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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 a stochastic trend in TFP, but instead of filtering data prior to estimation, we estimate the model in growth rates and stationary nominal ratios.

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## 1. 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 (2005) 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

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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 the following section we describe the model and characterise the shocks hitting the euro area economy. Section 3 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 4 we analyse the impulse response functions of the main macroeconomic variables to structural shocks.

## 2. 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 $\rho^k$ and innovation $\varepsilon_t^k$.

### 2.1. Firms

#### 2.1.1. 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 between domestic and foreign goods, with elasticity of substitution $\sigma^{\mathrm{d}}$ and $\sigma^{\mathrm{M}}$ respectively. The demand function for firm $j$ is given by

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

where $C_t$ is total consumption of private households, $C_t^{\mathrm{G}}$ and $I_t^{\mathrm{G}}$ denote government consumption and investment, $I_t^{\mathrm{inp}}$ 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 consumption 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 $L_t^j-\mathrm{LO}_t^j$

$$Y_t^j = \left(\mathrm{ucap}_t^jK_t^j\right)^{1-\alpha}\left(L_t^j-LO_t^j\right)^{\alpha}U_t^{Y^\alpha}K_t^{\mathrm{G}^{(1-\alpha_{\mathrm{G}})}}, \quad \text{with} \quad L_t^j = \left[\int_0^1 L_t^{i,j\frac{\theta-1}{\theta}}\mathrm{d}i\right]^{\frac{\theta}{\theta-1}}. \quad (2)$$

The term $\mathrm{LO}_t^j$ 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 ($\mathrm{ucap}_t^j$). There is an economy wide technology shock $U_t^Y$ which follows a random walk with drift

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

The share of overhead labour in total employment ($\mathrm{lol}_t^j$) follows an AR(1) process around its long run value

$$\mathrm{lol}_t^j = (1-\rho^{LOL})\mathrm{lol} + \rho^{\mathrm{LOL}}\mathrm{lol}_{t-1}^j + \varepsilon_t^{\mathrm{LOL}}. \quad (4)$$

The objective of the firm is to maximise the present discounted value of profits $\mathrm{Pr}_t^j$

$$\mathrm{Pr}_t^j = \frac{P_t^j}{P_t}Y_t^j - \frac{W_t}{P_t}L_t^j - i_t^K\frac{P_t^I}{P_t}K_t^j - \frac{1}{P_t}\left(adj^P\left(P_t^j\right) + adj^L\left(L_t^j\right) + adj^{UCAP}\left(ucap_t^j\right)\right), \quad (5)$$

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

$$\mathrm{adj}^L\left(L_t^j\right) = W_t\left(L_t^ju_t^L + \frac{\gamma_L}{2}\Delta L_t^{j^2}\right) \quad (6a)$$

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

$$\mathrm{adj}^{\mathrm{UCAP}}\left(\mathrm{ucap}_t^j\right) = PI_tK_t\left(\gamma_{\mathrm{ucap},1}\left(\mathrm{ucap}_t^j-1\right) + \frac{\gamma_{\mathrm{ucap},2}}{2}\left(\mathrm{ucap}_t^j-1\right)^2\right). \quad (6c)$$

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:

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

$$\frac{\partial \mathrm{Pr}_t^j}{\partial K_t^j} \Rightarrow \left((1-\alpha)\frac{Y_t^j}{K_t^j}\eta_t^j\right) = i_t^K\frac{P_t^{I,j}}{P_t^j} \quad (7b)$$

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

$$\frac{\partial \mathrm{Pr}_t^j}{\partial \mathrm{ucap}_t^j} \Rightarrow \left( (1-\alpha)\frac{Y_t^j}{K_t^j \mathrm{ucap}_t^j}\eta_t^j \right) = \frac{P_t^{I,j}}{P_t^j}\left(\gamma_{\mathrm{ucap},1} + \gamma_{\mathrm{ucap},2}\left(\mathrm{ucap}_t^j - 1\right)\right) \tag{7c}$$

$$\frac{\partial \mathrm{Pr}_t^j}{\partial Y_t^j} \Rightarrow \eta_t^j = 1 - 1/\sigma^{\mathrm{d}} - \gamma_P\left[\frac{1}{(1+r_t)}E_t\pi_{t+1}^j - \pi_t^j\right] \quad \text{with} \quad \pi_t^j = P_t^j/P_{t-1}^j - 1, \tag{7d}$$

where $\eta_t$ 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 Eq. (7a), the convex part of the adjustment cost function penalises in cost terms accelerations and decelerations of changes in employment. Eqs. (7b) and (7c) 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. Eq. (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

$$\eta_t = 1 - 1/\sigma^{\mathrm{d}} - \gamma_P\lfloor\beta(sfpE_t\pi_{t+1} + (1-sfp)\pi_{t-1}) - \pi_t\rfloor - u_t^P \quad 0 \le sfp \le 1. \tag{7'd}$$

### 2.1.2. 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 $I_t^{\mathrm{inp}}$, then real output of the investment goods sector is produced by the following linear production function,

$$I_t = I_t^{\mathrm{inp}} U_t^I \tag{8}$$

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

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

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

$$P_t^I = P_t^C / U_t^I. \tag{10}$$

## 2.2. Households

The household sector consists of a continuum of households $h \in [0,1]$. A share (1−slc) of these households is not liquidity constrained and indexed by $i \in [0,1-\mathrm{slc}]$. 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 $k \in [1-\mathrm{slc},1]$. 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.

### 2.2.1. Non 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 $T^{\mathrm{LS}}$. 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 $\mathrm{rp}_t^K$ on real assets arises because of uncertainty about the return of real assets. The Lagrangian of this maximisation problem is given by

$$\begin{aligned} \text{Max} \quad V_0^I = {} & E_0\sum_{t=0}^{\infty}\beta^t U\left(C_t^i, 1-L_t^i\right) \\ & -E_0\sum_{t=0}^{\infty}\lambda_t\beta^t \left( \begin{aligned} & \frac{(1+t_t^c)P_t^C}{P_t}C_t^i + \frac{P_t^I}{P_t}I_t^i + \frac{M_t^i}{P_t} + \frac{B_t^i}{P_t} + \frac{E_tB_t^{F,i}}{P_t} - \frac{M_{t-1}^i}{P_t} - \frac{(1+(1-t_t^i)i_{t-1})B_{t-1}^i}{P_t} \\ & -\frac{(1+(1-t_t^i)i_{t-1}^F)\left(1-risk\left(\frac{E_tB_{t-1}^F}{P_{t-1}Y_{t-1}}\right)-u_t^{B^F}\right)E_tB_{t-1}^{F,i}}{P_t} - \frac{(1-t_t^K)(i_{t-1}^K - rp_t^K)P_{t-1}^I K_{t-1}^i}{P_t} \\ & + \frac{t_t^K\delta P_{t-1}^I K_{t-1}}{P_t} - \frac{(1-t_t^w)W_t^i}{P_t}L_t^i + \frac{\gamma_w L_t^i}{2P_t}\frac{\Delta W_t^{i2}}{W_{t-1}^i} - \sum_{j=1}^n \mathrm{Pr}_t^{i,j} + T_t^{LS,i} \end{aligned} \right) \\ & -E_0\sum_{t=0}^{\infty}\xi_t\beta^t\left(K_t^i - J_t^i - (1-\delta)K_{t-1}^i\right) \end{aligned} \tag{11}$$

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

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

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

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

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]:

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

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

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

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

[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.

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

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 $Q_t$

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

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

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

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

### 2.2.2. Liquidity-constrained households

Liquidity-constrained households do not optimise 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

$$(1+t_t^c)P_t^c C_t^k = (1-t_t^w)W_t L_t + \mathrm{TR}_t^k - T_t^{LS,k} \quad (16)$$

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

### 2.2.3. 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

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

where $\eta_t^W$ 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 $\pi_t^W$ to inflation in the previous period.

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

with $0 \le \mathrm{sfw} \le 1$. Combining Eqs. (17) and (18) one can show that the (semi) elasticity of wage inflation with respect to the employment rate is given by $(\kappa/\gamma_W)$, i.e. it is positively related to the inverse of the labour supply elasticity and inversely related to wage adjustment costs.

### 2.2.4. Aggregation

The aggregate of any household specific variable $X_t^h$ in per-capita terms is given by $X_t = \int_0^1 X_t^h dh = (1-\mathrm{slc})X_t^i + slcX_t^k$ since households within each group are identical. Hence aggregate consumption is given by

$$C_t = (1-slc)C_t^i + \mathrm{slc}C_t^k \quad (19a)$$

and aggregate employment is given by

$$L_t = (1-slc)L_t^i + \mathrm{slc}L_t^k \quad \text{with} \quad L_t^i = L_t^k = L_t. \quad (19b)$$

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

## 2.3. 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

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

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.

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

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

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

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

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

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

$$\eta_t^X P_t^X = P_t \tag{23}$$

and import prices are given by

$$\eta_t^M P_t^M = E_t P_t^F. \tag{24}$$

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 are also subject to random shocks

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

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

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

### 2.4. 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., 2002). 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

$$\text{YGAP}_t = \left(\frac{\text{ucap}_t}{\text{ucap}_t^{ss}}\right)^{(1-\alpha)} \left(\frac{L_t}{L_t^{ss}}\right)^{\alpha}, \tag{27}$$

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

$$\text{ucap}_t^{ss} = (1 - \rho^{ucap})\text{ucap}_{t-1}^{ss} + \rho^{\text{ucap}}\text{ucap}_t^j \tag{28}$$

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

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

#### 2.4.1. 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

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

$$\Delta i_t^G = \left(1 - \tau_{\text{Lag}}^{\text{IG}}\right)\overline{\Delta i^G} + \tau_{\text{Lag}}^{\text{IG}} \Delta i_{t-1}^G + \tau_{\text{Adj}}^{\text{IG}}\left(\text{igy}_{t-1} - \overline{\text{igy}}\right) + \sum_i \tau_i^{\text{IG}} \text{ygap}_{t-i} + u_t^{\text{IG}} \tag{31}$$

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 $\text{POP}^{\text{NPART}}$ is treated as a government decision variable. We assume that unemployment benefits and pensions are indexed to wages with replacement rates $b^{\text{U}}$ and $b^{\text{R}}$ respectively and we formulate the following linear transfer rule

$$\text{TR}_t = b^{\text{U}} W_t\left(\text{POP}_t^W - POP_t^{\text{NPART}} - L_t\right) + b^{\text{R}} W_t \text{POP}_t^P + u_t^{\text{TR}}. \tag{32}$$

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

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

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

$$t_t^w = \tau_0^w Y_t^{\tau_1^w} U_t^{\text{TW}} \tag{34a}$$

where $\tau_0^w$ measures the average tax rate, and $\tau_1^w$ the degree of progressivity. A simple first-order Taylor expansion around a zero output gap yields

$$t_t^w = \tau_0^w + \tau_0^w \tau_1^w \text{ygap}_t \tag{34b}$$

Government debt ($B_t$) evolves according to

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

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

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

where $b^T$ is the government debt target.

#### 2.4.2. 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

$$\begin{aligned} i_t = {} & \tau_{\text{lag}}^{\text{INOM}} i_{t-1} \\ & + \left(1 - \tau_{\text{lag}}^{\text{INOM}}\right)\left[r^{\text{EQ}} + \pi^{\text{T}} + \tau_\pi^{\text{INOM}}(\pi_t^{\text{C}} - \pi^{\text{T}}) + \tau_{y,1}^{\text{INOM}} \text{ygap}_{t-1}\right] \\ & + \tau_{y,2}^{\text{INOM}}(\text{ygap}_t - ygap_{t-1}) + u_t^{\text{INOM}}. \end{aligned} \tag{37}$$

The central bank has a constant inflation target $\pi^{\text{T}}$ 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.

## 3. Estimation

Our technological assumptions imply that domestic and foreign GDP and its components are stationary in growth rates. Our model also implies stationarity of 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). Concerning nominal variables we assume that the domestic and foreign inflation target is a constant. This implies that domestic wage inflation rate ($\pi^w$), domestic and foreign price inflation ($\pi$,$\pi^F$) 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 [$i^F$, $\pi^F$, $\Delta y^F$] 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 $\Delta y^F$ 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. All real quantities are divided by the (linear) trend of active population, to obtain per-capita data. Relative linear trends in price indexes and real quantities have been removed, except for the trend in the wage share. The trend in the series of employment is also removed. Finally, 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.

Parameters like the discount rate and the depreciation rate are not estimated but kept constant over the estimation period. The same applies for steady state shares of government spending in GDP and the tax rates. A complete table of calibrated parameters and a discussion of the steady state relationships is reported in Appendix 1.

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:

$$\Delta g_t = \frac{b_{1,0}L^{\delta} + b_{1,1}L^{1+\delta} + \ldots + b_{1,n}L^{n+\delta}}{1-a_1L-\ldots-a_mL^m}u_{1,t} + \ldots + \frac{b_{k,0}L^{\delta} + b_{k,1}L^{1+\delta} + \ldots + b_{k,n}L^{n+\delta}}{1-a_1L-\ldots-a_mL^m}u_{k,t} + e_t \tag{38}$$

where $\Delta g_t$ is the growth rate of 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

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

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

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).

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 the lack of identification for some parameters[4]. In Table 1 we show prior distributions and posterior estimations of our structural parameters (for a discussion of our priors and details of the estimation of the shocks, see Appendix 2).

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% 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.

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 categories 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 (2008), 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 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.

[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.

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

[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 the output gap of 0.8.

**Table 1**
Estimation results for structural parameters

| Parameter name | Prior | | | Posterior | |
|---|---|---|---|---|---|
| | Distrib | Mean | st.dev. | Mean | st.dev. |
| $\sigma^C$ | 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 |
| $\kappa$ | 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 |
| $\gamma_{\mathrm{ucap},2}$ | Beta | 0.05 | 0.024 | 0.0453 | 0.0128 |
| $\omega^X$ | Beta | 0.8 | 0.08 | 0.8588 | 0.0196 |
| $\sigma^X$ | Gamma | 1.25 | 0.5 | 2.5358 | 0.32 |
| $\sigma^M$ | Gamma | 1.25 | 0.5 | 1.1724 | 0.2136 |
| $\tau_{\mathrm{Lag}}^{\mathrm{INOM}}$ | Beta | 0.85 | 0.075 | 0.9009 | 0.0155 |
| $\tau_{\pi}^{\mathrm{IINOM}}$ | Beta | 2 | 0.4 | 1.959 | 0.2066 |
| $\tau_{Y,1}^{\mathrm{INOM}}$ | Beta | 0.3 | 0.2 | 0.4274 | 0.1141 |
| $\tau_{Y,2}^{\mathrm{INOM}}$ | Beta | 0.3 | 0.2 | 0.0783 | 0.0277 |
| $\tau_{\mathrm{Lag}}^{\mathrm{CG}}$ | Beta | 0 | 0.4 | −0.4227 | 0.1041 |
| $\tau_{\mathrm{Adj}}^{\mathrm{CG}}$ | Beta | −0.5 | 0.2 | −0.1567 | 0.0442 |
| $\tau_0^{\mathrm{CG}}$ | Beta | 0 | 0.6 | −0.0754 | 0.1066 |
| $\tau_{\mathrm{Lag}}^{\mathrm{IG}}$ | Beta | 0.5 | 0.2 | 0.4475 | 0.0895 |
| $\tau_{\mathrm{Adj}}^{\mathrm{IG}}$ | Beta | −0.5 | 0.2 | −0.1222 | 0.0461 |
| $T_0^{\mathrm{IG}}$ | Beta | 0 | 0.6 | 0.1497 | 0.0996 |
| $b^U$ | Beta | 0 | 0.6 | 0.597 | 0.0627 |
| $\gamma_K$ | Gamma | 30 | 20 | 76.0366 | 20.5526 |
| $\gamma_I$ | Gamma | 15 | 10 | 1.1216 | 0.5185 |
| $\gamma_L$ | Gamma | 30 | 20 | 58.2083 | 12.2636 |
| $\gamma_P$ | Gamma | 30 | 20 | 61.4415 | 10.4208 |
| $\gamma_{\mathrm{PM}}$ | Gamma | 30 | 20 | 1.6782 | 0.9092 |
| $\gamma_{\mathrm{PX}}$ | Gamma | 30 | 20 | 26.1294 | 16.8398 |
| $\gamma_W$ | Gamma | 30 | 20 | 1.2919 | 0.8261 |
| $\gamma_{WR}$ | 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 |

Details of the model fit are shown in Appendix 3. Table 2 summarises 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 and Wouters (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 (see Appendix 3). 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.

## 4. 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.

Figs. 1–3 show the response for the estimated model to a government consumption, investment and transfers shock respectively. The government consumption and investment shocks raise

**Table 2**
Posterior variance decomposition — 90% highest probability interval

| | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1. Conditional 1-step ahead* | | | | | | | | | | | | |
| $g_t^Y$ | 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 |
| $\pi_t$ | 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 |
| $g_t^E$ | 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 |
| *2. Conditional 4-step ahead* | | | | | | | | | | | | |
| $g_t^Y$ | 0.57 | 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 |
| $\pi_t$ | 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 |
| $g_t^E$ | 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 |
| *3. Unconditional variance* | | | | | | | | | | | | |
| $g_t^Y$ | 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 |
| $\pi_t$ | 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 |
| $g_t^E$ | 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 |

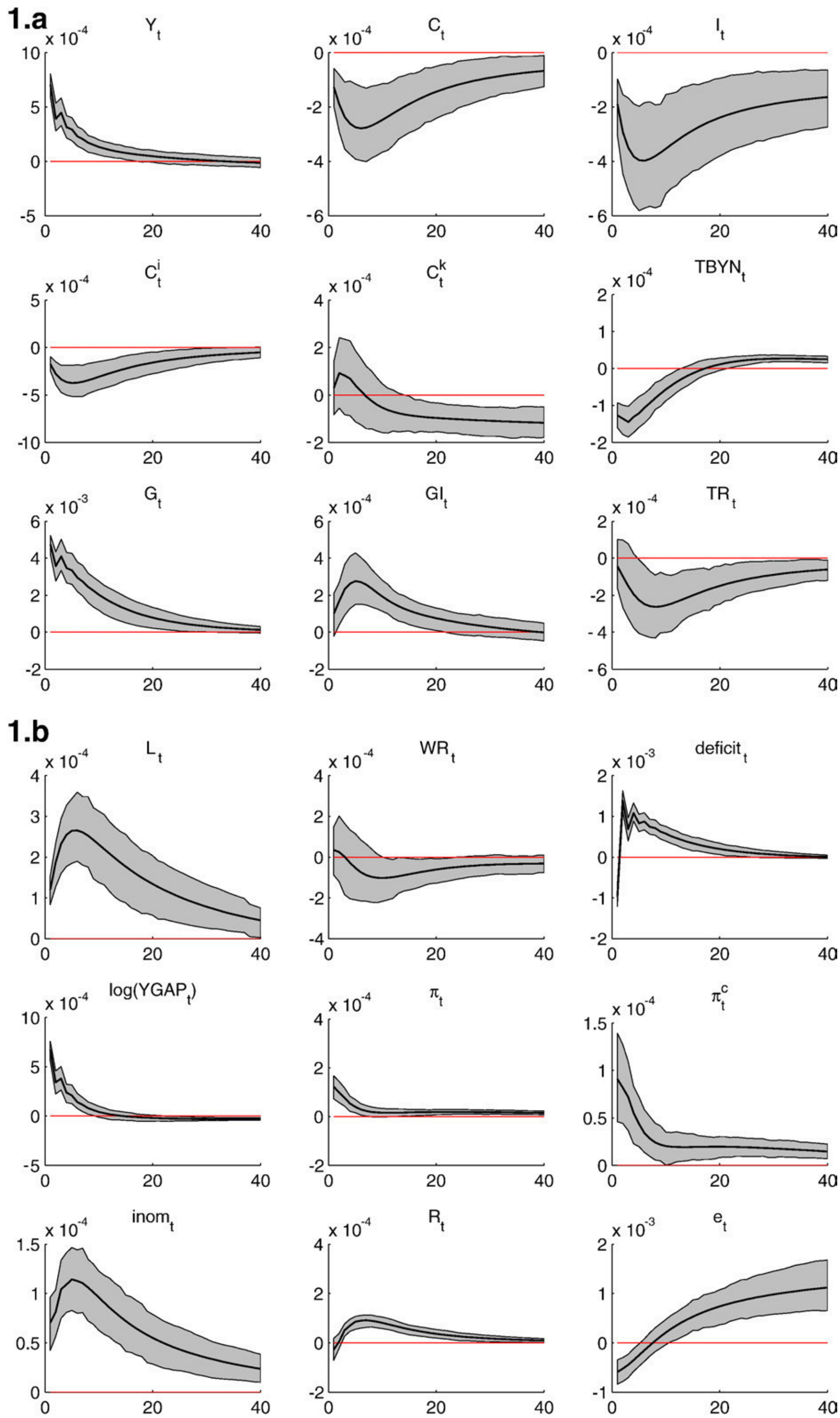


**Fig. 1.** Response to a government consumption shock.

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, that 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.

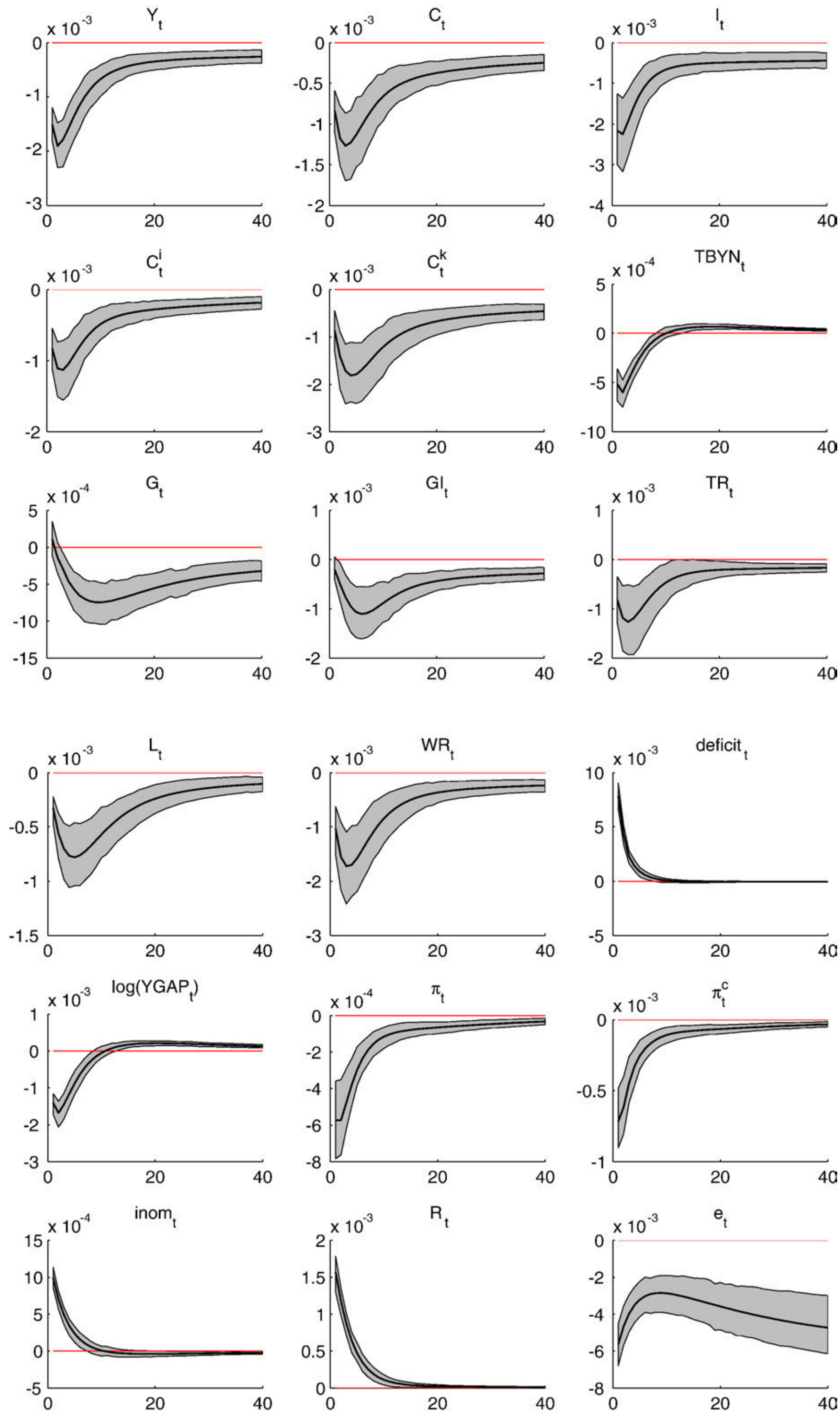


**Fig. 2.** Response to a monetary shock.

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 $\gamma_L$ is significantly different from zero. A sensitivity analysis (see Appendix 4) shows that when these parameters tend to zero (as assumed in Gali et al., 2007), the consumption response to a government spending shock 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

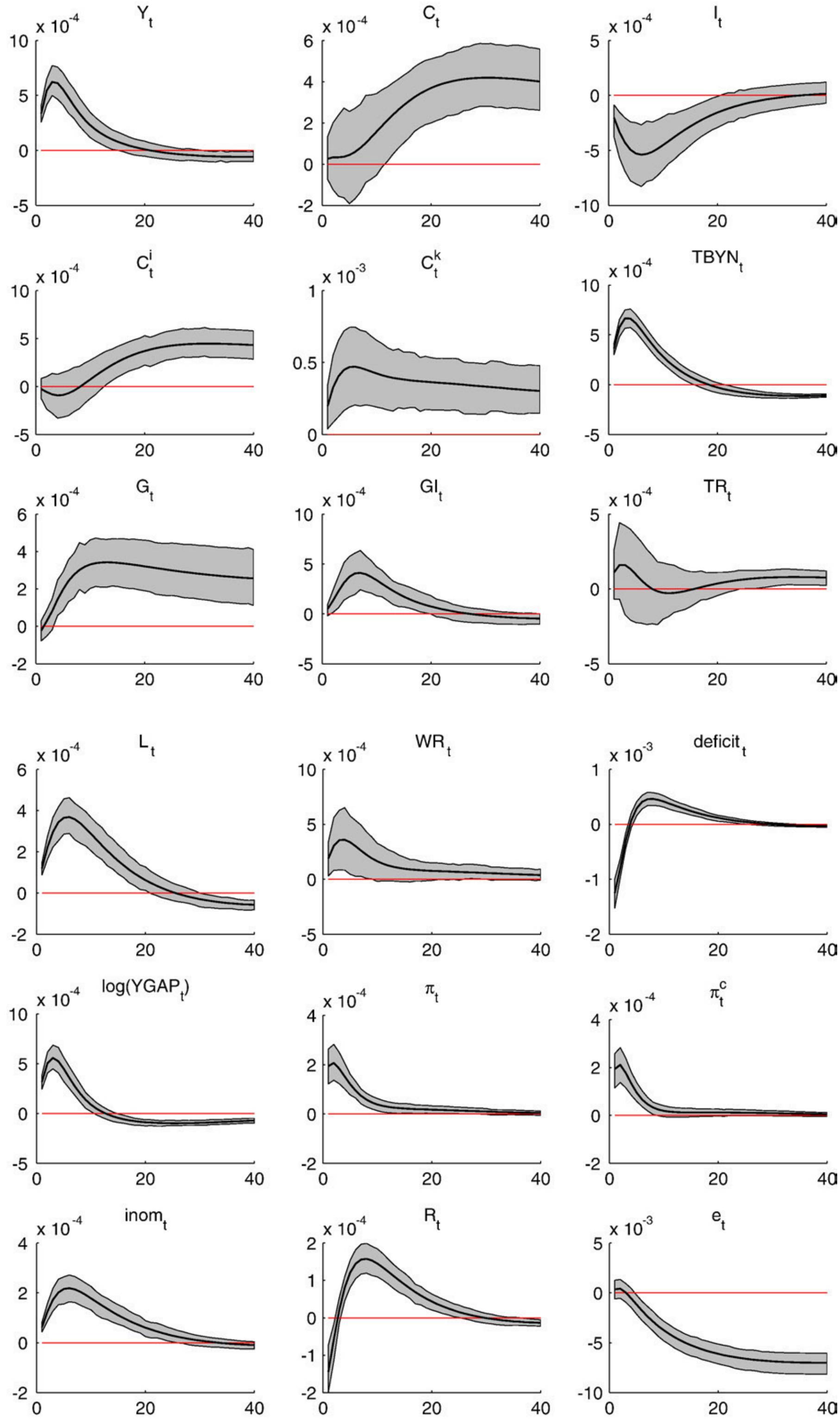


**Fig. 3.** Response to a shock to world demand.

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% 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

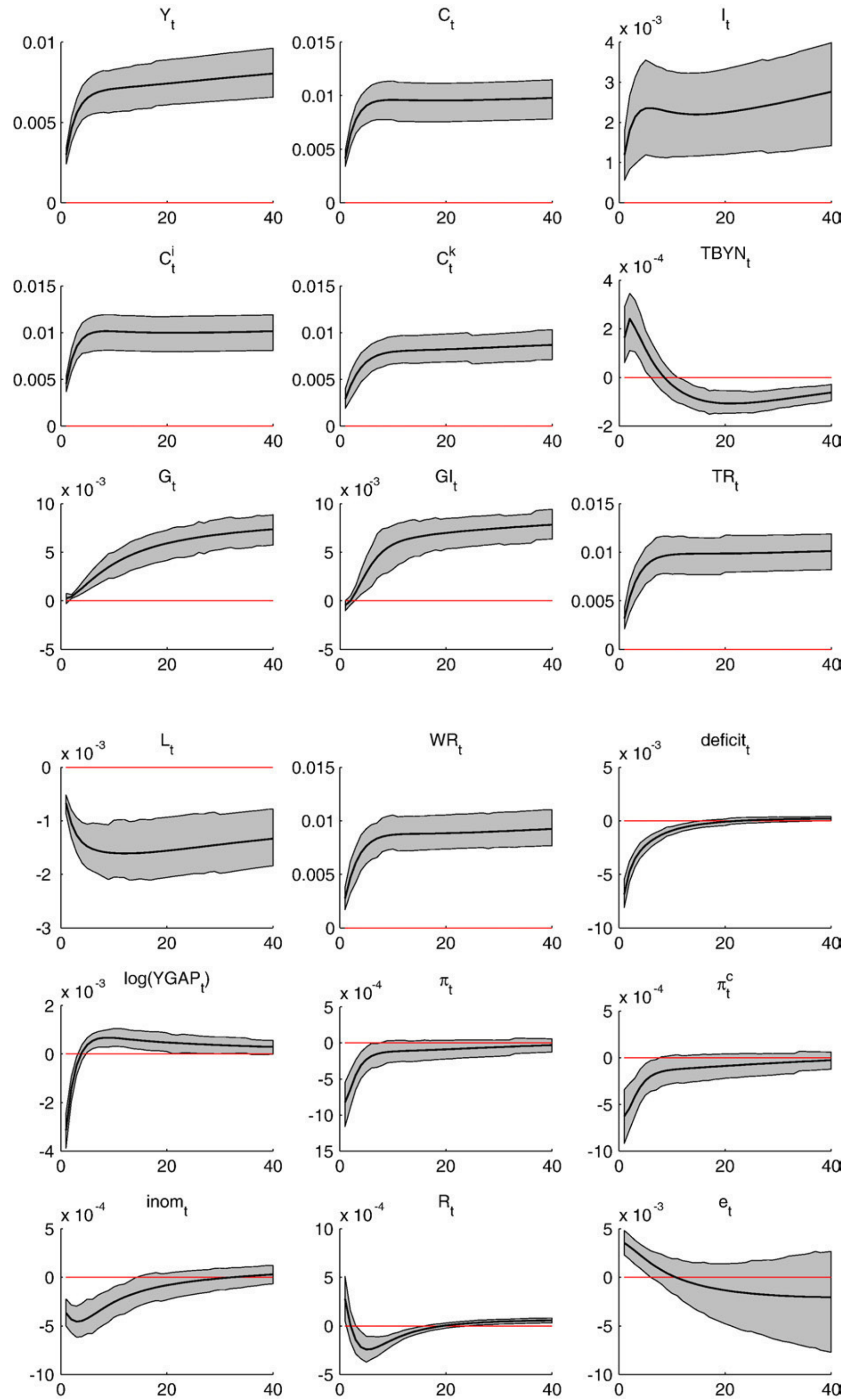


**Fig. 4.** Response to a shock to TFP.

then turns negative. Cumulated over the first year the multiplier is 0.56. This is somewhat smaller than the 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

[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.

positive and did the GDP multiplier exceed 1 in the post post-1980 period.

The effect of government investment on GDP is more favourable, because government investment has a positive supply effect, while a transfer shock has a large impact on (liquidity constrained) consumption (both are reported in Appendix 5).

Fig. 2 presents the level comparison of the estimated effect of an orthogonalised shock to nominal interest rates ($\varepsilon_t^{\mathrm{INOM}}$). 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 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.

Our last example of a demand shock is a shock to foreign demand. Fig. 3 presents the level comparison of the estimated effect of an orthogonalised shock to world output ($\varepsilon_t^{\mathrm{YF}}$). 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 gaps 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 $C^k$.

Fig. 4 presents the level comparison of the estimated effect of an orthogonalised shock to TFP ($\varepsilon_t^{Y}$). 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.

## 5. Conclusions

In this paper we have described the estimation of an open 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. The model can also match the declining wage share through the share of overhead labour in total employment and rising mark ups (see Appendix 6).

In future research we intend 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.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.econmod.2008.06.014.

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[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.