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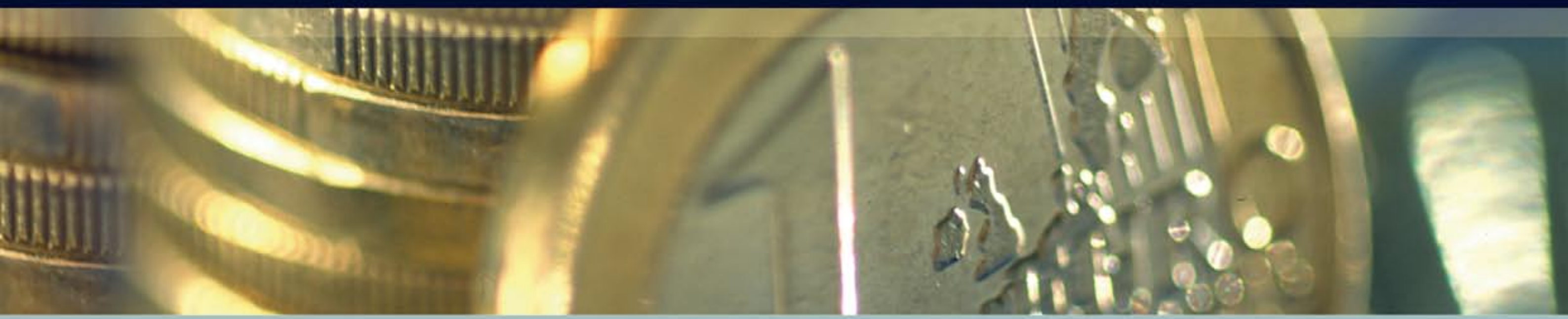

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QUEST III: An Estimated Open-Economy DSGE Model of the Euro Area with Fiscal and Monetary Policy

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Abstract:

This paper develops a DSGE model for an open economy and estimates it on euro area data using Bayesian estimation techniques. The model features nominal and real frictions, as well as financial frictions in the form of liquidity constrained households. The model incorporates active monetary and fiscal policy rules (for government consumption, investment, transfers and wage taxes) and can be used to analyse the effectiveness of stabilisation policies. To capture the unit root character of macroeconomic time-series we allow for stochastic trend in TFP, but instead of filtering data prior to estimation, we estimate the model in growth rates and stationary nominal ratios.

JEL Classification System: E32, E62, C11
Keywords: DSGE modelling, fiscal policy, stabilisation policies, euro area

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Introduction

In this paper we develop a Dynamic Stochastic General Equilibrium (DSGE) model for an open economy. We estimate this model on quarterly data for the euro area using Bayesian estimation techniques. Following Christiano, Eichenbaum and Evans (2001) considerable progress has been made in recent years in the estimation of New-Keynesian DSGE models which feature nominal and real frictions. In these models, behavioural equations are explicitly derived from intertemporal optimisation of private sector agents under technological, budget and institutional constraints such as imperfections in factor, goods and financial markets. In this framework, macroeconomic fluctuations can be seen as the optimal response of the private sector to demand and supply shocks in various markets, given the constraints mentioned above. DSGE models are therefore well suited to analyse the extent to which fiscal and monetary policies can alleviate existing distortions by appropriately responding to macroeconomic shocks.

Following Smets and Wouters (2003) DSGE models have been used extensively to study the effects of monetary policy and the stabilising role of monetary rules. In particular it has been demonstrated that an active role for monetary policy arises from the presence of nominal rigidities in goods and factor markets. So far, not much work has been devoted towards exploring the role of fiscal policy in the New Keynesian model. Our paper therefore extends this literature by incorporating and estimating reaction functions for government consumption, investment and transfers into a DSGE model.

There is substantial empirical evidence that prices and wages adjust sluggishly to supply and demand shocks as documented in numerous studies of wage and price behaviour, starting from early Phillips curve estimates (see, for example, Phelps, 1967) and extending to recent estimates using both backward as well as forward looking price and wage rules (see e.g. Gali et al., 2001). The recent work by Gali et al. (2007), Coenen and Straub (2005) and Forni et al. (2006) has also highlighted the presence of liquidity constraints as an additional market imperfection. The introduction of non-Ricardian behaviour in the model could give rise to a role for fiscal stabilisation, since liquidity constrained households do not respond to interest rate signals.

Obviously, a prerequisite for such an analysis is a proper empirical representation of the data generating process. The seminal work of Smets and Wouters (2003) has shown that DSGE models can in fact provide a satisfactory representation of the main macroeconomic aggregates in the Euro area. Also, various papers by Adolfson et al. (2007) have documented a satisfactory forecasting performance when compared to standard VAR benchmarks. This paper extends the basic DSGE model in four directions. First, it respects the unit root character of macroeconomic time series by allowing for stochastic trends in TFP. Unlike many other estimated DGSE models, we do not detrend our data with linear time trends or the Hodrick-Prescott filter, but we estimate the model in growth rates and nominal ratios. Secondly, it treats the euro area as an open economy, which introduces additional shocks to the economy through trade and the exchange rate. Thirdly, it adds financial market imperfections in the form of liquidity constrained households to imperfections in the form of nominal rigidities in goods and labour markets. Fourthly, it introduces a government sector with stabilising demand policies. We empirically identify government spending rules by specifying current government consumption, investment and transfers as functions of their own lags as well as current and lagged output and unemployment gaps and we allow a fraction of transfers to respond to deviations of government debt from its target. From the operation of the euro area unemployment insurance system we know that unemployment benefits provide quasi-automatic income stabilisation. Indeed we find a significant response of transfers to cyclical variations in employment. A priori government consumption is not explicitly countercyclical, though it can already provide stabilisation by keeping expenditure fixed in nominal terms over the business cycle. The empirical evidence suggests that fiscal policy is used in a countercyclical fashion in the euro area.

Our paper is structured as follows. In section one we describe the model and characterise the shocks hitting the euro area economy. Section two presents the empirical fit of our DSGE model and we present priors and posterior estimates as well as the variance decomposition of the model. In section three we analyses the impulse response functions of the main macro economic variables to structural shocks. Finally, in section 4 we use our model in a counterfactual analysis to identify two alternative explanations of the declining wage share in the euro area.

1. The Model

We consider an open economy which faces an exogenous world interest rate, world prices and world demand. The domestic and foreign firms produce a continuum of differentiated goods. The goods produced in the home country are imperfect substitutes for goods produced abroad. The model economy is populated by households and firms and there is a monetary and fiscal authority, both following rule-based stabilisation policies. We distinguish between households which are liquidity constrained and consume their disposable income and households who have full access to financial markets. The latter make decisions on financial and real capital investments. 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 follow an AR(1) process with autocorrelation coefficient ρ^k and innovation ε_t^k.

1.1 Firms:

1.1.1 Final output producers

There are n monopolistically competitive final goods producers. Each firm indexed by j produces a variety of the domestic good which is an imperfect substitute for varieties produced by other firms. Domestic firms sell to private domestic households, to investment goods producing firms, the government and to exporting firms. All demand sectors have identical nested CES preferences across domestic varieties and

[1] Lower cases denote logarithms, i.e. $z_t = log(Z_t)$. Lower cases are also used for ratios and rates.

between domestic and foreign goods, with elasticity of substitution σ^d and σ^M respectively. The demand function for firm *j* is given by

(1) $$Y_t^j = \frac{(1-s^M - u_t^M)}{n}\left(\frac{P_t}{P_t^j}\right)^{\sigma^d}\left(\frac{P_t^C}{P_t}\right)^{\sigma^M}\left[\left(C_t + C_t^G + I_t^G + I_t^{inp} + X_t\right)\right]$$

where C_t is total consumption of private households, C_t^G and I_t^G denote government consumption and investment, I_t^{inp} is the input of investment goods producing firms and X_t represents exports. The variables P_t, P_t^j and P_t^C represent the price index of final output, the price of an individual firm and the import price index. We make the assumption that individual firms are small enough such as to take P_t and P_t^C as given. Output is produced with a Cobb Douglas production function using capital K_t^j and production workers $L_t^j - LO_t^j$

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

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 of capacity utilisation ($ucap_t^j$). There is an economy wide technology shock U_t^Y which follows a random walk with drift

(3) $$u_t^Y = g_t^U + u_{t-1}^Y + \varepsilon_t^Y,$$

The share of overhead labour in total employment (lol_t^j) follows an AR(1) process around its long run value

(4) $$lol_t^j = (1-\rho^{LOL})lol + \rho^{LOL} lol_{t-1}^j + \varepsilon_t^{LOL},$$

The objective of the firm is to maximise the present discounted value of profits $\Pr_t^j$

(5)

$$\Pr_t^j = \frac{P_t^j}{P_t}Y_t^j - \frac{W_t}{P_t}L_t^j - i_t^K\frac{P_t^I}{P_t}K_t^j - \frac{1}{P_t}(adj^P(P_t^j) + adj^L(L_t^j) + adj^{UCAP}(ucap_t^j)).$$

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 capital. Adjustment costs are given by the following convex functional forms

(6a) $$adj^L(L_t^j) = W_t(L_t^j u_t^L + \frac{\gamma_L}{2}\Delta L_t^{j^2})$$

(6b) $$adj^P(P_t^j) = \frac{\gamma_P}{2}\frac{\Delta P_t^{j^2}}{P_{t-1}^j}$$

(6c) $$adj^{UCAP}(ucap_t^j) = PI_t K_t(\gamma_{ucap,1}(ucap_t^j - 1) + \frac{\gamma_{ucap,2}}{2}(ucap_t^j - 1)^2)$$

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:

(7a)
$$\frac{\partial \Pr_t^j}{\partial L_t^j} => \left(\alpha \frac{Y_t^j}{L_t^j - LO_t^j}\eta_t^j - \frac{W_t}{P_t^j}u_t^L - \frac{W_t}{P_t^j}\gamma_L \Delta L_t^j + E_t(\frac{W_{t+1}}{P_{t+1}^j}\frac{\gamma_L}{(1+r_t)}\Delta L_{t+1}^j)\right) = \frac{W_t}{P_t^j}$$

(7b) $$\frac{\partial \Pr_t^j}{\partial K_t^j} => \left((1-\alpha)\frac{Y_t^j}{K_t^j}\eta_t^j\right) = i_t^K \frac{P_t^{I,j}}{P_t^j}$$

(7c) $$\frac{\partial \Pr_t^j}{\partial ucap_t^j} => \left((1-\alpha)\frac{Y_t^j}{K_t^j ucap_t^j}\eta_t^j\right) = \frac{P_t^{I,j}}{P_t^j}(\gamma_{ucap,1} + \gamma_{ucap,2}(ucap_t^j - 1))$$

(7d) $$\frac{\partial \Pr_t^j}{\partial Y_t^j} => \eta_t^j = 1 - 1/\sigma^d - \gamma_P\left[\frac{1}{(1+r_t)}E_t\pi_{t+1}^j - \pi_t^j\right] \quad \text{with } \pi_t^j = P_t^j / P_{t-1}^j - 1 \ .$$

where η_t is the Lagrange multiplier of the technological constraint and the real interest rate r_t is used for discounting. 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 (7a), the convex part of the adjustment cost function penalises in cost terms accelerations and decelerations of changes in employment. Equations (7b-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 (7d) 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 of the aggregate price mark-up

(7d') $$\eta_t = 1 - 1/\sigma^d - \gamma_P \left[\beta (sfpE_t \pi_{t+1} + (1-sfp)\pi_{t-1}) - \pi_t \right] - u_t^P \quad 0 \leq sfp \leq 1$$

1.2.2 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 I_t^{inp}, then real output of the investment goods sector is produced by the following linear production function,

(8) $$I_t = I_t^{inp} U_t^I$$

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

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

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

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

1.2 Households:

The household sector consists of a continuum of households $h \in [0,1]$. A share $(1-slc)$ of these households are not liquidity-constrained and indexed by $i \in [0,1-slc)$. They have full access to financial markets, they buy and sell domestic and foreign assets (government bonds and equity). The remaining households are liquidity-constrained and indexed by $k \in [1-slc,1]$. These households do not trade on asset markets and consume their disposable income each period. Both 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 two household. 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 Non Liquidity constrained households

Households decide about four types of assets, domestic and foreign nominal bonds (B_t^i, B_t^{iF}), the stock of physical capital (K_t^i) and cash balances (M_t^i).The household receives income from labour, nominal bonds and rental income from lending capital to firms plus profit income from firms owned by the household. Income from labour is taxed at rate t^w, rental income at rate t^i. 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 yield risk-free nominal return equal to i_t. Foreign bonds are subject to an external financial intermediation premium *risk(.)*, which is a positive function of the economy wide level of foreign indebtedness. An equity premium rp_t^K on real assets arises because of uncertainty about the return of real assets. The Lagrangian of this maximisation problem is given by

(11)

$$
\begin{aligned}
&Max \quad V_0^I = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t^i, 1-L_t^i) \\
&- \mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t \beta^t \left(\begin{aligned}
&\frac{(1+t_t^c)P_t^C}{P_t} C_t^i + \frac{P_t^I}{P_t} I_t^i + \frac{M_t^i}{P_t} + \frac{B_t^i}{P_t} + \frac{E_t B_t^{F,i}}{P_t} - \frac{M_{t-1}^i}{P_t} - \frac{(1+(1-t_t^i)i_{t-1})B_{t-1}^i}{P_t} \\
&- \frac{(1+(1-t_t^i)i_{t-1}^F)(1-risk(\frac{E_t B_{t-1}^F}{P_{t-1}Y_{t-1}}) - u_t^{B^F})E_t B_{t-1}^{F,i}}{P_t} - \frac{(1-t_t^K)(i_{t-1}^K - rp_t^K)P_{t-1}^I K_{t-1}^i}{P_t} + \\
&\frac{t_t^K \delta P_{t-1}^I K_{t-1}}{P_t} - \frac{(1-t_t^w)W_t^i}{P_t} L_t^i + \frac{\gamma_w L_t^i}{2P_t} \frac{\Delta W_t^{i\,2}}{W_{t-1}^i} - \sum_{j=1}^{n} \mathrm{Pr}_t^{i,j} + T_t^{LS,i}
\end{aligned} \right) \\
&- \mathrm{E}_0 \sum_{t=0}^{\infty} \xi_t \beta^t \left(K_t^i - J_t^i - (1-\delta)K_{t-1}^i \right)
\end{aligned}
$$

The utility function is non-separable in consumption (C_t^i) and leisure ($1-L_t^i$) of the King, Plosser, Rebelo (1988) type. We also allow for habit persistence in consumption and leisure. Thus temporal utility for consumption is given by

$$
(12) \qquad U(C_t^i, 1-L_t^i) = \frac{\exp(\varepsilon_t^C)\left[\left(C_t^i - h^C C_{t-1}\right)\left(1-\exp(\varepsilon_t^L)\omega\left(L_t^i - h^L L_{t-1}\right)^{\kappa}\right)\right]^{1-\rho} - 1}{1-\rho}
$$

The investment decisions w. r. t. real capital are subject to convex adjustment costs, therefore we make a distinction between real investment expenditure (*I*) and physical investment (*J*). Investment expenditure of households including adjustment costs is given by

$$
(13) \qquad I_t^i = J_t^i \left(1 + \frac{\gamma_K}{2} \left(\frac{J_t^i}{K_t^i} \right) \right) + \frac{\gamma_I}{2} (\Delta J_t^i)^2
$$

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. The first order conditions of the household with respect to consumption and financial wealth are given by the following equations[2]:

$$\text{(14a)} \quad \frac{\partial U_0}{\partial C_t^i} \Rightarrow U_{C,t}^i - \lambda_t \frac{(1+t_t^c)P_t^C}{P_t} = 0$$

$$\text{(14b)} \quad \frac{\partial U_0}{\partial B_t^i} \Rightarrow -\lambda_t + \mathrm{E}_t\left(\lambda_{t+1}\beta(1+(1-t_t^i)i_t)\frac{P_t}{P_{t+1}}\right) = 0$$

$$\text{(14c)} \quad \frac{\partial U_0}{\partial B_t^{F,i}} \Rightarrow -\lambda_t + \mathrm{E}_t\left(\lambda_{t+1}\beta(1+(1-t_t^i)i_t^F)(1-risk(\frac{E_t B_t^F}{P_t Y_t}) - u_t^{B^F})\frac{P_t}{P_{t+1}}\frac{E_{t+1}}{E_t}\right) = 0$$

$$\text{(14d)} \quad \frac{\partial U_0}{\partial K_t^i} \Rightarrow -\xi_t + \mathrm{E}_t\left(\xi_{t+1}\beta(1-\delta) + \lambda_{t+1}\beta((1-t_t^K)(i_t^K - rp_t^i) + t_t^K\delta)\frac{P_t^I}{P_{t+1}}\right) = 0$$

$$\text{(14e)} \quad \frac{\partial U_0}{\partial J_t^i} \Rightarrow -\lambda_t \frac{P_{t-1}^I}{P_t}\left(1 + \gamma_K\left(\frac{J_t^i}{K_{t-1}^i}\right) + \gamma_I \Delta J_t^i\right) - E_t(\lambda_{t+1}\beta\frac{P_t^I}{P_{t+1}}\gamma_I \Delta J_{t+1}^i) + \xi_t = 0$$

All arbitrage conditions are standard, except for a trading friction on foreign bonds, which is modelled as a function of the ratio of net foreign assets to GDP. Using the arbitrage conditions, investment is given as a function of the variable Q_t

$$\text{(15a)} \quad \left(\gamma_K \frac{J_t^i}{K_{t-1}^i} + \gamma_I \Delta J_t^i\right) - \frac{\gamma_I}{(1+r_t)} E_t(\Delta J_{t+1}^i) = (Q_t - 1) \quad \text{with } Q_t = \frac{\xi_t}{\lambda_t}\frac{P_t}{P_t^I}$$

where Q_t is the present discounted value of the rental rate of return from investing in real assets

$$\text{(15b)} \quad Q_t = E_t\left(\frac{(1-\delta)}{(1-t_t^i)(1+i_t)/(1+{}_t\pi_{t+1}^I)}Q_{t+1}\right) + (1-t_t^K)(i_t^K - rp_t^K) + t_t^K\delta$$

where the relevant discount factor for the investor is the nominal interest rate minus expected inflation of investment goods. Also, because Q_t and π_t^I are negatively correlated there is a positive equity premium.

[2] With an interest rate rule as specified below, an optimality condition for money would only determine the desired money holdings of the household sector without any further consequence for the rest of the economy. For that reason any further discussion on money demand is dropped here.

1.2.2 Liquidity constrained households

Liquidity constrained households do not optimize but simply consume their entire labour income at each date. Real consumption of household *k* is thus determined by net wage income plus transfers minus a lump-sum tax

(16) $$(1+t_t^c)P_t^c C_t^k = (1-t_t^w)W_t L_t + TR_t^k - T_t^{LS,k}$$

It is assumed that liquidity constrained households possess the same utility function as Ricardian households.

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 weights *slc* and (*1-slc*) respectively. The trade union sets wages by maximising a weighted average of the utility functions of Ricardian and liquidity constrained 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. In addition we also allow for additional wage rigidity via sluggish adjustment of the real consumption wage

(17) $$\frac{W_t}{P_t^C} = \gamma_{WR}\frac{W_{t-1}}{P_{t-1}^C} + (1-\gamma_{WR})\frac{1}{\eta_t^W}\frac{(1+t_t^C)}{(1-t_t^W)}\frac{((1-slc)U_{1-L,t}^i + slcU_{1-L,t}^k)}{((1-slc)U_{c,t}^i + slcU_{c,t}^k)}$$

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.

(18)
$$\eta_t^W = 1 - 1/\theta - \gamma_W/\theta\left[\beta(\pi_{t+1}^W - (1-sfw)\pi_t) - (\pi_t^W - (1-sfw)\pi_{t-1})\right] + u_t^W$$

with $0 \le sfw \le 1$.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 $X_t = \int_0^1 X_t^h dh = (1-slc)X_t^i + slcX_t^k$ since households within each group are identical. Hence aggregate consumption is given by

(19a) $C_t = (1-slc)C_t^i + slcC_t^k$

and aggregate employment is given by

(19b) $L_t = (1-slc)L_t^i + slcL_t^k$ with $L_t^i = L_t^k = L_t$.

Since liquidity constrained households do not own financial assets we have $B_t^k = B_t^{k\,F} = K_t^k = 0$.

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 the demand of an individual household, investor or the government, then their preferences are given by the following utility function

(20a) $$Z^i = \left[(1-s^M - u_t^M)^{\frac{1}{\sigma^M}} Z^{d\,i\,\frac{\sigma^M-1}{\sigma^M}} + (s^M + u_t^M)^{\frac{1}{\sigma^M}} Z^{f\,i\,\frac{\sigma^M-1}{\sigma^M}}\right]^{\frac{\sigma^M}{(\sigma^M-1)}}$$

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.

(20b) $$Z^{d\,i} = \left[\sum_{h=1}^{n}\left(\frac{1}{n}\right)^{\frac{1}{\sigma^d}} Z_h^{d\,i\,\frac{\sigma^d-1}{\sigma^d}}\right]^{\frac{\sigma^d}{\sigma^d-1}} \quad , \quad Z^{f\,i} = \left[\sum_{h=1}^{m}\left(\frac{1}{m}\right)^{\frac{1}{\sigma^f}} Z_h^{f\,i\,\frac{\sigma^f-1}{\sigma^f}}\right]^{\frac{\sigma^f}{\sigma^f-1}}$$

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

$$(21) \qquad M_t = (s^M + u_t^M)\left[\rho^{PCPM}\frac{P_{t-1}^{\ C}}{P_{t-1}^{\ M}} + (1-\rho^{PCPM})\frac{P_t^C}{P_t^M}\right]^{\sigma^M}(C_t + I_t^{inp} + C_t^G + I_t^G)$$

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

$$(22) \quad X_t = (s^{M,W} + u_t^X)\left(\rho^{PWPX}\frac{P_{t-1}^{\ C,F}E_{t-1}}{P_{t-1}^{\ X}} + (1-\rho^{PWPX})\frac{P_t^{C,F}E_t}{P_t^X}\right)^{\sigma^X} Y_t^F$$

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

$$(23) \qquad \eta_t^X P_t^X = P_t$$

and import prices are given by

$$(24) \qquad \eta_t^M P_t^M = E_t P_t^F$$

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

$$(25) \qquad \eta_t^k = 1 - 1/\sigma^{v,k} - \gamma_{Pk}\left[\beta(sfp^k \cdot_t \pi_{t+1}^k + (1-sfp^k)\pi_{t-1}^k) - \pi_t^k\right] + u_t^{P,k}$$
$$k = \{X, M\}$$

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

$$(26) \qquad E_t B_t^F = (1 + i_t^F)E_t B_{t-1}^F + P_t^X X_t - P_t^M M_t$$

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

$$(27) \quad YGAP_t = \left(\frac{ucap_t}{ucap_t^{ss}} \right)^{(1-\alpha)} \left(\frac{L_t}{L_t^{ss}} \right)^{\alpha}.$$

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

$$(28) \quad ucap_t^{ss} = (1-\rho^{ucap})ucap_{t-1}^{ss} + \rho^{ucap} ucap_t^{j}$$

$$(29) \quad L_t^{ss} = (1-\rho^{Lss})L_{t-1}^{ss} + \rho^{Lss} L_t$$

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

1.4.1 Fiscal Policy

Both 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

$$(30) \quad \Delta c_t^G = (1-\tau_{Lag}^{CG})\overline{\Delta c^G} + \tau_{Lag}^{CG}\Delta c_{t-1}^G + \tau_{Adj}^{CG}(cgy_{t-1} - \overline{cgy}) + \sum_i \tau_i^{CG} ygap_{t-i} + u_t^{CG}$$

$$(31) \quad \Delta i_t^G = (1-\tau_{Lag}^{IG})\overline{\Delta i^G} + \tau_{Lag}^{IG}\Delta i_{t-1}^G + \tau_{Adj}^{IG}(igy_{t-1} - \overline{igy}) + \sum_i \tau_i^{IG} ygap_{t-i} + u_t^{IG}$$

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

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

Government revenues R_t^G are financed by taxes on consumption as well as capital and labour income.

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

Following the OECD estimates for revenue elasticities (van den Noord (2000)) we assume that consumption and capital income tax follow a linear scheme, and a progressive labour income tax schedule

(34a) $$t_t^w = \tau_0^w Y_t^{\tau_1^W} U_t^{TW}$$

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

(34b) $$t_t^w = \tau_0^w + \tau_0^w \tau_1^w ygap_t$$

Government debt (B_t) evolves according to

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

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

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

where b^T is the government debt target.

1.4.2 Central bank policy rule (interest rate rule)

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

(37)

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

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

2. Estimation

Our technological assumptions 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 government consumption to GDP ratio (*cgyn*), the government investment to GDP ratio (*igyn*), the government transfers to wages ratio (*trw*), the trade balance[3] 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 import (P^M/P) and export price (P^X/P) ratios. These variables, together with the exogenous technology shock to the investment good production (U^I) 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 the euro area over the period 1981Q1 to 2006Q1, taken from the ECB AWM data base and updated with Eurostat quarterly national accounts database. 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, except for the trend in wage share, which is not removed from the data;
3. the 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) 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. The reaction of wage taxes to output gap t_1^W is set to 0.8, following OECD estimates.

[3] Concerning the import and export share we remove a trade integration trend prior to estimation. As import and export data for the euro area include intra euro-area trade we also assumed the foreign demand and price terms in the export (22) and import price equation (24) were a weighted average of foreign and domestic terms, with a share of 0.5 of intra euro area trade in total trade.

TABLE 1. Calibrated parameters

Structural parameters		Steady states	
α	0.52	$\overline{cgy}$	0.203
α^G	0.9	$\overline{igy}$	0.025
β	0.996	$\overline{g^{UI}}$	0
δ	0.025	π, π^F	0.005
δ^G	0.0125	$\overline{g^{popW}}$	0.00113
τ^B	4.e-6	$\overline{g^Y}, \overline{g^{YF}}$	0.003
τ^{DEF}	4.e-3	$\overline{g^{UP}}$	0.0024
b^T	2.4	$\overline{ucap}$	1
σ^d	10	$\overline{L}$	0.65
ρ^{INOM}	0	$\omega^{WX} = \omega^X$	
ρ^{EX}, ρ^{IM}	0.975	θ	1.6
ρ^{LOL}	0.99	$TRWS$	0.36
t^K, t^c, τ_0^w	0.2		
τ_1^w	0.8		

Other parameters are determined according to steady state constraints:

- $\gamma_{ucap,1} = (1-\tau)*(1-\alpha)1/\mathrm{KSN}$, determined in order to assure the steady state constraint *ucap* = 1, where $KSN = K/Y*PI/P$ is the nominal capital to GDP share.
- ω is determined in order to assure the steady state condition $\overline{L} = 0.65$

The dynamical forms of government spending and government investment have been identified by estimating separately from the rest of the model an array of models of the general form:

(38)

$$\Delta g_t = \frac{b_{1,0}L^{\delta} + b_{1,1}L^{1+\delta} + ... + b_{1,n}L^{n+\delta}}{1 - a_1 L - ... - a_m L^m} u_{1,t} + ... + \frac{b_{k,0}L^{\delta} + b_{k,1}L^{1+\delta} + ... + b_{k,n}L^{n+\delta}}{1 - a_1 L - ... - a_m L^m} u_{k,t} + e_t$$

where Δg_t is the growth rate of the government spending or government investment, L is the lagged operator and $u_{i,t}$ are the inputs. The selection of the model is then taken considering both the R^{T^2} statistics, based on the response error, and information criteria.

For both government consumption and investment, the input is the output gap plus an error correction to assure stationarity of the nominal shares to GDP. This implied a two step-procedure, where first the dynamical structure was identified using a HP-filtered output gap. The obtained structure and coefficients are fed into the DSGE model, which is estimated given the previously identified coefficients. At this stage, we obtain a model based output gap which is again fed into the separated identification procedure to check the validity of the structure identified with HP-filtered output gap. The coefficients in the government spending rules are then estimated together with the other parameters in the DSGE model. Thus, the estimated government consumption rule takes the form

$$\Delta c_t^G = (1-\tau_{Lag}^{CG})\overline{\Delta c^G} + \tau_{Lag}^{CG}\Delta c_{t-1}^G + \tau_{Adj}^{CG}(cgy_{t-1} - \overline{cgy}) + \tau_1^{CG}\Delta ygap_t + u_t^{CG} \quad (30)$$

$$\Delta i_t^G = (1-\tau_{Lag}^{IG})\overline{\Delta i^G} + \tau_{Lag}^{IG}\Delta i_{t-1}^G + \tau_{Adj}^{IG}(igy_{t-1} - \overline{igy}) + \tau_1^{IG}\Delta ygap_t + u_t^{IG} \quad (31)$$

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 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) and for the overhead labour shock, where we set prior mean to 0.95. Standard errors have prior gamma distributions, with prior mean values at

- 0.5% for 'persistent shocks' (accounting for different trends in the data, like overhead labour,) and for shocks to risk premia;
- 0.25% for monetary shock;
- 5% for technology shock, preference and adjustment costs shocks, nominal GDP shares of government consumption, investment, transfers;
- 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 also set a neutral prior mean of b^U at 0. Persistence in the government spending rule has a prior at 0.5, while for investment and transfers this is set to 0.85.

For price and wage rigidities we roughly follow Smets and Wouters (2003), but allowing a wider variation in the upper bound (prior mean at 30). Capital and labour adjustment costs have similar priors, while for investment the prior is smaller (15). Prior consumption and leisure habits are set at 0.7. Inverse of intertemporal elasticities have prior gamma distributions with mean 1.25 and standard deviation 0.5 (2 and 1 for σ^C). The share of liquidity constrained households has a neutral prior at 0.5, with standard deviation 0.1, similar to Forni et al. (2006). Finally, the share of forward looking behaviour in hybrid Phillips curves and the price indexation coefficients in import and export equations have prior mean at 0.5 in the range [0, 1].

2.2 Posterior estimation

The draws from the posterior distribution have been obtained by taking two parallel chains of 300,000 runs of Metropolis. Convergence of the Markov Chain has been tested by cumulated means and by the diagnostics by Brooks and Gelman (1998). The shape of the likelihood at the posterior mode and the Hessian condition number have been also considered to highlight lack of identification for some parameters[4]. In Table 2.1 we show prior distributions and posterior estimations of our structural parameters (see Table A1 in the annex for estimates of standard errors of shocks and AR coefficients of autocorrelated shocks and Figure A1 for the plots of priors and posterior distributions).

The estimated fraction of forward looking price setting behaviour is high. The posterior mean for *sfp* is estimated at 0.87, which implies only 13 percent of firms keep prices fixed at the *t-1* level. The estimated share of liquidity-constrained consumers is 0.35, which is similar to estimates reported in Coenen and Straub (2005) and lower than in Forni *et al.* (2006). Note that our estimates also suggest a degree of habit persistence in consumption of 0.56 and an intertemporal elasticity of substitution of around 0.25.

[4] Only for two structural parameters does the likelihood not dominate the prior, namely for export price rigidity (γ_{PX}) and *risk*. See also Canova and Sala (2005) about identification problems in the Smets and Wouters model and in DSGE models in general.

TABLE 2.1: Estimation Results for structural parameters.

	Prior			Posterior	
Parameter name	**distrib**	**mean**	**std**	**mean**	**std**
σ^{C}	gamma	2	1	4.0962	0.813
slc	beta	0.5	0.1	0.3507	0.0754
h^{C}	Beta	0.7	0.1	0.5634	0.0412
h^{L}	Beta	0.7	0.1	0.8089	0.0778
κ	gamma	1.25	0.5	1.9224	0.4438
$risk$	beta	0.02	0.008	0.02	0.0074
rp	beta	0.02	0.008	0.0245	0.0026
$\gamma_{ucap,2}$	beta	0.05	0.024	0.0453	0.0128
ω^{X}	beta	0.8	0.08	0.8588	0.0196
σ^{X}	gamma	1.25	0.5	2.5358	0.32
σ^{M}	gamma	1.25	0.5	1.1724	0.2136
τ_{Lag}^{INOM}	beta	0.85	0.075	0.9009	0.0155
τ_{π}^{INOM}	beta	2	0.4	1.959	0.2066
$\tau_{Y,1}^{IINOM}$	beta	0.3	0.2	0.4274	0.1141
$\tau_{Y,2}^{INOM}$	beta	0.3	0.2	0.0783	0.0277
τ_{Lag}^{CG}	Beta	0	0.4	-0.4227	0.1041
τ_{Adj}^{CG}	Beta	-0.5	0.2	-0.1567	0.0442
τ_{0}^{CG}	beta	0	0.6	-0.0754	0.1066
τ_{Lag}^{IG}	Beta	0.5	0.2	0.4475	0.0895
τ_{Adj}^{IG}	beta	-0.5	0.2	-0.1222	0.0461
τ_{0}^{IG}	Beta	0	0.6	0.1497	0.0996
b^{U}	beta	0	0.6	0.597	0.0627
γ_{K}	gamma	30	20	76.0366	20.5526
γ_{I}	gamma	15	10	1.1216	0.5185
γ_{L}	gamma	30	20	58.2083	12.2636
γ_{P}	gamma	30	20	61.4415	10.4208
γ_{PM}	gamma	30	20	1.6782	0.9092
γ_{PX}	gamma	30	20	26.1294	16.8398
γ_{W}	gamma	30	20	1.2919	0.8261
γ_{WR}	beta	0.5	0.2	0.2653	0.1315
Sfp	beta	0.5	0.2	0.8714	0.0567
$Sfpm$	beta	0.5	0.2	0.7361	0.1227
$Sfpx$	beta	0.5	0.2	0.918	0.0473
Sfw	beta	0.5	0.2	0.7736	0.1565

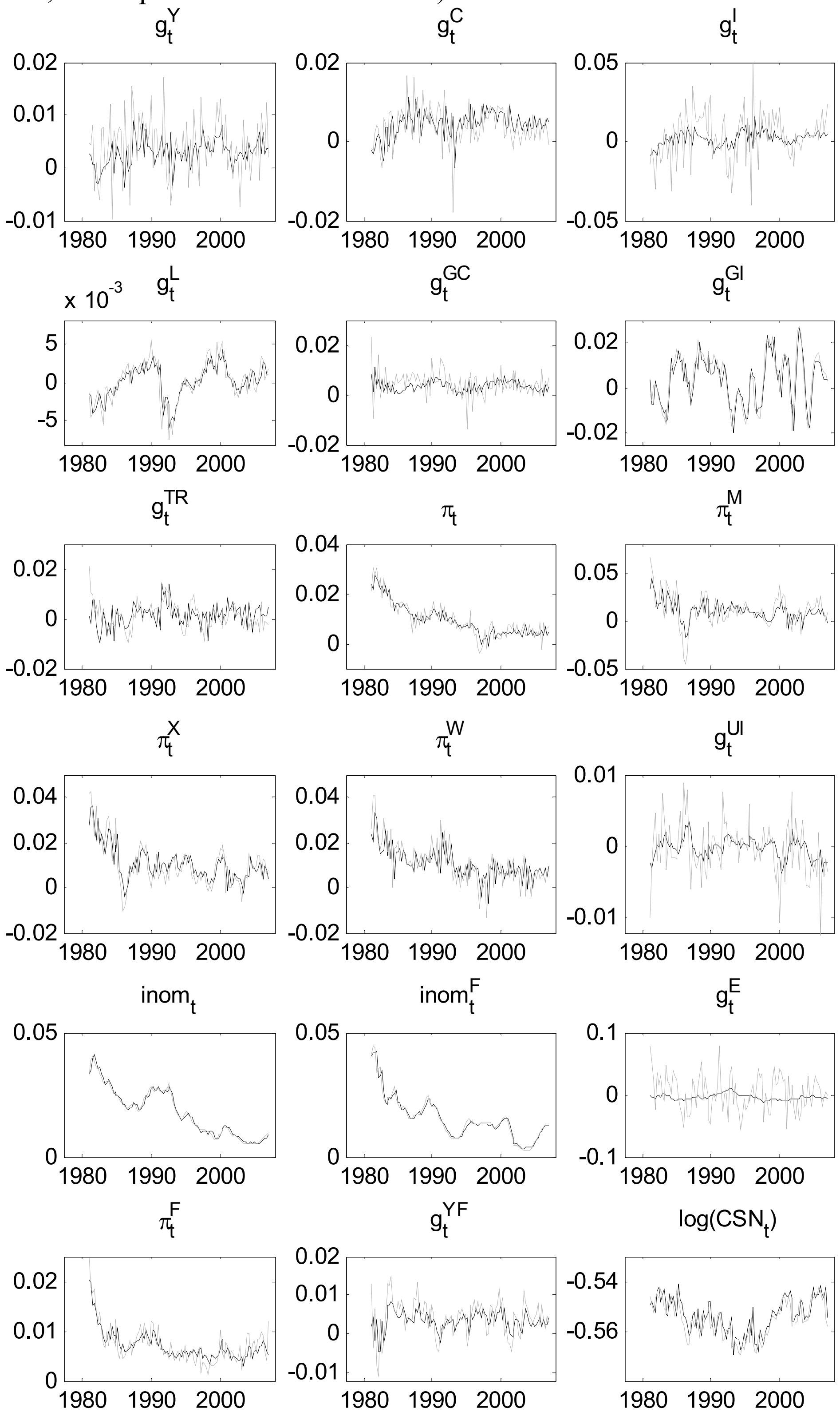
The estimated fiscal response parameters are counter-cyclical for government transfers. We find a positive response of transfers to the employment gap b^U (=0.6). Government consumption responds negatively to the current change in the output gap. The investment rule appears procyclical, with a high degree of persistence. The only parameter relevant for stabilisation policy on the revenues side is the degree of progressivity of wage taxes. Due to a lack of reliable data on tax rates we do not estimate this parameter but set it corresponding to the OECD estimate of the elasticity of tax revenues with respect to the output gap[5].

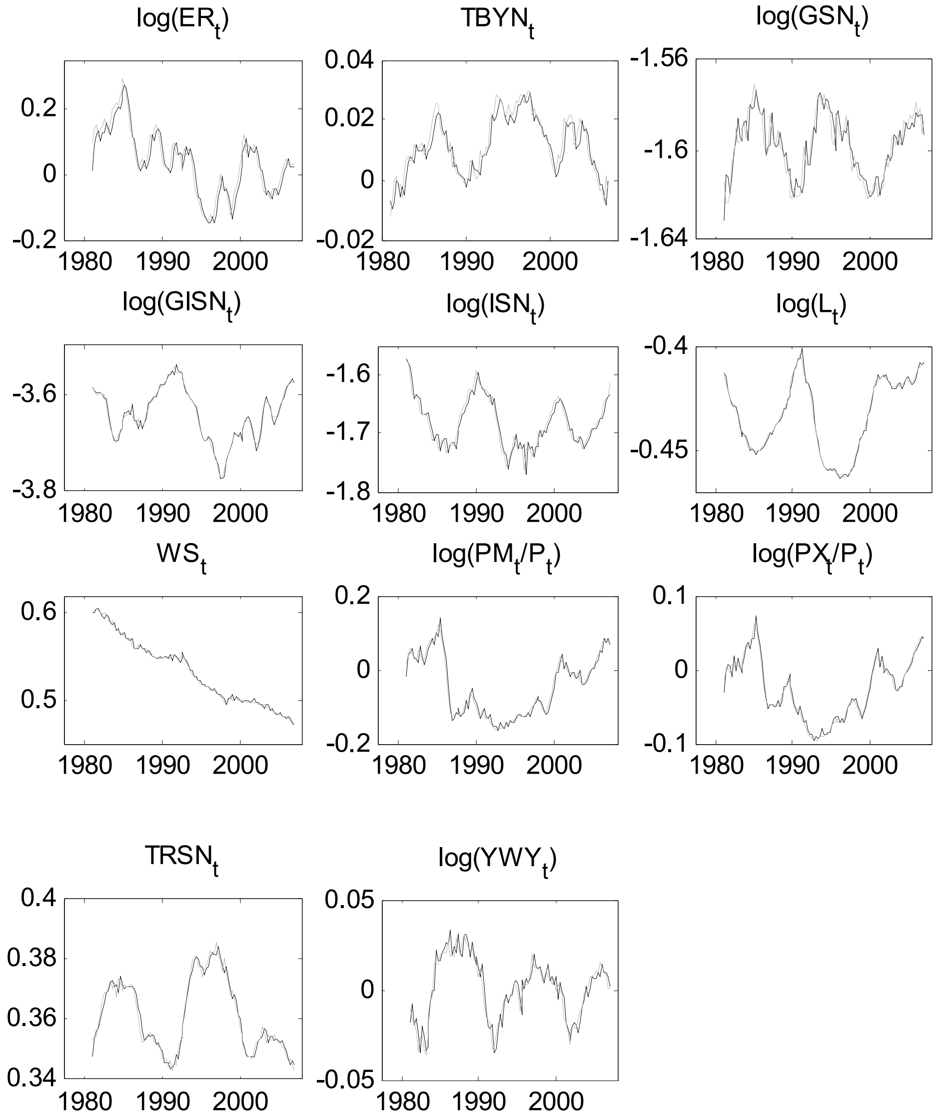
By way of comparison, other studies that have analysed the actual behaviour of fiscal authorities have mainly focused on the overall deficit rather than on government expenditure catagories seperately. Gali and Perotti (2003) assess the extent to which the constraints associated with the Maastricht Treaty and the Stability and Growth pact have made fiscal policy in EMU countries more procyclical. They find discretionary fiscal policy (as measured by the primary cyclically adjusted deficit of general government) was procyclical in EMU countries before Maastricht and essentially acyclical after Maastricht. They also find an increase in the degree in counter-cyclicality of non-discretionary fiscal policy (as measured by the difference between the total primary deficit and the cyclically-adjusted primary deficit) in EMU countries. In contrast, von Hagen and Wyplosz (2007), using data until 2006, find that the primary cyclically adjusted deficit has become countercyclical after 1992 and was acyclical before. European Commission (2004, Ch.3) also find evidence of a change in the response of the total primary budget balance to the output gap, with an insignificant impact of the cycle on primary balances before 1994 and a significant positive impact of the output gap on the primary balance post 1994. Concerning transfers, our results are consistent with those of Darby and Melitz (2007), who find that age- and health-related social expenditure as well as incapacity benefits all react to the cycle in a stabilising manner.

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}), as well as for inflations (π, 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 nominal ratios to GDP of consumption (*cyn*), government consumption (*cgyn*), government investment (*igyn*), investment (*iyn*), 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*), import to GDP deflator (*PM/P*), export to GDP deflator (*PX/P*).

[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.

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




log(ER_t)
TBYN_t
log(GSN_t)
log(GISN_t)
log(ISN_t)
log(L_t)
WS_t
log(PM_t/P_t)
log(PX_t/P_t)
TRSN_t
log(YWY_t)
1980 1990 2000

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 Woutyers, 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 1981Q1). The marginal data density of the DSGE has been obtained from the two-chain, 300,000 replications of the Metropolis-Hastings Algorithm using the modified harmonic mean formula suggested by Geweke. Similarly to other estimated DSGE's in the literature, our base model has a better marginal likelihood than BVAR's. 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. Comparison of the fit of the base model and of BVAR's.

	Marginal likelihood
BVAR(1)	6752.695
BVAR(2)	6835.592
BVAR(3)	6831.757
BVAR(4)	6835.782
BVAR(5)	6836.935
BVAR(6)	6828.311
BVAR(7)	6837.512
BVAR(8)	6835.597
BVAR(9)	6835.392
BVAR(10)	6827.01
BVAR(11)	6825.155
BVAR(12)	6829.694
DSGE model	7066.91

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. Comparison of the fit of the base model and a VAR(1) with error 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	0.005581	0.003838	0.005459	0.00482
g_t^C	0.005357	0.00349	0.00501	0.004114
g_t^I	0.015205	0.010913	0.014945	0.013367
g_t^G	0.00462	0.0037	0.00443	0.004028
g_t^{IG}	0.005466	0.003365	0.011552	0.00761
g_t^{TR}	0.005454	0.002583	0.005077	0.00341
g_t^L	0.001489	0.001214	0.002099	0.001488
π_t^W	0.007895	0.004743	0.007112	0.00552
$inom_t$	0.001156	0.00086	0.002804	0.00162
π_t	0.003208	0.002401	0.003706	0.00290
π_t^M	0.012617	0.009285	0.014677	0.01213
π_t^X	0.006065	0.004675	0.00728	0.00582
g_t^E	0.02927	0.020961	0.027276	0.024352

2.4 Variance decompositions

In Tables 2.4-6 we report the posterior intervals of the variance decomposition for conditional variance (1-step and 4-step ahead) and unconditional variance. The short run variation of GDP growth is mainly driven by shocks to productivity, the private demand components, in particular investment, and trade. Monetary and fiscal policy shocks play a relatively small role and explain a portion in the range of 5-13% of the short term variation. Price and wage mark up shocks play an even smaller role. The long run decomposition of GDP growth does not change strongly, except for a slightly larger role of the wage mark up shock and productivity and a smaller contribution of investment. Notice, these results are difficult to compare with variance decompositions from other models, since we are looking at GDP growth, instead of GDP levels. Inflation in the short run is mainly driven by shocks to the price mark up, while the long run variation is dominated by shocks to the wage mark up. Monetary policy shocks play a negligible role in the variation of inflation both in the short and the long run. This is in line with decomposition presented by Smets et al. (2007). The variance of the growth rate of the nominal exchange rate is largely driven by trade and risk premium shocks both in the short and the long run. There is a small role for both domestic and foreign monetary policy shocks. The short run variation in the nominal consumption share is driven by various shocks (trade, investment, own consumption shock, as well as risk premium and productivity shocks) while the productivity shock plays a more dominant role for the 4-step ahead conditional variance. The investment share is mainly driven by its own shock and the productivity shock. Unconditional variances of the nominal shares are dominated by the productivity shock. The trade balance ratio is mainly driven by trade and risk premium shocks, while the wage mark-up shock plays an important role in explaining the variance in employment and the wage share.

TABLE 2.4. Posterior variance decomposition – 90% Highest Probability Interval. (Conditional 1-step ahead)

	Wage mark-up	Price mark-up	Monetary policy	Fiscal policy	Investment	Consumption	Trade	Risk premium	TFP	Labour demand	Rest of the world	Foreign monetary shock
g_t^Y	0	0.966	4.65	1.252	14.105	2.182	13.875	3.721	20.603	0.001	0.223	2.521
	1.345	2.747	10.312	2.378	24.577	10.482	26.632	11.599	36.855	0.233	0.53	6.629
$inom_t$	0.432	5.278	45.603	0.133	1.707	1.368	1.55	3.804	3.075	0.005	0.133	1.429
	4.643	15.732	67.876	0.561	6.979	5.491	5.296	10.274	13.218	0.239	0.403	4.389
π_t	3.827	48.599	0.975	0.06	1.53	2.787	0.284	1.109	1.913	0.082	0.111	0.403
	20.677	77.162	4.308	0.336	6.744	10.506	1.867	5.08	9.662	0.95	0.518	1.918
π_t^C	3.571	34.17	1.705	0.012	0.743	0.799	8.67	6.224	0.61	0.063	0.132	2.096
	17.576	57.625	5.513	0.189	4.335	6.33	25.783	14.829	6.434	0.897	0.543	5.489
π_t^M	0	0.18	0.896	0	0	0	68.748	9.255	0.097	0.005	0.063	2.719
	1.222	0.535	2.379	0.031	0.103	0.702	84.23	20.14	0.545	0.135	0.25	6.744
π_t^X	1.024	0.124	0.102	0.003	0.15	0.308	88.844	0.14	0.054	0.022	0.016	0.044
	5.543	1.547	0.556	0.04	0.979	1.96	96.214	0.779	1.033	0.256	0.084	0.241
g_t^E	0	0	2.142	0.017	0	0.271	38.587	25.247	0.646	0.001	0.212	8.917
	0.681	0.092	4.598	0.119	0.763	2.874	57.276	39.882	2.191	0.128	0.72	15.245
csn	0	0.043	0.134	1.826	14.968	12.76	18.079	6.294	7.847	0.051	0.179	1.959
	2.364	0.654	1.597	3.226	25.775	25.666	33.383	17.875	17.976	0.582	0.446	5.607
gsn	0	0.033	1.931	23.496	9.225	2.113	20.566	0.232	6.079	0.001	0.137	0.477
	0.793	0.832	5.88	35.953	17.869	8.912	36.984	4.273	19.64	0.149	0.342	2.705
isn	0	0	0	0.29	75.713	1.411	1.213	2.05	5.013	0.016	0.081	0.845
	0.853	0.241	0.717	0.587	85.002	4.607	3.265	5.842	9.602	0.146	0.226	2.076
igsn	0	0.27	1.109	38.167	4.016	0.425	4.246	1.032	22.631	0	0.063	0.561
	0.449	0.937	3.706	51.212	9.138	3.681	10.138	4.276	40.491	0.072	0.196	2.221
tbyn	0	0	0.901	0.085	0.642	1.116	44.177	16.036	0.083	0.001	0.652	5.613
	0.338	0.347	2.886	0.223	2.229	3.725	73.333	36.526	0.532	0.078	1.152	12.684
L	21.579	0.067	1.515	0.366	6.236	0	1.953	3.985	12.121	5.28	0.309	1.659
	45.533	0.843	6.329	0.904	15.011	5.694	5.603	9.852	25.13	25.225	0.742	3.808
ws	48.197	4.998	0	0.564	1.021	0.183	6.136	0.009	1.51	1.23	0	0
	64.433	12.606	0.606	1.265	7.076	9.329	14.21	4.991	7.356	10.785	0.05	1.738
trw	3.097	0.008	0.202	74.653	0.847	0	0.29	0.425	1.538	0.685	0.048	0.188
	9.492	0.156	1.148	88.97	3.021	1.053	1.147	2.085	5.138	4.753	0.158	0.754
csn^k	45.779	2.634	0	7.135	3.206	0	7.538	1.047	0.621	0.306	0	0.278
	61.687	7.757	1.456	12.663	10.26	4.994	16.051	7.389	3.391	4.61	0.116	2.633
csn^i	3.395	0	0.042	1.486	12.13	11.791	14.82	5.237	8.476	0	0.192	1.369
	16.511	0.1	1.283	2.729	22.015	27.941	29.276	14.843	18.869	0.181	0.46	4.343

TABLE 2.5. Posterior variance decomposition – 90% Highest Probability Interval. (Conditional 4-step ahead)

	Wage mark-up	Price mark-up	Monetary policy	Fiscal policy	Investment	Consumption	Trade	Risk premium	TFP	Labour demand	Rest of the world	Foreign monetary shock
g_t^Y	0.573	0.791	3.989	1.233	11.317	1.969	16.297	4.078	24.331	0.059	0.313	2.249
	3.456	2.297	8.86	2.439	20.285	9.452	28.698	10.332	41.259	0.419	0.664	5.14
$inom_t$	2.299	2.085	11.408	0.322	5.87	8.309	2.789	10.828	2.895	0.031	0.669	3.673
	18.312	9.625	26.407	0.787	15.265	20.109	10.1	21.801	12.391	0.728	1.587	8.304
π_t	12.938	19.846	1.823	0.052	2.119	6.043	0.697	2.039	1.909	0.219	0.234	0.608
	43.949	45.58	6.288	0.457	10.044	19.083	3.278	7.909	11.466	2.039	0.94	2.783
π_t^C	10.347	15.697	2.096	0.029	1.754	3.821	5.893	6.232	0.841	0.181	0.226	1.829
	37.18	34.37	6.671	0.337	8.174	14.525	20.164	14.819	8.903	1.82	0.93	4.991
π_t^M	0.418	0.212	0.837	0.003	0.064	0.174	68.001	9.48	0.117	0.018	0.194	2.457
	3.095	0.724	2.309	0.032	0.391	0.873	83.211	19.887	0.733	0.247	0.479	6.31
π_t^X	3.09	0.222	0.244	0.006	0.284	0.805	76.307	0.312	0.109	0.057	0.031	0.087
	13.409	1.921	1.201	0.089	2.107	4.647	91.057	1.691	2.204	0.629	0.174	0.48
g_t^E	0.013	0.018	2.244	0.02	0.039	0.342	37.883	24.073	0.656	0.002	0.276	9.046
	0.724	0.168	4.703	0.12	0.835	2.908	56.28	38.621	2.181	0.13	0.788	15.385
csn	0.003	0.011	0.088	0.865	12.445	19.81	6.602	8.716	14.58	0.052	0.412	2.173
	2.984	0.211	0.817	1.843	24.593	37.484	13.859	19.559	28.388	0.795	0.961	4.491
gsn	0.092	0.273	1.734	17.113	7.506	2.047	11.323	0.325	21.707	0.012	0.283	0.49
	3.5	1.123	5.232	30.961	16.112	11.066	24.777	3.065	39.201	0.421	0.687	1.766
isn	0.001	0	0.001	0.176	66.502	2.281	0.771	2.449	6.737	0.021	0.203	0.962
	1.162	0.183	0.273	0.477	80.88	8.617	2.03	7.513	15.264	0.224	0.509	2.293
igsn	0.025	0.038	0.152	78.792	0.497	0.034	0.294	0.189	6.678	0.001	0.018	0.067
	0.517	0.224	0.856	90.025	2.073	0.981	0.909	0.923	15.324	0.043	0.093	0.412
tbyn	0.01	0.003	0.93	0.126	1.105	3.608	23.475	30.158	0.265	0.003	2.229	9.295
	0.837	0.119	2.472	0.37	4.228	9.317	40.287	50.312	0.773	0.093	3.213	13.586
L	38.021	0.128	1.087	0.281	5.169	0.001	1.606	3.627	7.943	2.374	0.349	1.349
	66.582	0.941	5.311	0.787	14.072	5.574	4.387	9.24	19.422	9.483	0.845	3.188
ws	63.646	1.407	0.125	0.099	0.228	3.877	0.846	0.118	0.806	1.757	0.004	0.042
	83.758	4.429	1.143	0.29	1.783	15.08	2.346	2.051	3.788	12.747	0.061	0.466
trw	18.638	0.057	0.534	30.644	2.706	0.001	0.763	1.95	4.302	1.148	0.203	0.681
	40.738	0.53	2.966	57.057	8.248	3.122	2.471	5.831	11.843	5.504	0.545	1.863
csn^k	72.439	0.548	0.047	1.848	0.779	0.634	1.067	0.719	0.368	0.173	0.003	0.098
	86.666	2.255	0.357	4.939	4.095	6.975	2.759	3.99	3.023	4.799	0.135	0.993
csn^i	6.455	0	0.067	0.731	10.318	14.873	4.802	7.466	13.487	0.001	0.378	1.623
	25.02	0.082	0.768	1.554	21.369	32.976	11.461	16.996	25.968	0.18	0.87	3.661

TABLE 2.6. Posterior variance decomposition – 90% Highest Probability Interval. (Unconditional variance)

	Wage mark-up	Price mark-up	Monetary policy	Fiscal policy	Investment	Consumption	Trade	Risk premium	TFP	Labour demand	Rest of the world	Foreign monetary shock
g_t^Y	1.959	0.811	4.017	1.215	10.692	2.284	15.606	4.097	24.094	0.075	0.375	2.693
	5.595	2.347	8.745	2.37	19.044	10.292	27.371	10.282	40.416	0.528	0.745	5.542
$inom_t$	12.237	0.339	1.545	0.236	4.011	9.181	2.477	7.865	5.35	0.087	0.355	1.331
	41.207	1.514	3.808	0.948	20.184	34.775	6.814	18.296	17.481	1.318	1.155	4.039
π_t	25.437	9.128	1.08	0.066	1.531	3.697	0.718	2.321	2.593	0.336	0.129	0.349
	60.978	22.619	4.379	0.355	11.451	19.403	3.236	7.696	16.839	3.644	0.586	1.665
π_t^C	23.333	7.158	1.042	0.053	1.411	3.423	3.156	4.054	2.109	0.312	0.112	0.834
	57.303	17.748	4.454	0.314	11.078	18.272	10.584	10.799	15.644	3.459	0.562	2.783
π_t^M	3.152	0.204	0.809	0.021	0.365	0.951	58.345	7.859	0.438	0.051	0.211	2.272
	12.386	0.655	2.136	0.093	2.826	4.418	75.868	17.296	3.193	0.732	0.46	5.673
π_t^X	7.938	0.173	0.337	0.018	0.565	1.125	52.166	0.856	0.737	0.155	0.049	0.126
	29.026	1.318	1.503	0.125	5.322	8.741	75.642	3.326	7.432	1.812	0.213	0.56
g_t^E	0.527	0.023	2.136	0.033	0.268	0.946	36.767	23.047	0.937	0.007	0.5	9.345
	2.86	0.191	4.478	0.145	1.645	3.847	54.777	37.199	2.561	0.212	1.005	15.48
csn	0.41	0.006	0.014	0.085	3.814	1.726	0.641	1.236	60.317	0.087	0.031	0.138
	8.179	0.031	0.107	0.491	20.661	10.162	2.647	6.681	83.618	0.706	0.217	0.768
gsn	3.878	0.142	0.762	12.681	4.431	1.603	5.727	0.257	32.794	0.152	0.129	0.239
	16.231	0.616	2.784	26.87	11.245	7.434	15.604	1.571	53.367	1.415	0.411	0.923
isn	0.423	0.002	0.007	0.028	7.682	0.237	0.102	0.134	56.755	0.054	0.011	0.049
	8.799	0.029	0.076	0.346	30.473	5.829	0.788	2.342	84.711	0.585	0.103	0.368
igsn	0.036	0.004	0.016	90.311	0.089	0.009	0.034	0.02	1.151	0.001	0.002	0.011
	0.898	0.052	0.201	98.44	0.623	0.304	0.267	0.23	7.327	0.055	0.027	0.115
tbyn	0.709	0.002	0.413	0.102	0.786	3.452	18.037	35.407	0.277	0.001	1.944	6.04
	5.843	0.065	1.234	0.508	4.834	13.513	32.705	60.979	1.019	0.083	2.942	9.509
L	41.385	0.01	0.013	0.013	0.487	0.01	0.069	0.206	6.033	2.066	0.009	0.028
	87.536	0.101	0.431	0.119	7.752	0.685	0.52	1.601	37.96	14.695	0.076	0.228
ws	17.045	0.214	0.133	0.018	0.12	1.567	0.201	0.128	0.223	23.587	0.011	0.051
	63.013	1.058	0.923	0.076	0.656	6.893	0.638	0.712	1.053	72.265	0.083	0.256
trw	39.387	0.01	0.013	0.2	0.48	0.021	0.068	0.19	5.986	1.627	0.007	0.027
	86.046	0.099	0.419	3.75	7.622	0.664	0.514	1.521	36.937	14.032	0.072	0.22
csn^k	59.105	0.084	0.072	0.312	0.217	0.591	0.171	0.118	3.104	3.975	0.004	0.022
	85.889	0.446	0.456	1.375	2.609	3.019	0.539	0.911	12.521	25.205	0.033	0.16
csn^i	2.467	0.007	0.029	0.084	3.758	1.575	0.553	0.91	52.13	0.071	0.032	0.105
	23.495	0.048	0.179	0.425	19.421	8.743	2.283	5.982	80.318	1.42	0.195	0.632

3. Impulse Response Analysis

We now proceed to investigate the effects of various structural shocks on the euro area economy. We use the estimated DSGE model to analyse the impulse responses of the main economic variables to structural shocks and the uncertainty surrounding these effects. The magnitude of the shocks is given by the posterior estimate of one standard deviation of the shock, i.e. we used the full joint posterior distribution of structural parameters and shocks to produce the Bayesian uncertainty bounds of the IRFs.

Figures 2 to 4 show the response for the estimated model to a government consumption, investment and transfers shock respectively. The government consumption and investment shocks raise government spending as a share of output, but spending gradually returns to baseline. An increase in government consumption raises GDP temporarily, however it crowds out the interest sensitive demand components such as private investment and consumption of Ricardian households, while consumption of liquidity constrained households rises because of higher wage income. However, in the medium run liquidity constrained consumers also cut back consumption spending because of an increase in lump sum taxes, needed to finance the government spending shock. Notice, however, the aggregate consumption multiplier of government consumption is negative. This result seems at first sight in conflict with the findings of Gali *et al.* (2007). They show that allowing for a fraction of credit constrained consumers exceeding 25%, a model with sticky prices can account for a positive consumption response to a government spending shock. However, their model assumes no nominal wage rigidities and no labour adjustment costs (in our notation $\gamma_w = \gamma_L = 0$). In contrast our estimation results show that especially the labour adjustment cost parameter γ_L is significantly different from zero. A sensitivity analysis (see annex) shows that when these parameters tend to zero (as assumed in Gali *et al* (2007)), the consumption response to a government spending shocks tends to become positive in our model too. The economic interpretation of this result is simple. Negligible wage and labour adjustment costs imply a stronger positive short run impact of an increase in government consumption on labour income and therefore a stronger response of private consumption.

Our results can also be compared to Coenen and Straub (2005). They estimate a DSGE model for the euro area similar to Smets and Wouters (2003), but introduce non-Ricardian households in the model similar to our liquidity constrained consumers. For a lower share of non-Ricardian households (between 0.25 and 0.37) they find a short-lived rise in liquidity- constrained consumption, but falling below its steady state level already after a few quarters, caused by a rise in lump-sum taxes due to the build up of government debt. Forni *et al.* (2006) find a positive response of consumption to both a government purchases and a government employment shock, but assume no fiscal response to cyclical conditions and no labour adjustment costs

To assess the impact of the government spending shocks on output in terms of traditional "multipliers", the impact effect for a 1 percent of government spending shock on GDP is 0.73 in the first quarter, falling to 0.45 in the fourth. It remains positive for seven to eight years, and then turns negative. Cumulated over the first year the multiplier is 0.56. This is somewhat smaller than results reported in Roeger and in 't Veld (2004) for the QUEST II model, which shows multipliers for the largest four European countries between 0.85 and 0.95[6]. The estimated impact fiscal multiplier is within the range found in empirical studies of fiscal policy using structural vector autoregression (SVAR) models. Blanchard and Perotti (2002) applied SVAR methodology to study the effects of fiscal policy in the US and various authors have extended the SVAR methodology to include other countries. Perotti (2005) finds large differences in the effects of fiscal policy, with the responses of GDP and consumption having become weaker over time. Only for the US is the consumption response found positive and did the GDP multiplier exceed 1 in the post 1980 period.

The effect of government investment on GDP is more favourable (see figure 3), because government investment has a positive supply effect. Because of this the effect is also less inflationary and therefore requires a smaller interest rate response of the central bank. However one should notice that the government investment multiplier hinges importantly on the output elasticity of public capital which is not estimated. The parameter is calibrated such as to obtain a marginal product of public capital equal to the marginal product of private capital in the steady state.

Figure 4 shows the responses to a government transfer shock. The increase in transfers raises disposable incomes and boosts liquidity-constrained consumption C^k directly. There is a negative impact on consumption of non liquidity-constrained consumers, but this is much smaller and aggregate consumption is positively affected by the transfer shock. Again, fiscal policy crowds out private investment.

Figure 5 presents the level comparison of the estimated effect of an orthogonalised shock to nominal interest rates (ε_t^{INOM}). The shock leads to a rise in the (annualised) nominal short-term interest rate of 0.4 percentage points on impact. The real short-term interest rate increases by more. The monetary policy shock is not very persistent and nominal interest rates return quickly to base. The shock leads to a hump-shaped fall in output. The maximum effect on investment is about three times as large as that on consumption and the peak effects occur after about two quarters. Inflation also peaks in the second quarter[7] but we do not see the hump-shaped response in consumer price inflation that is a persuasive feature of many estimated VARs. This could be due to our small open economy assumption where we do not allow the Euro exchange rate to affect export prices of the rest of the world. This implies that the appreciation of the Euro is immediately passed on to domestic consumer prices. In a more realistic multi country setting the inflation response would likely be more delayed. Real wages fall in response to the monetary policy shock and employment is also negatively affected. Fiscal spending falls but the decline is less than that of GDP as fiscal policy acts counter-cyclically and partly offsets to effects of the monetary contraction.

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[6] There the government consumption shock is a weighted average of government purchases and wage expenditures. Wage expenditure shocks have larger effects on GDP than government purchases shocks.
[7] Lack of inflation inertia and inflation persistence has been a feature of many DSGE models. Cogley and Sbordone (2005) show that allowing for a shifting trend in the inflation target can improve the empirical description of the inflation process.

FIGURE 2. Response to a government consumption shock.

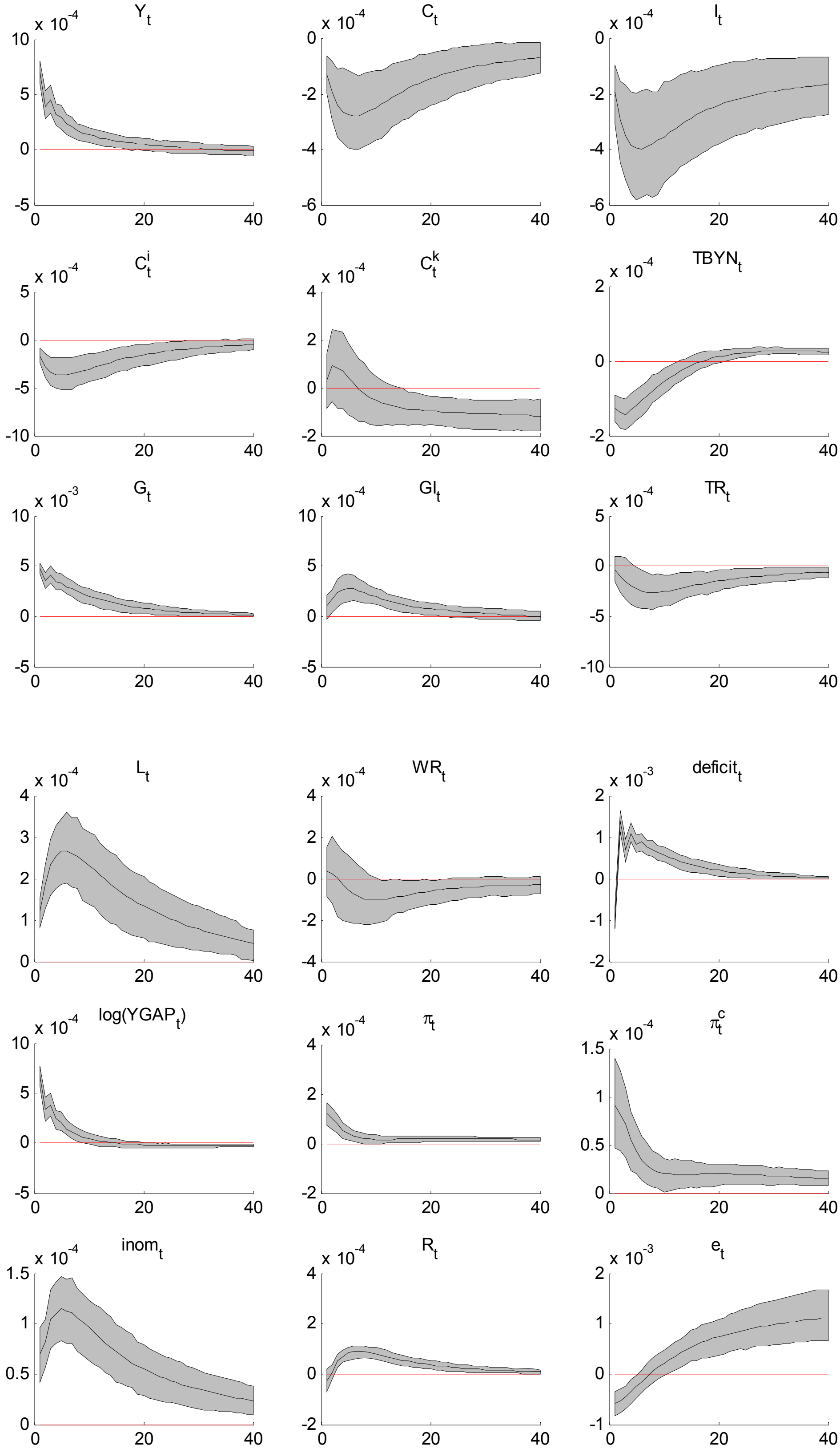


FIGURE 3. Response to a government investment shock.

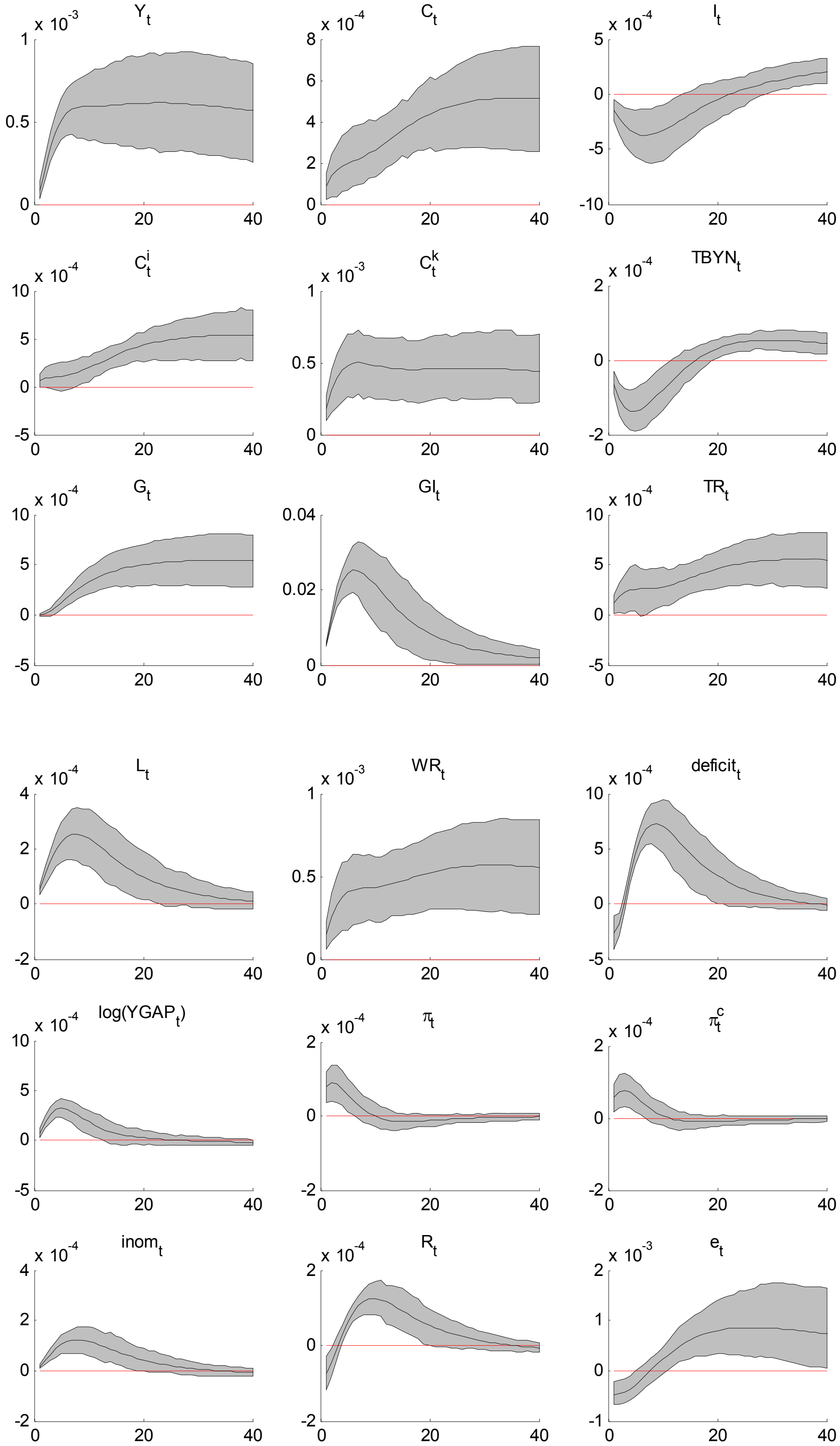


FIGURE 4. Response to a government transfers shock.

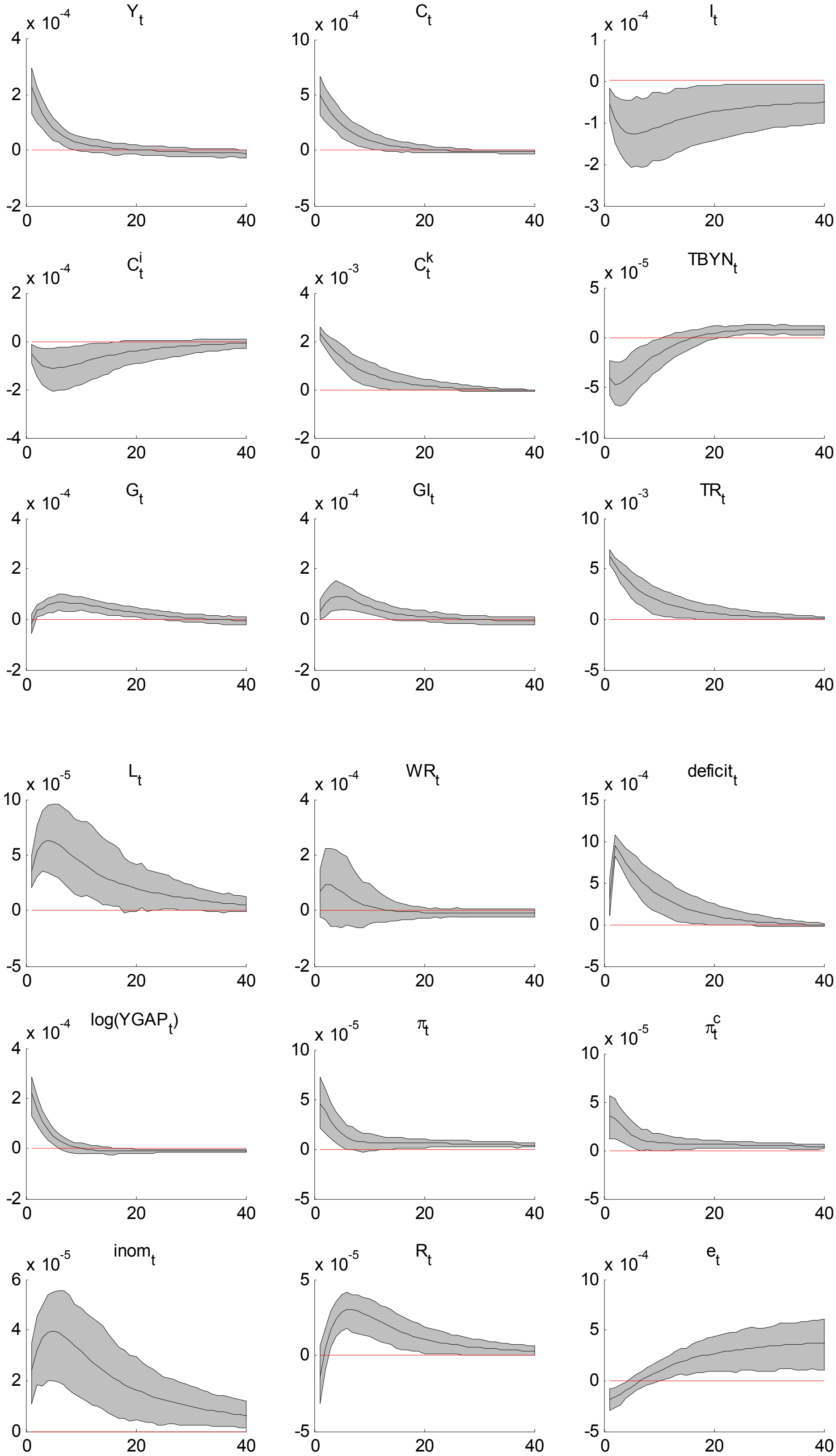


FIGURE 5. Response to a monetary shock

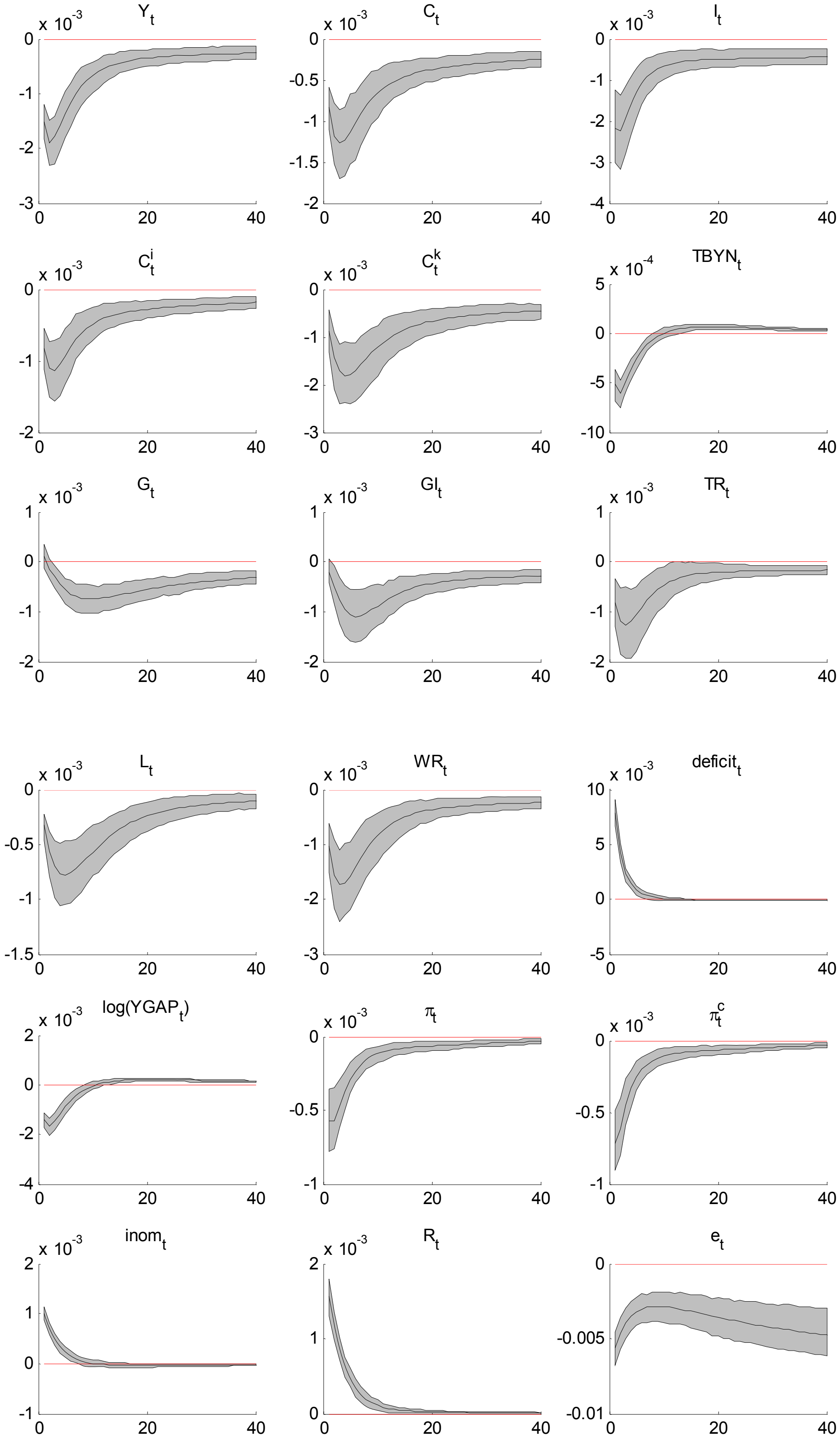


FIGURE 6.   Response to a shock to world demand.

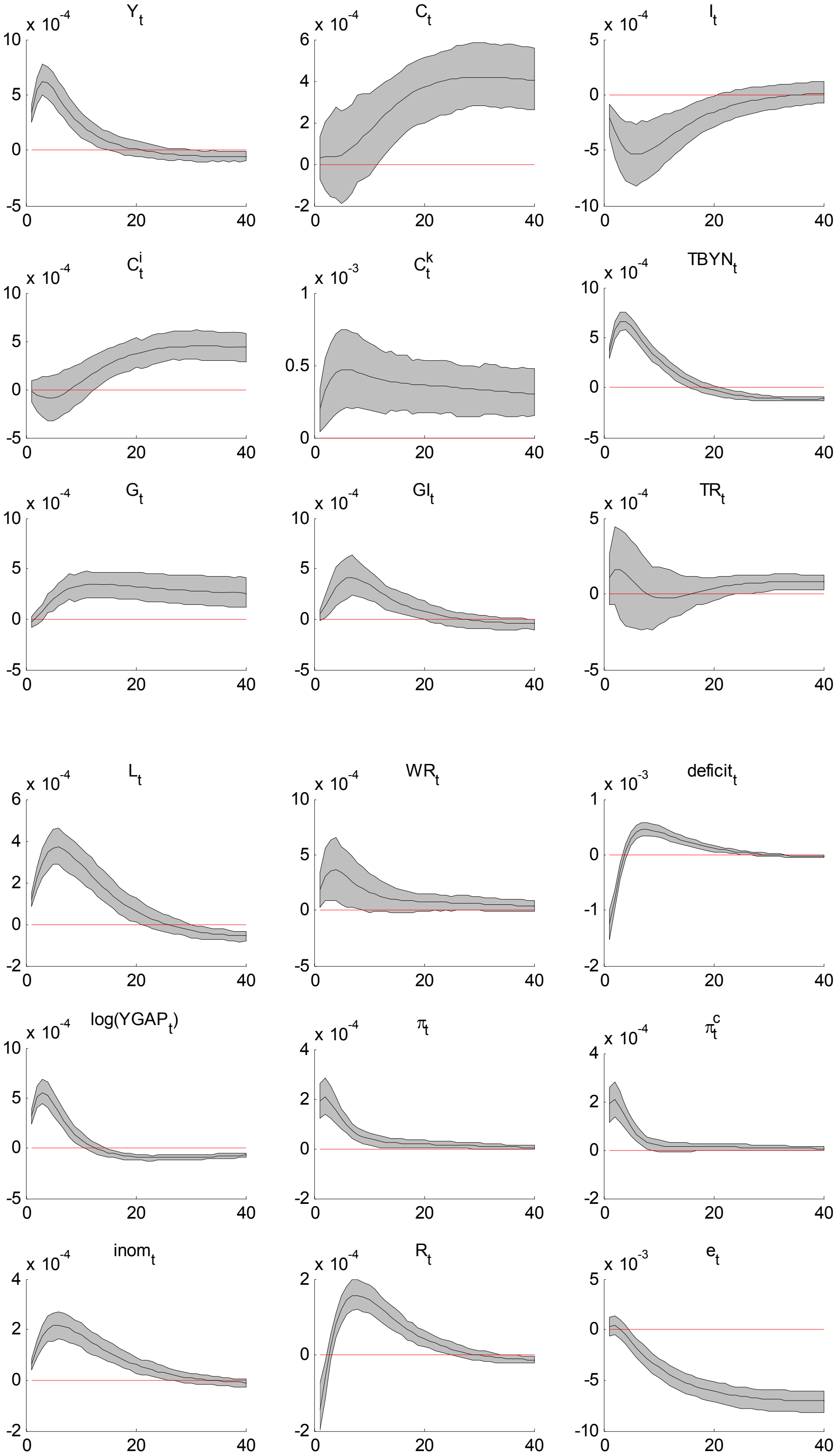
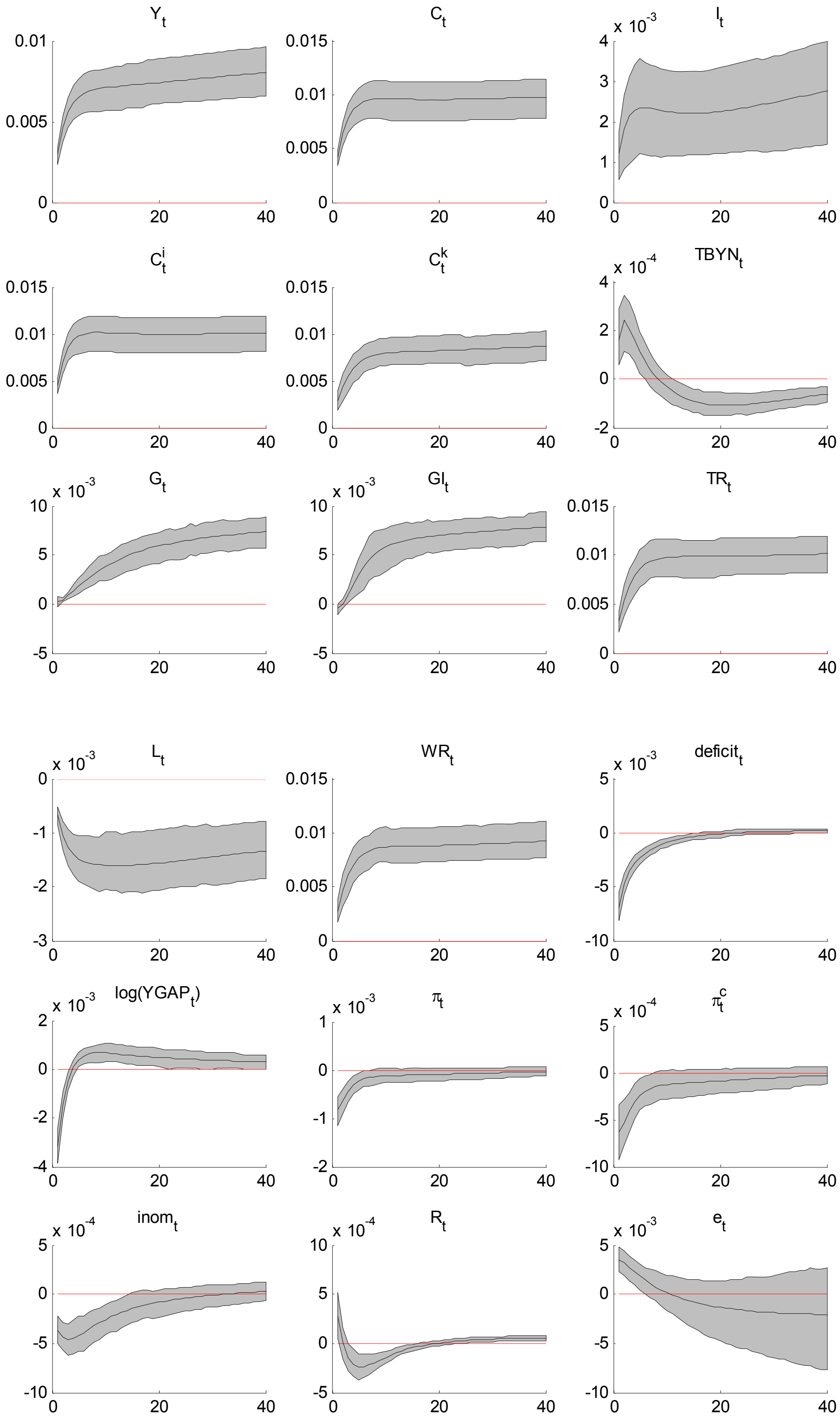


FIGURE 7. Response to a shock to TFP.



Our last example of a demand shock is a shock to foreign demand. Figure 6 presents the level comparison of the estimated effect of an orthogonalised shock to world output (ε_t^{YF}). Because of nominal rigidities an increase in world demand leads first to an increase in capacity utilisation and employment. The initial excess demand is only gradually reduced by an increase in domestic prices. In the long run there is a positive output effect resulting from the terms of trade effect induced by a permanent shift in world demand for domestic goods. Government expenditure increases in line with nominal GDP (government purchases and investment) and the wage sum (government transfers), but they increase by less than would be the case if there was no active fiscal policy as the output and employment gap are positive. Thus fiscal policy limits the increase in aggregate demand and stabilises output. The overall effect of fiscal stabilisation is to reduce the initial increase in employment. Automatic stabilisation via transfers also smoothes consumption of liquidity-constrained households C^k.

Figure 7 presents the level comparison of the estimated effect of an orthogonalised shock to TFP (ε_t^{Y}). Because TFP follows a random walk, the productivity shock results in a permanent increase of output, consumption and investment. The real wage also rises, but there is a rather persistent negative employment effect. It is well known (see Gali, 1999) that with nominal rigidities supply shocks lead to a demand externality. Because firms lower prices insufficiently as a response to a cost-reducing shock, there is a lack of aggregate demand which makes it optimal for individual firms to lower employment. Expansionary government consumption partially compensates for the shortfall in demand. The automatic stabilisation via government transfers work in the same direction, since they respond to the decline in employment and boost consumption of liquidity constrained households.

4 Medium term trends: the case of a declining wage share

A continuously declining wage share over the sample period is an important stylised fact for the European economy. In our empirical analysis we allow for two mechanisms which allow the model to match this fact, namely a declining share of overhead labour and a secular increase in the mark up of prices over marginal cost. Unfortunately both shocks are not directly observable; however, they can be identified by using the model because they affect first order conditions differently. The overhead labour shock only affects the labour demand equation while the mark up shock affects labour demand and investment in a similar fashion. Both explanations have some empirical validity. It is likely that structural reforms in the goods market and in particular large scale privatisations which occurred in various euro area member states over the sample period may have lead to a decline in overhead labour. It is also likely that the economy-wide mark up has increased over the sample period due to an increasing share of services in total output. As documented in many sectorial studies on mark ups (see for example Oliveira Martins *et al.*, 1997) the service sector tends to have higher mark ups (the absence of both shocks in the US case is also consistent with a relatively stable US wage share). In the following we use the model in a counterfactual analysis in order to first determine the relative importance of the two explanations in accounting for the evolution of the wage share and second for explaining the economic consequences of these trends.

As can be seen from Figures 8 and 9, our estimates indicate that the share of overhead labour in total employment *LOL* has fallen by about 20% points and mark ups have increased by about 5% points. As shown in figure 10, the decline in overhead labour explains about 50% of the decline in the wage share. Both effects explain a large fraction of the decline (60-70%).

The reduction in overhead labour increases productivity without increasing the marginal product of production workers (marginal productivity of labour actually falls), this leads to a decline in the wage share. Because firms can supply the same output with less labour and the marginal product of labour has declined, the reduction in overhead labour does not by itself lead to an increase in factor demand. In fact it reduces the demand for labour since the reduction of fixed costs reduces the marginal product of labour. Therefore there is a new equilibrium with less labour input, lower GDP, lower real wages but higher average productivity.

The increase in the price mark up affects the measured mark up directly and leads to a reduction of both factor inputs. In contrast to a reduction in overhead labour the mark up shock reduces labour and capital inputs simultaneously.

Finally, we can ask the question whether both shocks acted independently or whether there is a correlation between them. Theoretically it is plausible that a reduction in overhead labour could have removed entry barriers and thus have led to a reduction in mark ups, suggesting a positive correlation, i.e. *corr(lol,eta)* > 0. Alternatively it is also possible that an increase in the mark up could have increased overhead labour via some rent sharing agreements between workers and firms, implying a negative correlation, i.e. *corr(lol,eta)* < 0 , and therefore restrict the decline in LOL. A small negative correlation (*corr(lol,eta)* = -0.22) can be observed in the reconstruction of the historical shocks (smoothed shocks).

FIGURE 8. Counterfactual experiment: solid lines are for the case when the level of LOL remains fixed at the values of begin of 80's; dashed lines show the actual data.

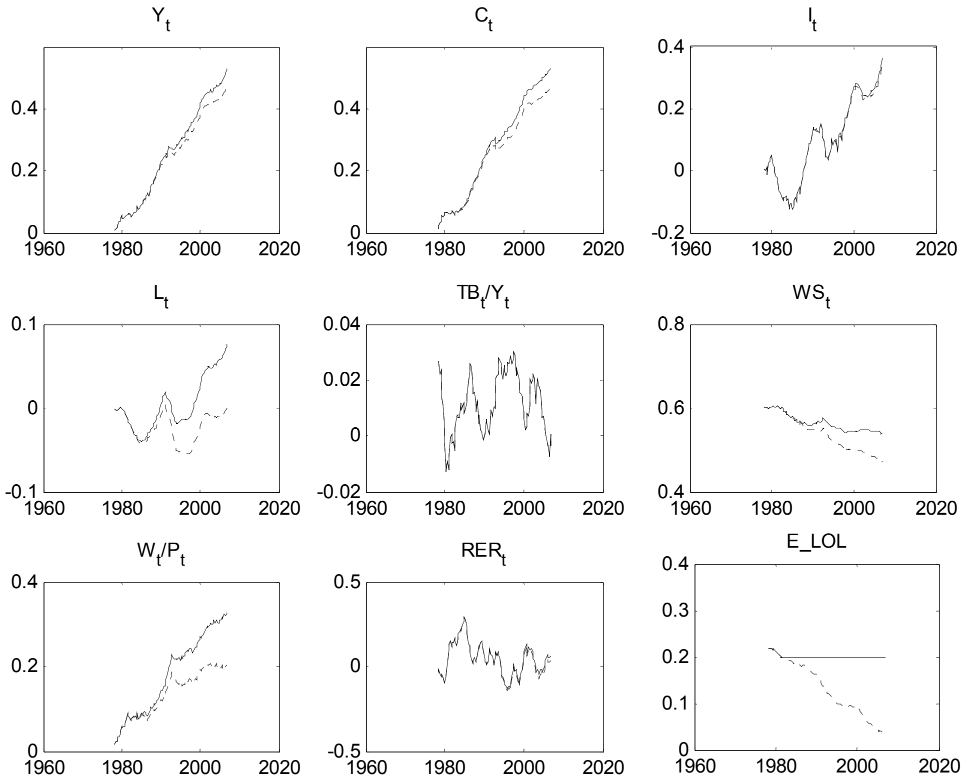


FIGURE 9. Counterfactual experiment: solid lines are for the case when the level of mark-up shocks remains fixed at the values of begin of 80's; dashed lines show the actual data.

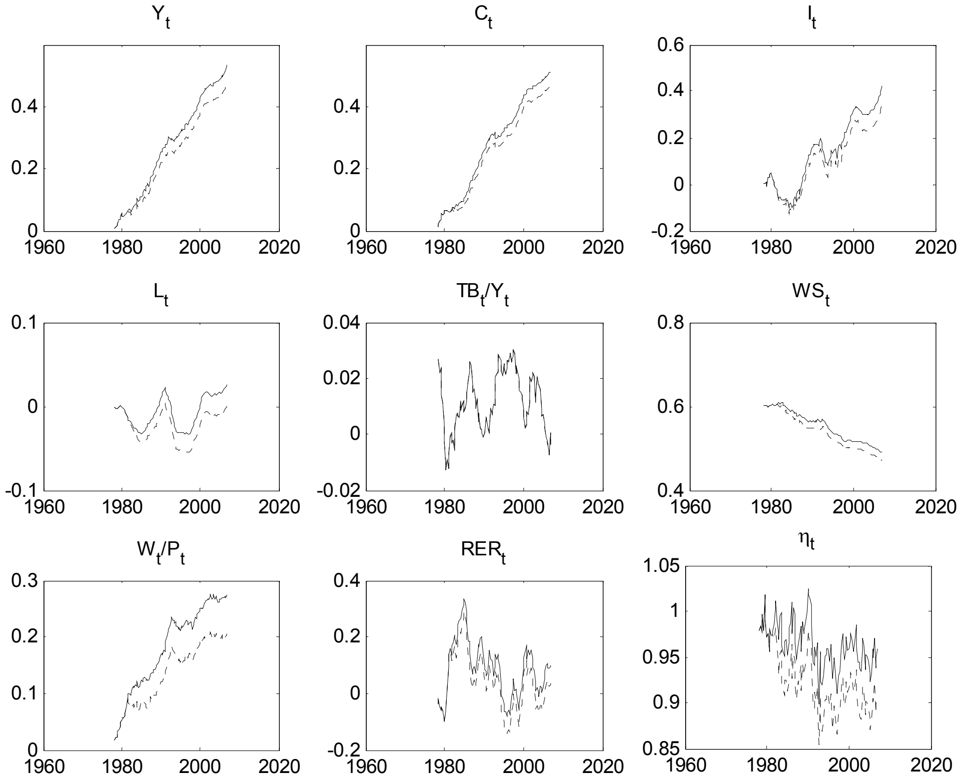
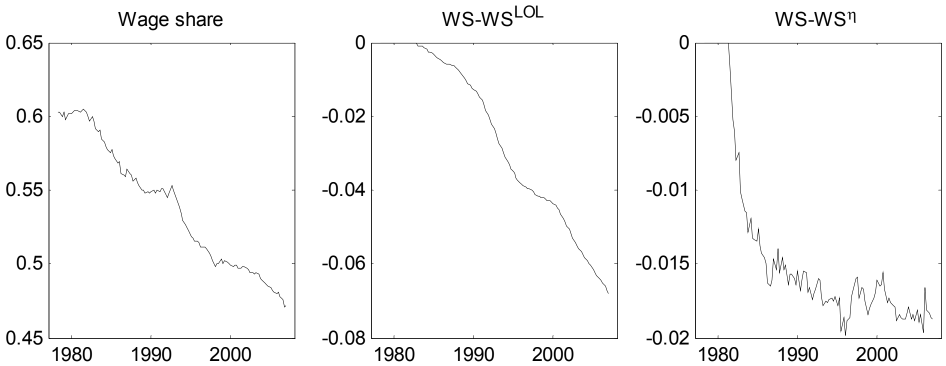


FIGURE 10. Counterfactual experiment:
upper plots show the actual wage share, the decline of the actual wage share which is explained by the decrease in labour overhead and in price mark-up. The bottom plot compares the actual wage share data with the two counterfactual experiments.



5 Conclusions

In this paper we have described the estimation of an open economy DSGE model for the euro area. So far most estimated DSGE models have mainly been concerned with monetary policy analysis. We have extended the model by incorporating fiscal reaction functions that allow the model to be used for fiscal policy analysis. Fiscal policy is effective in the model as we allow for financial market rigidities that force some households to consume their current wage and transfer income. Our paper differs also from other estimated DSGE models in that it treats the euro area as an open economy and is not estimated using detrended data, which allows us to analyse the effects of non stationary productivity shocks.

In future research we intent to extend this analysis in various directions. It would be interesting to explore how the stabilising properties of the estimated rules compare to simple optimal rules. We have also disregarded automatic stabilisation from other revenue components. This requires a more careful analysis of various tax rules. In future research, more attention will also have to be devoted to fiscal stabilisation at the level of euro area member states.

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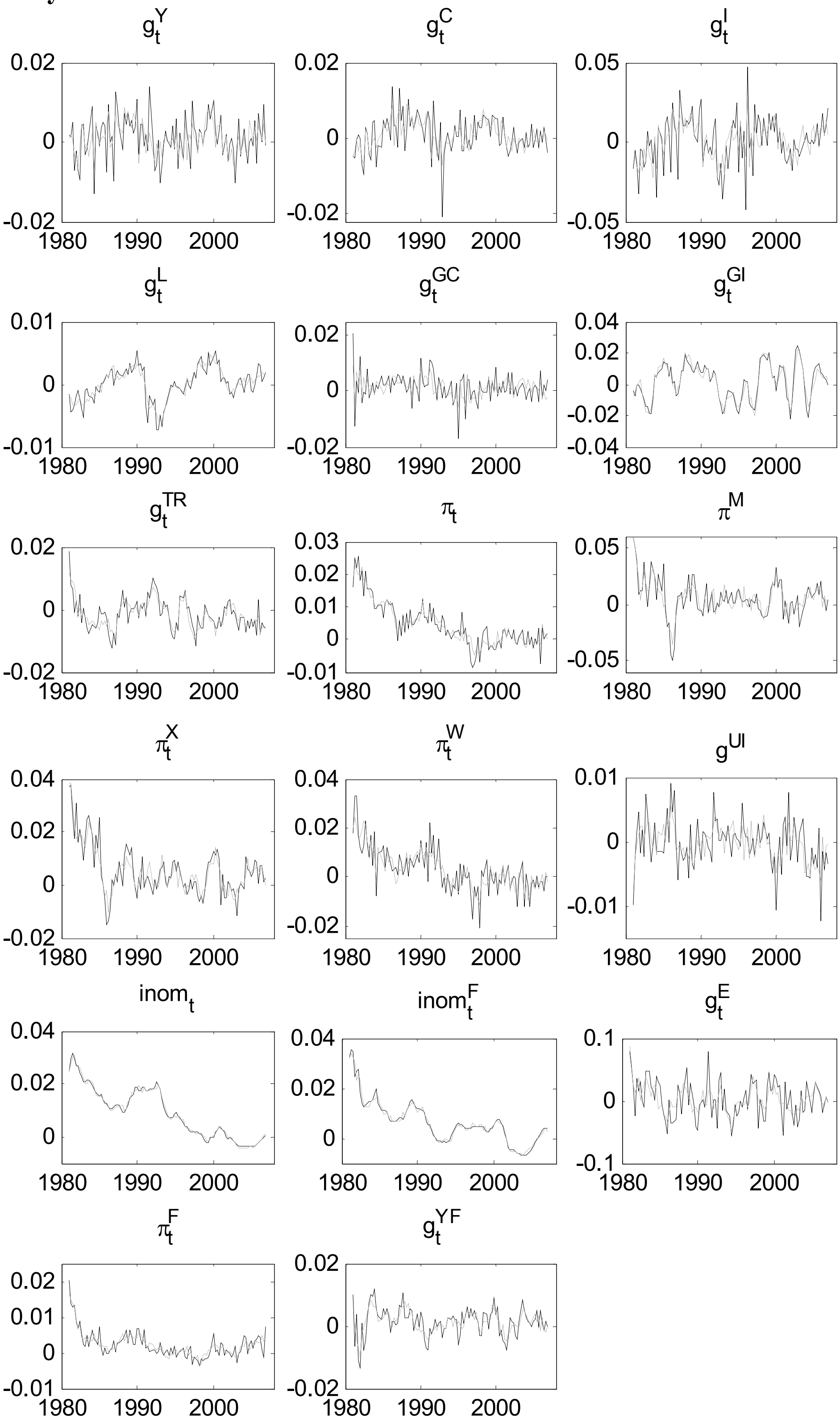
FIGURES

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



ANNEX 1 The steady state

The DSGE model implies a number of long run restrictions for growth rates, nominal shares and price ratios. The determination of the steady state of the model is described below, where steady state is denoted by the endogenous names without the index *t*.

Long run growth rates and inflations are calibrated as follows:

$$g^{Y} = 0.003$$
$$\pi = 0.005$$
$$g^{UI} = 0$$
$$g^{POP} = 0.00113$$

The steady state of real per capita GDP growth rate determines all the real growth rates of the model, except for investment, which is given by:
$g^{I} = g^{Y} + g^{UI}$.

The steady state of GDP deflator inflation defines the steady state of all inflation rates in the model and also of nominal wage inflation, as:
$\pi^{W} = \pi + g^{Y}$

The technology growth is determined by:

$$g^{UP} = \frac{\alpha + \alpha^{G} - 1}{\alpha} g^{Y} - \frac{(2-\alpha - \alpha^{G})}{\alpha} g^{UI}$$

Nominal interest rate is given by:
$i = \pi + 1/\beta - 1$

The model allows for a generalised case, where the rate of time preference in the domestic and foreign countries is different, implying different steady state nominal interest rates. The net foreign asset share to GDP is thus given by:

$$\frac{E\ B^{F}}{P\,Y_{t}} = byn^{F} = (i^{F} - i)/\,risk$$

This implies a steady state level for the nominal trade balance share:
$tbyn = (-i + \pi + g^{Y} + g^{POP})byn^{F}$

By combining the GDP equilibrium condition and equations (21-24), the identity $(exyn - imyn) = tbyn$ can be expressed only in terms of trade balance, real exchange rate and foreign to domestic GDP ratio, *ywy*. The latter ratio is calibrated at 1, allowing to obtain *ER* from *tbyn*. From this all the price ratios can be determined as:

$$P^M / P^Y = ER^{\alpha^X}$$

$$P^C / P^Y = \left[s^M + (1 - s^M)\left(P^M / P^Y\right)^{(1-\sigma^M)} \right]^{\frac{1}{1-\sigma^M}}$$

$$P^X / P^Y = 1$$

where α^X is the share of intra trade, calibrated at 0.5. The import and export shares are also determined as:

$$imyn = s^M \left[\frac{P^C}{P^M} \right]^{\sigma^M - 1} (1 - tbyn)$$

$$exyn = s^{M,W} (ER^{\alpha^X s^{M,W}})^{\sigma^X}$$

In the case when the domestic rate of time preference is equal to the one of the rest of the world, the above listed steady state conditions simplify to:

$$byn^F = tbyn = 0$$

$$ER = (P^C / P^Y) = (P^M / P^Y) = (P^X / P^Y) = 1$$

$$imyn = exyn = s^M = s^{M,W} .$$

From the closure of the trade balance equations, the steady state of the domestic variables can be finally solved. First, from capital accumulation, we get:

$$ik = \delta$$

$$ik^G = \delta^G$$

and, from capital FOC, we also get:

$$kyn = (1 - t^K)(1 - \tau)(1 - \alpha) / (1/\beta - 1 + rp + \delta)$$

This defines the nominal investment share:

$$iyn = ik \cdot kyn$$

The government shares are calibrated to match observed ratios:

$$cgyn = 0.203$$

$$igyn = 0.025$$

The consumption share is thus given by:

$$cyn = 1 - (iyn + cgyn + igyn + tbyn)$$

The wage share is simply given by:

$$ws = (1 - \tau)\alpha$$

Calibrated constants are:

$t^P = 0.2$

$\tau = 0.1$

$\alpha = 0.52$

$\alpha^G = 0.9$

$\beta = 0.996$

$\delta = 0.025$

$\delta^G = 0.0125$

where α is set to match the nominal wage share at the end of the sample, while β is set to match the very small difference in the levels of interest rate and inflation in the end of sample.

The steady state of employment rate is set at 0.65. This implies a restriction for ω, which is a function of the steady state of employment rate and of other model parameters.

The steady state of *ucap* is set at 1, implying

$\gamma_{ucap,1} = (1-\tau)(1-\alpha)/kyn$

The steady state of the GDP share of government debt *byn* is set at 2.4 (60% yearly), while the level of nominal transfer share is estimated, implying the steady state of lump sum tax:

$taxyn = (i - \pi - g^Y - g^{POP})byn + igyn + cgyn + trw - (t^W + ssc)ws - t^P(1-ws) - t^C \cdot cyn$

where

$ssc = t^W = t^C = t^K = 0.2$

This allows to determine the steady state of the share of liquidity constrained consumers

$cyn^k = [(1 - t^W - ssc)ws + trw - taxyn]/(1 + t^C)$

and hence the non-liquidity constrained ones are:

$cyn^j = (cyn - slc \cdot cyn^k)/(1 - slc)$.

ANNEX 2 Mapping acceptability of the prior domain.

The prior assumptions used for the Bayesian estimation have been preliminary checked, to assess the acceptability domain of the model within the prior space, i.e. to detect the occurrence of unstable behaviour of indeterminacy. This is performed following the Monte Carlo Filtering approach shown in Ratto (2008). We generated a Monte Carlo sample of model parameters from prior distributions and for each element of the sample we have checked the rank condition for the eigenvalues of the linearised model. This analysis showed that 94.4% of the prior domain is acceptable, 5.1% of the prior domain provides explosive solutions while only a 0.4% gives indeterminacy. The large portion of the acceptability domain allows us to state that our prior space is well defined and subsequent posterior update is not affected by large portion of violations of Blanchard Kahn conditions.

Concerning the explosive behaviour, sensitivity analysis showed that this is mostly driven by

- too small values of *sfp*, *sfpx* and *sfw*;
- too small values for τ_{π}^{INOM} ;
- too large values of σ^{X} ;
- large *negative* values of τ_{Lag}^{CG}.

ANNEX 3 Sensitivity analysis of consumption response to government spending shock

In this annex we discuss the sensitivity analysis of the consumption response to government spending shock. In particular we are interested in the detailed mapping of the model parameterisations that drive towards a positive or a negative response in the short term.
We apply the same Monte Carlo sample used for the acceptability analysis shown in ANNEX 2 and solve the model for each MC realisation. This allows to obtain the prior uncertainty distribution of the first quarter response of Δc_t versus u^{CG}, that we report in Figure A1.1. In Figure A1.1 it can be seen that under the prior assumptions implied by the model structure and prior distributions, the model puts a somewhat larger prior probability for a negative response (the mode of the histogram is on the negative part). Nonetheless, the prior probability of a positive response is also significantly larger than zero. This is the result of the combination of the prior distribution for liquidity constrained households, which is evenly and neutrally distributed between negative and positive responses, and the prior distribution for Ricardian households, which is always negative.

In order to understand more clearly the conditions under which a positive response is more likely than a negative one, we perform a detailed sensitivity analysis. In particular we apply global sensitivity analysis techniques to map the function

$$Y = (\Delta c_t \text{ vs. } \mathrm{u}^{\mathrm{CG}}) = f(\mathbf{X})$$

where **X** is the vector of model parameters. The details about the estimation method can be found in Ratto et al. (2007) and Ratto (2008). The approach we adopt is in practice the estimation of a non-parametric regression model on the MC sample used for Figure A1:

$$Y = f(\mathbf{X}) \approx f_0 + \sum_{j=1}^{k} f_i(X_i) + e$$

where $f_0 = E(Y)$ is the mean of Y, *e* is the residual of the non parametric regression model and $f_i(X_i) = E(Y \mid X_i) - f_0$ are the non-parametric regression terms for each model parameter, i.e. the conditional expectation of *Y*, given X_i. The quantity $\mathrm{cov}(f_i, Y)$ is the so-called *correlation ratio* or non-parametric *R*-squared and provides the portion of variance of *Y* that is explained by each model parameter X_i. Hence, the $f_i(X_i)$ terms provide the best least-squares predictors of *Y*, based on univariate functions of single model parameters. This MC approach to sensitivity is typical in global sensitivity analysis (see e.g. Saltelli *et al.*, 2004) and detects the effect of each model parameter by varying all the other parameters *at the same time*. This provides an extremely powerful measure of sensitivity, since a significant pattern in terms of conditional expectations $E(Y \mid X_i)$ tells that changing the value of X_i implies a shift *in the mean* of *Y*, i.e. tells that one is able to drive the sign of *Y* whatever the values of the remaining model parameters. This contrasts with other sensitivity analysis typically found in the literature, which are performed moving one parameter at a time around a base point in the prior space. This latter approach may be heavily prone to the base point around which the analysis is performed.

In Figure A2 we show the plots of $f_i(X_i)$ for the most important parameters driving the consumption response (continuous lines). Dotted lines show the width of the 90% confidence bands of the estimated non-parametric curves, that allow to appreciate the significance of the $f_i(X_i)$ functions. The values in the y –axis tell exactly by how much one can expect to change the value of the consumption response with respect to its prior mean values by varying each single parameter. These plots allow a rather interesting and informative discussion.

1. most parameters display a rather non-linear pattern, with rather sharp negative or positive peaks towards the bounds of their prior distributions;
2. labour and wage adjustment cost coefficients γ_L display a decreasing pattern: when they tend to zero, the $f_i(X_i)$ patterns show a rather non-linear and peaked positive values while increasing adjustment costs tend to drive smoothly towards a negative consumption response;
3. price adjustment cost coefficient γ_P has an opposite behaviour and increasing γ_P drives a positive consumption response, while γ_P towards zero implies a sharp negative tendency for this response;
4. large values of σ^C and *slc* also drive a positive response of consumption;
5. the patterns for τ_{Adj}^{CG} and ρ^{CG} suggest that the more persistent is *G* spending, the more negative will be the consumption response;
6. the shape for monetary policy parameters suggests that the more the monetary authority is active, the smaller (i.e. more negative) will be the consumption response: in fact positive C response is associate to high τ_{lag}^{INOM} values and small τ_{π}^{INOM} , $\tau_{Y,1}^{INOM}$ and $\tau_{Y,2}^{INOM}$
7. the transfer rule also affects the consumption response: the larger the response to unemployment, the more negative tends to be the consumption response.

One would also expect an effect of γ_W. This is extremely non-linear and the simple smoothing technique on a single Monte Carlo sample does not allow to visualize the effect of γ_W. In Figure A1.2 we show the prior uncertainty distribution of the consumption response when γ_W has been fixed at zero. Now the aggregate consumption is evenly distributed around zero, implying the probability of a positive response versus government spending is increased. This is due to the much more skewed distribution of liquidity constrained households towards positive values. Fixing contemporaneously $\gamma_L = \gamma_W = 0$ as in Gali et al (2007), we get that the prior distribution of the response of aggregate consumption versus government spending is almost entirely on positive values.

FIGURE A1.1 Prior uncertainty distribution of the response of aggregate consumption growth to government spending shock

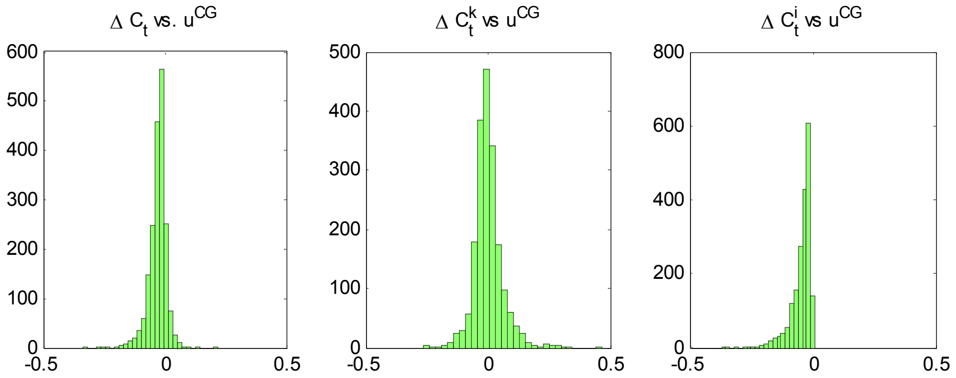


FIGURE A1.2 Prior uncertainty distribution of the response of aggregate consumption growth to government spending shock when $\gamma_W = 0$.

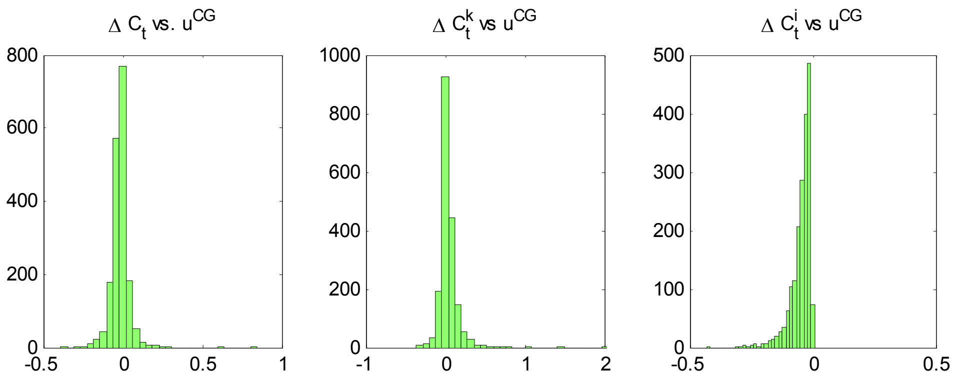


FIGURE A1.3 Prior uncertainty distribution of the response of aggregate consumption growth to government spending shock when $\gamma_L = \gamma_W = 0$.

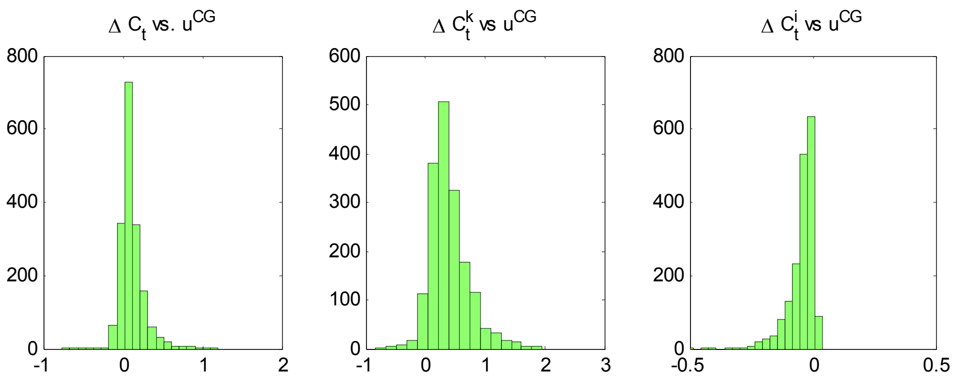
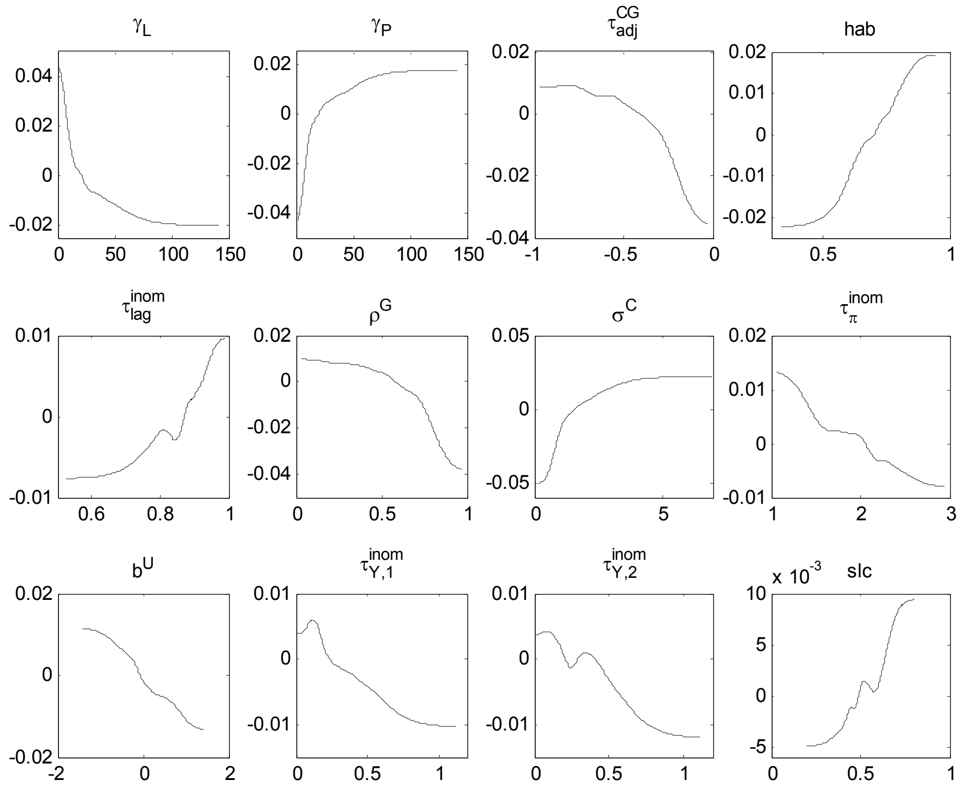


FIGURE A2. Sensitivity analysis of the response of aggregate consumption to government spending shock.



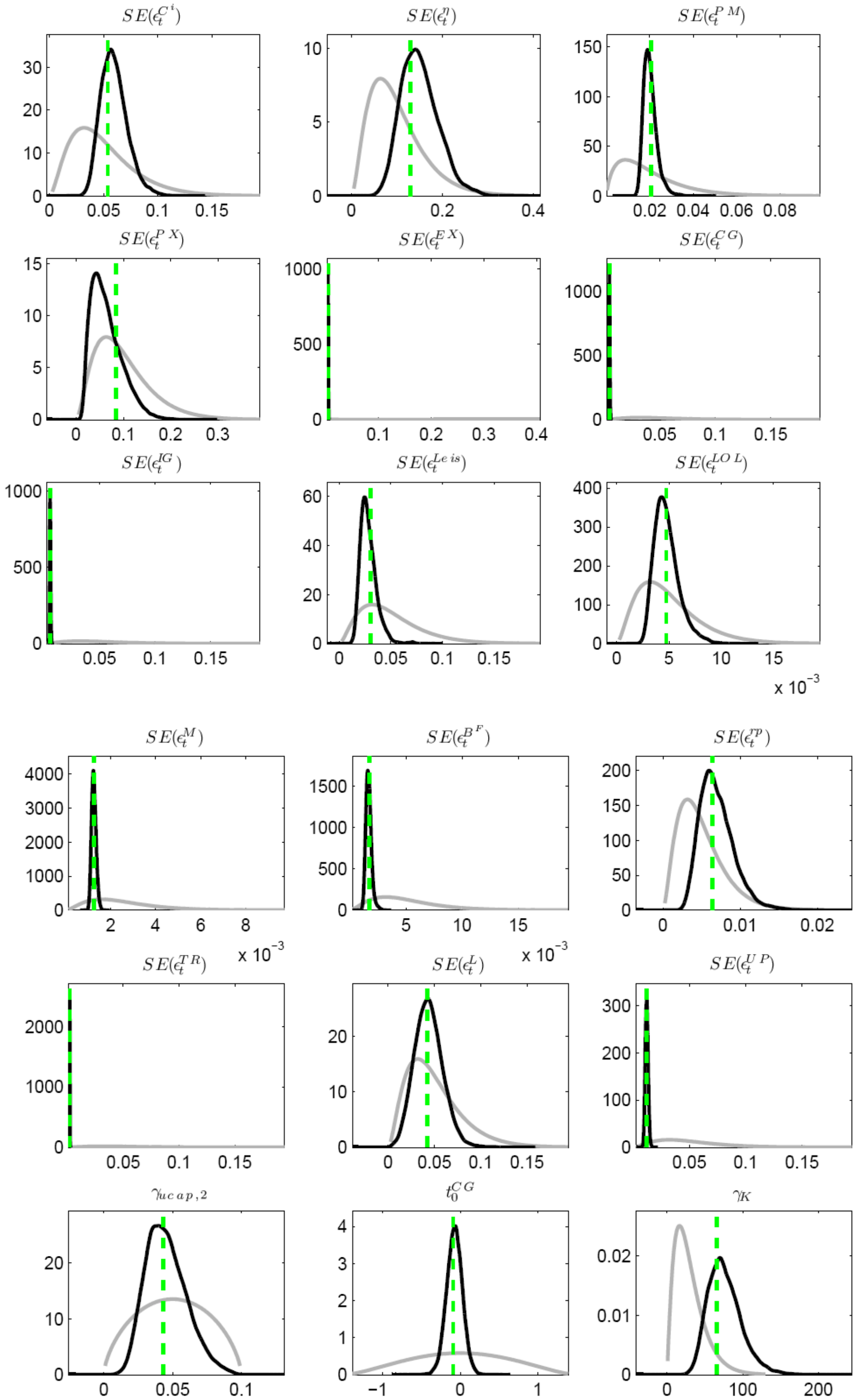
Note: Non-parametric regression of the prior sample of the first quarter response of Δc_t vs. u^{CG}. Plots show the shape of the non-parametric curves of the most relevant factors driving the consumption response.

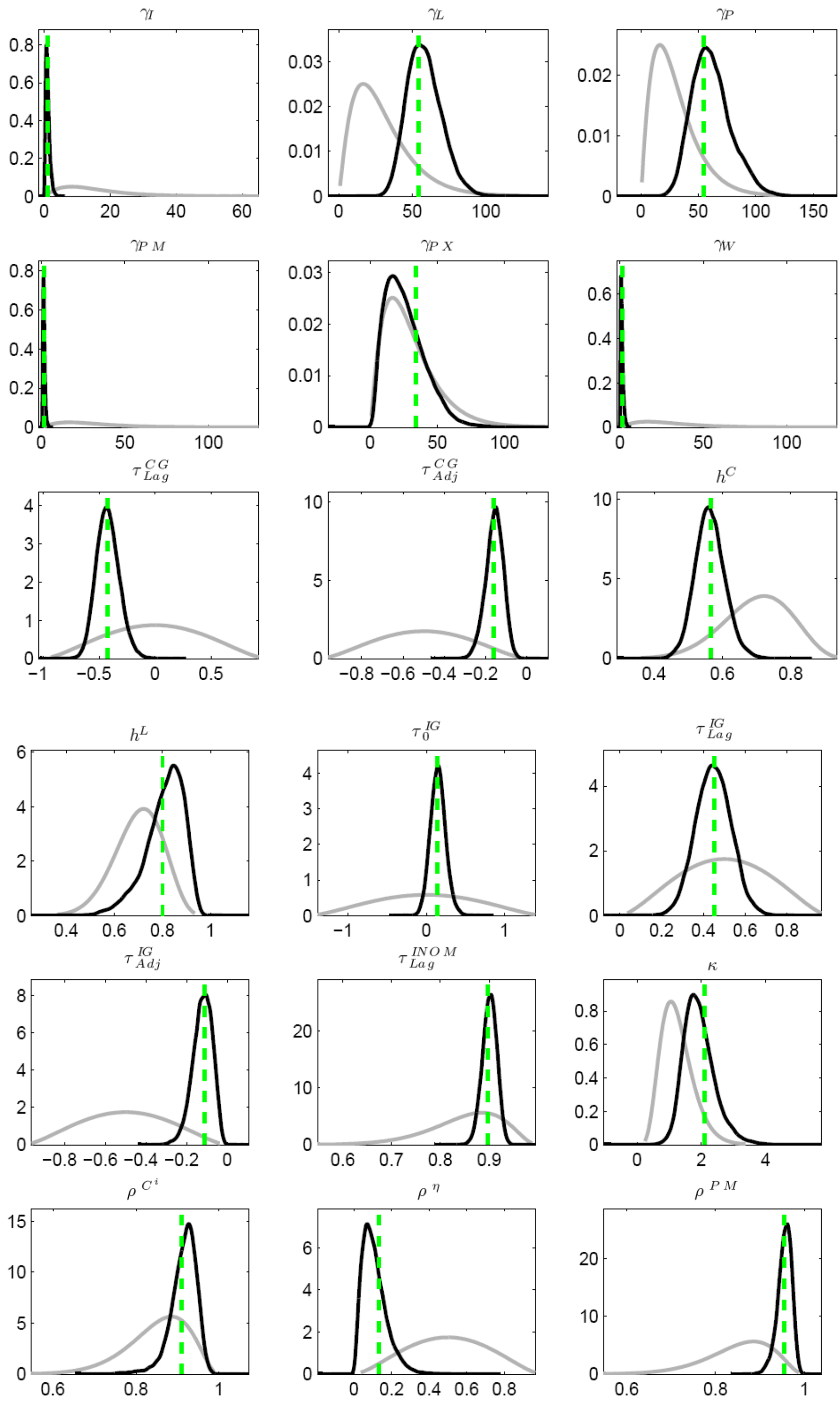
ANNEX 4

TABLE A1: Estimation Results for exogenous shocks

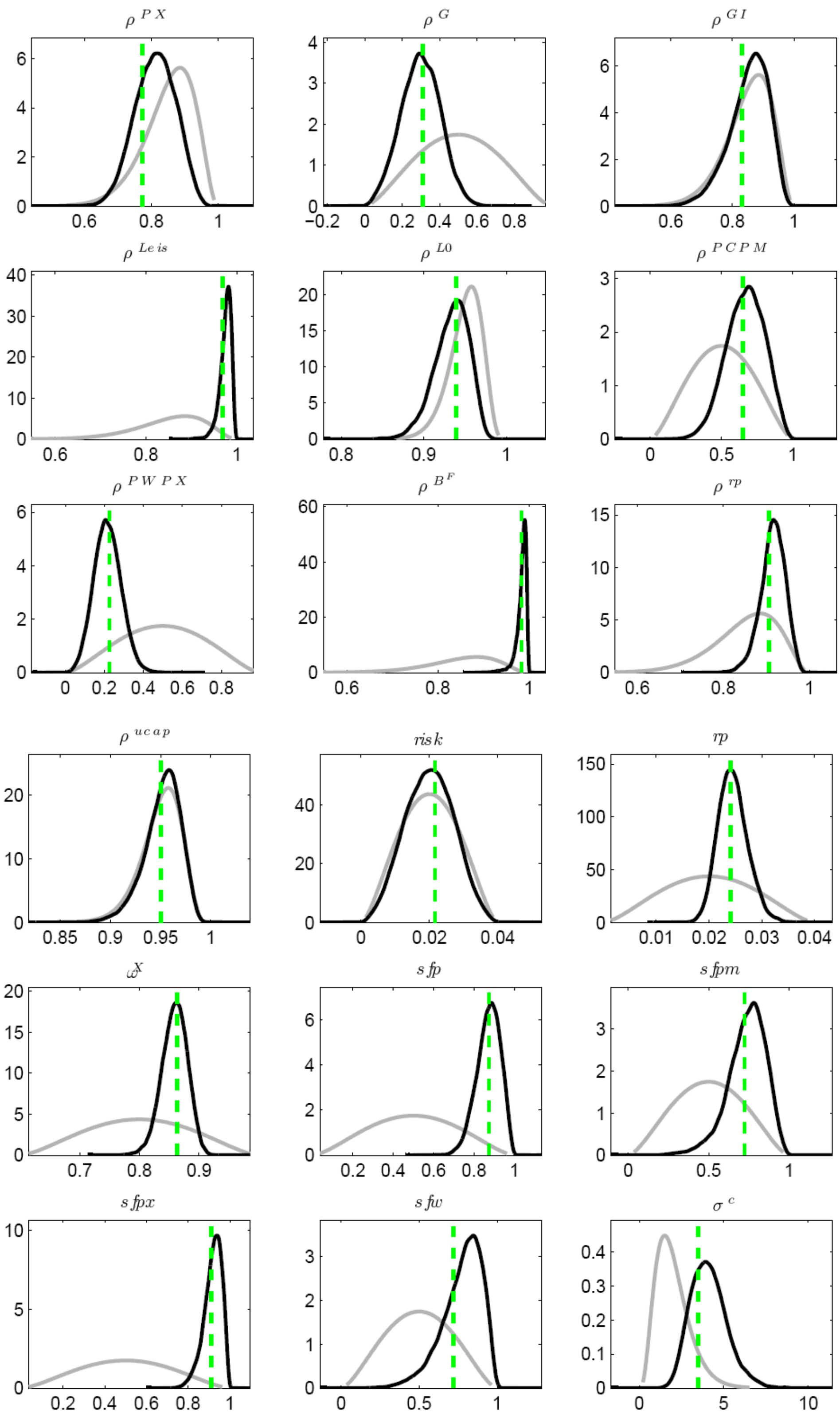
Parameter name	Prior			posterior	
	distrib	mean	std	mean	std
σ^{C^k}	gamma	0.05	0.03	0.0597	0.0107
σ^{τ}	gamma	0.1	0.06	0.15	0.0246
σ^{PM}	gamma	0.02	0.015	0.0202	0.0038
σ^{PX}	gamma	0.1	0.06	0.0648	0.0355
σ^{EX}	gamma	0.005	0.03	0.0044	4.37E-04
σ^{CG}	gamma	0.05	0.03	0.0048	3.46E-04
σ^{IG}	gamma	0.05	0.03	0.0056	4.17E-04
σ^{Leis}	gamma	0.05	0.03	0.0283	0.0078
σ^{LOL}	gamma	0.005	0.003	0.0048	0.001
σ^{INOM}	gamma	0.003	0.0015	0.0013	9.88E-05
σ^{B^F}	gamma	0.005	0.003	0.0017	2.40E-04
σ^{rp}	gamma	0.005	0.003	0.007	0.0017
σ^{TR}	gamma	0.05	0.03	0.0022	1.57E-04
σ^{W}	gamma	0.05	0.03	0.0437	0.0156
σ^{UP}	gamma	0.05	0.03	0.0121	0.0013
ρ^{C}	beta	0.85	0.075	0.9144	0.0295
ρ^{η}	beta	0.5	0.2	0.1095	0.0771
$\rho^{\eta M}$	beta	0.85	0.075	0.9557	0.0164
$\rho^{\eta X}$	beta	0.85	0.075	0.8109	0.0668
ρ^{CG}	beta	0.5	0.2	0.2983	0.1
ρ^{IG}	beta	0.85	0.075	0.853	0.0797
ρ^{Leis}	beta	0.85	0.075	0.975	0.0159
ρ^{Lss}	beta	0.95	0.02	0.9334	0.0188
ρ^{UI}	beta	0.5	0.2	0.6652	0.1409
ρ^{PWPX}	beta	0.5	0.2	0.2159	0.0686
ρ^{B^F}	beta	0.85	0.075	0.9842	0.0103
ρ^{rp}	beta	0.85	0.075	0.9148	0.0233
ρ^{ucap}	beta	0.95	0.02	0.9517	0.0187
ρ^{TR}	beta	0.85	0.075	0.8636	0.0428

Figure A3. Prior distributions (grey lines), posterior distributions (black lines) and posterior mode (dotted lines) of the estimated parameters.





γ_I
γ_L
γ_P
γ_{PM}
γ_{PX}
γ_W
τ^{CG}_{Lag}
τ^{CG}_{Adj}
h^C
h^L
τ^{IG}_0
τ^{IG}_{Lag}
τ^{IG}_{Adj}
τ^{INOM}_{Lag}
κ
ρ^{C^i}
ρ^{η}
ρ^{PM}


ρ PX
ρ G
ρ GI
ρ Leis
ρ L0
ρ PCPM
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ρ BF
ρ rp
ρ ucap
risk
rp
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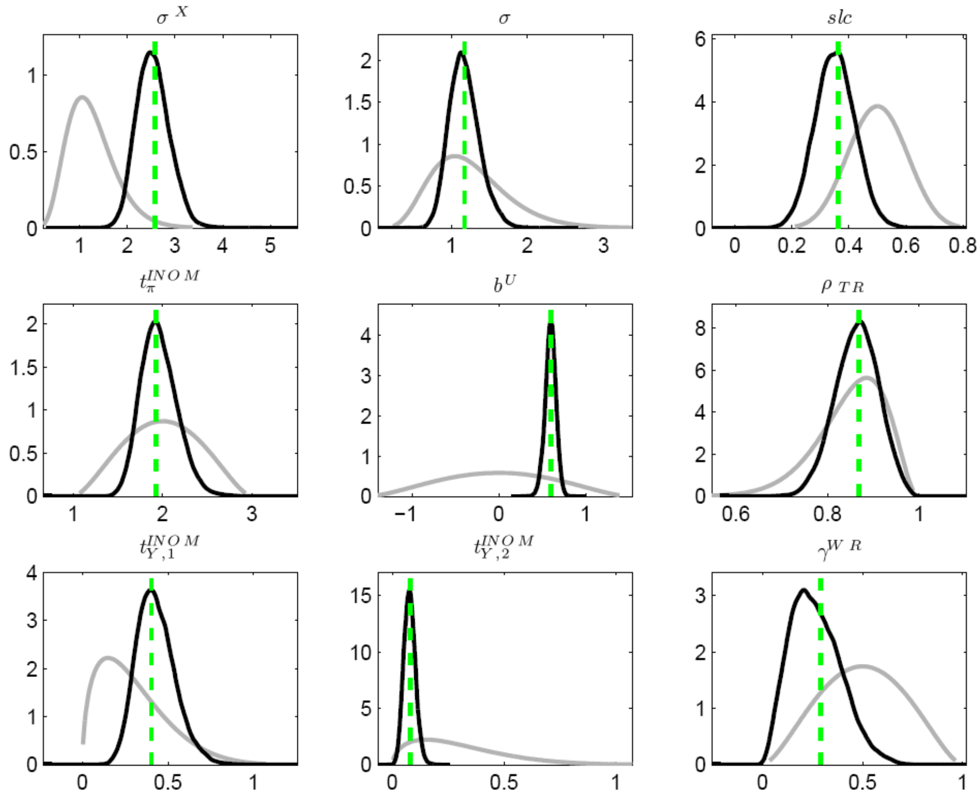
σ c


σ X
σ
slc
t_π^INOM
b^U
ρ TR
t_Y,1^INOM
t_Y,2^INOM
γ^WR