AN OPEN ECONOMY MODEL OF THE EURO AREA AND THE US*

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1. INTRODUCTION

In this article we present the medium sized open-economy Dynamic Stochastic General Equilibrium (DSGE) model of the euro area and the US developed by Alves, Gomes and Sousa (2007). We take stock of recent developments of the so-called New Open Economy Macroeconomics. Therefore the model presented here shares a number of common features with models developed at other policy institutions (like the Global Economy Model (GEM) at the International Monetary Fund) as well as other central banks (for instance, with the New Area Wide Model at the European Central Bank).

The main purpose of the model is to provide a theoretically consistent representation of the behaviour of the euro area economy. Such model can then be used to study how various shocks are transmitted to the key euro area macroeconomic variables. Currently the model is calibrated drawing on the results of similar studies. At a later stage, an estimated version of the model will allow the identification of structural shocks which can be an important input for monetary policy analysis. A major advantage of the model presented here relative to traditional models is that it is derived from strong theoretical micro foundations. As such, it is likely to be less prone to stability problems such as those pointed out in Lucas's famous critique (see Lucas, 1976). These type of models have been gaining increasing popularity, both in the academia and in policy making institutions, as they are much more in line with current academic thinking than traditional macroeconometric models while at the same time displaying desireable empirical properties. A disadvantage of these models is that they cannot be of such a large scale as that of traditional macro models given problems of tractability. The model presented here reflects such simplification.

A distinguishing feature of the model presented in this article is the open economy dimension which, as can be inferred from the results, seems to be important even in the context of a large economy such as that of the euro area. This is confirmed by the results of other studies, such as that of Adolfson *et al.* (2005) who compare the empirical properties of a closed and an open economy model of the euro area and find differences in the transmission mechanism of monetary policy between the two types of models. They also find that open economy shocks are of high relevance in explaining the fluctuations in output and inflation in the short to medium term. In the case of our model we find that the inclusion of open economy features, in particular of the exchange rate, can lead to significant changes in the way the macro variables react to shocks. This is particularly striking in the case of the response of inflation to a monetary policy shock which tends to be much stronger in an open economy setting than in closed economy models.

* The opinions are solely those of the authors and do not necessarily represent those of the Banco de Portugal. The authors thank the comments of Isabel Horta Correia, José Ferreira Machado and Nuno Alves.

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Even though the open economy setup seems more appropriate to deal with the euro area, any model is not without caveats. In respect to the model presented in this paper, one potentially important feature that we have left out at a first stage is the existence of tradable and non-tradables goods or of a distribution sector (as in Corsetti and Dedola, 2005 or Corsetti, Dedola and Leduc, 2006). This is important in particular to model the exchange rate passthrough to domestic prices, namely to reduce the tendency in these models for changes in exchange rates or foreign prices to be transmitted more quickly to domestic prices than is usually found in the data. However, we have excluded this given that we have in mind estimating the model and data for this sectoral breakdown is particularly difficult to find. Nevertheless, we have resorted to an alternative mechanism, namely the introduction of import adjustment costs, in order to slow down the passthrough.

The article is organised as follows. In the next section we present the model. In section 3 we discuss the calibration. In section 4 we analyse the impulse response functions to several shocks. Section 5 concludes.

2. THE MODEL

The model consists of two countries, the euro area and the US. The two countries may have a different size but they share the same structure. Therefore, in the presentation of the model we focus mainly on the euro area. The model features a number of frictions that have become quite standard in the related literature (*e.g.* as in the closed economy models by Christiano, Eichenbaum and Evans, 2005, or Smets and Wouters, 2003). The general structure of the model is summarised in Chart 1.

The model has four types of agents besides the monetary authority: firms, households, the government and a financial intermediary. Regarding firms, in each country there are firms producing intermediate goods sold both in the domestic and the foreign market. In the model only the intermediate goods are traded internationally. Markets are segmented and firms are local currency pricers, *i.e.* the price of their goods is set in the currency of the export market (for instance, the price of euro area exports is set in USD and not in euros). We assume that firms set their prices *à la* Calvo (Calvo, 1983).[1] In the case of the euro area, after log-linearising the corresponding first order condition, the following Philips curve relation for the goods sold domestically is obtained:

$$\hat{\pi}_{EA,t}^{EA} = \frac{\gamma_D}{1+\beta\gamma_D}\hat{\pi}_{EA,t-1}^{EA} + \frac{\beta}{1+\beta\gamma_D}\mathrm{E}_t\hat{\pi}_{EA,t+1}^{EA} + \frac{1-\gamma_D}{1+\beta\gamma_D}\hat{\bar{\pi}}_{EA,t} - \frac{\beta(1-\gamma_D)}{1+\beta\gamma_D}\mathrm{E}_t\hat{\bar{\pi}}_{EA,t+1} + \\ + \frac{(1-\beta\xi_D)(1-\xi_D)}{(1+\beta\gamma_D)\xi_D}\widehat{RMC}_{EA,t}^{EA}$$

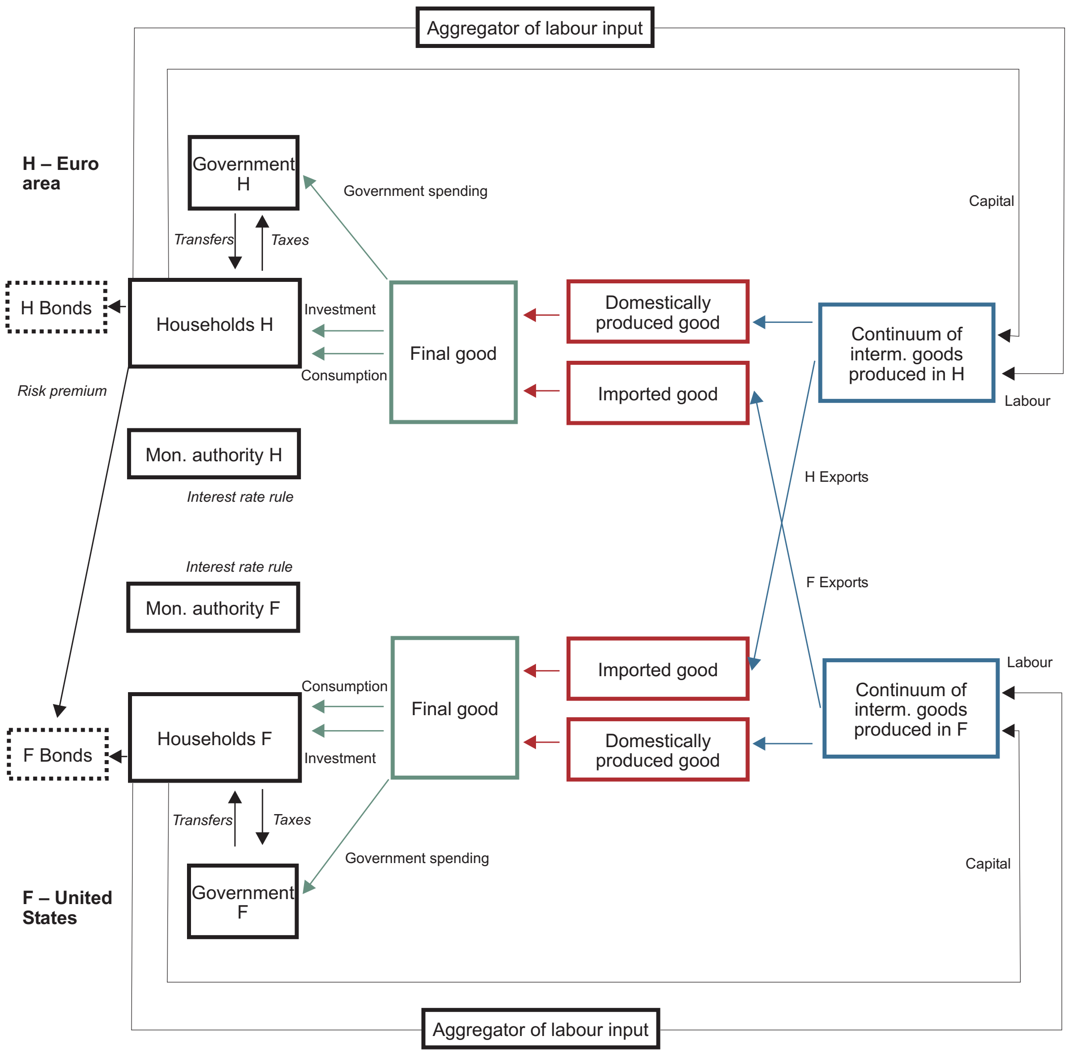
where hatted variables denote variables in log-deviations from the steady state.[2] $\hat{\pi}_{EA,t}^{EA}$ is the rate of change of domestically produced prices which is a function of past and expected future domestic inflation and of past and expected values of the inflation objective $\left(\hat{\bar{\pi}}_{EA,t}\right)$ plus an additional term that constitutes a markup over real marginal cost $\left(\widehat{RMC}_{EA,t}^{EA}\right)$. β, γ_D, and ξ_D are parameters. A similar expression is obtained for exports.

(1) Under Calvo pricing only a random fraction of the firms can change their prices optimally in each period. The other firms have either to keep their prices fixed or, as assumed in this paper, mechanically update their prices according to a scheme decided beforehand.

(2) The practice of log-linearising DSGE models which implies a first order approximation around the steady state is common in the literature. This aims at overcoming the difficulties in solving the exact model given that it is highly non-linear.

Chart 1

STRUCTURE OF THE MODEL



The production technology for each intermediate good i is Cobb-Douglas, combining capital services $\left(K^{s}_{EA,t}(i)\right)$ with domestic labour $L_{EAT,t}(i)$:

$$Y_{EA,t}(i) = \varepsilon^{N}_{EA,t}\left[K^{s}_{EA,t}(i)\right]^{\alpha}\left[z_{EA,t}L_{EA,t}(i)\right]^{1-\alpha}$$

where $\varepsilon^{N}_{EA,t}$ is a neutral technology shock which is assumed to be stationary but persistent. $z_{EA,t}$ is the level of technological progress. Note that we assume that there can be technological progress, *i.e.* $z_{EA,t}$ is assumed to be stochastic and has a unit root. This implies that all real variables will have a unit root and will have to be stationarised by dividing their level by $z_{EA,t}$.

As for the final good sector, there is a single final good produced in each country that can be used both for consumption (private and public) and for investment. The final good sector is perfectly competitive and merely combines a bundle of domestically produced intermediate goods $\left(Y^{EA}_{EA,t}\text{ for the euro area}\right)$ and a bundle of imported intermediate goods $\left(Y^{EA}_{US}\right)$ into the final good $\left(Y^{F}_{EA,t}\right)$. The technology used to produce the final good is a Constant Elasticity of Substitution (CES) production function:

$$Y_{EA,t}^{F}=\left[(d_F)^{\frac{\lambda_F}{1+\lambda_F}}\left(Y_{EA,t}^{EA}\right)^{\frac{1}{1+\lambda_F}}+(1-d_F)^{\frac{\lambda_F}{1+\lambda_F}}\left(\zeta_t Y_{US,t}^{EA}\right)^{\frac{1}{1+\lambda_F}}\right]^{1+\lambda_F},0<d_F<1$$

where $\frac{1+\lambda_F}{\lambda_F}$ is the elasticity of substitution between domestic goods and imports and d_F is a parameter that governs the home bias in the final goods production (in this case, the higher d_F, the higher the preference for euro area goods). A quadratic adjustment cost (ζ_t) to changing the composition of domestic and foreign components in the final good is introduced with the purpose of slowing down the pass-through of foreign production prices.

In each country, the representative household derives utility from consumption and money (which provides transaction services) and disutility from the amount of hours worked. In what regards consumption we assume internal habit formation.[3] Households decide on how much to consume/spend and also set wages. We follow Erceg, Henderson and Levin (2000) and assume that, in each period, households face a constant probability of not being able to reoptimise their wage. When households are not reoptimising they update wages as a function of past inflation, the inflation target and a compensation for trend productivity growth. The households that are allowed to reoptimise choose the wage which approximately equates the present value of the marginal return to working (measured in consumption units) to the present value of the marginal cost of working (*i.e.* the disutility of working) plus a markup. As a result, the aggregate real wage is a function of expected and past real wages and expected, current and past inflation. Households own and rent capital to the intermediate goods firms. We assume that there are adjustment costs when there are changes in investment. Households can also change the degree of utilisation of the capital stock (*i.e.* the level of capital services that are rented), even though such changes also imply an adjustment cost.

The financial intermediary included in the model have a rather passive role as in Christiano, Eichenbaum and Evans (2005). Intermediate firms borrow the wage bill from the financial intermediary which creates a demand for funds. In turn, the supply of funds stems from the deposits of households in the financial intermediary and the increase of the money supply.

The model includes a simple government sector. The model does not include any fiscal rule. The government in each country buys the final good $\left(P_{EA,t}G_{EA,t}\right)$, makes nominal transfers to households $TR_{EA,t}$ and receives taxes from households (both on payrolls $\tau_{W,t}W_{EA,t}\frac{L_{EA,t}}{n}$, where $\tau_{W,t}$ is the tax rate on the nominal wage $W_{EA,t}$ and $\frac{L_{EA,t}}{n}$ is the number of hours worked in the euro area; and on consumption expenditures $\tau_{C,t}P_{EA,t}C_{EA,t}$ where $\tau_{C,t}$ is the tax rate on consumption $P_{EA,t}G_{EA,t}$). The government budget is balanced every period which implies:

$$P_{EA,t}G_{EA,t}+TR_{EA,t}=\tau_{C,t}P_{EA,t}C_{EA,t}+\tau_{W,t}W_{EA,t}\frac{L_{EA,t}}{n}$$

we assume that government expenditures are exogenous, *i.e.* we assume that government purchases $\left(\hat{g}_{EA,t}\ \text{log}-\text{linearised and stationary terms}\right)$ in log-linearised and stationary terms) follows an autoregressive process of the following form:

(3) Under habit formation, an increase in current consumption lowers the marginal utility of consumption in the current period and increases it in the next period. The fact that habits are considered internal means that the habit formation depends on the individual consumer's past consumption.

$$\hat{g}_{EA,t} = \rho^G g^G_{EA,t-1} + e^G_{EA,t}$$

where $e^G_{EA,t}$ is a government spending shock.

As for the monetary authority, the central bank is assumed to set the short-term rate according to a generalised Taylor rule. In log-linearised terms:

$$\hat{R}_{EA,t} = \phi_R \hat{R}_{EA,t-1} + (1-\phi_R)\left[\hat{\bar{\pi}}_{EA,t} + \phi_\Pi \left(\hat{\pi}_{EA,t} - \hat{\bar{\pi}}_{EA,t}\right) + \phi_Y \left(\widehat{gdp}^F_{EA,t}\right)\right] +$$
$$+\phi_{\Delta\pi}\left(\hat{\pi}_{EA,t} - \hat{\pi}_{EA,t-1}\right) + \phi_{\Delta Y}\left(\widehat{gdf}^F_{EA,t} - \widehat{gdf}^F_{EA,t-1}\right) + \hat{\varepsilon}^R_{EA,t}$$

$o < \phi_R < 1$ *i.e.* the short-term interest rate $\hat{R}_{EA,t}$ is set to the previous period interest rate (interest rate smoothing), the inflation objective $\left(\hat{\bar{\pi}}_{EA,t}\right)$, deviations of inflation from the objective $\phi_\Pi\left(\hat{\pi}_{EA,t} - \hat{\bar{\pi}}_{EA,t}\right)$ and deviations of Gross Domestic Product (GDP) from steady state $\left(\widehat{gdp}^F_{EA,t}\right)$. As in Smets and Wouters (2003), two additional terms are included, namely the change in inflation and the change in deviations of GDP from steady state. Finally $\hat{\varepsilon}^R_{EA,t}$ is the monetary policy shock which is assumed to be i.i.d.

Finally, international financial markets are incomplete and foreign bond holdings are subject to a risk-premium, following Benigno (2001). This leads to the following modified uncovered interest parity (UIP) condition (all variables in deviation from steady state):

$$E_t\left(\Delta\hat{S}_{t+1}\right) = \hat{R}_{US,t} - \hat{R}_{EA,t} + \chi'(\ )\hat{b}^{EA}_{US,t} + \hat{\varepsilon}^S_t$$

where the expected change in the euro dollar exchange rate for one period ahead $\left(E_t\left(\Delta\hat{S}_{t+1}\right)\right)$ is a function of the interest rate differential between the two economies $\left(\hat{R}_{US,t} - \hat{R}_{EA,t}\right)$ plus a risk premium component which is proportional $\left(\chi'(\ ) < 0\right)$ to the euro area's net external assets $\left(\hat{b}^{EA}_{US,t}\right)$. $\hat{\varepsilon}^S_t$ is a shock to UIP.

3. CALIBRATION

The model is calibrated for the euro area and the US at a quarterly frequency. Table 1 in Annex 1 summarises the calibration made indicating the sources of the parameter values. Most parameters are obtained from the calibrated version of the New Area Wide Model of Coenen, McAdam and Straub (2007) which in turn largely rely on the estimated closed economy model for the euro area of Smets and Wouters (2003). The remaining parameters are either implicitly obtained or assumed. The only exception is the risk premium parameter which is obtained from Adolfson *et al.* (2007). In the assumptions made we have closely followed the literature. In addition, we keep the differences between the two economies as small as possible *i.e.*, we chose different parameter values for the two economies only when we found evidence strongly favouring that choice. The main differences in the calibration of the euro area and the US correspond to the population size, the tax rates (with a labour income tax rate of almost 46 per cent in the euro area and about 30 per cent in the US and a tax rate on consumption of around 18 per cent in the euro area and close to 8 per cent in the US), the share of imports (where the share of US goods in euro area imports, 18 per cent, is larger than vice-versa, 13 per cent) and also the parameters governing the home bias.

4. MODEL RESPONSES TO SHOCKS

In this section we illustrate the properties of the model by comparing the impulse responses of a number of variables of the model to standard shocks.[4] In particular we show the responses of real GDP, consumption, investment, hours worked, the real wage, the short-term interest rate (quarterly rate, annualised), inflation (year-on-year rate), the real exchange rate, exports and imports. The shocks we consider are monetary policy shocks, technology shocks, a government spending shock and a risk premium shock. For illustrative purposes, for the first three shocks we show a comparison with a version of the Smets-Wouters (2003) model calibrated with similar parameters as the ones of the open economy model. In the following all variables shown are expressed in percentage deviations from steady state with the exception of the interest rate, inflation and the real exchange rate which are expressed as percentage point deviations from steady state.

4.1. Monetary policy shock

Chart 2 displays the dynamic responses of several variables to a one-period monetary policy shock *i.e.* an exogenous change in $\hat{\varepsilon}^{R}_{EA,t}$ which is i.i.d. The shock is calibrated so that the annualised interest rate in the euro area falls on impact by 25 basis points. Once the shock hits the economy, the nominal interest rate is determined endogenously by the monetary policy rule.

According to the model, the policy rate remains below its steady state level for almost two years. At the same time, the decrease in the interest rate stimulates demand. The monetary policy shock leads to a hump-shaped increase in real GDP, real consumption and real investment in the euro area. As expected, real investment responds more strongly than consumption. The peak impact on real GDP occurs about 6 quarters after the shock. The fact that it takes time for the economy to return to the steady state reflects the nominal rigidities introduced in the model that increase the propagation of the shock. Features such as habit persistence in consumption, sticky prices and wages and adjustment costs in investment lead to persistent responses of the macroeconomic variables to the single period monetary policy shock.

The open economy framework introduces a new channel for the transmission of monetary policy shocks, namely the exchange rate channel. The decrease in the euro area interest rate, together with a muted response to the shock by the US monetary authority, leads to a real exchange rate depreciation. In fact, the real exchange rate depreciates on impact and then returns to its steady state value, consequently implying a competitiveness gain. This is translated into a slight decline in imports and, initially, a rise in exports that is later reversed.

Following the shock, hours worked increase, as firms want to produce more to satisfy increased demand. Higher demand for labour puts upward pressure on nominal wages. The effect on real wages will depend on the nominal rigidities (on both wages and prices), on the degree of workers' market power and also on the utility parameters (governing the disutility from work). In the model, real wages increase following a surprise decline in interest rates, in line with the stylised facts following an unanticipated monetary policy shock in the euro area (Peersman and Smets, 2001, Alves *et al.*, 2006). Note that the increases in hours

(4) All the results are obtained with Dynare, a matlab toolbox aimed at simulating and estimating DSGE models. The Dynare code used can be obtained from the authors.

Chart 2 (to be continued)

IMPULSE RESPONSES TO A MONETARY POLICY SHOCK

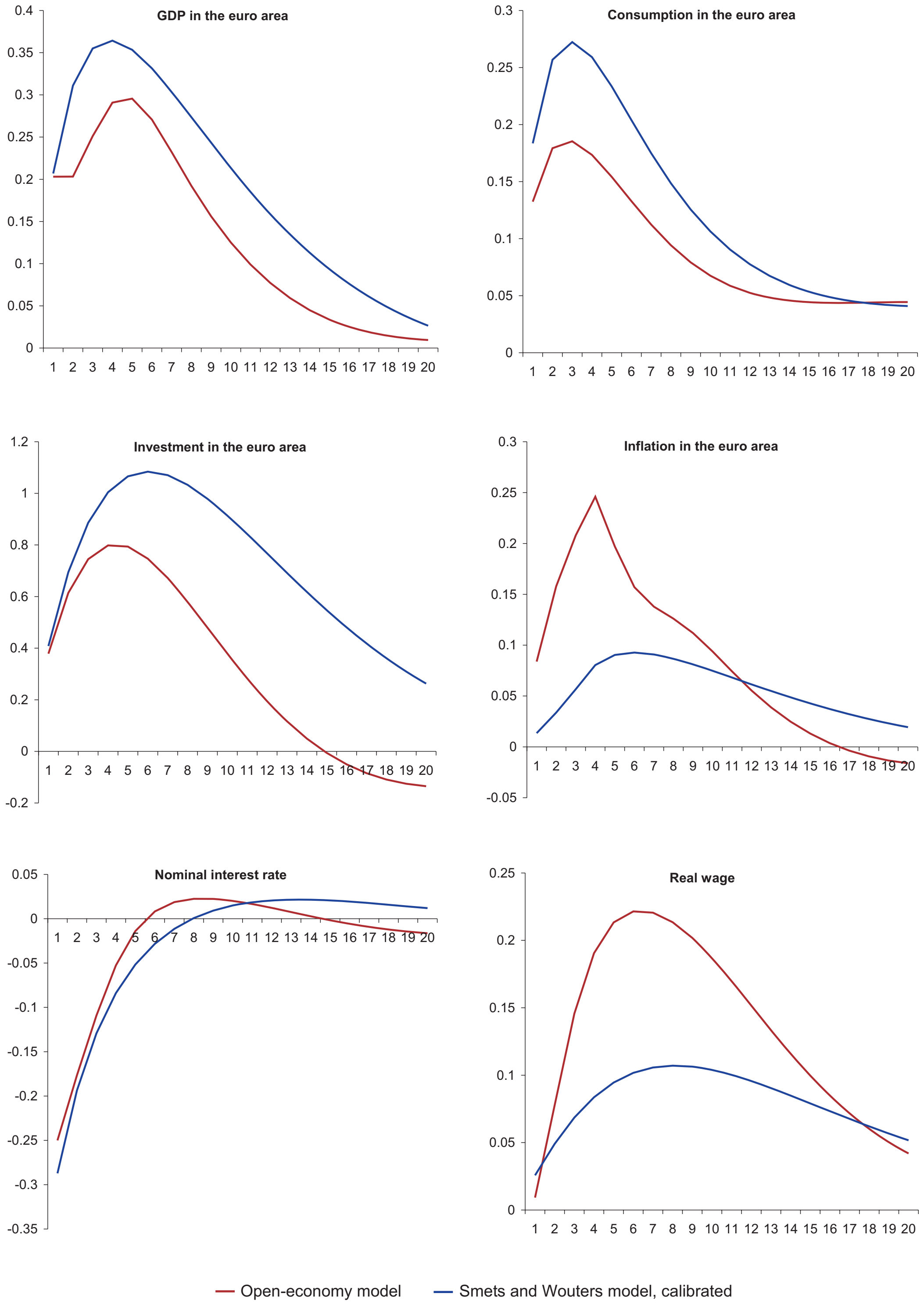
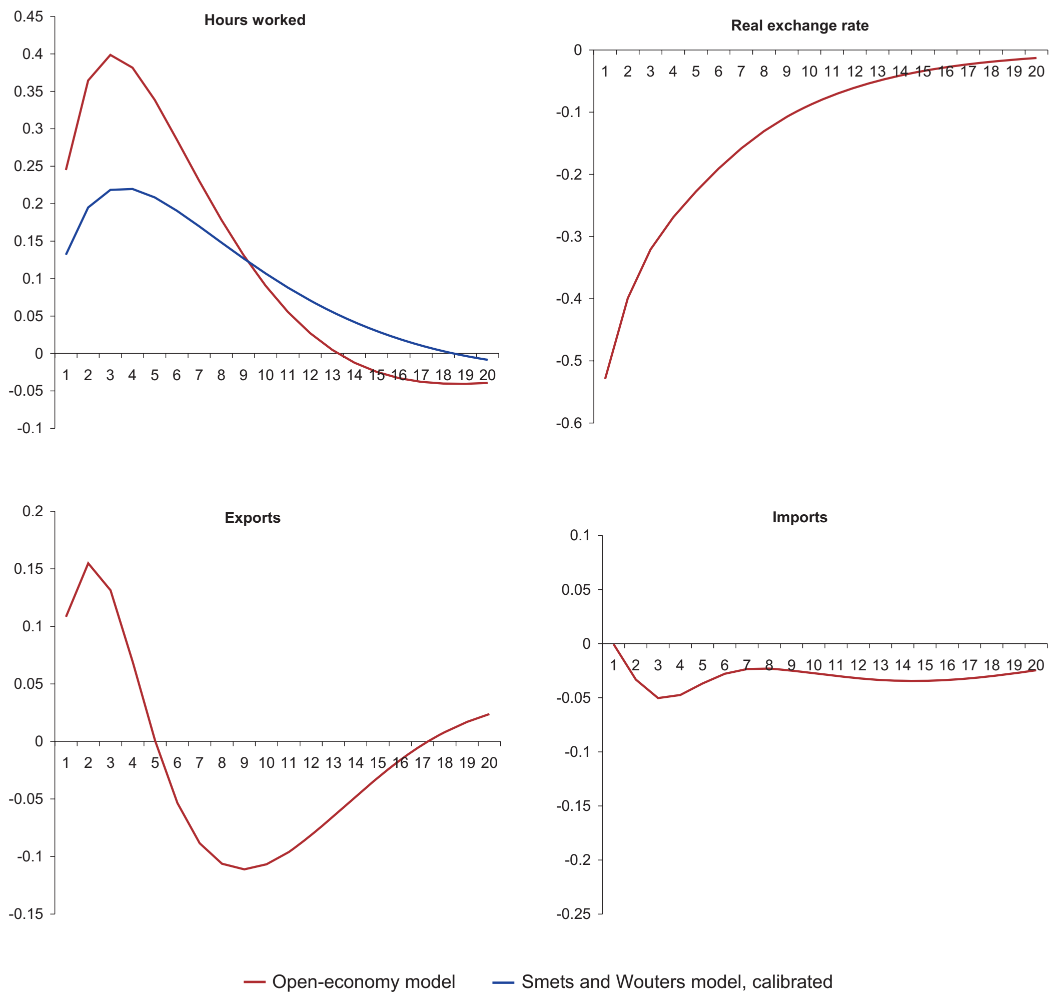


Chart 2 (continued)

IMPULSE RESPONSES TO A MONETARY POLICY SHOCK



worked and the real wage contribute to the expansion in consumption. As regards inflation, the annual rate increases after the shock and then gradually returns to the steady-state.

As regards the comparison with the closed economy model, it can be seen that the response of GDP is similar in both models. However, consumption and investment tend to increase more in response to the monetary policy shock in the case of the closed-economy model used in the comparison. An interesting difference regards the response of inflation. In the open economy model inflation rises much more in response to the monetary policy shock which partly seems to result from the nominal depreciation of the currency brought about by the shock. Thus, for monetary policy shocks, the open economy dimension seems to play an important role.

4.2. Technology shock

Chart 3 depicts the impulse responses to a transitory, though persistent, technology shock (*i.e.* an exogenous increase in $\varepsilon^{N}_{EA,t}$). The shock is calibrated such that the maximum effect on GDP in the euro

Chart 3 (to be continued)

IMPULSE RESPONSES TO A TECHNOLOGY SHOCK

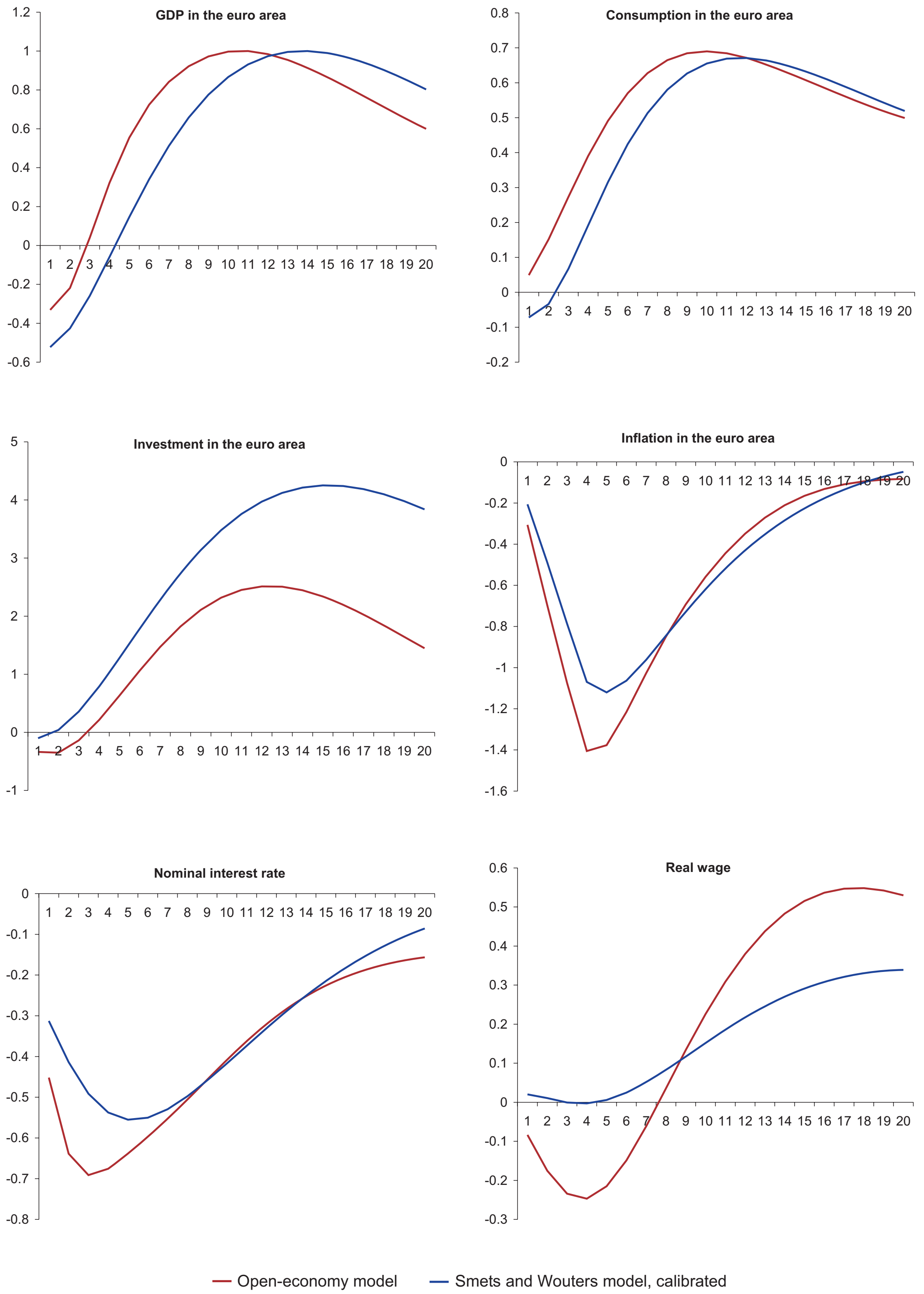
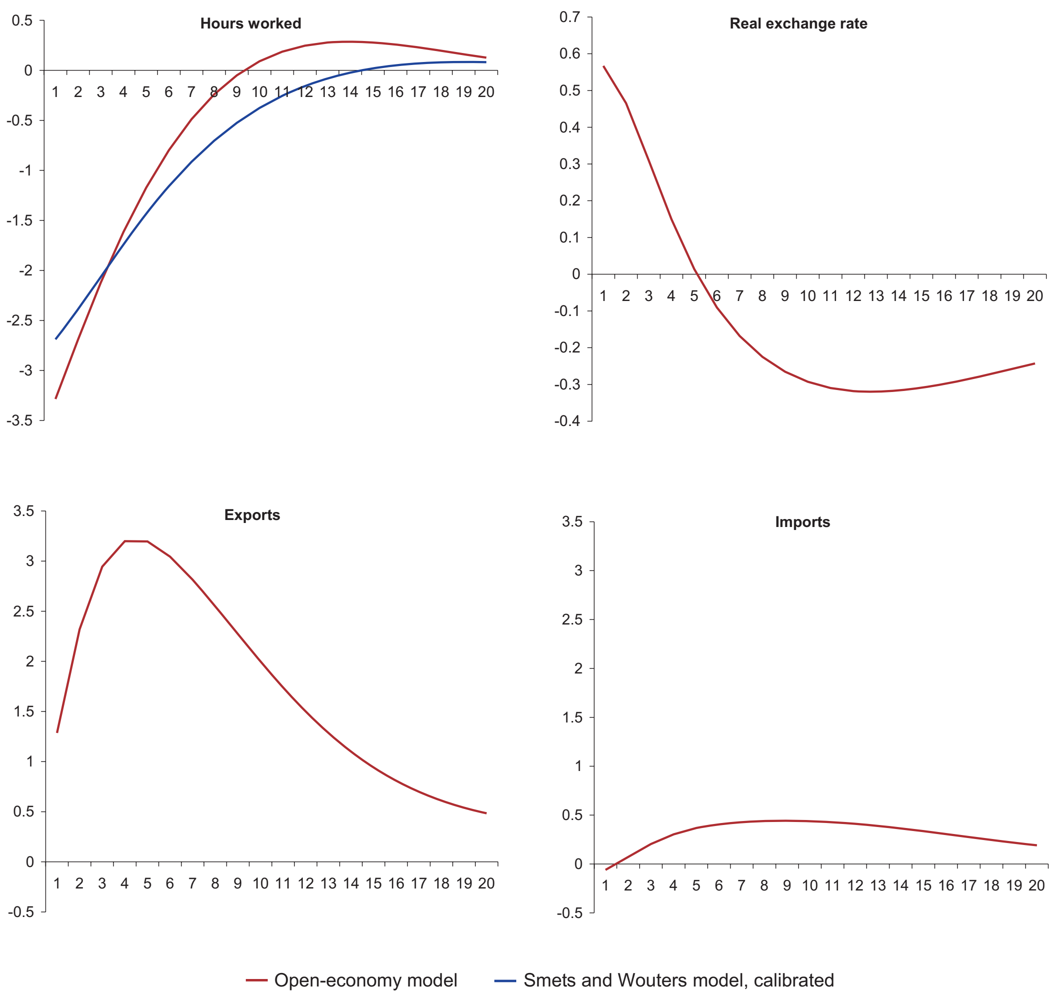


Chart 3 (continued)

IMPULSE RESPONSES TO A TECHNOLOGY SHOCK



area is one per cent (in deviations from the steady state).

The impulse responses of the model to a positive technological shock show that both consumption and investment rise after the shock.[5] Hours worked fall initially which is a result similar to the one found in Smets and Wouters, 2003, and Alves, *et al.*, 2006. One explanation for this fall is that when labour becomes more productive it may be more profitable for firms to use less of this input to produce more output, given that the real wage will rise. Given the general equillibrium setup, this also corresponds to the optimal decision of households given the constraints they face.

The technology shock expands temporarily the production capacity of the economy and therefore lowers the marginal cost of production. Therefore, firms want to lower their prices but, given that only a fraction of the firms are re-optimizing in each period, this will happen only gradually. The decline in inflation explains why the short-term interest rate declines while GDP is increasing. The real exchange rate appreciates but then falls and returns to the steady-state from below. The real exchange rate ap-

(5) Given that in the short-term the technology shock leads to a stronger fall in quarterly inflation than the decline in the quarterly interest rate, the real interest rate increases in the short-term. This helps to explain the initial temporary fall of GDP and investment below steady state.

preciation explains the rise in imports. Given that we also see an expansion in the foreign country, euro area exports also increase.

In terms of the comparison with the closed economy model, the responses of the open and closed economy models are broadly similar, notwithstanding some differences in terms of the strength of the response. This is particularly the case of investment, which seems much more reactive in the closed economy version of the model, and also regarding the real wage which in the case of the euro area open economy model shows a decline in the first year and a half while in the closed economy version the real wage increases.

4.3. Government spending shock

The government spending shock is calibrated such that the government spending-to-output ratio increases by one percentage point on impact. Government spending is modelled as an autoregressive process with an autoregressive coefficient of 0.9. The increase in government spending leads to an initial rise in GDP but crowds out investment and consumption (see Chart 4). Even though the effect on consumption is at odds with the results in the VAR literature (where usually consumption either does not react or rises following an unanticipated increase in government spending, see Adão and Brito, 2006, for example), this result is found in New-Keynesian models with Ricardian agents. The explanation for this behaviour is that the increase in government spending lowers the present value of after tax income and therefore generates a negative wealth effect that induces the fall in consumption. Additionally, the shock implies an increase in the number of hours worked and initially a rise in the real wage.[6] The euro real exchange rate *vis-à-vis* the dollar depreciates slightly. Nevertheless, exports show a very slight decline and imports show an increase that is reversed later. Inflation increases slightly which, together with higher GDP, leads to a tightening of monetary policy.

In comparison with the closed economy model, the main differences in the impulse responses occur in the case of investment, which declines by less in the open economy model, and that of inflation, which seems to react more to the shock, probably reflecting the exchange rate depreciation. It should be noted though that the response of inflation is very small.

4.4. UIP shock

The risk premium shock is a shock to the modified uncovered interest rate parity equation. This open-economy shock is defined so that the euro real exchange rate depreciates by 1 per cent on impact, as can be seen in Chart 5. Initially, the real exchange rate depreciation, by generating a negative wealth effect associated with the deterioration of the terms of trade, leads to a drop in consumption and in investment in the euro area. At the same time the real depreciation leads to a shift in demand towards domestic goods. Therefore euro area exports increase while imports decline. GDP increases above its steady state value following the shock, as a result of the improved contribution from net external demand. The increased demand for euro area goods is translated into an increase in hours worked. The real wage initially declines but recovers after a period of around one year. Given the increase in inflation the monetary authority reacts by raising interest rates.

(6) It should be noted that given the restriction that the government budget be balanced every period, the initial positive shock to government spending is to a large extent off-set by a decline in transfers. In addition, there is also a small off-setting effect due to an increase in labour income tax revenues (as the real wage increases) which more than compensates the decline in tax revenues due to the fall in consumption.

Chart 4 (to be continued)

IMPULSE RESPONSES TO A GOVERNMENT SPENDING SHOCK

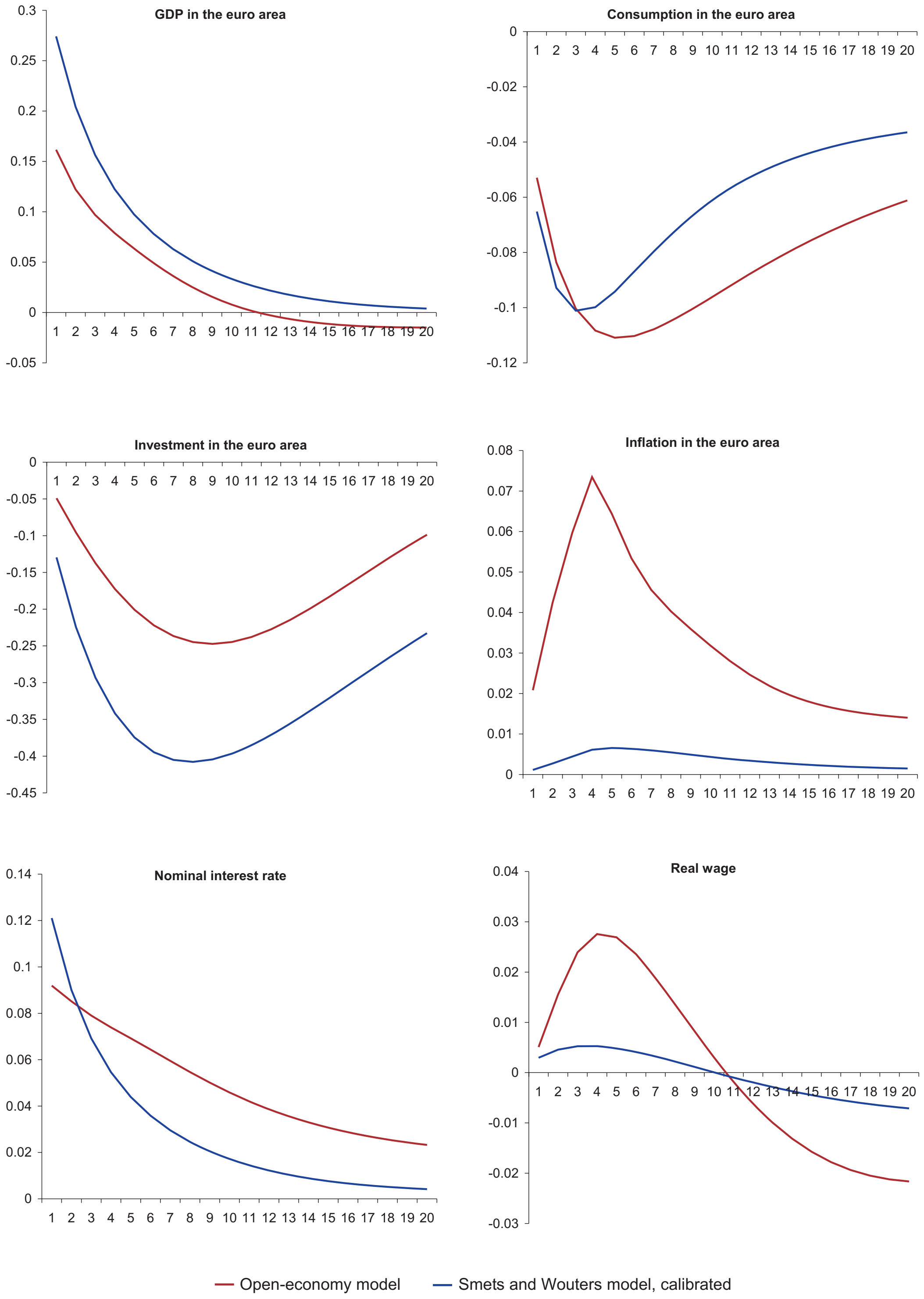


Chart 4 (continued)

IMPULSE RESPONSES TO A GOVERNMENT SPENDING SHOCK

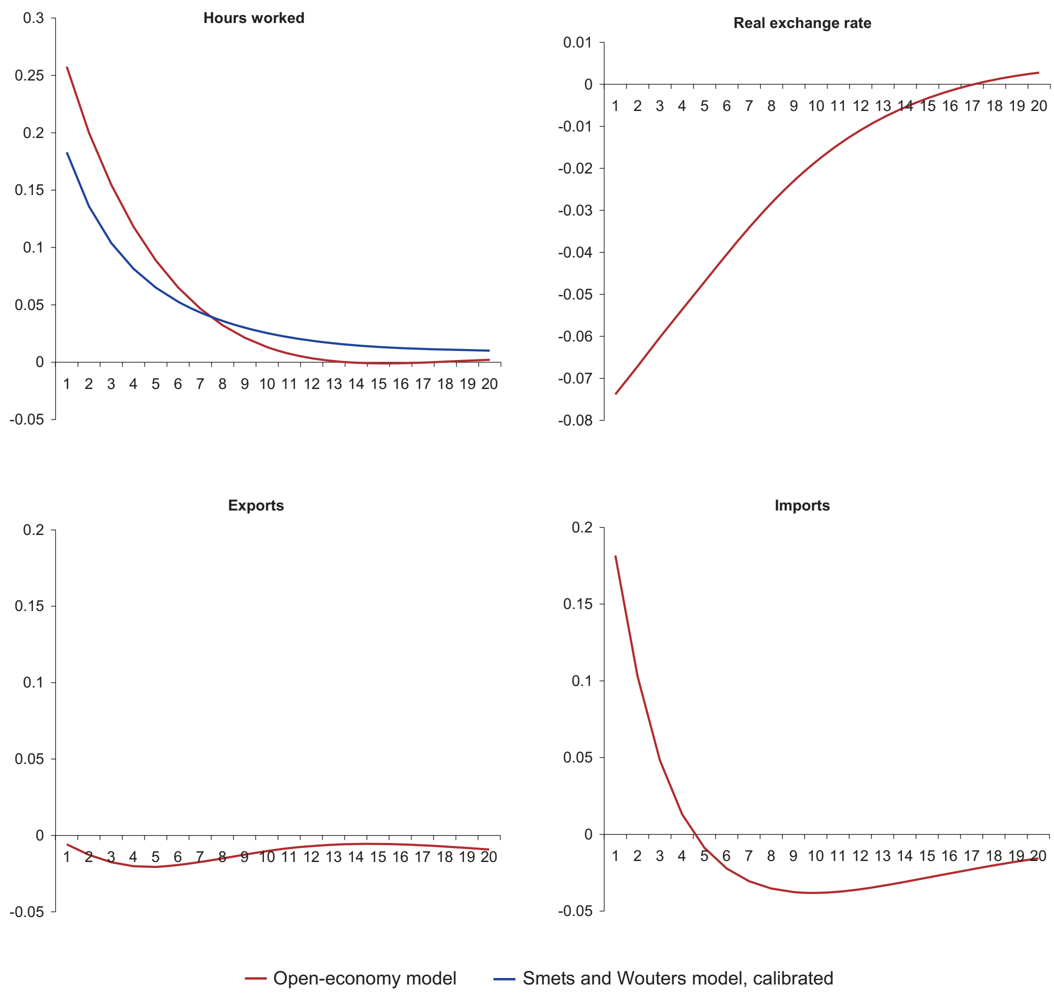


Chart 5 (to be continued)

IMPULSE RESPONSES TO AN UNCOVERED INTEREST RATE PARITY SHOCK

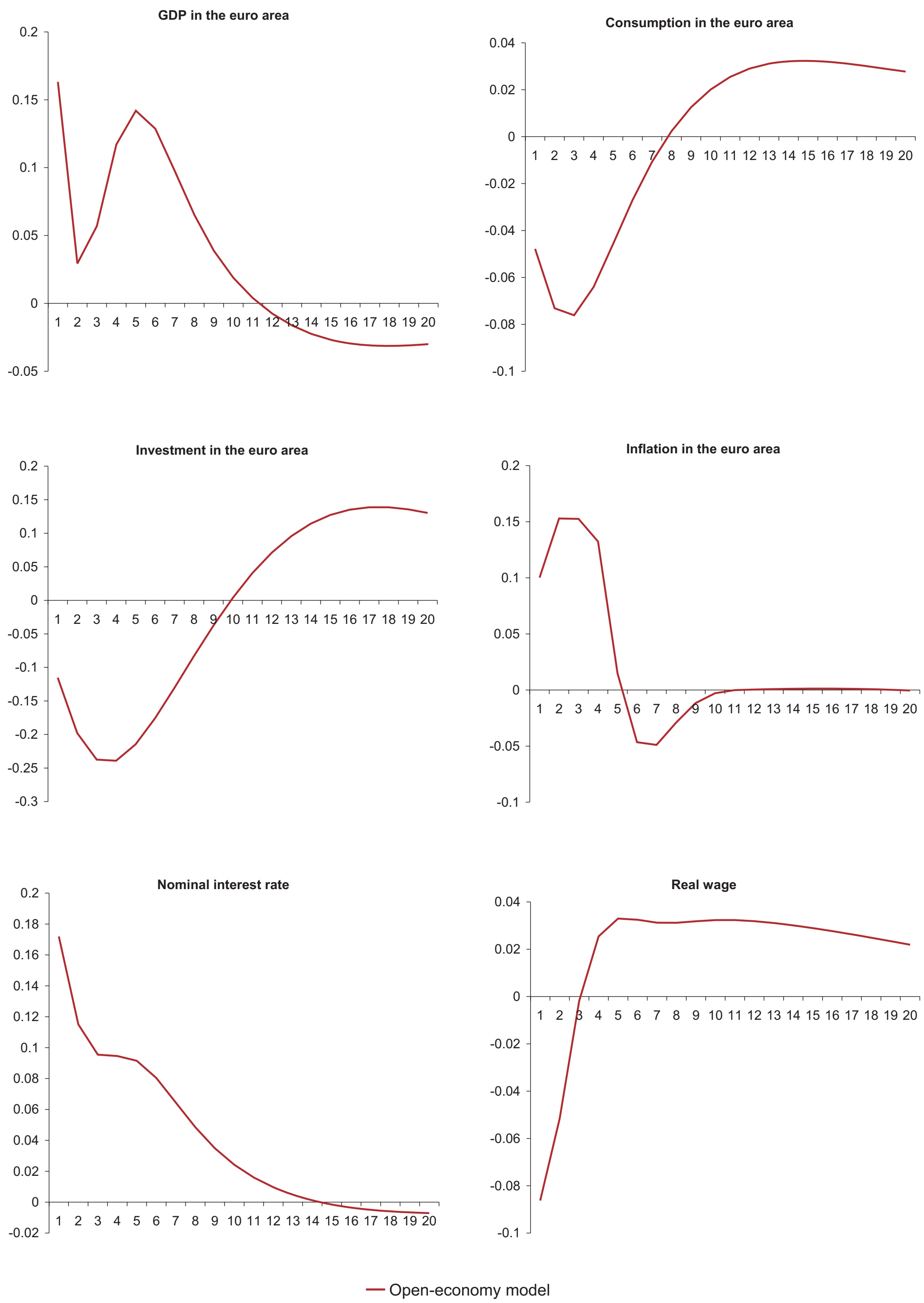
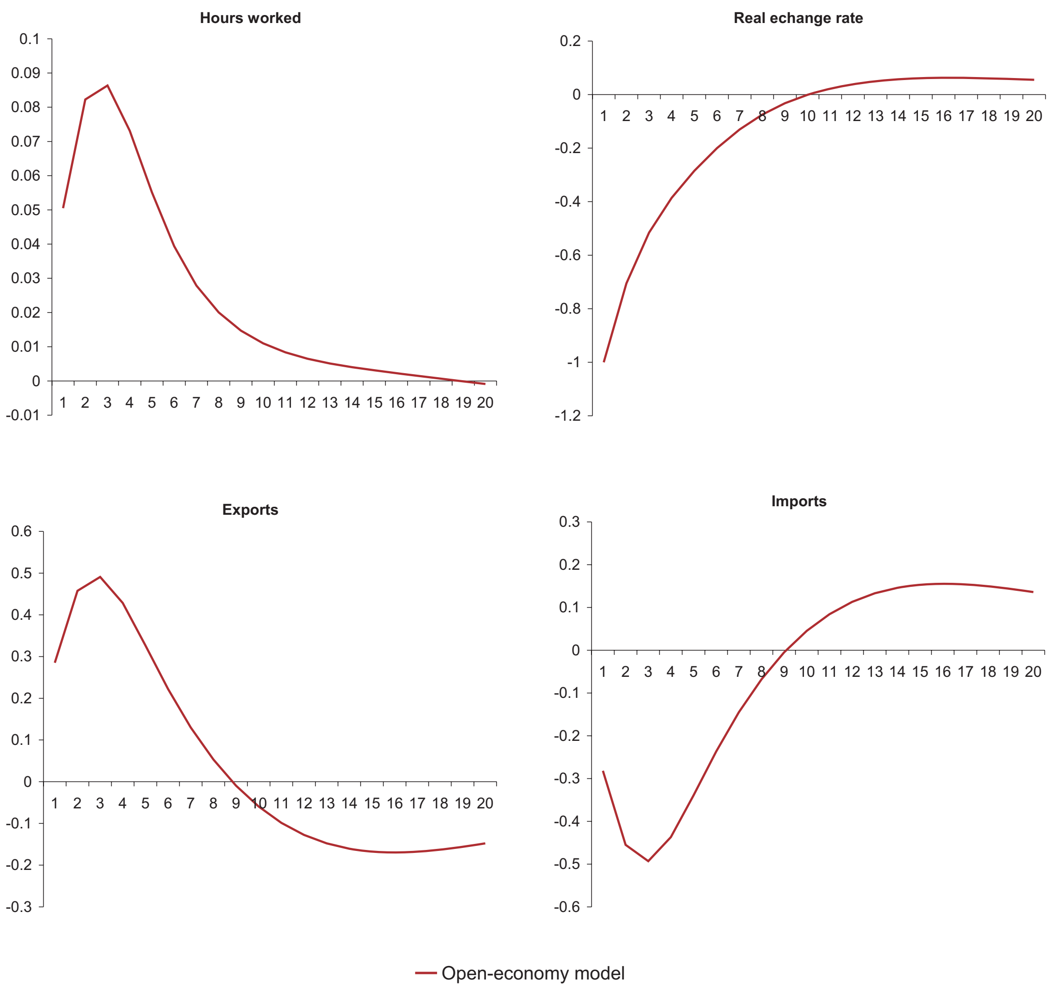


Chart 5 (continued)

IMPULSE RESPONSES TO AN UNCOVERED INTEREST RATE PARITY SHOCK



5. CONCLUDING REMARKS

DSGE models are being increasingly used by central banks for modelling and forecasting and in some countries replacing traditional large-scale macroeconomic models. Nevertheless, the use of these models for policy analysis is still undergoing a learning phase. This article aims at contributing to the current state of knowledge by considering the implications of the open economy dimension. The results suggest that this feature is indeed important, in particular for assessing the impact of monetary policy shocks. A follow up study will estimate the model for the euro area and the US in order to test whether the results obtained still apply when confronted with the data. Further refinements of the model for introducing other channels of transmission of shocks in the economy could also be envisaged (for instance more detailed open economy features, richer government or financial sectors or frictions in the labour market to allow for unemployment).

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Annex 1 Calibration

The parameter values are shown in Table 1. The two countries are of slightly different size, namely the euro area stands for 42 per cent of total population (*i.e.* the euro area plus the US). The utility function parameter values are the same in both economies. In particular, the habit persistence (b) parameter is set to 0.6 in both the euro area and the US.

In both countries we set the discount factor of consumers (β) to around 0.99 and the per capita gross growth rate of technology (μ_{zEA}) to 1.004 quarterly (*i.e.* 1.6 per cent in terms of the annual rate). Together with an annual gross inflation of 1.02 this implies a long run gross nominal interest rate of 1.0165 quarterly in both economies. We calibrate the depreciation rate (δ) to 0.025 quarterly.

Regarding the production function, the Cobb-Douglas parameter α is set to 0.3 in both countries while the CES function parameter (λ_F) is set to 2 both in the euro area and the US, which implies an intratemporal elasticity of substitution between home and foreign goods of 1.5. The consumption to output ratio is calibrated to be 0.6 in the euro area and 0.62 in the US.

As for price setting, the average duration of price contracts is set to 10 quarters in the domestic sector (ξ_D=0.9) and 1.4 quarters in the export sector sector (ξ_X=0.3). The degree of price indexation (γ_D) is set to 0.5 in both economies. The price markup is set to 0.3 both in the domestic and the import sector in the two economies $(\lambda_D$ and $\lambda_M)$.

Wage contracts last on average 4 quarters (ξ_W=0.75) and the degree of wage indexation is set to 0.75 (γ_W) in the two countries. The wage markup is set to 0.3 (λ_W). *Per capita* hours worked $\left(\frac{L_{EA}}{n}\right)$ are calibrated so that households spend roughly 30 per cent of their time working.

The import adjustment cost parameter ζ is set to 2.5 in both economies and the parameter of the risk premium function (*i.e*. the first derivative of the risk premium), χ', is calibrated to -0.1 following the estimates of Adolfson *et al*. (2005). The share of imports on domestic output is set to 18 per cent in the euro area while for the case of the US it is derived from the other parameters of the model resulting in a share of imports of 13 per cent. d_F and d_F^* are determined by solving a non-linear system and using the values for the other model parameters (see Alves, Gomes and Sousa, 2007).

The tax rate on consumption is 0.183 in the euro area and 0.077 in the US. The tax rate on labour income (including social security contributions) is 0.46 in the euro area and 0.3 in the US.

The parameters assumed in the monetary policy rule are close to those estimated in Smets and Wouters (2003), namely a coefficient of 1.5 on inflation and coefficients of 0.1 on output, changes in inflation and changes in output. Following Coenen, McAdam, Straub, we chose a parameter of 0.9 for the interest rate smoothing parameter which is close to the value estimated in Smets and Wouters (2003).

As for the autoregressive coefficients in the shock processes, we have assumed a high degree of persistence for technology, labour supply, consumer preference, government spending and risk premium shocks and no persistence for the remaining shocks.

Table 1

CALIBRATED PARAMETERS AND RATIOS

	Euro area		United States		Source
Population size	n	0.42	$1-n$	0.58	CMS
Inflation rate (gross)	π_{EA}	1.02^0.25	π_{US}	1.02^0.25	Assumption
Per capita hours	$\frac{L_{EA}}{n}$	0.285	$\frac{L_{US}}{1-n}$	0.285	Assumption
Consumption-output ratio	$\frac{c_{EA}}{y^F_{EA/n}}$	0.6	$\frac{c_{US}}{y^F_{US/(1-n)}}$	0.62	CMS
Share of government spending	$\frac{g_{EA}}{y^F_{EA/n}}$	0.21	$\frac{g_{US}}{y^F_{US/(1-n)}}$	0.20	Implicit (US)
Share of investment	$\frac{i_{EA}}{y^F_{EA/n}}$	0.188	$\frac{i_{US}}{y^F_{US/(1-n)}}$	0.179	Implicit (US)
Share of imports	$\frac{y^{EA}_{US}}{y^F_{EA/n}}$	0.18	$\frac{y^{US}_{EA}}{y^F_{US/(1-n)}}$	0.13	Implicit (US)
Productivity growth (gross)	μ_{zEA}	1.016^0.25	μ_{zUS}	1.016^0.25	Assumption
Discount factor	β	1.03^-0.25	β^*	1.03^-0.25	CMS
Depreciation rate	δ	0.025	δ^*	0.025	Assumption
Tax rate on consumption	τ_C	0.183	τ^*_C	0.077	CMS
Tax rate on labour income	τ_W	0.459	τ^*_W	0.296	CMS
Share of capital income in value added	α	0.3	α^*	0.3	Assumption
Habit persistence parameter	b	0.6	b^*	0.6	CMS
Import adjustment cost	ζ	2.5	ζ^*	2.5	CMS
CES parameter of imported and domestic interm. goods	λ_F	2	λ^*_F	2	CMS
CES parameter of imported and domestic interm. goods	d_F	0.83	d^*_F	0.87	Implicit
Goods markup	λ_D		λ^*_D		
Wage markup	λ_W	0.3	λ^*_W	0.3	CMS
Import price markup	λ_M		λ^*_M		
Degree of price indexation	γ_D	0.5	γ^*_D	0.5	CMS
Degree of wage indexation	γ_W	0.75	γ^*_W	0.75	CMS
Calvo setting					
Domestic goods	ξ_D	0.9	ξ^*_D	0.9	
Exports	ξ_X	0.3	ξ^*_X	0.3	CMS
Wages	ξ_W	0.75	ξ^*_W	0.75	
	ϕ_R	0.9	ϕ^*_R	0.9	
	ϕ_Π	1.5	ϕ^*_Π	1.5	
Taylor rule parameters	ϕ_Y	0.1	ϕ^*_Y	0.1	Assumption
	$\phi_{\Delta\Pi}$	01	$\phi^*_{\Delta\Pi}$	0.1	
	$\phi_{\Delta Y}$	0.1	$\phi^*_{\Delta Y}$	0.1	

Shock processes

	Euro area		United States		Source
Shock AR, interest rate	ρ_R	0	ρ^*_R	0	Assumption
Shock AR, government	ρ_G	0.9	ρ^*_G	0.9	Assumption
Shock AR, technological	ρ_{μ_z}	0.9	$\rho^*_{\mu_z}$	0.9	Assumption

	Other		Source
Stationary holdings of United States bonds	b^{EA}_{US}	0	Assumption
Relative United States / Euro area price	p_{US}	1	Implicit
Risk premium	$\chi'()$	-0.1	Adolfson, *et al.* (2005)
Shock AR, exchange rate	ρ_S	0.9	Assumption

CMS-Coenen, McAdam and Straub (2007).