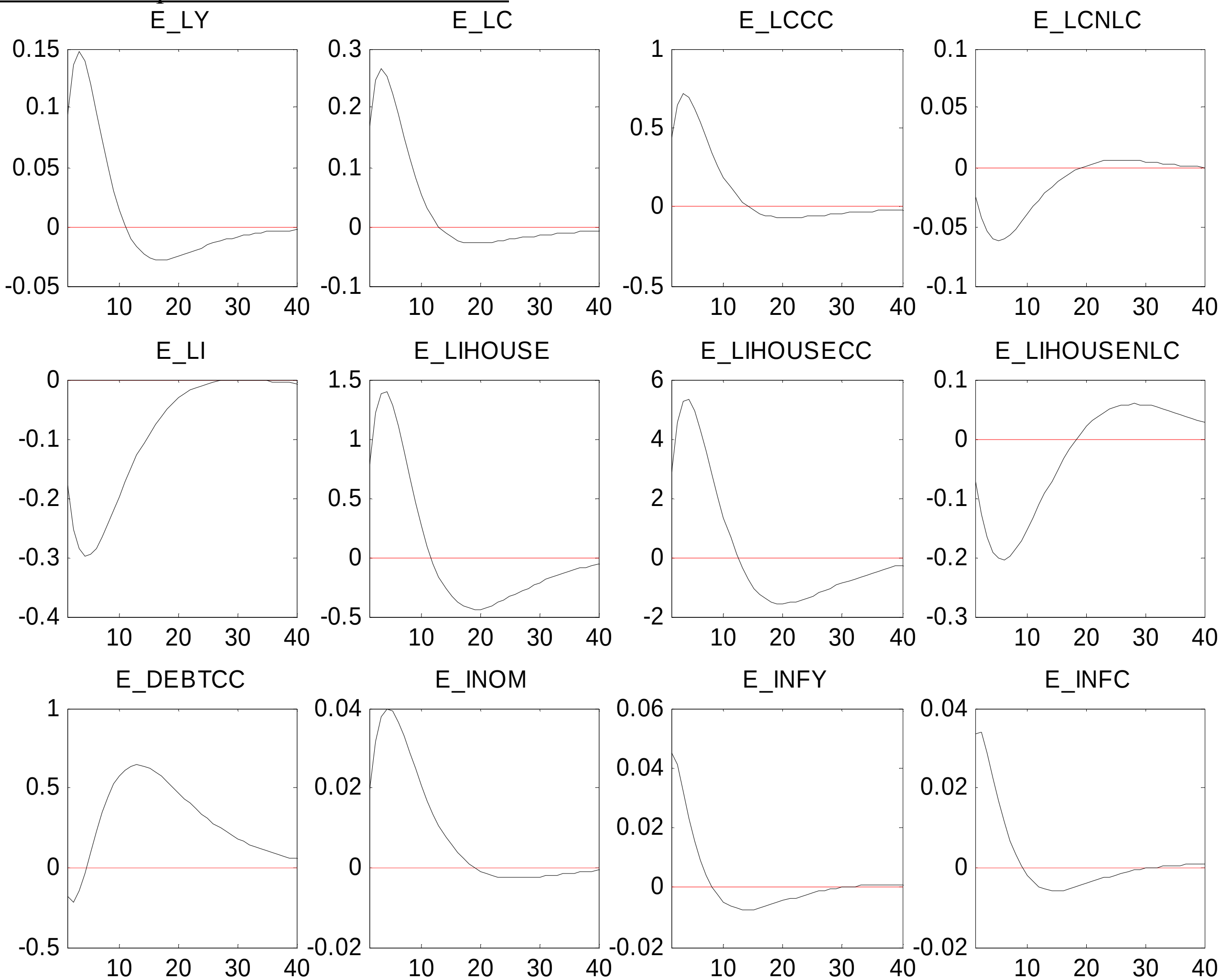
FIGURE 6: IRF's to a negative 1% land risk premium shock





E_INFLAND
E_INFHOUSE
x 10^-3 E_INFCONSTR
E_R
E_E
E_LER
E_LWR
E_LL
E_TBYN
E_INFM
E_INFX

FIGURE 7: IRF's to a positive 1% DEBTCC shock



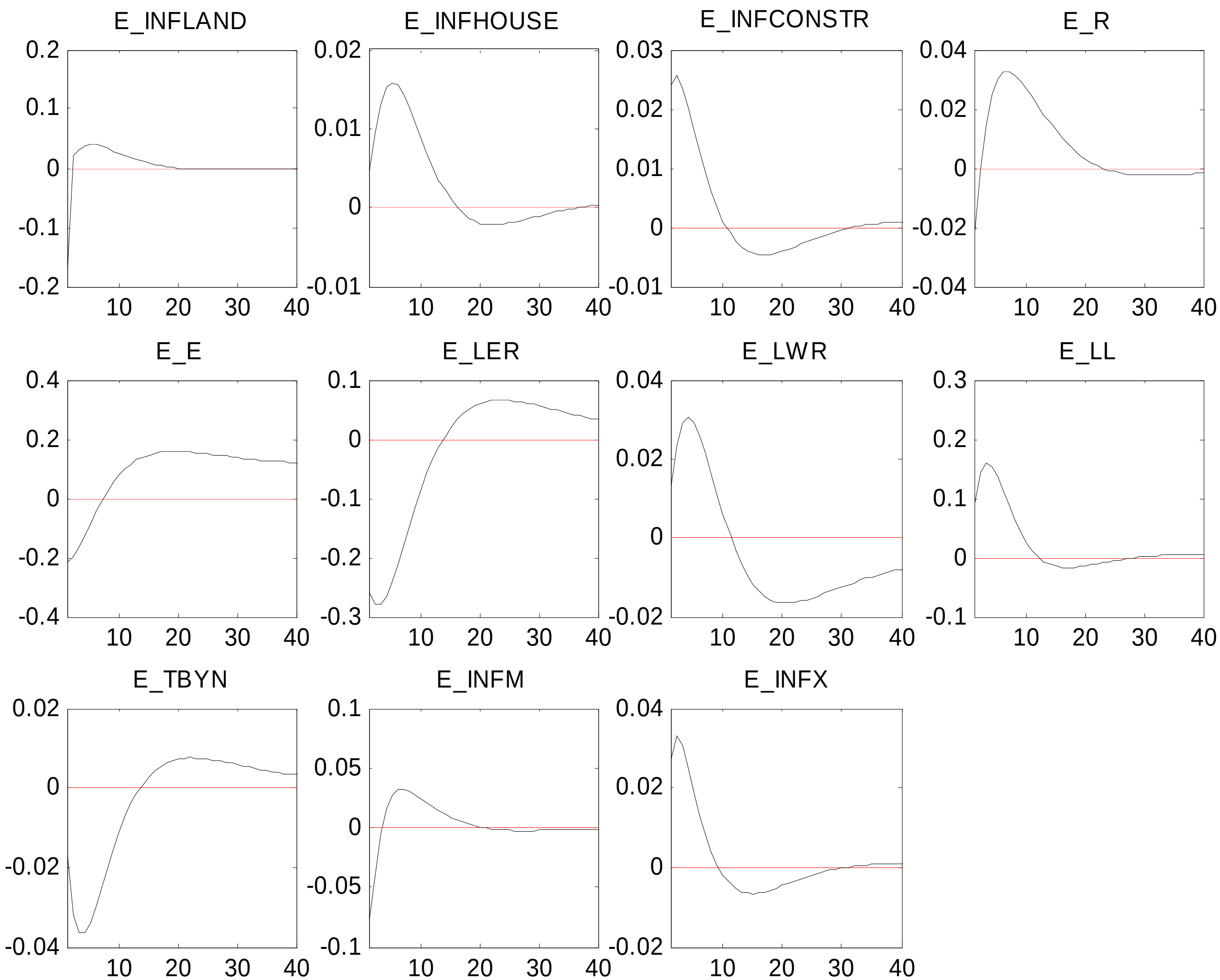

E_INFLAND
E_INFHOUSE
E_INFCONSTR
E_R
E_E
E_LER
E_LWR
E_LL
E_TBYN
E_INFM
E_INFX

FIGURE 8. Estimated historical evolution of the main fundamental and non-fundamental shocks of the model (1989Q1-2008Q4)

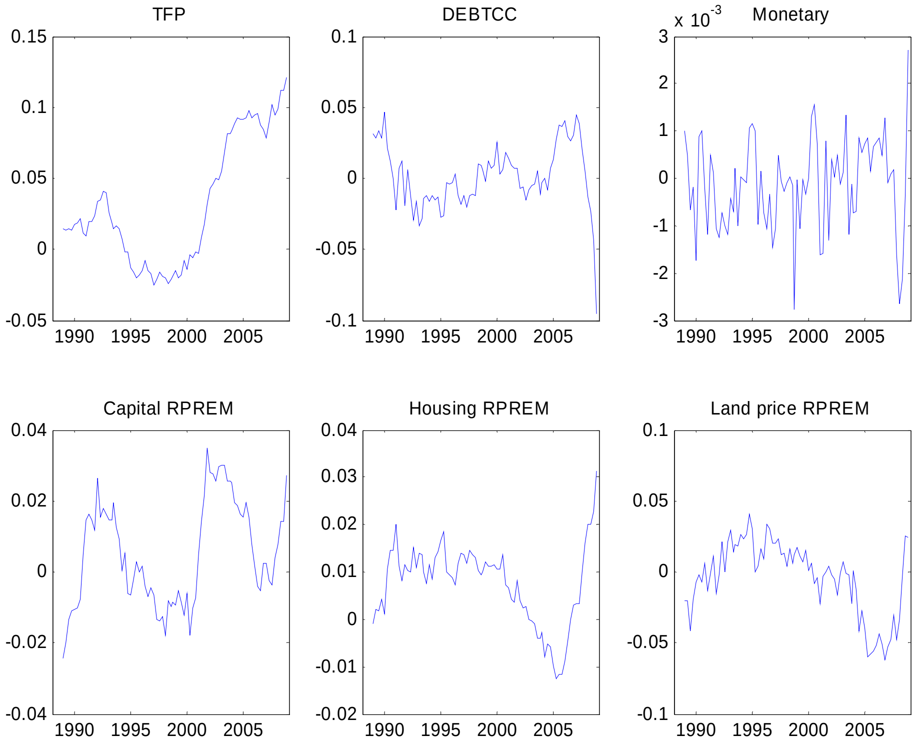


FIGURE 9. GDP growth decomposition (1989Q1-2008Q4)

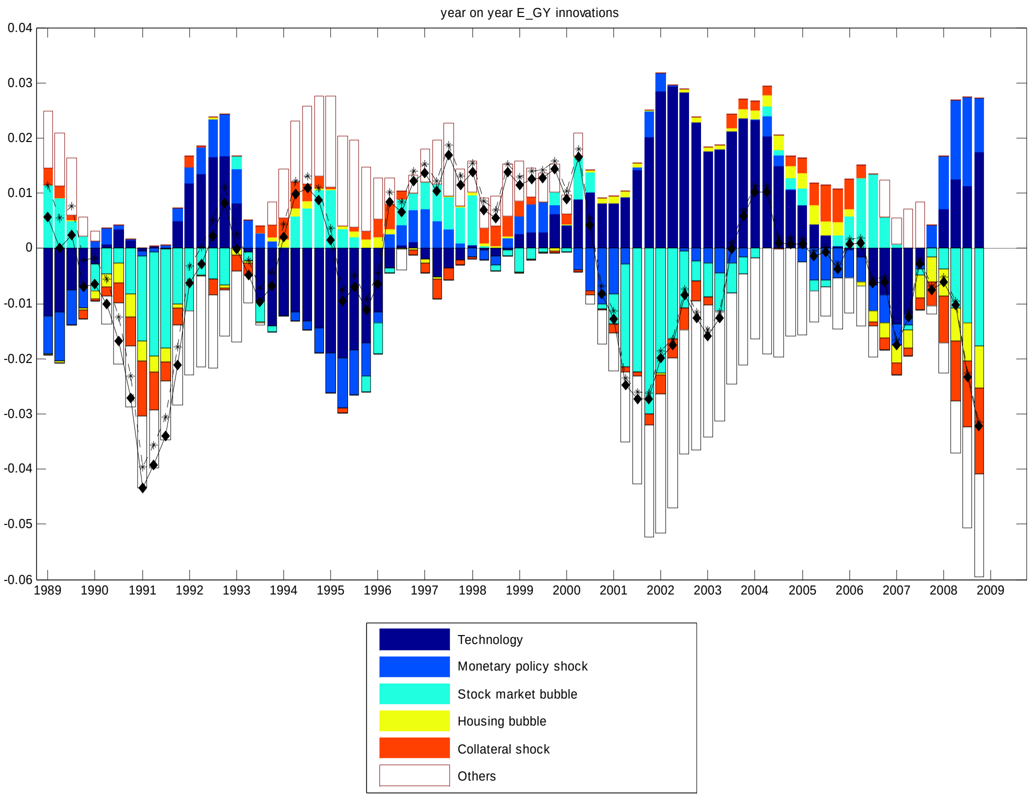


FIGURE 10: Consumption growth decomposition (1989Q1-2008Q4)

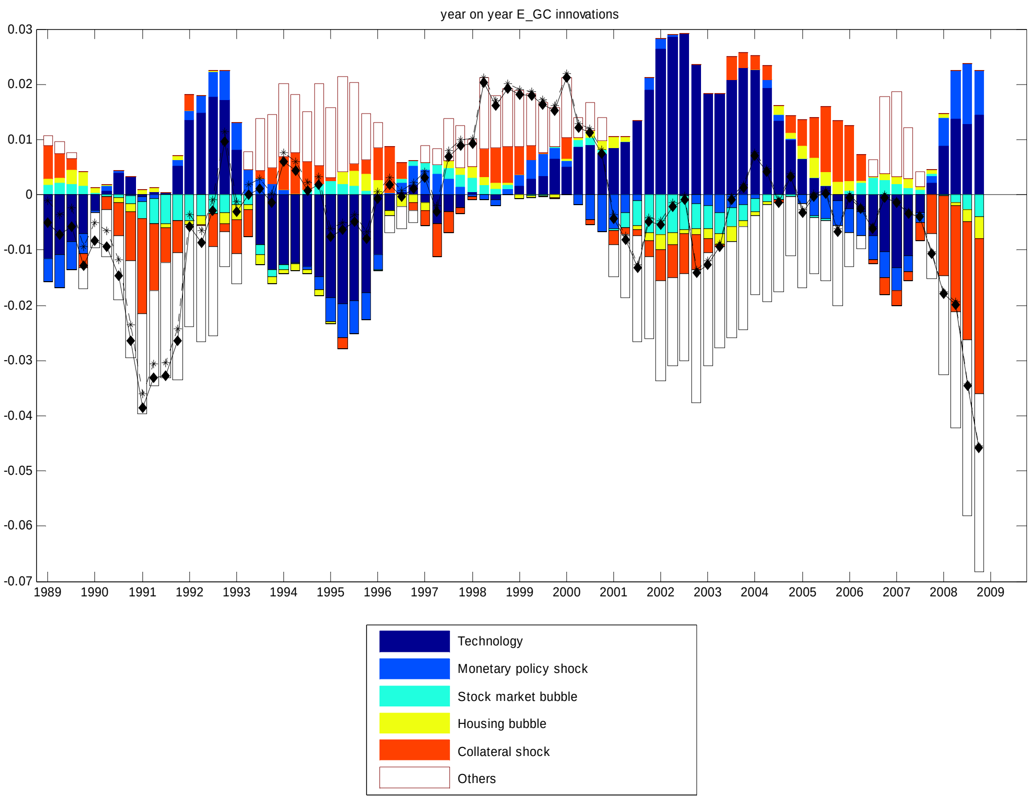


FIGURE 11: Residential investment growth decomposition (1989Q1-2008Q4)

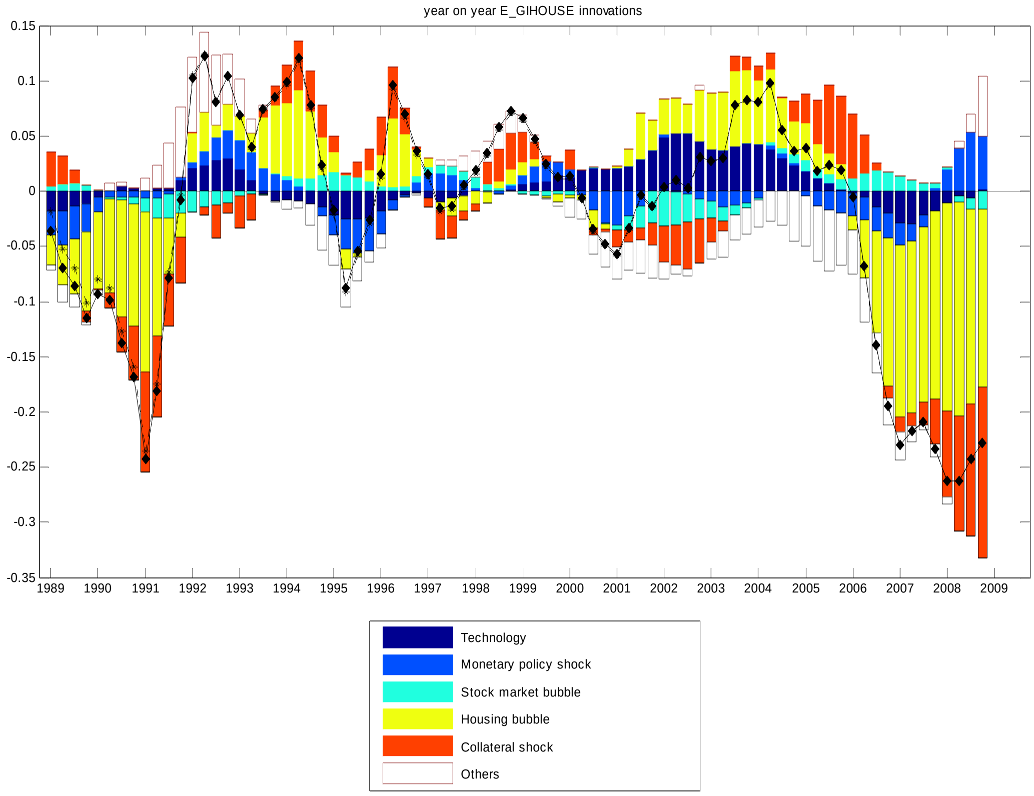


FIGURE 12: Residential investment growth decomposition credit-constrained (1989Q1-2008Q4)

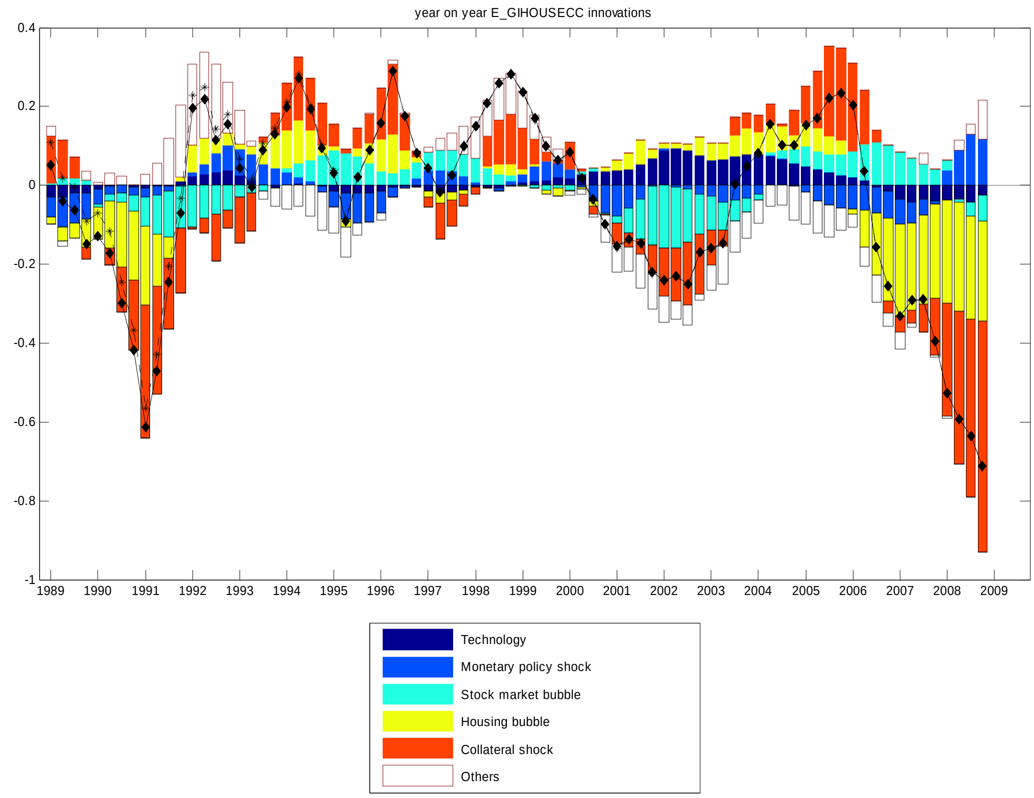
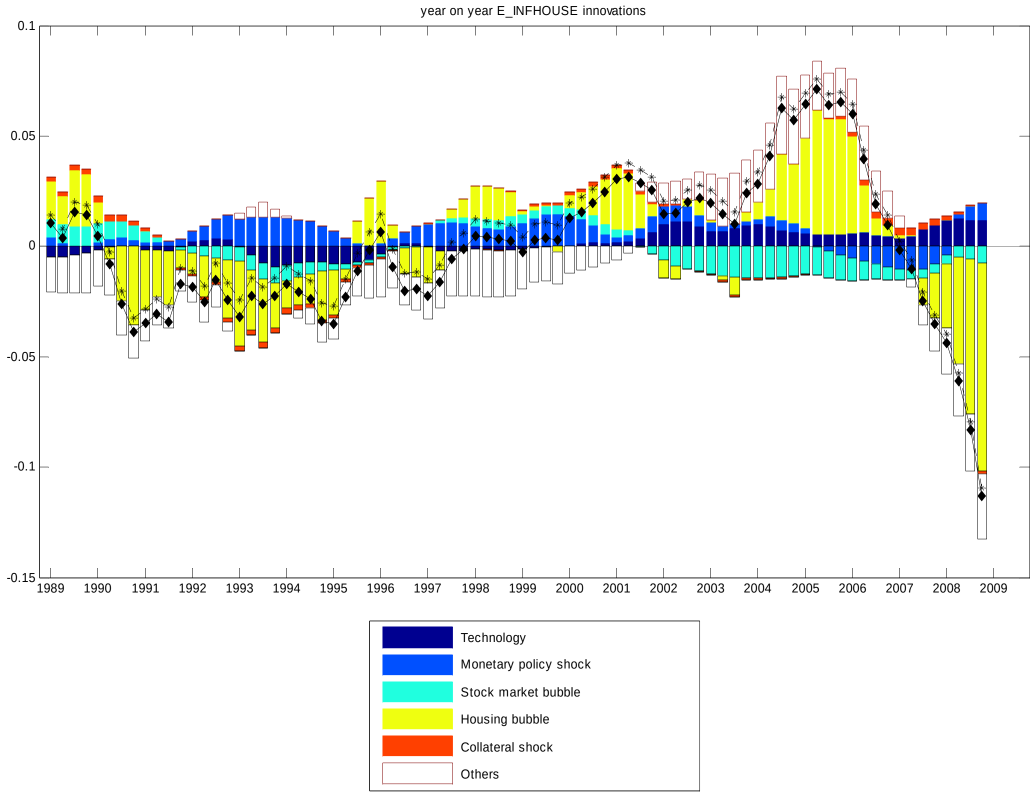


FIGURE 13: House price inflation decomposition (1989Q1-2008Q4)



ANNEX
TABLE A1: Estimation Results for exogenous shocks

Parameter name		Prior			Posterior	
		distrib	mean	std	mode	std
σ^{C^k}	E_EPS_CNLC	gamma	0.05	0.03	0.0154	0.0041
σ^{χ^c}	E_EPS_DEBTCCT	gamma	0.01	0.007	0.0162	0.0036
σ^{η}	E_EPS_ETA	gamma	0.1	0.06	0.0079	0.002
$\sigma^{\eta Constr}$	E_EPS_ETACONSTR	gamma	0.1	0.06	0.028	0.011
$\sigma^{\eta M}$	E_EPS_ETAM	gamma	0.1	0.06	0.053	0.0151
$\sigma^{\eta X}$	E_EPS_ETAX	gamma	0.1	0.06	0.033	0.012
σ^{TB}	E_EPS_TB	gamma	0.005	0.003	0.0026	0.0004
σ^{CG}	E_EPS_G	gamma	0.005	0.003	0.0068	0.0007
σ^{IG}	E_EPS_IG	gamma	0.005	0.003	0.0209	0.0021
σ^{Leis}	E_EPS_L	gamma	0.05	0.03	0.1494	0.0178
σ^{INOM}	E_EPS_M	gamma	0.003	0.0015	0.001	0.0002
σ^{PC}	E_EPS_PC	gamma	0.003	0.0015	0.0017	0.0002
σ^{B^F}	E_EPS_RPREME	gamma	0.005	0.003	0.0023	0.0007
σ^{rp}	E_EPS_RPREMK	gamma	0.005	0.003	0.0064	0.0012
$\sigma^{rphouse}$	E_EPS_RPREMHOUSECC	gamma	0.01	0.006	0.0044	0.0018
σ^{rpland}	E_EPS_RPREMLANDE	gamma	0.01	0.006	0.0125	0.0023
σ^{TR}	E_EPS_TR	gamma	0.005	0.003	0.0029	0.0005
σ^{W}	E_EPS_W	gamma	0.05	0.03	0.0177	0.0071
σ^{UP}	E_EPS_LTFP	gamma	0.05	0.03	0.0068	0.0009
ρ^{C}	RHOCNLCE	beta	0.85	0.075	0.8343	0.0558
	RHODEBTCCTE	beta	0.85	0.075	0.8984	0.0551
ρ^{η}	RHOETAE	beta	0.5	0.2	0.9446	0.0404
$\rho^{\eta Constr}$	RHOETACONSTRE	beta	0.5	0.2	0.9175	0.0667
$\rho^{\eta M}$	RHOETAME	beta	0.85	0.075	0.859	0.0495
$\rho^{\eta X}$	RHOETAXE	beta	0.85	0.075	0.8679	0.0492
ρ^{CG}	RHOGE	beta	0.5	0.2	0.3578	0.1337
ρ^{IG}	RHOIGE	beta	0.85	0.075	0.9218	0.047
ρ^{Leis}	RHOLE	beta	0.85	0.075	0.5435	0.0545
ρ^{TR}	RHOTRE	beta	0.85	0.075	0.9407	0.0417
ρ^{B^F}	RHORPEE	beta	0.85	0.075	0.9402	0.0206
ρ^{rp}	RHORPKE	beta	0.85	0.075	0.8808	0.0301
$\rho^{rphouse}$	RHORPHOUSECCE	beta	0.85	0.075	0.9217	0.0275
ρ^{rpland}	RHORPLANDE	beta	0.85	0.075	0.8897	0.023
ρ^{lss}	LLAGE	beta	0.95	0.02	0.9297	0.0171
ρ^{ucap}	UCAPLAGE	beta	0.95	0.02	0.971	0.0138

Appendix 2: Identifying disequilibria in the housing market using error correction models

An alternative approach to discover disequilibria in the housing market is provided by the error correction literature. Such an approach has been provided by McCarthy et al. (2004) to the US housing market. In this appendix we present the approach and update the estimates to 2008Q4. The starting point is a standard housing demand equation, where household aim for a certain ratio between consumption spending and the housing stock. They are willing to reallocate spending from consumption to residential investment if the user cost of housing is low or house prices are low compared to consumer prices. Like for a standard investment problem the user cost of housing is given by the nominal interest rate minus expected house price inflation plus the depreciation rate for houses.

A.1 $h_t = const + c_t - \sigma uc_t - \sigma(p_t^h - p_t^c)$ and $uc = i_t - \pi_{t+1}^{h,e} + \delta$

It is further assumed that in the short run the supply of houses is predetermined, therefore housing demand essentially determines the (equilibrium) house price

A.2 $((p_t^h - p_t^c)^* = \frac{1}{\sigma}(c_t - h_t) - uc_t$

The equilibrium price reflects demand conditions. It will be high in case consumption is high (relative to the existing stock of houses, thus signalling a willingness on the part of households to increase demand for houses in order to re-establish an equilibrium ratio between h and c. The equilibrium price will also be high if the user cost is low, i. e. in the case of low nominal interest rates or high expected house price inflation. With low user costs, households are willing to substitute consumption for housing.

The actual house price can deviate from the equilibrium price because of sluggish price adjustment. However, given estimates of the right hand side of equation A.2 one can compare the "equilibrium price" to the actual house price. When the actual price exceeds the equilibrium price, this can be interpreted as a situation where prices exceed their fundamental values determined by preferences of households.

Notice, however, this approach is not without problems. Problem number one is a proper assessment of future house price expectations. There is nothing in the model which determines house price expectations (future house prices) as a function of underlying fundamentals (such as real long run income growth, equilibrium interest rate, target inflation rate). Generally, house price expectations are modelled as a distributed lag of past house prices. I. e; this approach is silent about the existence of house price bubbles. (if house prices are accelerating then the implied distributed lag price expectations will be below the current price. This lowers the equilibrium price and therefore it may suggest a disequilibrium with too high house prices. But notice this result comes about by construction there is no economic argument judging the appropriateness of ,the past house price evolution). In fact there is the problem that a bubble remains undetected, since any increase in house prices leads to a decline in the user cost which in turn signals an increase in the equilibrium price.

Empirical results for the US:

For the empirical analysis we follow Mc Carthy et al. 2004 and estimate the following equation

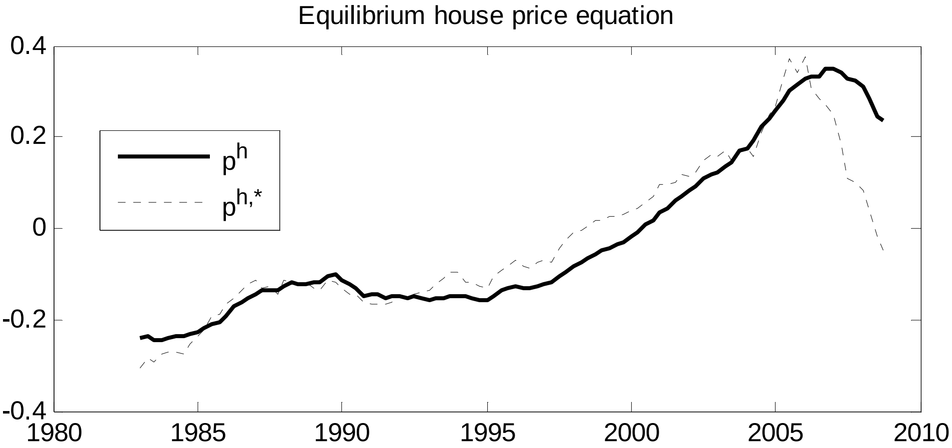
A.2 $((p_t^h - p_t^c)^* = \alpha_1(c_t - h_t) + \alpha_2 uc_t$

For the construction of the user cost we use the (30 year) mortgage rate as the nominal interest rate and set the quarterly depreciation rate to 1% and we approximate house price expectations with a 12 quarter moving average of past house price inflation rates.. OLS results provide the following values for regression coefficients:

Const	1.0463
α_1	1.2151
α_2	-0.1605

The equilibrium price is compared to actual price in Figure 1, which reproduces fairly well the results in Mc Carthy et al (2004) for house price data up to 2003. Morever, we can see that equilibrium price remains above the actual price up to 2006q1. Two quarters before house prices have reached their peak the error correction method signals an overvaluation

Figure 1



The short run dynamics is then described by the following equation:

$$\Delta p_t^h = \lambda_1(p_{t-1}^h - p_{t-1}^{h*}) + \lambda_2 \Delta c_t + \lambda_3 \Delta uc_t + \lambda_4 \Delta p_{t-1}^h$$

with estimated coefficients

λ_1	-0.0233
λ_2	0.1104
λ_3	-0.0342
λ_4	0.3893

The RMSE of the one step ahead predictions of house price inflation from this short run dynamic equation is 0.0058.
In this context, QUEST III fit results compare reasonably well, with a RMSE of 0.00624 for the full specification and 0.00625 for the small housing sector sub-model.