Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through

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Abstract

In this paper we develop a dynamic stochastic general equilibrium (DSGE) model for an open economy, and estimate it on Euro area data using Bayesian estimation techniques. The model incorporates several open economy features, as well as a number of nominal and real frictions that have proven to be important for the empirical fit of closed economy models. The paper offers: *i*) a theoretical development of the standard DSGE model into an open economy setting, *ii*) Bayesian estimation of the model, including assesments of the relative importance of various shocks and frictions for explaining the dynamic development of an open economy, and *iii*) an evaluation of the model's empirical properties using standard validation methods.

Keywords: DSGE model; Open economy; Monetary Policy; Nominal rigidities; Bayesian Inference; Business cycle.

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1. Introduction

In this paper we develop a dynamic stochastic general equilibrium (DSGE) model for an open economy and estimate it on Euro area data. We extend the closed economy DSGE model of Christiano, Eichenbaum and Evans (2005) and Altig, Christiano, Eichenbaum and Lindé (2003) by incorporating open economy aspects into it. Our model combines elements of their closed economy setting with some of the features and findings of the New Open Economy Macroeconomics literature.[1]

In our model, the consumers attain utility from consumption of domestically produced goods as well as imported goods, which are supplied by domestic and importing firms, respectively. We allow for incomplete exchange rate pass-through in both the import and export sectors by including nominal price rigidities (i.e., there is local currency price stickiness), following for example Smets and Wouters (2002).

Following Christiano, Eichenbaum and Evans (2005), a number of nominal and real frictions such as sticky prices, sticky wages, variable capital utilization, capital adjustment costs and habit persistence are included in the theoretical model. The relevance of these frictions will be empirically determined in the estimation procedure. In addition, we allow for stochastic fiscal policy in the model since prior research have shown the potential importance of such shocks for explaining business cycles (see e.g. Christiano and Eichenbaum, 1992).

Apart from bringing in the exchange rate channel, we also include a working capital channel (i.e., firms borrow money from a financial intermediary to finance part of their wage bill). The working capital channel implies that an interest rate change will directly affect firms' marginal costs. Consequently, both these channels will have effects on the transmission of monetary policy. Examining the role of the working capital channel is of particular interest, since Christiano, Eichenbaum and Evans (2005) obtain a low estimated degree of price stickiness when allowing for working capital when matching the impulse responses after a monetary policy shock. In contrast, Smets and Wouters (2003a, 2003b) obtain a much higher degree of estimated price stickiness in a model without the working capital channel. As in Altig et al. (2003), we include a stochastic unit-root technology shock which induces a common trend in the real variables of the model. This allows us to work with raw data when estimating the DSGE model. Compared to Smets and Wouters (2003a, 2003b) we also allow for a larger set of structural shocks, mainly due to the open economy aspects in our model. The relative importance of the various identified shocks for explaining the business cycle fluctuations will be determined in the estimation, and an interesting feature of the analysis in this paper is to examine to what extent the frictions and shocks differ between the open and closed economy setting.

We estimate the model using Bayesian estimation techniques. Smets and Wouters (2003a, 2003b) have shown that one can successfully estimate closed economy DSGE models using Bayesian methods, and that the forecasting performance of such models is quite good compared to standard, as well as Bayesian, vector autoregressive (VAR) models. We extend their work to the open economy setting, and by using data for the Euro area we offer a comparison to their closed economy framework.

In the paper we adopt the assumption that foreign inflation, output and interest rate are exogenously given. This approximation is perhaps more suitable for a small open economy, but given the results by Lindé (2003) it is probably a less rudimentary statement than modeling the Euro area as a closed economy.[2] In addition, there is some empirical support for the small open economy approx-

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[1] Important contributions to the literature on monetary policy in open economies are Benigno and Benigno (2003), Chari, Kehoe and McGrattan (2002), Corsetti and Pesenti (2001), Galí and Monacelli (2004), Kollmann (2001), and Schmitt-Grohé and Uribe (2001) among others. In general, these models have though been calibrated and not estimated. See Lane (1999) for a survey of the New Open Economy Macroeconomics literature.

[2] Lindé (2003) shows that "rest of GDP" (i.e., output minus consumption and investment) moves significantly after a shock to monetary policy using a VAR on Euro area data. Since government expenditures are not cyclical this suggests that fluctuations in net exports are important.

imation. By estimating a VAR model with ten Euro area variables and three foreign variables (”rest of the world” inflation, output and interest rate), we find that the Euro area variables account for a small fraction of the variation in the foreign variables (around 10(20) percent at the one(five) year horizon).[3]

We provide an evaluation of the open economy DSGE model's empirical properties to validate the model fit. More specifically, we compare vector autocovariance functions and unconditional second moments in the benchmark model and the data. We also provide a relative model comparison using marginal likelihoods to assess the importance of the various shocks and frictions that have been included in the model.

The interesting results related to the open economy aspects of the model are the following. The estimated model is able to capture the volatility and persistence in the real exchange rate strikingly well. Bouakez (2004) has shown that a model with time-varying markups, which are decreasing in the relative price of goods, can replicate the properties of the real exchange rate, in contrast to standard sticky price models in which the fluctuations in the real exchange rate do not generally last beyond the duration of the price contracts. However, Bouakez's model using HP-filtered data can not jointly account for the dynamics in inflation and the real exchange rate, because it underpredicts the inflation volatility. In contrast, our model is able to match the joint conditional inflation and real exchange rate dynamics using undetrended data. The key ingredient behind this success of the model, is it embodies a couple of shocks that have rather persistent effects on exchange rate dynamics, while accounting for much less of the fluctuations in quantities and prices. This finding is in line with the arguments of Duarte and Stockman (2005), and is attributed to the model setup which share many of the features emphasized by Devereux and Engel (2002) as necessary to generate highly volatile exchange rates which are “disconnected” from the rest of the economy.

Moreover, the model yields a high elasticity of substitution between domestic and imported goods. We find a value of around 11 when including this parameter in the estimation. As Obstfeld and Rogoff (2000) have shown, a high elasticity of substitution can explain the observed large home bias in trade. The typical estimates for the substitution elasticity between home and foreign goods are around 5 to 20 using micro data (see the references in Obstfeld and Rogoff, 2000). However, using macro data the estimates are usually a lot lower, in the range of $1.5 - 2$, see e.g. Collard and Dellas (2002).

Although our model embodies a number of mechanisms that have proven useful to generate persistence in inflation such as variable capital utilization, the working capital channel and a time-varying inflation target, we still find that price stickiness is an important feature for firms active in the domestic, export and import sectors. For the domestic firms, our preferred model implies an average duration of the price contracts of about 4.5 quarters under the assumption of capital being specific to each firm.[4] This number appears to be in line with microeconomic evidence for Euro area countries, see e.g. Mash (2004) and the references therein. For the firms active in the consumption and investment import sectors, our results suggest that the average duration is less than 2 quarters, while it is about 3 quarters for the firms in the export sector. Given that incomplete exchange rate pass-through in the model is induced solely by nominal rigidities this amounts to about $20 - 40$ percents pass-through to the import and export prices.

Finally, we find that many shocks matter for the fluctuations in output and inflation in the open economy framework. That is, “open economy shocks” are important for the determination of the “domestic variables” since we find that there is a high elasticity of substitution between domestic and imported consumption goods which implies that relative prices and the exchange rate channel are

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[3] The identifying assumption in the analysis is that that Euro area shocks have no contemporaneous effects on the foreign variables. Moreover, it should be noticed that the results are not much affected by changing the lag-length.

[4] See e.g. Altig et al. (2004) for a thorough discussion about the role of economy wide capital markets vs. firm-specific capital for the interpretation of price stickiness parameter.

very important for the dynamics of the model. For output both productivity and imported investment markup shocks are important, while for inflation imported consumption and investment markup shocks together with movements in the inflation target appear to matter the most in the medium to long run.

The paper is organized as follows. In Section 2 the theoretical model is derived and described with particular emphasis on its open economy aspects. Section 3 contains a short description of the data used, and discusses measurement issues that arise when taking the theoretical model to the data. In Section 4, we first discuss which parameters we have chosen to calibrate, and the prior distributions for the parameters we have chosen to estimate. We then report our estimation results and validate the model fit. The empirical properties of the estimated DSGE model are compared with the actual data using autocovariance functions and unconditional second moments. In Section 5 we explore the importance of nominal and real frictions in the model. Section 6 shows the impulse responses from different shocks and discusses the role of various shocks in explaining business cycles. Lastly, Section 7 provides some conclusions.

2. The open economy DSGE model

We build on the work of Christiano et al. (2005) and Altig et al. (2003) and extend their DSGE model to an open economy.[5] As in their model, households maximize a utility function consisting of consumption, leisure and cash balances. However, in our open economy model the households consume a basket consisting of domestically produced goods and imported goods. These products are supplied by domestic and importing firms, respectively. Note also that consumption preferences are subject to habit formation.

Households can save in domestic bonds *and/or* foreign bonds and hold cash. This choice balances into an arbitrage condition pinning down expected exchange rate changes (i.e., an uncovered interest rate parity (UIP) condition). As in the closed economy model households rent capital to the domestic firms and decide how much to invest in the capital stock given certain capital adjustment costs. These are costs to adjusting the investment rate as well as costs of varying the utilization rate of the capital stock. Further, along the lines of Erceg, Henderson and Levin (2000), each household is a monopoly supplier of a differentiated labour service which implies that they can set their own wage. This gives rise to an explicit wage equation with Calvo (1983) stickiness.

Domestic firms determine the capital and labour inputs used in their production which is exposed to stochastic technology growth as in Altig et al. (2003). The firms (domestic, importing and exporting) all produce differentiated goods and set prices according to an indexation variant of the Calvo model. By including nominal rigidities in the importing and exporting sectors we allow for (short-run) incomplete exchange rate pass-through to both import and export prices. In what follows we provide the optimization problems of the different firms and the households. We also describe the behavior of the fiscal authority, the central bank, and illustrate how the foreign economy develops.

2.1. Firms

There are three categories of firms operating in this model economy; domestic, importing and exporting firms. The intermediate domestic firms produce a differentiated good, using capital and labour inputs, which they sell to a final good producer who uses a continuum of these intermediate goods in her production. The importing firms, in turn, transform a homogenous good, bought in the world market, into a differentiated import good, which they sell to the domestic households. The exporting firms

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[5] A more detailed presentation of the model, along with Appendices A, B, C and D, are provided in the working paper version of this paper, see Adolfson et al. (2005).

pursue a similar scheme. The exporting firms buy the domestic final good and differentiate it by brand naming. Each exporting firm is thus a monopoly supplier of its specific product in the world market.

2.1.1. Domestic firms

The domestic firms consist of three types. One hires labour from the households and transforms it into a homogeneous input good, denoted H. The other type of firm buys H, rents capital and produces an intermediate good Y_i, which it sells to a final goods producer. There is a continuum of these intermediate goods producers, each of which is a monopoly supplier of its own good and is competitive in the markets for inputs. The last type of firm transforms the intermediate product into a homogenous final good, which is used for consumption and investment by the households.

The production function of the *final good firm* takes the form

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{1}{\lambda_{d,t}}} di\right]^{\lambda_{d,t}}, \; 1 \leq \lambda_{d,t} < \infty, \tag{2.1}$$

where $\lambda_{d,t}$ is a stochastic process determining the time-varying markup in the domestic goods market. This process is assumed to follow

$$\lambda_{d,t} = \left(1 - \rho_{\lambda_d}\right)\lambda_d + \rho_{\lambda_d}\lambda_{d,t-1} + \varepsilon_{\lambda_d,t}, \; \varepsilon_{\lambda_d,t} \sim i.i.d.N\left(0, \sigma^2_{\lambda_d}\right).$$

Note that in our benchmark model we assume that these markup shocks are white noise and set $\rho_{\lambda_d} = 0$. However, in our sensitivity analysis we will also explore the consequences of allowing the shocks to be persistent, that is $\rho_{\lambda_d} > 0$.

The final good firm takes its output price, P_t, and its input prices $P_{i,t}$ as given. Profit maximization leads to the following first order condition

$$\frac{Y_{i,t}}{Y_t} = \left(\frac{P_t}{P_{i,t}}\right)^{\frac{\lambda_{d,t}}{\lambda_{d,t}-1}}. \tag{2.2}$$

By integrating (2.2) and using (2.1), we obtain the following relation between the price of the final good and the prices of intermediate goods

$$P_t = \left[\int_0^1 P_{i,t}^{\frac{1}{1-\lambda_{d,t}}} di\right]^{(1-\lambda_{d,t})}. \tag{2.3}$$

Output of *intermediate good firm* i is given by the following production function:

$$Y_{i,t} = z_t^{1-\alpha}\epsilon_t K_{i,t}^{\alpha} H_{i,t}^{1-\alpha} - z_t\phi, \tag{2.4}$$

where z_t is a permanent technology shock, ϵ_t is a covariance stationary technology shock, and $H_{i,t}$ denotes homogeneous labour hired by the i^{th} firm. In (2.4), $K_{i,t}$ is the capital services stock which may differ from the physical capital stock since we allow for variable capital utilization in the model. Also, a fixed cost is included to ensure that profits are zero in steady state. The fixed cost is assumed to grow at the same rate as consumption, investment, the real wage, and output do in steady state. If the fixed cost did not grow with z_t, the fixed cost term would eventually become irrelevant and profits would systematically become positive because of the presence of monopoly power. Moreover, we rule out entry into and exit out of the production of intermediate good i.

The process for the permanent technology level z_t is exogenously given by

$$\mu_{z,t} = (1 - \rho_{\mu_z})\mu_z + \rho_{\mu_z}\mu_{z,t-1} + \varepsilon_{z,t}, \; \varepsilon_{z,t} \sim i.i.d.N\left(0, \sigma_z^2\right), \tag{2.5}$$

where $\mu_{z,t} \equiv \frac{z_t}{z_{t-1}}$. For the stationary shock in (2.4), we assume $\mathrm{E}(\epsilon_t) = 1$ and that $\hat{\epsilon}_t = (\epsilon_t - 1)/1$ has the following univariate representation:

$$\hat{\epsilon}_t = \rho_\epsilon \hat{\epsilon}_{t-1} + \varepsilon_{\epsilon,t}, \ \varepsilon_{\epsilon,t} \ \tilde{} \ i.i.d.N\left(0, \sigma_\epsilon^2\right). \tag{2.6}$$

Throughout the paper, a variable with a hat denotes log-linearized variables (i.e, $\hat{X}_t = \frac{dX_t}{X}$).

Solving the cost minimization problem facing the intermediate firm i in period t is (assuming that $P_{i,t}$ is given, the firm is constrained to produce $Y_{i,t}$), it is possible to show that equilibrium real marginal cost (mc_t) follows

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} \left(r_t^k\right)^{\alpha} \left(\bar{w}_t R_t^f\right)^{1-\alpha} \frac{1}{\epsilon_t}. \tag{2.7}$$

where $r_t^k \equiv R_t^k / P_t$ is the real rental rate of capital, determined by

$$r_t^k = \frac{\alpha}{1-\alpha} \bar{w}_t \mu_{z,t} R_t^f k_t^{-1} H_t. \tag{2.8}$$

In (2.8), $\bar{w}_t \equiv \frac{W_t}{P_t z_t}$ where W_t is the nominal wage rate per unit of aggregate homogeneous labour H_t, and $k_t \equiv K_t / z_{t-1}$ is the scaled level of capital services. The inclusion of the gross effective nominal rate of interest paid by firms, R_t^f, reflects the assumption that a fraction, ν, of the intermediate firms' wage bill has to be financed in advance. The end of period labour costs of the firm are $W_t H_{i,t} R_t^f$ and

$$R_t^f \equiv \nu R_{t-1} + 1 - \nu, \tag{2.9}$$

where R_{t-1} is the gross nominal interest rate.[6]

The price setting problem of the intermediate firms is similar to the one in Smets and Wouters (2003b), following Calvo (1983). Each intermediate firm faces a random probability $(1-\xi_d)$ that it can reoptimize its price in any period. The reoptimized price is denoted P_t^{new}. Notice that we suppress the subindex i in P_t^{new}. We do this because all firms that are allowed to reoptimize will always set the same price. With probability ξ_d the firm is not allowed to reoptimize, and its price in period $t+1$ is then updated according to the scheme $P_{t+1} = (\pi_t)^{\kappa_d} \left(\bar{\pi}_{t+1}^c\right)^{1-\kappa_d} P_t$, i.e. it is indexed to last period's inflation, $\pi_t = \frac{P_t}{P_{t-1}}$, and the current inflation target, $\bar{\pi}_{t+1}^c$ where κ_d is an indexation parameter.[7] If the period t optimizing firm is not allowed to change its price during s periods ahead, the price in period $t+s$ will be $(\pi_t \pi_{t+1} ... \pi_{t+s-1})^{\kappa_d} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_d} P_t^{new}$. Thus, firm i faces the following optimization problem when setting its price:

$$\max_{P_t^{new}} \mathrm{E}_t \sum_{s=0}^{\infty} (\beta \xi_d)^s \upsilon_{t+s} \left[((\pi_t \pi_{t+1} ... \pi_{t+s-1})^{\kappa_d} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_d} P_t^{new}) Y_{i,t+s} - MC_{i,t+s} \left(Y_{i,t+s} + z_{t+s}\phi\right) \right], \tag{2.10}$$

subject to (2.7) and (2.2). In (2.10), the firm is using the stochastic discount factor $(\beta \xi_d)^s \upsilon_{t+s}$ to make profits conditional upon utility. β is the households' discount factor, while υ_{t+s} is the marginal utility of the households' nominal income in period $t+s$, which is exogenous to the intermediate firms, and $MC_{i,t}$ is the firm's nominal marginal cost.

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[6] A difference compared to Christiano et al. (2001) is that the nominal interest rate that the firms pay on their loans is R_{t-1} instead of R_t, which reflects our assumption that the households purchase one-period zero-cupon bonds with certain nominal payout in period $t+1$.

[7] The inflation target process is described in subsection 2.4.

From the aggregate price index (2.3), it follows that the average price in period t is given by

$$P_t = \left[\xi_d \left(P_{t-1} \left(\pi_{t-1}\right)^{\kappa_d} \left(\bar{\pi}^c_t\right)^{1-\kappa_d} \right)^{\frac{1}{1-\lambda_{d,t}}} + \left(1-\xi_d\right) \left(P^{new}_t\right)^{\frac{1}{1-\lambda_{d,t}}} \right]^{1-\lambda_{d,t}}, \tag{2.11}$$

where we have exploited the fact that all firms that reoptimize set the same price, P^{new}_t. Log-linearizing and combining the first-order condition of the firms' optimization problem in (2.10) with (2.11), we obtain the following aggregate Phillips curve relation

$$\begin{aligned} \left(\widehat{\pi}_t - \widehat{\bar{\pi}}^c_t\right) &= \frac{\beta}{1+\kappa_d\beta}\left(\mathrm{E}_t\widehat{\pi}_{t+1} - \rho_\pi \widehat{\bar{\pi}}^c_t\right) + \frac{\kappa_d}{1+\kappa_d\beta}\left(\widehat{\pi}_{t-1} - \widehat{\bar{\pi}}^c_t\right) \\ &\quad - \frac{\kappa_d\beta\left(1-\rho_\pi\right)}{1+\kappa_d\beta}\widehat{\bar{\pi}}^c_t + \frac{(1-\xi_d)(1-\beta\xi_d)}{\xi_d\left(1+\kappa_d\beta\right)}\left(\widehat{mc}_t + \widehat{\lambda}_{d,t}\right). \end{aligned} \tag{2.12}$$

Note that by letting $\kappa_d = 1$, this relation reduces to the Phillips curve in Altig et al. (2003), while setting $\kappa_d = 0$ results in a purely forward-looking Phillips curve.

2.1.2. Importing firms

The import sector consists of firms that buy a homogenous good in the world market. There are two different types of these importing firms; one that turns the imported product into a differentiated *consumption* good $C^m_{i,t}$ (through access to a "differentiating" technology, i.e. brand naming), and another that turns it into a differentiated *investment* good $I^m_{i,t}$.

The final import consumption and investment goods are a composite of a continuum of i differentiated imported consumption and investment goods, each supplied by a different firm, which follow the CES functions:

$$C^m_t = \left[\int_0^1 \left(C^m_{i,t}\right)^{\frac{1}{\lambda^{m,c}_t}} di \right]^{\lambda^{m,c}_t}, \qquad I^m_t = \left[\int_0^1 \left(I^m_{i,t}\right)^{\frac{1}{\lambda^{m,i}_t}} di \right]^{\lambda^{i}_t},. \tag{2.13}$$

where $1 \leq \lambda^{m,j}_t < \infty$ for $j = \{c, i\}$. The processes for the time varying markups on the import consumption and investment goods are assumed to follow

$$\lambda^{m,j}_t = \left(1-\rho_{\lambda^{m,j}}\right)\lambda^{m,j} + \rho_{\lambda^{m,j}}\lambda^{m,j}_{t-1} + \varepsilon_{\lambda^{m,j},t},\ \varepsilon_{\lambda^{m,j},t} \sim i.i.d.N\left(0, \sigma^2_{\lambda^{m,j}}\right), \tag{2.14}$$

for $j = \{c, i\}$.

The different importing firms buy the homogenous good at price P^*_t in the world market. In order to allow for incomplete exchange rate pass-through to the consumption and investment import prices we assume local currency price stickiness. The importing firms follow Calvo price setting and are allowed to change their price only when they receive a random price change signal. Each importing *consumption* firm faces a random probability $(1 - \xi_{m,c})$ that it can reoptimize its price in any period. Each importing *investment* firm faces a different probability $(1 - \xi_{m,i})$ that it can reoptimize. Let the reoptimized price for an imported consumption (investment good) be denoted $P^{m,c}_{new,t}$ ($P^{m,i}_{new,t}$). With probability $\xi_{m,c}$ ($\xi_{m,i}$) the firm does not reoptimize, and its price is then indexed to last period's inflation and the current inflation target according to the following scheme $P^{m,j}_{t+1} = \left(\pi^{m,j}_t\right)^{\kappa_{m,j}} \left(\bar{\pi}^c_{t+1}\right)^{1-\kappa_{m,j}} P^{m,j}_t$ for $j = \{c, i\}$.[8]

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[8] The updating scheme allows for the possibility that importing firms update to the domestic inflation target. Since the profit maximization for the importing firms involve own prices relative to the aggregate import price, as well as the firms marginal cost which is $S_t P^*_t$, it is not obvious why the domestic inflation target should be included in the updating scheme. By including the indexation parameter in the estimation, we evaluate which specification that is supported by the data.

Log-linearizing and combining the first-order conditions of the importing firms maximization programs with the aggregate import prices indices for the importing consumption and investment goods, we obtain the following Phillips curve relations, respectively:

$$\begin{aligned}\left(\widehat{\pi}_t^{m,j}-\widehat{\bar{\pi}}_t^c\right) &= \frac{\beta}{1+\kappa_{m,j}\beta}\left(\mathrm{E}_t\widehat{\pi}_{t+1}^{m,j}-\rho_\pi\widehat{\bar{\pi}}_t^c\right)+\frac{\kappa_{m,j}}{1+\kappa_{m,j}\beta}\left(\widehat{\pi}_{t-1}^{m,j}-\widehat{\bar{\pi}}_t^c\right) \\ &\quad -\frac{\kappa_{m,j}\beta\left(1-\rho_\pi\right)}{1+\kappa_{m,j}\beta}\widehat{\bar{\pi}}_t^c+\frac{(1-\xi_{m,j})(1-\beta\xi_{m,j})}{\xi_{m,j}\left(1+\kappa_{m,j}\beta\right)}\left(\widehat{mc}_t^{m,j}+\widehat{\lambda}_t^{m,j}\right),\end{aligned} \tag{2.15}$$

where $\widehat{mc}_t^{m,j}=\widehat{p}_t^*+\widehat{s}_t-\widehat{p}_t^{m,j}$ for $j=\{c,i\}$. Note that the markup shocks, $\widehat{\lambda}_t^{m,j}$, are observationally equivalent to shocks to the elasticity of substitution among imported consumption/investment goods, up to a scaling factor with an opposite sign (a positive substitution elasticity shock is a negative markup shock).[9]

2.1.3. Exporting firms

The exporting firms buy the *final* domestic good and differentiate it by brand naming. Subsequently they sell the continuum of differentiated goods to the households in the foreign market. The marginal cost is thus the price of the domestic good P_t. Each exporting firm i faces the following demand $\tilde{X}_{i,t}$ for its product:

$$\tilde{X}_{i,t}=\left(\frac{P_{i,t}^x}{P_t^x}\right)^{-\frac{\lambda_{x,t}}{\lambda_{x,t}-1}}\tilde{X}_t, \tag{2.16}$$

where we assume that the export price $P_{i,t}^x$ is invoiced in the local currency of the export market. $\lambda_{x,t}$ determines the stochastic markup on the differentiated export goods.[10] The exogenous process for the markup is assumed to be given by

$$\lambda_{x,t}=\left(1-\rho_{\lambda_x}\right)\lambda_x+\rho_{\lambda_x}\lambda_{x,t-1}+\varepsilon_{\lambda_x,t},\ \varepsilon_{\lambda_x,t}\ \tilde{}\ i.i.d.N\left(0,\sigma_{\lambda_x}^2\right). \tag{2.17}$$

In order to allow for incomplete exchange rate pass-through in the export market, we assume that export prices are sticky in the foreign currency. To model this we use the Calvo setup. When setting their prices, the export firms care about the relative price between the firms' own price and the aggregate export price, as well as the price of the domestic good since this is the export firms' marginal cost. Therefore, when an export firm is not allowed to optimize its price, the firm is assumed to index the price to last period's (export price) inflation and the domestic inflation target. The price in period $t+1$ is thus $P_{t+1}^x=\left(\pi_t^x\right)^{\kappa_x}\left(\bar{\pi}_{t+1}^c\right)^{1-\kappa_x}P_t^x$. The export firms maximize profits (denoted in the local currency), and combining the log-linearized first order condition with the aggregate export price index, we obtain the following aggregate export inflation equation

$$\begin{aligned}\left(\widehat{\pi}_t^x-\widehat{\bar{\pi}}_t^c\right) &= \frac{\kappa_x}{1+\beta\kappa_x}\left(\widehat{\pi}_{t-1}^x-\widehat{\bar{\pi}}_t^c\right)+\frac{\beta}{1+\beta\kappa_x}\left(\mathrm{E}_t\widehat{\pi}_{t+1}^x-\rho_\pi\widehat{\bar{\pi}}_t^c\right) \\ &\quad -\frac{\beta\kappa_x\left(1-\rho_\pi\right)}{1+\beta\kappa_x}\widehat{\bar{\pi}}_t^c+\frac{(1-\beta\xi_x)(1-\xi_x)}{\xi_x\left(1+\beta\kappa_x\right)}\left(\widehat{mc}_t^x+\widehat{\lambda}_{x,t}\right),\end{aligned} \tag{2.18}$$

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[9] The flexible price problem is relevant for the steady state we are linearzing around, and can be described by setting $\xi_{m,j}=0$ for $j\epsilon\{c,i\}$. In a flexible price environment the imported goods firms therefore must set the following price $P_t^{m,j}=\lambda_t^{m,j}S_tP_t^*$ for $j=\{c,i\}$.

[10] The steady state markup for the exporting firms is by assumption unity, i.e. $\lambda_x=1$. This assumption enables us to assume that the foreign and domestic price level coincide in the steady state when we consider a steady state with a non-depreciating nominal exchange rate (i.e. a constant real exchange rate equal to unity).

where $\widehat{mc}_t^x = \widehat{p}_t - \widehat{s}_t - \widehat{p}_t^x$.

Further, the domestic economy is assumed to be small in relation to the foreign economy and plays a negligible part in aggregate foreign consumption. Assuming that aggregate foreign consumption and investment follows CES functions, foreign demand for the (aggregate) domestic consumption and investment goods, C_t^x and I_t^x respectively, are given by

$$C_t^x = \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} C_t^*, \qquad I_t^x = \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} I_t^*, \tag{2.19}$$

where C_t^*, I_t^* and P_t^* denote the foreign consumption, investment and price level, respectively. Notice that the specification in (2.19) allows for short run deviations from the law of one price which occur because export prices (in the local currency) are sticky.[11]

2.2. Households

There is a continuum of households, indexed by $j \in (0,1)$, which attain utility from consumption, leisure and cash balances. When maximizing their intertemporal utility households decide on their current level of consumption as well as their amount of cash holdings, foreign bond holdings and their domestic deposits. They also choose the level of capital services provided to the firms, their level of investment and their capital utilization rate. The households can increase their capital stock by investing in additional physical capital (I_t), taking one period to come in action, or by directly increasing the utilization rate of the capital at hand (u_t). The j^{th} household's preferences are

$$\mathrm{E}_0^j \sum_{t=0}^{\infty} \beta^t \left[\zeta_t^c \ln\left(C_{j,t} - bC_{j,t-1}\right) - \zeta_t^h A_L \frac{\left(h_{j,t}\right)^{1+\sigma_L}}{1+\sigma_L} + A_q \frac{\left(\frac{Q_{j,t}}{z_t P_t}\right)^{1-\sigma_q}}{1-\sigma_q} \right], \tag{2.20}$$

where $C_{j,t}$ and $h_{j,t}$ denote the j^{th} household's levels of aggregate consumption and work effort, respectively. $Q_{j,t}/P_t$ are real assets the household chooses to hold in non-interest bearing form. This value is scaled with z_t in order to render real balances stationary. Finally, we allow for habit persistence in preferences by including $bC_{j,t-1}$. The time series representation for the preference shocks are

$$\hat{\zeta}_t^i = \rho_{\zeta^i} \hat{\zeta}_{t-1}^i + \varepsilon_{\zeta^i,t}, \; \varepsilon_{\zeta^i,t} \; \tilde{} \; i.i.d.N\left(0, \sigma_{\zeta^i}^2\right),$$

where $\mathrm{E}\left(\zeta_t^i\right) = 1$ and $\hat{\zeta}_t^i = (\zeta_t^i - 1)/1$, $i \; \epsilon \; \{c, h\}$. We will refer to ζ_t^c as consumption preference shocks and ζ_t^h as labour supply shocks.

Aggregate consumption is assumed to be given by a CES index of domestically produced and imported goods according to:

$$C_t = \left[(1-\omega_c)^{1/\eta_c}\left(C_t^d\right)^{(\eta_c-1)/\eta_c} + \omega_c^{1/\eta_c}\left(C_t^m\right)^{(\eta_c-1)/\eta_c}\right]^{\eta_c/(\eta_c-1)}, \tag{2.21}$$

where C_t^d and C_t^m are consumption of the domestic and imported good, respectively. ω_c is the share of imports in consumption, and η_c is the elasticity of substitution between domestic and foreign

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[11] By assuming that the elasticity (η_f) is the same for consumption and investment in (2.19), we can use foreign output ($Y_t^* = C_t^* + I_t^*$) as the only "demand variable", and we therefore do not need to take a stand on how much of the exporting goods are used for consumption and investment purposes respectively.

consumption goods. By maximizing (2.21) subject to the budget constraint $P_tC_t^d + P_t^{m,c}C_t^m = P_t^cC_t$, we obtain the following consumption demand functions

$$C_t^d = (1-\omega_c)\left[\frac{P_t}{P_t^c}\right]^{-\eta_c} C_t, \qquad C_t^m = \omega_c\left[\frac{P_t^{m,c}}{P_t^c}\right]^{-\eta_c} C_t, \tag{2.22}$$

where the CPI price index (defined as the minimum expenditure required to buy one unit of C_t) is given by

$$P_t^c = \left[(1-\omega_c)(P_t)^{1-\eta_c} + \omega_c\left(P_t^{m,c}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)}. \tag{2.23}$$

As with consumption, total investment is assumed to be given by a CES aggregate of domestic and imported investment goods (I_t^d and I_t^m, respectively):

$$I_t = \left[(1-\omega_i)^{1/\eta_i}\left(I_t^d\right)^{(\eta_i-1)/\eta_i} + \omega_i^{1/\eta_i}\left(I_t^m\right)^{(\eta_i-1)/\eta_i}\right]^{\eta_i/(\eta_i-1)}, \tag{2.24}$$

where ω_i is the share of imports in investment, and η_i is the elasticity of substitution between domestic and imported investment goods. Because prices of the domestically produced investment goods coincide with the prices of the domestically produced consumption goods we have the following investment demand functions:

$$I_t^d = (1-\omega_i)\left[\frac{P_t}{P_t^i}\right]^{-\eta_i} I_t, \qquad I_t^m = \omega_i\left[\frac{P_t^{m,i}}{P_t^i}\right]^{-\eta_i} I_t, \tag{2.25}$$

where the aggregate investment price P_t^i is given by

$$P_t^i = \left[(1-\omega_i)(P_t)^{1-\eta_i} + \omega_i\left(P_t^{m,i}\right)^{1-\eta_i}\right]^{1/(1-\eta_i)}. \tag{2.26}$$

The law of motion for the households physical capital stock is given by

$$\bar{K}_{t+1} = (1-\delta)\bar{K}_t + \Upsilon_t F(I_t, I_{t-1}) + \Delta_t \tag{2.27}$$

and is assumed to be identical for all households.[12] $F(I_t, I_{t-1})$ is a function which turns investment into physical capital. We will adopt the specification of Christiano, Eichenbaum and Evans (2005) and assume that

$$F(I_t, I_{t-1}) = \left(1 - \tilde{S}\left(I_t/I_{t-1}\right)\right) I_t \tag{2.28}$$

where $\tilde{S}(\mu_z) = \tilde{S}'(\mu_z) = 0$, and $\tilde{S}''(\mu_z) \equiv \tilde{S}'' > 0$. Note that only the parameter $\tilde{S}''$ is identified and will be used in the log-linearized model. In (2.27), Υ_t is a stationary investment-specific technology shock, given by the following exogenous AR(1)-process

$$\hat{\Upsilon}_t = \rho_\Upsilon \hat{\Upsilon}_{t-1} + \varepsilon_{\Upsilon,t}, \tag{2.29}$$

where $\hat{\Upsilon}_t = (\Upsilon_t - 1)/1$ and $\varepsilon_{\Upsilon,t}$ ~ $i.i.d.N\left(0, \sigma_\Upsilon^2\right)$.[13]

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[12] The variable, Δ_t, reflects that households have access to a market where they can purchase new, installed capital, $\bar{K}_{t+1}$. Households wishing to sell $\bar{K}_{t+1}$ are the only suppliers in this market, while households wishing to buy $\bar{K}_{t+1}$ are the only source of demand. Since all households are identical, the only equilibrium is one in which $\Delta_t = 0$. We nevertheless introduce this variable as a convenient way to define the price of capital, $P_{k',t}$. See Christiano, Eichenbaum and Evans (2005) for further details.

[13] In the Altig et al. (2003) model this is a trend-stationary technology shock, but for simplicity we here assume that it is stationary without a trend.

Households face two forms of uncertainty. There is aggregate uncertainty that stems from aggregate shocks. In addition, the households face idiosyncratic uncertainty. Being a monopoly supplier of its own labour, it sets its wage rate. However, it can only adjust its wage at exogenously and randomly determined points in time. In modeling this, we follow Calvo (1983). We further restrict the analysis by making assumptions which guarantee that the frictions do not cause households to become heterogeneous. We do this by allowing households to enter into insurance markets against the outcomes of these frictions. The assumption of complete domestic financial markets in this economy - i.e., that each household can insure against any type of idiosyncratic risk through the purchase of the appropriate portfolio of securities - preserves the representative agent framework. This implies that we do not need to keep track of the entire distribution of the households' wealth, which would otherwise become a state variable. Since households are identical *ex ante* they are willing to enter such insurance contracts. As a result, all households face the same budget constraint in each period which (in nominal terms) is given by

$$\begin{aligned}
&M_{j,t+1}+S_tB^*_{j,t+1}+P^c_tC_{j,t}\left(1+\tau^c_t\right)+P^i_tI_{j,t}+P_t\left(a(u_{j,t})\overline{K}_{j,t}+P_{k',t}\Delta_t\right)= \qquad (2.30)\\
&R_{t-1}\left(M_{j,t}-Q_{j,t}\right)+Q_{j,t}+\left(1-\tau^y_t\right)\tfrac{W_{j,t}}{1+\tau^w_t}h_{j,t}+\left(1-\tau^k_t\right)R^k_tu_{j,t}\overline{K}_{j,t}+R^*_{t-1}\Phi(\tfrac{A_{t-1}}{z_{t-1}},\widetilde{\phi}_{t-1})S_tB^*_{j,t}\\
&-\tau^k_t\left[\left(R_{t-1}-1\right)\left(M_{j,t}-Q_{j,t}\right)+\left(R^*_{t-1}\Phi(\tfrac{A_{t-1}}{z_{t-1}},\widetilde{\phi}_{t-1})-1\right)S_tB^*_{j,t}+B^*_{j,t}\left(S_t-S_{t-1}\right)\right]+TR_t+D_{j,t},
\end{aligned}$$

where the subscript j denotes household choice variables and upper-case variables without the subscript denote economy-wide averages. The terms on the left hand side of the equality show how the household use their resources, while the terms on the right hand side show what resources the households have at their disposal. $P^i_tI_{j,t}$ is nominal resources spent by the household on investment goods. All interest rates are expressed as gross rates, i.e. $R_t = 1 + r_t$. Households hold their financial assets in the form of cash balances, domestic bank deposits and foreign bonds. They earn interest on the amount of their nominal domestic assets that are not held as cash, i.e. $M_{j,t} - Q_{j,t}$. The interest rate they earn is R_{t-1}, since we think of the deposits paying out a nominal amount with certainty (i.e., a zero coupon bond). They can also save in foreign bonds, which pay a risk-adjusted pre-tax gross interest rate of $R^*_{t-1}\Phi(A_{t-1}/z_{t-1},\widetilde{\phi}_{t-1})$.

Following Lundvik (1992) and Benigno (2001), the term $\Phi(\frac{A_t}{z_t},\widetilde{\phi}_t)$ is a premium on foreign bond holdings, which depends on the real aggregate net foreign asset position of the domestic economy, $A_t \equiv \frac{S_tB^*_{t+1}}{P_t}$. The function $\Phi(\frac{A_t}{z_t},\widetilde{\phi}_t)$ is assumed to be strictly decreasing in A_t and to satisfy $\Phi(0,0) = 1$. Consequently, this function captures imperfect integration in the international financial markets. If the domestic economy as a whole is a net borrower (so $B^*_{t+1} < 0$), domestic households are charged a premium on the foreign interest rate. If the domestic economy is a net lender ($B^*_{t+1} > 0$), households receive a lower remuneration on their savings. The introduction of this risk-premium is needed in order to ensure a well-defined steady-state in the model (see Schmitt-Grohé and Uribe, 2003, for further details). $\widetilde{\phi}_t$, in turn, is a time varying shock to the risk premium.

Since households own the physical capital stock, the capital adjustment costs are paid by the households, which explains the presence of $a(u_t)P_t$ in the budget constraint. Here, $a(u)$ is the utilization cost function, satisfying $a(1) = 0$, $u = 1$ and $a' = \left(1-\tau^k\right)r^k$ in steady state, and $a'' \geq 0$. u_t is the utilization rate, that is $u_t = K_t/\bar{K}_t$. For reasons discussed previously, $P_{k',t}\Delta_t$ is present to be able to compute the price of capital in the model. τ^c_t is a consumption tax, τ^w_t is a pay-roll tax (assumed for simplicity to be paid by the households), τ^y_t is a labour-income tax, and τ^k_t is a capital-income tax. TR_t are lump-sum transfers from the government and $D_{j,t}$ is the household's net cash income from participating in state contingent securities at time t.

We will now state the first-order conditions for the households' problem, where we make use of the fact that the households' average (aggregate) choices coincide in equilibrium. To render stationarity of all variables, we need to divide all quantities with the trend level of technology z_t, and multiply the Lagrangian multiplier $\psi_{z,t} \equiv \upsilon_t z_t P_t$ (υ_t being the Lagrangian multiplier on households budget constraint 2.30 which is expressed in nominal terms) with it.[14] After scaling with the technology level, we obtain the following set of first-order conditions

$$\text{w.r.t. } C_t : \frac{\zeta_t^c}{c_t - bc_{t-1}\frac{1}{\mu_{z,t}}} - \beta b \mathrm{E}_t \frac{\zeta_{t+1}^c}{c_{t+1}\mu_{z,t+1} - bc_t} - \psi_{z,t}\frac{P_t^c}{P_t}\left(1+\tau_t^c\right) = 0, \tag{2.31}$$

$$\text{w.r.t. } M_{t+1} : -\psi_{z,t} + \beta \mathrm{E}_t[\frac{\psi_{z,t+1}}{\mu_{z,t+1}}\frac{R_t}{\pi_{t+1}} - \frac{1}{\mu_{z,t+1}}\frac{\psi_{z,t+1}}{\pi_{t+1}}\tau_{t+1}^k\left(R_t - 1\right)] = 0, \tag{2.32}$$

$$\text{w.r.t. } \bar{K}_{t+1} : \quad \begin{aligned} &-P_{k',t}\psi_{z,t} + \beta \mathrm{E}_t[\tfrac{\psi_{z,t+1}}{\mu_{z,t+1}}((1-\delta)P_{k',t+1} \\ &\qquad + \left(1-\tau_{t+1}^k\right) r_{t+1}^k u_{t+1} - a\left(u_{t+1}\right))] = 0, \end{aligned} \tag{2.33}$$

$$\text{w.r.t. } I_t : \quad \begin{aligned} &-\psi_{z,t}\tfrac{P_t^i}{P_t} + P_{k',t}\psi_{z,t}\Upsilon_t F_1(i_t, i_{t-1}, \mu_{z,t}) \\ &\qquad + \beta \mathrm{E}_t[P_{k',t+1}\tfrac{\psi_{z,t+1}}{\mu_{z,t+1}}\Upsilon_{t+1}F_2(i_{t+1}, i_t, \mu_{z,t+1})] = 0, \end{aligned} \tag{2.34}$$

$$\text{w.r.t. } u_t : \ \psi_{z,t}\left(\left(1-\tau_t^k\right) r_t^k - a'(u_t)\right) = 0, \tag{2.35}$$

$$\text{w.r.t. } Q_t : \ \zeta_t^q A_q \bar{q}_t^{-\sigma_q} - \left(1-\tau_t^k\right)\psi_{z,t}\left(R_{t-1} - 1\right) = 0, \tag{2.36}$$

$$\text{w.r.t. } B_{t+1}^* : \quad \begin{aligned} &-\psi_{z,t}S_t + \beta \mathrm{E}_t[\tfrac{\psi_{z,t+1}}{\mu_{z,t+1}\pi_{t+1}}(S_{t+1}R_t^*\Phi(a_t, \widetilde{\phi}_t) \\ &\qquad -\tau_{t+1}^k S_{t+1}\left(R_t^*\Phi(a_t, \widetilde{\phi}_t) - 1\right) - \tau_{t+1}^k\left(S_{t+1} - S_t\right))] = 0, \end{aligned} \tag{2.37}$$

where we have used $z_t\omega_t = \psi_{z,t}P_{k',t}$ (from the foc w.r.t. Δ_t; ω_t is the Lagrangian multiplier on the lam of motion for capital, 2.27).

By combining the households' first order conditions for domestic and foreign bond holdings (2.32 and 2.37, respectively) we obtain, after log-linearization, the following modified uncovered interest rate parity condition:

$$\widehat{R}_t - \widehat{R}_t^* = \mathrm{E}_t\Delta\widehat{S}_{t+1} - \widetilde{\phi}_a\widehat{a}_t + \widehat{\widetilde{\phi}}_t, \tag{2.38}$$

where we have assumed that the premium on foreign bond holdings follows the function $\Phi(a_t, \widetilde{\phi}_t) = \exp\left(-\widetilde{\phi}_a\left(a_t - \bar{a}\right) + \widetilde{\phi}_t\right)$ where $\mathrm{E}\left(\widetilde{\phi}_t\right) = 0$. Because of imperfect integration in the international financial markets, the net foreign asset position $\widehat{a}_t$ of the domestic economy thus enters the interest rate parity condition. The exogenous source of risk-premium variation is assumed to be given by the following process

$$\widehat{\widetilde{\phi}}_t = \rho_{\widetilde{\phi}}\widehat{\widetilde{\phi}}_{t-1} + \varepsilon_{\widetilde{\phi},t}, \ \varepsilon_{\widetilde{\phi},t} \sim i.i.d.N\left(0, \sigma_{\widetilde{\phi}}^2\right). \tag{2.39}$$

2.2.1. Wage setting equation

Each household is a monopoly supplier of a differentiated labour service requested by the domestic firms. This implies that the households can determine their own wage. After having set their wages, households inelastically supply the firms' demand for labour at the going wage rate.

In modeling this wage equation we follow Erceg et al. (2000) and Christiano et al. (2005), and introduce wage stickiness à la Calvo. Each household sells its labour ($h_{j,t}$) to a firm which transforms household labour into a homogeneous input good H using the following production function:

$$H_t = \left[\int_0^1 \left(h_{j,t}\right)^{\frac{1}{\lambda_w}} dj\right]^{\lambda_w}, \ 1 \leq \lambda_w < \infty, \tag{2.40}$$

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[14] As explained earlier, we let small letters indicate that a variable have been stationarized.

where λ_w is the wage markup. This firm takes the input price of the j^{th} differentiated labour input as given, as well as the price of the homogenous labour services. The demand for labour that an individual household faces is determined by

$$h_{j,t} = \left[\frac{W_{j,t}}{W_t} \right]^{\frac{\lambda_w}{1-\lambda_w}} H_t. \tag{2.41}$$

In every period each household faces a random probability $1 - \xi_w$ that it can change its nominal wage. The j^{th} household's reoptimized wage is set to $W_{j,t}^{new}$, taking into account the probability ξ_w that the wage will not be reoptimized in the future. The households that can not reoptimize set their wages according to $W_{j,t+1} = \left(\pi_t^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c\right)^{(1-\kappa_w)} \mu_{z,t+1} W_{j,t}$,where $\mu_{z,t+1} = \frac{z_{t+1}}{z_t}$.Consequently, non-optimizing households index their wage rate to last period's CPI inflation rate, the current inflation target, as well as adding the permanent technology growth factor to their wage. If a period t optimizing household is not allowed to change its wage during s periods ahead, the wage in period $t+s$ is $W_{j,t+s} = \left(\pi_t^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c ... \bar{\pi}_{t+s}^c\right)^{(1-\kappa_w)} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right) W_{j,t}^{new}$.

The first-order condition for the wage rate is given by

$$\mathrm{E}_t \sum_{s=0}^{\infty} \left(\beta \xi_w\right)^s h_{j,t+s} \left[-\zeta_{t+s}^h A_L \left(h_{j,t+s}\right)^{\sigma_L} + \frac{W_t^{new}}{z_t P_t} \frac{z_{t+s} \upsilon_{t+s} P_{t+s}}{\lambda_w} \frac{\left(1 - \tau_{t+s}^y\right)}{\left(1 + \tau_{t+s}^w\right)} \frac{\left(\frac{P_{t+s-1}^c}{P_{t-1}^c}\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c ... \bar{\pi}_{t+s}^c\right)^{(1-\kappa_w)}}{\frac{P_{t+s}^d}{P_t^d}} \right] = 0, \tag{2.42}$$

where $-\zeta_{t+s}^h A_L \left(h_{j,t+s}\right)^{\sigma_L}$ is the marginal disutility of labour in period $t+s$ (see 2.20). Log-linearizing equation (2.42), using (2.41) and the aggregate wage index yields the log-linearized wage equation. When wages are fully flexible ($\xi_w = 0$), the real wage is set as a markup λ_w over the current ratio of the marginal disutility of labour and the marginal utility of additional income. In this case the households' wage decision is equivalent to the first order condition for their choice of labour input (adjusted for the average wage markup λ_w), i.e

$$-\zeta_t^h A_L H_t^{\sigma_L} + \left(1 - \tau_t^y\right) \frac{\psi_{z,t}}{\lambda_w} \frac{\bar{w}_{j,t}}{1 + \tau_t^w} = 0. \tag{2.43}$$

2.3. Government

The government in this economy collects tax revenues resulting from the taxes τ_t^k, τ_t^y, τ_t^c and τ_t^w, and spend resources on government consumption, G_t. The resulting fiscal surplus/deficit plus the seigniorage are assumed to be transferred back to the households in a lump sum fashion (TR_t in 2.30). Consequently, there is no government debt.

We will assume that tax-rates and government expenditures are given exogenously by a simple VAR-model. Let $\tau_t = \left[\begin{array}{ccccc} \hat{\tau}_t^k & \hat{\tau}_t^y & \hat{\tau}_t^c & \hat{\tau}_t^w & \tilde{G}_t \end{array} \right]'$, where $\tilde{G}_t$ denotes detrended (HP-filtered) government expenditures. The fiscal policy VAR-model is given by

$$\Gamma_0 \tau_t = \Gamma\left(L\right) \tau_{t-1} + \varepsilon_{\tau,t},\ \varepsilon_{\tau,t} \sim N\left(0, \Sigma_\tau\right). \tag{2.44}$$

When estimating this process in the data, we tested and could not reject the null hypothesis that the off-diagonal terms in Γ_0 were zero.

2.4. The central bank

Rather than assuming that monetary policy aims at optimizing a specific loss function, we approximate the behavior of the central bank with an instrument rule. Following Smets and Wouters (2003a), the policy maker is assumed to adjust the short run interest rate in response to deviations of CPI inflation from the inflation target $\left(\hat{\pi}^c - \widehat{\bar{\pi}}^c\right)$, the output gap $(\hat{y})$ and the real exchange rate $(\hat{x})$. We also allow for interest rate smoothing. Although instrument rules are not based on optimizing behavior, they appear to perform well from an empirical viewpoint, and it is not obvious that these rules perform substantially worse than optimal rules from a welfare perspective.[15]

Thus, monetary policy is approximated with the following rule (expressed in log-linear form)

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left(\widehat{\bar{\pi}}_t^c + r_\pi\left(\hat{\pi}_{t-1}^c - \widehat{\bar{\pi}}_t^c\right) + r_y \hat{y}_{t-1} + r_x \hat{x}_{t-1}\right) + r_{\Delta\pi}\Delta\hat{\pi}_t^c + r_{\Delta y}\Delta\hat{y}_t + \varepsilon_{R,t}, \quad (2.45)$$

where $\widehat{R}_t$ is the short-rate interest rate, $\hat{\pi}_t^c$ the CPI inflation rate, $\hat{y}_t$ the output gap and $\hat{x}_t$ denotes the log-linearized real exchange rate, which is given by

$$\hat{x}_t = \hat{S}_t + \hat{P}_t^* - \hat{P}_t^c.$$

The output gap is measured as the deviation from the trend value of output in the economy, and thus not as the deviation from the flexible price level as in Smets and Wouters (2003a). We assume that the central bank responds to the model-consistent measure of the CPI inflation rate index, $\hat{\pi}_t^c$, but omits indirect taxes $\hat{\tau}_t^c$, i.e.

$$\widehat{\pi}_t^c = \left((1-\omega_c)\left(\gamma^{d,c}\right)^{1-\eta_c}\right)\widehat{\pi}_t^d + \left((\omega_c)\left(\gamma^{mc,c}\right)^{(1-\eta_c)}\right)\widehat{\pi}_t^{m,c}, \quad (2.46)$$

where $\gamma^{d,c}(\gamma^{mc,c})$ is the steady-state relative price between domestically produced(imported) goods and the CPI. $\widehat{\bar{\pi}}_t^c$ is a time-varying inflation target and $\varepsilon_{R,t}$ is an interest rate shock. We will refer to the first as an inflation target shock and the latter as a monetary policy shock. The deviation of the inflation target from the steady-state inflation rate is assumed to follow the process

$$\widehat{\bar{\pi}}_t^c = \rho_\pi \widehat{\bar{\pi}}_{t-1}^c + \varepsilon_{\bar{\pi}^c,t}. \quad (2.47)$$

2.5. Market clearing conditions

In equilibrium the final goods market, the loan market and the foreign bond market must clear. The final goods market clears when the demand from the households, the government and the foreign market can be met by the production of the final good firm. The loan market, in turn, clears when the demand for liquidity from the firms (financing their wage bills) equals the supplied deposits of the households plus the monetary injection by the central bank. The foreign bond market is in equilibrium when the positions of the export and importing firms equals the households' choice of foreign bond holdings.

2.5.1. The aggregate resource constraint

The equilibrium resource constraint from the production perspective satisfies

$$C_t^d + I_t^d + G_t + C_t^x + I_t^x \leq \epsilon_t z_t^{1-\alpha} K_t^\alpha H_t^{1-\alpha} - z_t\phi - a(u_t)\bar{K}_t. \quad (2.48)$$

By substituting (2.22), (2.25), and (2.19) into (2.48), we obtain

$$\begin{aligned}(1-\omega_c)\left[\frac{P_t^c}{P_t}\right]^{\eta_c} c_t + (1-\omega_i)\left[\frac{P_t^i}{P_t}\right]^{\eta_i} i_t + g_t + \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} y_t^* \frac{z_t^*}{z_t} \\ \leq \epsilon_t\left(\frac{1}{\mu_{z,t}}\right)^\alpha k_t^\alpha H_t^{1-\alpha} - \phi - a(u_t)\bar{k}_t \frac{1}{\mu_{z,t}},\end{aligned} \quad (2.49)$$

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[15] Onatski and Williams (2004) find that instrument rules perform relatively well compared to optimal rules in the Smets and Wouters (2003a) model, and that they are more robust to different parameter estimates.

where we have used the assumption that $Y_t^* = C_t^* + I_t^*$, scaled K_t and $\bar{K}_t$ with z_{t-1}, and stationarized the other real variables with z_t. Note that Y_t^* has been scaled with z_t^* which is the reason why $\frac{z_t^*}{z_t}$ appears in the formula. z_t^* is supposed to follow a similar process as z_t. We will maintain the assumption that $\mu_z = \mu_z^*$, and treat $\tilde{z}_t^* = \frac{z_t^*}{z_t}$ as a stationary shock which measures the degree of asymmetry in the technological progress in the domestic economy versus the rest of the world. By assuming $z_0^* = z_0 = 1$ this implies that the technology levels must be the same in steady state, $\tilde{z}^* = 1$. We assume that the asymmetric technology shock follows the process (log-linearized)

$$\widehat{\tilde{z}}_{t+1}^* = \rho_{\tilde{z}^*} \widehat{\tilde{z}}_t^* + \varepsilon_{\tilde{z}^*,t+1}. \tag{2.50}$$

2.5.2. Evolution of net foreign assets

The evolution of net foreign assets at the aggregate level satisfies

$$S_t B_{t+1}^* = S_t P_t^x \left(C_t^x + I_t^x\right) - S_t P_t^* \left(C_t^m + I_t^m\right) + R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_{t-1}) S_t B_t^*, \tag{2.51}$$

where we notice that $R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_t)$ is the risk-adjusted gross nominal interest rate. Multiplying through with $1/(P_t z_t)$, using $\frac{C_t^x}{z_t} + \frac{I_t^x}{z_t} = \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} \frac{Y_t^*}{z_t^*} \frac{z_t^*}{z_t}$ and our definition of $a_t \equiv \frac{S_t B_{t+1}^*}{P_t z_t}$, we have the stationarized NFA-equation

$$a_t = \left(mc_t^x\right)^{-1} \left(\gamma_t^{x,*}\right)^{-\eta_f} y_t^* \tilde{z}_t^* - \left(mc_t^x \gamma_t^{x,*}\right)^{-1} \left(c_t^m + i_t^m\right) + R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_{t-1}) \frac{a_{t-1}}{\pi_t \mu_{z,t}} \frac{S_t}{S_{t-1}},$$

where $mc_t^x \equiv \frac{P_t}{S_t P_t^x}$, and $\gamma_t^{x,*} \equiv P_t^x / P_t^*$.

2.5.3. Loan market clearing

We also have the money market clearing condition, which reads

$$\nu_t W_t H_t = \mu_t M_t - Q_t, \tag{2.52}$$

or equivalently, in its stationarized form,

$$\nu_t \bar{w}_t H_t = \frac{\mu_t \bar{m}_t}{\pi_t \mu_{z,t}} - \bar{q}_t, \tag{2.53}$$

where $\bar{m}_t \equiv \frac{M_t}{P_{t-1} z_{t-1}}$ and $\bar{q}_t \equiv \frac{Q_t}{P_t z_t}$.

2.6. Foreign economy

As discussed previously, we adopt the assumption that foreign inflation, output and interest rate are exogenously given. Let $X_t^* \equiv \left[\begin{array}{ccc} \pi_t^* & \hat{y}_t^* & R_t^* \end{array}\right]'$ where π_t^* and R_t^* are quarterly foreign inflation and interest rates, and $\hat{y}_t^*$ foreign HP-filtered output. The foreign economy is modeled as a VAR model,

$$F_0 X_t^* = F(L) X_{t-1}^* + \varepsilon_{x^*,t}, \quad \varepsilon_{x^*,t} \sim N\left(0, \Sigma_{x^*}\right). \tag{2.54}$$

When estimating the VAR, we assume and cannot reject that F_0 in (2.54) is lower triangular with an additional zero restriction on the response of output on contemporaneous inflation. This structure of F_0 is equivalent to assuming predetermined expectations in the Phillips curve and output equation. Since we could not reject this structure of F_0, we are able to identify the effects of a specific foreign shock.

3. Data and measurement issues

3.1. Data

To estimate the model we use quarterly Euro area data for the period 1970:1-2002:4.[16] The data set we employ was first constructed by Fagan et al. (2001). We have chosen to match the following set of fifteen variables, the GDP deflator, the real wage, consumption, investment, the real exchange rate, the short-run interest rate, employment, GDP, exports, imports, the consumption deflator, the investment deflator, foreign output, foreign inflation and the foreign interest rate. To calculate the likelihood function of the observed variables we apply the Kalman filter. As in Altig et al. (2003), the non-stationary technology shock induces a common stochastic trend in the real variables of the model. To make these variables stationary we use first differences and derive the state space representation for the following vector of observed variables

$$\tilde{Y}_t = \begin{array}{l} [\ \pi_t^d \quad \Delta\ln(W_t/P_t) \quad \Delta\ln C_t \quad \Delta\ln I_t \quad \hat{x}_t \quad R_t \quad \hat{E}_t \quad \Delta\ln Y_t ... \\ \qquad \Delta\ln\tilde{X}_t \quad \Delta\ln\tilde{M}_t \quad \pi_t^{def,c} \quad \pi_t^{def,i} \quad \Delta\ln Y_t^* \quad \pi_t^* \quad R_t^*\ ]'. \end{array} \tag{3.1}$$

In comparison with the previous literature, we have chosen to work with a large number of variables, in order to be able to identify the estimated parameters in a satisfactory way. The foreign variables are included in the estimation because they enable identification of the asymmetric technology shock $(\tilde{z}_t^*)$.[17]

For the Euro area there is no (official) data on aggregate hours worked, H_t. Due to these data limitations we use employment E_t in our empirical estimations. Since employment is likely to respond more slowly to shocks than hours worked, we model employment using Calvo-rigidity (following Smets and Wouters, 2003a). We assume that only a fraction $(1-\xi_e)$ of the firms can adjust the level of employment to the preferred amount of total labour input. The rest of the firms ξ_e are forced to keep the level of employment they had in the last period, $E_{i,t+1} = E_{i,t}^{new}$. The difference is taken up by each worker's labour input (unobserved hours per worker). That is, each worker supplies its labour inelastically after having set his or her wage. The aggregate employment equation then follows[18]

$$\Delta\hat{E}_t = \beta \mathrm{E}_t \Delta\hat{E}_{t+1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{\xi_e}\left(\hat{H}_t - \hat{E}_t\right). \tag{3.2}$$

We have adjusted the raw data for three series. First, there is an upward trend in the employment series for the Euro area, presumably reflecting an increasing degree of part-time employment (apart from population growth). Since hours worked and employment per capita are stationary variables in the model, we decided to remove a linear trend in this variable prior to estimation. Second, the shares of import and export to output are increasing during the sample period, from about 0.15 to 0.36.

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[16] We use the period 1970:1-1979:4 to compute a prior of the state for the unobserved variables, and then use the period 1980:1-2002:4 for inference.

[17] We have also experimented with an alternative strategy which exploits the fact that the real variables contain the same stochastic trend as output. In this case the vector with observed variables is defined as

$$\tilde{Y}_t = \begin{array}{l} [\ \pi_t^d \quad \ln(W_t/P_t) - \ln Y_t \quad \ln C_t - \ln Y_t \quad \ln I_t - \ln Y_t \quad \hat{x}_t \quad R_t \quad \hat{E}_t \quad \Delta\ln Y_t ... \\ \qquad \ln\tilde{X}_t - \ln Y_t \quad \ln\tilde{M}_t - \ln Y_t \quad \pi_t^{def,c} \quad \pi_t^{def,i} \quad \ln Y_t^* - \ln Y_t \quad \pi_t^* \quad R_t^*\ ]'. \end{array}$$

As can be seen in Adolfson et al. (2005), the estimation results for the model with this vector of observable variables are very similar to the ones reported in the current manuscript.

[18] We assume that firm i faces the following problem $\min_{E_{i,t}^{new}} \sum_{s=0}^{\infty} (\beta\xi_e)^s \left(n_i E_{i,t}^{new} - H_{i,t+s}\right)^2$, where n_i is hours per worker in firm i. By log-linearizing the first order condition of this optimization problem and combining that with the log-linearized employment aggregator, we obtain the aggregate employment equation in the main text. Notice that $\hat{H}_t$ and $\hat{E}_t$ coincide if $\xi^e = 0$.

Although these numbers are distorted by the fact that a part of this increase reflects intra-Euro trade, they also convey a clear pattern of increasing trade. In our model, import and export are assumed to grow at the same rate as output. Therefore, we decided to remove the excessive trend of import and export in the data, to render the export and import shares stationary.[19]

For all other variables in (3.1), we use the actual series (seasonally adjusted with the X12-method). It should be pointed out that the stationary variables x_t and E_t (the real exchange rate and employment, respectively) are measured as percentage deviations around the mean, i.e. $\hat{x}_t = (x_t - x)/x$ and $\hat{E}_t = (E_t - E)/E$, respectively. Note also that the Fagan data set includes foreign (i.e., rest of the world) output and inflation, but not foreign interest rates. In the VAR for the exogenous foreign variables, we therefore use the Fed funds rate as a proxy for R_t^*.

In Figure 1, the solid line depict the data that we match with the model along with the "fitted" values from the model (the dashed line represent the one-sided estimates from the Kalman filter which can loosely be interpreted as the in-sample fit of the model).

3.2. Measurement issues

Here we describe how consumption, investment, export, import and output should be measured in the model in order to correspond to the data. In the data, the real GDP identity is given by

$$Y_t = \tilde{C}_t + \tilde{I}_t + G_t + \tilde{X}_t - \tilde{M}_t. \tag{3.3}$$

In the theoretical model, we have (2.48) which can be written as

$$\left(C_t^d + C_t^m\right) + \left(I_t^d + I_t^m\right) + G_t + C_t^x + I_t^x - \left(C_t^m + I_t^m\right) \leq \epsilon_t z_t^{1-\alpha} K_t^{\alpha} H_t^{1-\alpha} - z_t \phi - a(u_t)\bar{K}_t. \tag{3.4}$$

By comparing the resource constraints in the theoretical model (3.4) and in the data (3.3), a natural way to measure quantities in the model is given by

$$\begin{aligned} \tilde{C}_t &\equiv C_t^d + C_t^m, \\ \tilde{I}_t &\equiv I_t^d + I_t^m, \\ \tilde{M}_t &\equiv C_t^m + I_t^m, \\ \tilde{X}_t &\equiv C_t^x + I_t^x. \end{aligned}$$

This way of measuring quantities in the model implies adjusting the model-based concepts for consumption, investment, import and export with the appropriate relative prices.[20]

We must also take into account that we have capital utilization costs in our theoretical model. Because of these adjustment costs, the GDP identity in the theoretical model is not directly comparable with the data, as can be seen from (3.4) and (3.3). Since the adjustment costs tend to be cyclical, we have chosen to add the adjustment costs to investment, instead of interpreting them as the residual in the real GDP identity in the data. Output is then measured in accordance with (2.4) at the aggregate level.

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[19] In terms of our model these strong increases in import and export shares would imply that the weights of foreign consumption/investment in the consumption/investment bundles, i.e. ω_c/ω_i, are increasing over time.

[20] For instance, by combining the demand schedules in (2.22), we have that

$$\tilde{C}_t = C_t^d + C_t^m = \left((1-\omega_c) \left[\frac{P_t}{P_t^c} \right]^{-\eta_c} + \omega_c \left[\frac{P_t^{m,c}}{P_t^c} \right]^{-\eta_c} \right) C_t.$$

The nominal GDP identity in the data is given by

$$P_tY_t = (1+\tau_t^c)\left(P_tC_t^d + P_t^{m,c}C_t^m\right) + \left(P_tI_t^d + P_t^{m,i}I_t^m\right) + P_tG_t + (P_t^xC_t^x + P_t^xI_t^x) - \left(P_t^{m,c}C_t^m + P_t^{m,i}I_t^m\right),$$

and consequently, the deflators for consumption and investment are measured as

$$P_t^{def,c} \equiv \frac{(1+\tau_t^c)\left(P_tC_t^d + P_t^{m,c}C_t^m\right)}{C_t^d + C_t^m}, \qquad P_t^{def,i} \equiv \frac{P_tI_t^d + P_t^{m,i}I_t^m}{I_t^d + I_t^m}. \tag{3.5}$$

Finally, the growth rate in foreign output, $\Delta \ln Y_t$, is measured as $\ln \mu_z + \Delta \hat{y}_t^* + \Delta \widehat{\tilde{z}}_t^*$ where $\widehat{\tilde{z}}_t^*$ is given by (2.50) and $\hat{y}_t^*$ is given from (2.54).

4. Estimation

4.1. Calibrated parameters

A number of parameters are kept fixed throughout the estimation procedure. Most of these parameters can be related to the steady state values of the observed variables in the model, and are therefore calibrated so as to match the sample mean of these.[21] The money growth rate μ is related to the steady state level of inflation, $\pi = \mu/\mu_z$, and is set to 1.01 (per quarter). If the steady state growth rate of output is around 0.5 percent quarterly, this number implies a steady state quarterly inflation rate of around 0.5 percent as well.[22] The discount factor β is set to 0.999, which implies a nominal interest of 5.5 percent (annually) in steady state assuming a capital-income tax of around 10 percent.[23] This value of β is quite high, but a lower value results in an even higher nominal interest rate, and thus an implausible high real interest rate in our view. To match the sample mean of the investment-output and labour income-output ratios, the depreciation rate δ is set to 0.013 and the share of capital in production α to 0.29. The constant in the labour disutility function A_L is set to 7.5, implying that the agents devote around 30 percent of their time to work in steady state. Following Christiano, Eichenbaum and Evans (2005), the labour supply elasticity σ_L is set to 1, and the markup power in the wage setting λ_w is set to 1.05.

The share of imports in aggregate consumption ω_c and investment ω_i are calibrated to match the sample average of the import-output ratio ($\frac{\tilde{M}}{Y}$) and the ratio of domestic consumption and investment over imported consumption and investment in the Euro area (see Andrés, Ortega and Vallés, 2003). This implies that ω_c is set to 0.31, and ω_i to 0.55, respectively. Since our measures of import and export in the data contain intra-Euro trade, these numbers probably exaggerate the degree of openness in the model to some extent. On the other hand, there is a clear upward trend in the import and export ratios over time.

Throughout the analysis, we maintain the assumption the persistence coefficient in the AR(1)-process for the inflation target, ρ_π, equals 0.975 (see 2.47). Smets and Wouters (2003a, 2003b) assume that $\rho_\pi = 1$. This difference has negligible effects in the empirical analysis that follows, but at a more fundamental level it actually implies that we assume that inflation is stationary whereas Smets

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[21] In Appendix A in Adolfson et al. (2005) we show how to calculate the steady state in the model.

[22] Note that since we estimate some of the parameters that affect the steady state (like μ_z), the steady state values for some variables (e.g. inflation) will change slightly during the estimation procedure.

[23] This follows from the first order condition of the households' bond holdings, $R = \frac{\pi\mu_z - \tau^k\beta}{(1-\tau^k)\beta}$, and the sample means of the capital-income tax τ^k and the output growth rate μ_z.

and Wouters assume that inflation is non-stationary. If anything, the data appear to prefer our specification.[24]

The (steady state) government expenditure-output ratio (g_r), the labour-income tax, the consumption tax, and the cash to money ratio (measured as M_1/M_3) are all set equal to their sample means. This implies $g_r = 0.2037$, $\tau^y = 0.1771$, $\tau^c = 0.1249$, and $A_q = 0.3776$, respectively. Since we lack data on capital-income taxes as well as pay-roll taxes we approximate these with AR(1) processes, and set the persistence parameters ρ_{τ^k} and ρ_{τ^w} to 0.9. The standard deviations for the shocks $\varepsilon_{\tau^k,t}$ and $\varepsilon_{\tau^w,t}$ are set to 1 percent. These values are in line with the estimates for the other fiscal policy variables, where we used two lags in (2.44) based on various information criteria and a simple likelihood ratio test. Although both the persistence coefficients and standard deviations for the fiscal policy variables are quite high, we still find that these variables have small dynamic effects in the model. Presumably due to the assumption of Ricardian households and that the fiscal shocks are transitory and do not generate any wealth effects for the infinitely lived households. There are two reasons for keeping the fiscal policy shocks in the model nevertheless. First, they reduce the degree of stochastic singularity in the model. As is clear from the previous section, we match the model to more variables than estimated shocks, which would not be possible if we did not include the fiscal policy shocks. Second, although the dynamic effects are small, the steady state values of the fiscal policy variables matter for the dynamic effects of the other shocks in the model.

The interest rate rule choice also implies that the curvature parameter related to money demand σ_q is not identified when money growth is not included as an observable variable. We therefore keep σ_q fixed at 10.62, following the findings in Christiano, Eichenbaum and Evans (2005).[25]

Finally, based in various information criteria and a likelihood ratio test, we choose to include 4 lags in the foreign VAR (2.54).

4.2. Prior distributions of the estimated parameters

Bayesian inference starts out from a prior distribution of the model's non-calibrated parameters. This prior distribution describes the available information prior to observing the data used in the estimation. The observed data is then used to update the prior, via Bayes theorem, to the posterior distribution of the model's parameters. This distribution may then be summarized in terms of the usual measures of location (e.g. mode and mean) and spread (e.g. standard deviation and probability intervals).

The Bayesian estimation technique allows us to use the prior information from earlier studies at both the macro and micro level in a formal way. Table 1 shows the assumptions for the prior distribution of the estimated parameters. The location of the prior distribution of the 51 parameters we estimate corresponds to a large extent to those in Smets and Wouters (2003a) and the findings in Altig et al. (2003) on U.S. data. For all the parameters bounded between 0 and 1 we use the beta distribution. This consequently applies to the nominal stickiness parameters ξ, the indexation parameters κ, the habit persistence b, the tax rates τ, and the persistence parameters of the shock processes ρ. The domestic price and wage stickiness parameters are set so that the average length between price, or wage, adjustments is 3 quarters. In contrast, the stickiness parameters pertaining to import and export prices are set lower so as to get a reasonable degree of exchange rate pass-through.

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[24] We investigated this by comparing the log marginal likelihood of the benchmark model (-1909.34, see Table 1) with the log marginal likelihood for a specification of the model where $\rho_\pi = 1$ were imposed. As the latter estimation produced a log marginal likelihood of -1912.10, the data slightly prefers our specification. However, it should be emphasized that the posterior mode for the estimated parameters were very little affected.

[25] In our setting, money demand shocks are badly identified since they have very small real effects. Introducing a household money demand shock (making A_q in (2.20) time-varying) would have zero effects, but introducing a firm money demand shock (making v time-varying) would have some real effects due to its influence on the effective interest rate, see (2.9).

The prior standard deviation of these parameters are twice as large as their domestic counterparts, reflecting a greater prior uncertainty. For all the shocks which we allow to be serially correlated, we set the prior mean of the autoregressive coefficient to 0.85.

For parameters assumed to be positive, such as the standard deviations of the shocks, σ, and the substitution elasticities between and within goods, η and λ (where λ can be interpreted as the markup), we use the inverse gamma distribution. The prior mode of the substitution elasticity between foreign and domestic investment goods is set to 1.5, which is a standard value used in the macro literature, see ,e.g., Chari et al. (2002). Likewise, the prior mode of the substitution elasticity among goods in the foreign economy is set to 1.5 with 4 degrees of freedom.[26] The prior mean of the gross markup in the domestic and import sectors are all set to 1.20, implying substitution elasticities across domestic goods as well as across imported consumption/investment goods of 6. We let the data quite freely determine the size of the average markup by setting the degree of freedom to 2 for these parameters. Following Cooley and Hansen (1995), we set the standard deviation of the stationary technology shock to 0.7 percent. The size of the unit root technology shock, in turn, is set to 0.2 a priori based on the findings of Altig et al. (2003) on US data. From Altig et al. we also take the standard deviation of the monetary policy shock σ_R which is set to 0.15. The standard deviation of the risk premium shock, $\sigma_{\tilde{\phi}}$, and the prior on the risk premium parameter related to net foreign assets, $\tilde{\phi}$, are set to 0.05 and 0.01, respectively, based on an estimated UIP-equation on Swedish data, see Lindé, Nessén and Söderström (2003). For some of the shocks, the earlier literature give less guidance and we rely on simple regressions to pin down the prior distribution of their processes. For example, the inflation target shock $\varepsilon_{\widehat{\bar{\pi}}^c,t}$ is set to 0.05, which is the standard error of regressing the HP-trend in domestic inflation on its first lag. At the same time, we impose a persistence parameter for this shock to be 0.975 (see the discussion in Section 4.1). The standard deviation of the asymmetric technology shock $\widehat{\tilde{z}}_t^*$ is set to 0.40. This number is estimated from the residuals of a first-order autoregression of the series obtained when subtracting the HP-trend in domestic output from the HP-trend in foreign output.

The standard error for the domestic markup shock, $\sigma_{\lambda_d,t}$, is set to 0.3.[27] This is the resulting standard error of the residuals when computing a first-order autoregression of the high frequency component of domestic inflation (measured as the HP-filtered inflation rate). Following Smets and Wouters (2003a, 2003b), we initially assume that this shock is not serially correlated, i.e. we impose that $\rho_{\lambda_d} = 0$. We will, however, do some sensitivity analysis of the effects when this shock is allowed to be serially correlated (see Section 5). The standard deviations of the markup shocks in the import and export sectors, i.e. $\sigma_{\lambda^{m,c},t}$, $\sigma_{\lambda^{m,i},t}$ and $\sigma_{\lambda_x,t}$ are all set to 0.3. For some of the disturbances that we have even less information about, it is difficult to carry out similar exercises. We therefore set their standard deviations to 0.2. This pertains to the two preference shocks $\varepsilon_{\zeta^c,t}$, $\varepsilon_{\zeta^h,t}$ and the investment specific technology shock $\varepsilon_{\Upsilon,t}$. In order to let the data determine the importance of the disturbances, the degree of freedom is set to 2. This gives a rather uninformative prior.

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[26] Notice that we do not include the substitution elasticity between foreign and domestic consumption goods, η_c, (see equation (2.21)) in the final set of estimated parameters in Table 1. The reasons are discussed in the beginning of Section 4.3.

[27] It is important to note that we found it convenient to rescale the parameter multiplying the markup shocks in the Phillips curves for the domestic, import and export goods with the inverse of $\frac{(1-\xi_j)(1-\beta\xi_j)}{\xi_j(1+\kappa_j\beta)}$ for $j = \{d, mc, mi, x\}$ so that the shocks in these equations enter in an additive way, in order to decrease the degree of non-linearity when estimating the model. Similarly, we rescaled the investment specific technology shock, the labour supply shock and the consumption preference shock so that these shocks enter in an additive fashion as well. Although this was not of any major importance for the baseline estimation of the model, we found it important when carrying out the sensitivity analysis because the effective prior standard deviation of the shocks changes with the value of the nominal/real friction parameters. Therefore, to obtain the size of the four truly fundamental markup shocks, the estimated standard deviations reported in Tables 1 and 2 should be multiplied by their respective scaling parameter (e.g., $\frac{\xi_d(1+\kappa_d\beta)}{(1-\xi_d)(1-\beta\xi_d)}$ in the case of the domestic markup shock). Smets and Wouters (2003b) adopt the same strategy.

For the steady state quarterly gross growth rate, μ_z, we use the normal distribution. We center the prior around 1.006, implying an annual growth rate of about 2.4 percent. Note that as we work with GDP data, this number is a mixture of productivity growth and population growth. For most of the parameters in the monetary policy rule we also use the normal distribution. The prior mean is set to standard values, following Smets and Wouters (2003a), which mitigates the problems with indeterminacy when solving the model and computing the likelihood. The prior mean on the inflation coefficient is set to 1.7, and the lagged interest rate coefficient to 0.8. The output reaction of 0.125 per quarter corresponds to a standard Taylor response of 0.5 for the annualized interest rate. Finally, we also allow for an interest rate response to the real exchange rate, but the prior mean of this parameter is set to zero.

4.3. Posterior distributions of the estimated parameters

The joint posterior distribution of all estimated parameters is obtained in two steps. First, the posterior mode and Hessian matrix evaluated at the mode is computed by standard numerical optimization routines (Matlab's fmincon and a slightly modified version of Christopher Sims' optimizer csminwel). The likelihood is computed by first solving the model and then using the Kalman filter (see Appendix C in Adolfson et al., 2005). Second, draws from the joint posterior are generated using the Metropolis-Hastings algorithm. The proposal distribution is taken to be the multivariate normal density centered at the previous draw with a covariance matrix proportional to the inverse Hessian at the posterior mode. See Schorfheide (2000) and Smets and Wouters (2003a) for details. The results are reported in Table 1. It shows the posterior mode of all the parameters along with the approximate posterior standard deviation obtained from the inverse Hessian at the posterior mode. In addition, it shows the mean along with the 5th and 95th percentiles of the posterior distribution.[28] Figures 2a-2c summarizes this information visually by plotting the prior and the posterior distributions for the estimated parameters.

Before turning to the results in Table 1, it should be noticed that we do not include the substitution elasticity between foreign and domestic consumption goods, η_c, (see equation 2.21) in the final set of estimated parameters. When η_c is included, with the same prior as η_i and η_f, it is driven to a very high number (around 11). The reason why the model wants η_c to be high is not surprising. According to the data, consumption goods constitute a large part of imports. But, aggregate consumption is a very smooth process whereas the standard deviation of aggregate imports is considerably higher (about $3-4$ times, see Figure 1). From equation (2.22), it is clear that one way for the model to account for this anomaly is by choosing η_c to be high so that C_t^m fluctuates a lot whereas $C_t^m + C_t^d$ does not (remember that the import equals $C_t^m + I_t^m$). It is thus clear that η_c needs to be high in order to account for the joint consumption and import dynamics. However, due to problems with convergence in the Metropolis-Hastings algorithm, we decided to calibrate η_c because this parameter is negatively correlated with the standard deviation of the markup shock on imported consumption goods, $\sigma_{\lambda_{m,c}}$ in the generated Markov chains. When calibrating η_c, we decided to keep it fixed at the value of 5 throughout the analysis. This value was chosen because it produced a marginal likelihood about the same size as when keeping η_c fixed to 11. Lower values of η_c (e.g., 3), produced drastically lower marginal likelihoods.

We report two estimation results in Table 1, one where we keep the capital utilization rate fixed at the value estimated by Altig et al. (2003), i.e. $\sigma_a = 0.049$, and another where we do not allow

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[28] A posterior sample of 500,000 post burn-in draws was generated. Convergence was checked using standard diagnostics such as CUSUM plots and ANOVA on parallel simulation sequences. In most cases, we had convergence after around $200,000 - 300,000$ draws, but in a few cases more draws were needed. To obtain convergence, we found it to be of critical importance to obtain a good estimate of the Hessian matrix, and typically the modified version of Sims optimizer csminwel produced more accurate Hessian matrices than Matlab's fmincon.

for variable capital utilization, i.e. $\sigma_a = 10^6$. Initially, we included this parameter in the estimations, but encountered problems with convergence in the Metropolis-Hastings algorithm due to the high correlation with some other parameters. Presumably, the reason for this problem was that we could not include capacity utilization as an observable variable (it is not available on Euro area data). We therefore decided to present estimation results for the model with and without variable capital utilization, and let the marginal likelihood indicate the most probable specification for the variables at hand.[29]

From the results in Table 1, we see that the model without variable capital utilization is preferable under the assumed priors. The Bayes factor is 3134 in favor of the model without variable capital utilization and this specification is therefore used in the remaining part of the paper. This choice is, however, not of any greater importance for the key results of the paper, since the parameter estimates are in general similar for the models with and without variable capital utilization.

A particularly interesting result in Table 1 is that the degree of domestic price stickiness is not affected by whether we allow for variable capital utilization or not, in contrast to the findings by Christiano, Eichenbaum and Evans (2005). For both specifications of the models, we find the degree of sticky prices to be around 0.9 - which is in line with the findings by Smets and Wouters (2003a, 2003b) - whereas Christiano, Eichenbaum and Evans (2005) obtain an estimate of the price stickiness of 0.60 in the model with variable capital utilization and 0.92 in the model without. In addition, our model do not yield a lower degree of domestic price stickiness when including the working capital channel. Again, this is in contrast with the results in Christiano, Eichenbaum and Evans (2005) who obtain an estimate of the price stickiness of 0.60 in the model with working capital and 0.89 in the model without. There are several possible reasons why the results differ. One obvious candidate is that the data sets are different. However, Smets and Wouters (2003b) report high price stickiness also for U.S. data. Another candidate is that the estimation techniques differ. Our paper and Smets and Wouters' paper use Bayesian estimation techniques whereas Christiano, Eichenbaum and Evans (2005) match the impulse responses to a monetary policy shock only. In contrast, when matching the impulse response functions for three identified shocks, Altig et al. (2004) obtain about the same amount of price stickiness as we do. The estimation technique does consequently not seem to matter for the obtained results to any greater extent. Instead, the main reason behind the different results appears to be that the working capital channel is able to produce a lot of inflation inertia (without price stickiness) to a monetary policy shock, but not so much for other shocks. Since monetary policy shocks are not the main shocks behind the business cycles, we obtain different results in the model when we match all the variability in the data and not just the impulse response functions to a monetary policy shock as Christiano, Eichenbaum and Evans (2005) do. Moreover, allowing for a time-varying inflation target, which in principle should be able to lower the intrinsic inflation persistence and/or correlation in the shocks, does not seem to produce lower persistence in this multivariate setting.

The implied average contract duration, assuming that the households own the capital stock and rent it to the firms each period, is around 8 quarters. However, under the interpretation that the domestic intermediate firms own the capital stock, we can apply the formulas derived in Altig et al. (2004), to compute the average contract duration to about 4.7 quarters instead. This is a substantially lower number, and not in conflict with the microeconomic evidence for EU countries, see e.g. Mash (2004) and the references therein.

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[29] The marginal likelihood of a model i is defined as $m_i = \int L_i(\theta_i; x) p_i(\theta_i) d\theta_i$, where $L_i(\theta_i; x)$ is the usual likelihood function of the model's parameter vector conditional on the observed data x. $p_i(\theta_i)$ is the prior distribution of the model's parameters. m_i is the unconditional probability of the observed data, under the assumed prior distribution, and is therefore a measure of model fit. The marginal likelihood is a relative measure and should be compared across competing models. The Bayes factor comparing two models i and j is defined as $B_{ij} = m_i/m_j$. The marginal likelihood is computed numerically from the posterior draws using the modified harmonic estimator in Geweke (1999).

The estimated sticky price parameters for the other sectors (e.g. $\xi_{m,c}$, $\xi_{m,i}$ and ξ_x) are substantially lower than ξ_d, suggesting 2-3 quarters stickiness in these sectors. However, as will be evident from the results in the next section, whether one allows for correlated markup shocks or not is important for the location of the posterior distributions of the ξ-parameters. A more robust finding is that the indexation parameters (i.e. the κ's) are quite low, suggesting that the estimated Phillips curves are mostly forward-looking, a finding consistent with the single-equation estimation results of Galí, Gertler and López-Salido (2001) on Euro area data. Although the domestic Phillips curve is mostly forward-looking, we still find domestic inflation persistence to be intrinsic in the following sense. If we generate artificial time series from the estimated model with and without the time-varying inflation target and estimate simple AR(1) models on the generated inflation series, we find the autocorrelation coefficient to be about 0.81 and 0.77 on average, respectively.[30] So in this sense, accounting for a time-varying inflation target do not generate substantially lower inflation persistence in our multivariate setting, in contrast to the univariate results by Levin and Piger (2004).

Further, we see that the unconditional variances of the markup shocks in the import and export sectors are considerably higher than in the domestic sector. Moreover, the posterior mode for the average markup is about the same in the domestic sector as in the importing investment sector (the net markups are around 20 percent in these sectors), whereas the markups are considerably higher for the firms that import consumption goods (around 60 percent). Thus, the data suggests that the domestic households' willingness to substitute among the importing consumption goods is rather limited in comparison with the importing investment goods.

The estimated model implies the import/export to output ratio to be around 12 percent in the steady state. This number appears to be a reasonable estimate for the average inter-Euro import/export to output ratio during the sample period ($1980Q1 - 2002Q4$), but it is about $4 - 5$ percent lower than the current estimates of inter-Euro trade with the rest of the world (see e.g. Table 1.1 in ECB Statistics pocket book, January 2005). Due to the increasing import/export-output share, the model is most likely underestimating the "true" steady state value. But as mentioned in Section 3.1, the model is not designed to capture the increasing import/export to output ratios. Despite this limitation, the intention is nonetheless that the model should be able to capture the dynamics of the open economy variables.

The posterior mode of the persistence parameter in the unit-root technology process is estimated to be 0.72. This number compares quite favorably to the estimate in Altig et al. (2003). In addition, the persistence coefficient for the Kydland-Prescott type of stationary technology shock is estimated to be about 0.91. This is close to the standard value of 0.95 commonly used in the real business cycle literature (see e.g. Cooley and Hansen, 1995). Smets and Wouters obtain a much higher number of about 0.997.[31] We attribute our lower estimate to the inclusion of the unit-root technology shock, which accounts for a substantial amount of the lower frequency component in the real variables. In general, although some shocks quite naturally are found to be highly autocorrelated (i.e., the asymmetric technology and risk-premium shocks), the persistence coefficients for most of the shocks are substantially lower than found by Smets and Wouters (2003a, 2003b). In addition to the inclusion of the unit-root shock, part of the lower persistence is explained by the open economy aspects of the model, which is an extra source of internal propagation. Further, the posterior mode for the gross quarterly steady state growth rate (μ_z) is centered around 1.005, implying an annual steady state growth rate of about 2 percent for the Euro area.

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[30] This is also the reason why the vector autocovariance function for inflation display a high degree of persistence (see Section 4.4). Inflation persistence in the DSGE model is mostly generated by (unobserved) correlated shocks that are not included in standard VARs.

[31] Note that the difference between a persistence coefficient of 0.91 and 0.995 is huge in terms of the persistence of a shock. The former number implies that 0.02 of a unit increase are in effect after 40 quarters while the latter implies 0.82.

4.4. Model fit

In Figure 1 we report the Kalman filtered one-sided estimates of the observed variables, computed for the posterior mode of the estimated parameters in the benchmark model along with the actual variables. Roughly speaking, the one-sided estimates correspond to fitted values in a regression. As is evident from the figure, the in-sample fit of the model is satisfactory. In Figure 3, we report the two-sided estimates (basing inference on the full sample) of the unobserved (quarterly) shocks in the benchmark model. It is important to note that we plot the shock series, for example $\hat{\epsilon}_t$ and not the innovations $\varepsilon_{\epsilon,t}$. From the figure, we see that the annualized time-varying inflation target drops from about $0.8 \times 4 + 2 = 5.2$ percent in the beginning of the 1980's to about 2 percent (which is the posterior mode of the long-run inflation target) in the beginning of 2000 with the introduction of the Euro. The asymmetric technology shock series (remember $\tilde{z}_t^* = \frac{z_t^*}{z_t}$) is very persistent and has an upward trend due to the fact that growth in the Euro area was on average lower than the growth rate in the world economy during this period (i.e., $\Delta \ln z_t^*$ is higher than $\Delta \ln z_t$, implying that $\tilde{z}_t^*$ must start out below the steady state with $\tilde{z}^* = 1$, due to our assumption that $\mu_{z^*} = \mu_z$). The two-sided series for the risk-premium shock is also in line with our a priori expectations. It gradually builds up during the 1980s and reaches its maximum around 1990 when we know there was a lot of turmoil in the exchange rate market. It then gradually returns to zero during the latter part of the 1990s and the beginning of 2000. For the other shocks, we have less strong a priori beliefs to evaluate the outcome of these shocks against. We are therefore reluctant to say that the two-sided estimates of these shocks can be considered as evidence against the plausibility of the model. This is one important reason for why we carry out an independent assessment of the models' fit below.

To further assess the conformity of the data and the model we conduct a posterior predictive analysis where the actual data are compared to artificial time series generated from the estimated benchmark DSGE model. More specifically, we compare vector autocovariance functions in the model and the data (see, e.g., Fuhrer and Moore, 1995, and Gavin, Dittmar and Kydland, 2005).[32]

The vector autocovariance functions are computed by estimating an unrestricted VAR model on Euro area data for the period $1970Q2 - 2002Q4$. We include the following 10 variables in the estimated VAR; annualized domestic inflation π_t, the real wage $\Delta \ln(W_t/P_t)$, consumption $\Delta \ln C_t$, investment $\Delta \ln I_t$, the real exchange rate x_t, the annualized nominal short-term interest rate R_t, employment $\hat{E}_t$, output $\Delta \ln Y_t$, exports $\Delta \ln \widetilde{X}_t$ and imports $\Delta \ln \widetilde{M}_t$. All real variables are included in growth rates (first differences in logs, $\Delta \ln$).[33] To compute the vector autocovariance functions in the model, we draw n_s parameter combinations from the posterior distribution and simulate n_s artificial data sets of the same length as for the Euro area. We then use the n_s data sets to estimate vector autocovariance functions (see Hamilton, 1994), using exactly the same VAR specification as was applied on the actual data. In Figure 4, we report the obtained median vector autocovariance function in the DSGE model (thin line) along with the 2.5 and 97.5 percentiles (dotted lines) in the generated distribution. The thick line refers to the actual data. In order to be able to convey the results in one figure, we report the results for a subset of variables included in the VARs; π_t, x_t, R_t, $\Delta \ln Y_t$, $\Delta \ln \widetilde{X}_t$ and $\Delta \ln \widetilde{M}_t$.

By and large, we see that the vector autocovariance functions in the model and the data compare very well, giving additional credibility to the estimated DSGE model. Indeed, most of the autocovariances in the model look a lot like those computed in the data. However, there are some exceptions.

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[32] Fuhrer and Moore (1995) and Dittmar, Gavin and Kydland (2005) compare vector autocorrelation functions, whereas we report auto covariance functions in order to examine the ability of our model to explain the absolute variances as well. In Adolfson et al. (2005), we also report univariate unconditional moments, but since they give a very similar picture as the vector autocovariance functions, they are not reported here.

[33] We use 3 lags in the estimated VARs because 4 lags produce characteristic roots outside the unit circle in the VAR estimated on Euro area data. We have also done the calculations with the foreign variables $\Delta \ln Y_t^*$, π_t^* and R_t^* included in the estimated VARs (not imposing block exogeneity), but the results were found to be very similar.

First, we see that the inflation persistence is a little bit too low in the model relative to the data. This reflects the fact that in the data, the inflation series is very persistent (see Figure 1) and that one very important source of inflation persistence in the benchmark model is the inflation target shock (see Figure 6). When generating artificial samples in the DSGE model, the typical sequence drawn for this shock will not be as persistent as in the data because of the large decrease in the inflation target shock (see Figure 3). Consequently we will tend to underestimate the inflation persistence in the model relative to the data. Also, in the data, contemporaneously higher inflation seems to be associated with lower import growth today to a greater extent than can be replicated by the model. Moreover, in the model higher interest rates in previous periods (R_{t-h}) are associated with too high output growth today ($\Delta \ln Y_t$) relative to the data. We also notice that the autocovariance function for exports are too high and persistent in the model relative to the data. This implies that the unconditional persistence and standard deviation for exports are too high in the model. From Figure 1, it is apparent that the one-sided estimates from the Kalman filter follow the actual values rather well, so the reason why exports are overly volatile in the model relative to the data is that the estimated shock processes come out slightly correlated in the Kalman filter. Finally, higher domestic inflation (π_{t-h}) in the model is a signal of higher future imports ($\Delta \ln \widetilde{M}_t$), because it will be more profitable to consume and invest imported goods in this case, but in the data this covariance is (surprisingly) strongly negative.

To sum up, although there seems to be room for improvements in some aspects, we think our model does a very good job in replicating conventional statistics for measuring the fit of a model. In particular, the model is able to generate highly volatile and persistent real exchange rates, and to explain the joint behavior of a large set of key macroeconomic variables very well. For exports, the model does less well. Presumably, the results would have been improved if we had been able to include some price variable related to exports in the estimation of the model.

5. The role of frictions and shocks

After validating a good fit of the open economy DSGE model, we can proceed with establishing the role of the various frictions and shocks that are included in the model. This relative model comparison is carried out using the marginal likelihood. Table 2 shows the posterior mode and marginal likelihood when some of the nominal and real frictions in the model are turned off as well as some other modifications of the model. This is done in an attempt to assess the importance of the different frictions in the model. The columns report the estimated parameter vector (posterior mode) when; *i*) there is no wage stickiness, *ii*) there is no (domestic) price stickiness, *iii*) there is no habit formation, *iv*) there is no investment adjustment cost, *v*) the LOP holds in imports, *vi*) the LOP holds in exports, *vii*) there is no working capital channel, *viii*) we allow for persistent domestic markup shocks, and *ix*) the markup shocks are i.i.d. (uncorrelated) in all sectors. For ease of comparison the benchmark results are also reproduced.

The results in Table 2 show that all the nominal and real frictions play an important role in the model, in particular price stickiness in the domestic and import sectors and investment adjustment costs are important. Since most of the parameters governing the role of nominal and real frictions are far from zero, these findings are not surprising. It is, however, somewhat surprising that although the price stickiness parameters related to the import goods are not particularly high, they still appear to be of crucial importance for the models' empirical performance. Table 2 also indicates that a version of the model without the working capital channel is preferable, the Bayes factor is 65 in favor of the model without working capital.

The next to the last column in Table 2 contains results when allowing the markup shocks in the domestic Phillips curve to be serially correlated. We assume the same prior for the persistence parameter, ρ_{λ_d}, as for the other shocks. A striking result is that the serially correlated domestic markup shocks produce a much lower domestic price stickiness parameter, ξ_d shrinks from 0.88 to 0.66. This implies a fall in the average price contract duration from 8 to 3 quarters. Under the interpretation that the domestic intermediate firms own the capital stock, the resulting price contract duration is slightly less than 2 quarters. However, the fall in ξ_d is accompanied with a posterior mode for ρ_{λ_d} of 0.995, which is a very high number. Also, the Bayes factor is 487 in favor of the model with white noise domestic markup shocks, so the data appear to be supportive of the benchmark specification of the model. However, the analysis of marginal likelihoods should not be over-emphasized, given its sensitivity to the choice of prior distribution, and we can not rule out the model with correlated shocks with certainty. Our interpretation is that the data offer two explanations behind the high inflation inertia that we see; either a rather high degree of price stickiness or highly correlated shocks.

The last column in Table 2 displays the results when all markup shocks are assumed to be white noise. This restriction is associated with a large drop in log marginal likelihood. Thus, the specification with correlated markup shocks in the import and export sectors are clearly preferable. In particular, the correlated markup shocks play an important role in accounting for the behavior of the real exchange rate. Moreover, it is interesting to note that the posterior estimates of the stickiness parameters (the ξ's) are very similar in this case, ranging from $0.85 - 0.91$. With uncorrelated markup shocks, we also find a larger role for indexation to past inflation, in particular in the domestic and export sectors. This is not surprising, when less of the persistence is generated by correlated shocks there must be a larger role for intrinsic persistence (i.e. lagged inflation) to account for the inflation dynamics.

In Table 3, we examine the role of various shocks in the model. We shut down some of the shocks, and study the impact on the estimated parameters (posterior mode) and the marginal likelihood. What we learn from this exercise is that when considering the relatively large set of observable variables that we match, all shocks appear to matter, but in particular we find that technology shocks and the markup shocks in the Phillips curves for imported consumption/investment goods and export goods are the most important.

Regarding the role of the time-varying inflation target, the marginal likelihoods are not very informative. The Bayes factor is only 2 in favor of the model without the time-varying inflation target. Given our choice of priors, the data are hence not very instructive about the model choice in this case. We also learn from Table 3 that the fiscal policy shocks are not very important for the empirical performance of the model, suggesting that more work is needed to incorporate fiscal policy shocks in a more realistic way than what was done in this paper.[34] For instance, amending the model with "rule-of-thumb" consumers and production in the government sector along with the introduction of government debt/endogenous tax/government spending rules might be an interesting avenue for future research.

6. Impulse response functions and variance decompositions

6.1. Impulse response functions to a monetary policy shock

Figure 5 reports the impulse response functions (median and 5th, 95th percentiles) to a monetary policy shock (one-standard deviation increase in $\varepsilon_{R,t}$). To understand how the nominal frictions shape the impulse response functions, we also include the responses when all nominal frictions are taken out of the model, so prices and wages are flexible (we set $\xi_d = \xi_{m,c} = \xi_{m,i} = \xi_x = \xi_w = 0.01$). The results for the benchmark model are graded on the left y-axis, and the flexible price-wage version of the model

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[34] When we shut down the fiscal policy shocks, we set all the steady state tax rates and the tax-rate shocks to nil. We also set shocks to government expenditures to nil, but keep steady state government expenditures as share of output to 0.2 in the model.

(dashed line) is graded on the right y-axis. Notice that the inflation and nominal interest rates are reported as annualized quarterly rates, while the quantities are reported as log-level deviations from steady state (i.e., percentage deviations).[35]

In the figure, we see that following an unanticipated temporary increase in the nominal interest rate, the responses are hump-shaped with the exception of the real exchange rate which jumps down (i.e., appreciates) and then returns to zero from below. The effect on aggregate quantities - output, investment, consumption, export and import - peaks after about one to two years, whereas the effect on inflation reaches its maximum after one year. The responses of the real variables are well in line with the literature that have used identified VARs to study the effects of monetary policy shocks, but the latter results indicate that inflation in the model is somewhat less inertial than the typical estimates in the VAR literature.[36] The single most important reason why the effect on inflation occurs somewhat faster in the model is that the capital utilization cost is set to a very high number ($\sigma_a = 10^6$). However, as pointed out by Christiano, Eichenbaum and Evans (2005), it is the combination of real and nominal frictions that enables their model to reproduce the impulse response functions in the VAR. Here, we use Bayesian methods and fit the model to all the variation in the data, and not just the dynamic effects of a policy shock. Still, we find the empirical relevance of the nominal and real frictions to be such that the impulse response functions to a policy shock are very similar to the ones generated in identified VARs. In our view, this gives a lot of credibility to the analysis and further support to the view that the "conventional wisdom" about the effects of monetary policy applies even in the open economy framework. There is, however, one exception and that is the real exchange rate. Although the nominal frictions in the model provides some persistence in the real exchange rate following a policy shock, it is evident that the model does not provide us with a hump-shaped response of the real exchange rate which is a persuasive feature of estimated VARs, see, e.g., Eichenbaum and Evans (1995), Faust and Rogers (2003), and Lindé, Nessén and Söderström (2003). Lindé, Nessén and Söderström show that if the sensitivity of the risk-premium related to net foreign assets is large enough (i.e. $\widetilde{\phi}_a$ is above 1.5), it is possible to obtain a hump-shaped response of the real exchange rate, but they argue that this number is implausibly high. With flexible prices and wages, monetary policy has very small effects on aggregate quantities, and a strong immediate effect on inflation. The behavior of the real exchange rate in this case is the classic response implied by the UIP condition. An initial appreciation is followed by a strong and persistent depreciation (over-shooting).

6.2. Variance decompositions

We report the variance decompositions of the 5th, 50th and 95th percentiles of the posterior distribution for some selected variables in Table 4.[37] The purpose is to make a formal assessment of the contribution of each structural shock to fluctuations in the endogenous variables at different horizons. We focus here on the 1, 4, 8 and 20 quarters horizon. We define short run as being 1-4 quarters, medium run as 8 quarters, and the long run to be 20 quarters.[38]

The technology shocks (the stationary, unit-root, investment-specific and asymmetric technology shocks) account for about 30 percent of the output fluctuations in the short run, and then gradually increase to about 45 percent in the long run. The three "supply shocks" in the model, the two

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[35] That is, annualized inflation is measured as $4\pi\hat{\pi}_t$ where π is the steady-state gross quarterly inflation rate and $\hat{\pi}_t$ is the quarterly inflation rate. Similarly, the annualized nominal interest rate is measured as $4R\hat{R}_t$.

[36] See, for example, Christiano, Eichenbaum and Evans (2005), and Altig et al (2003, 2004) for US evidence, and Angeloni et al. (2003) for Euro area evidence.

[37] Note that as we report the 5th,50th and 95th percentiles of the posterior distribution for each shock in Table 4, the fractions reported do not exactly sum up to unity at each horizon.

[38] The longer the horizon, the more of the fluctuations is due to the unit-root technology shock. In the limit, this shock accounts for 100 percent of the fluctuations in aggregate quantities in this model, since this is the only permanent shock.

productivity shocks ($\mu_{z,t}$ and ϵ_t) and the labour supply shock account for about 40 percent of the fluctuations in output in the long-run, results well in line with Smets and Wouters (2003a). Evidently, the data do not support the idea of a predominant part of business cycles being due to technology shocks. In order to account for the observed joint fluctuations in the large set of variables that we study, the model needs other shocks than the technology ("closed economy") shocks to account for the movements in output. For instance, we find that the markup shocks account for about 15 percent in the short to medium run and as much as 33 percent in the long run of the output fluctuations. In particular, the export markup shock is important in the short run and the importing investment markup shock is important in the long run.[39] However, the result that other shocks than technology are import for macroeconomic fluctuations are supported by identified VARs, see e.g. Galí (1999) and Altig et al. (2003, 2004). By and large, the relative importance of technology and non-technology shocks in our model are in line with their results. Monetary policy shocks account for about 15 percent of output fluctuations in the short run and less than 5 percent in the long run.

Turning to inflation, the domestic markup shocks account for most of the fluctuations in the short run, which is not surprising given the small coefficient on marginal cost in (2.12) implied by our estimates ξ_d and κ_d. Despite the small coefficient on marginal cost, the labour supply shock is one of the most important sources of inflation volatility in the short and medium run because this shock is the predominant source of variation in the real wage. In the long run, since the labour supply shock is less persistent, the inflation target shock appears to be the single most important source of inflation volatility. But also the import consumption markup and the investment-specific technology shock are central sources of inflation volatility in the long run.

Import and export markup shocks account for most of the fluctuations in the real exchange rate and exports. In the short and medium run, they account for about $50-60$ percent, and in the long run they account for as much as 65 percent. The nominal rigidities in the model imply that the return of the real exchange rate to the steady state is slow for the markup shocks, in particular they also enable the imported investment and consumption markup shocks and the investment specific technology shocks to produce hump-shaped impulse responses of the real exchange rate. Consequently, these shocks are also the most important source of fluctuations in the real exchange rate in the medium to long run. Given our relatively simplistic modelling of the import and export sectors, these shocks most likely capture a whole range of mechanisms and shocks that do not feature in the model (e.g., oil prices, intermediate import inputs in production etc.). It is also notable that the the risk-premium shocks do not appear to be an important source of variation in the real exchange rate. However, as can be seen from Table 2, if we assume that all markup shocks are white noise, then the role of risk premium shocks are enhanced considerably. Nevertheless, the model appears to have the right propagation regarding the real exchange rate since the typical autocovariance function from an estimated VAR implied by the DSGE model are well in line with the one generated from the data (see Figure 4). For imports, the export and import markup shocks play a prominent role as well. However, quite naturally also investment-specific markup shocks are an important source of variation, as imported investment goods are a substantial part in the investment CES basket, and investment itself is a highly volatile process.

Monetary policy shocks are a prominent source of interest volatility in short run, whereas in the medium to long run, investment-specific and inflation target shocks are predominantly important. Since investment specific shocks have rather large real effects in the short and medium run, this is not surprising.

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[39] Even if the variance in the imported consumption markup shock process is much higher than in the process for the imported investment markup shock, it is still the case that the imported investment markup shock is much more important for the output fluctuations in the long run. This emphasizes the role of the supply side of the imported investment goods.

At a more general level, we find a small role for the exogenous fiscal and foreign shocks. In the short run, the foreign shocks account for around 10 percent of the fluctuations in output, export, import and the real exchange rate, but in the long run fiscal and foreign shocks together most likely account for less than 5 percent.

Another distinct feature of Table 5 is that many shocks have dynamic effects on many of the variables. That is, "open economy" shocks have important dynamic effects on "closed economy" variables and vice versa, suggesting a substantial amount of internal propagation within the model due to the open economy aspects of it. The key parameter behind this propagation mechanism is the high value of the substitution elasticity between domestic and imported consumption goods, η_c, that the data strongly prefer. Given the results in Table 3, which conveyed that most shocks matter for the empirical fit of the model, this result is perhaps not surprising. Our interpretation is that the open economy frictions and shocks appear to add interesting dynamics to the closed economy setting in Smets and Wouters (2003a).

Finally, in Figure 6 we plot the historical decompositions for four subsets of shocks along with the actual time series that we fit our model to. From the figure, we can learn the role of various shocks during the sample period. Notice that the figure depicts the raw data, and not the steady state deviations. In general, we see that the "domestic shocks" - in particular the technology shocks - account for most of the variation in the domestic variables (inflation, interest rate and output), and that "open economy shocks" account for most of the variation in the real exchange rate. During the sample period, the strong positive trend for the asymmetric technology shock explains the appreciating real exchange rate, which is why the "closed economy shocks" explain little of the variation in the real exchange rate during the sample, but technology shocks - where the asymmetric technology shock is included - explain the downward trend in the real exchange rate. The monetary policy shocks, and in particular variations in the inflation target explain about 400 basis points of the downturn in inflation during the sample, where the estimated steady state level is around 2 percent.

7. Conclusions

In this paper, we have modified the benchmark closed economy monetary business cycle model of Christiano, Eichenbaum and Evans (2005) into an open economy model. The key features of the open economy part of the model is incomplete pass-through of exchange rate movements to prices of import goods used in private consumption and as investment in the physical capital stock, as well as incomplete pass-through of exchange rate movements to prices of export goods sold to the foreign economy. Another open economy feature of the model is the domestic households' ability to borrow and lend at a risk-adjusted nominal interest rate in the world financial market. Following Smets and Wouters (2003a, 2003b), we introduce a large number of shocks in the economy, and estimate the model using Bayesian techniques on Euro area data.

We do an extensive test for the role of various frictions, and find strong support for the nominal and real frictions we embed into the model; sticky prices in the domestic, import and export sectors, sticky wages, investment adjustment costs and habit persistence in consumption. We do not find evidence that variable capital utilization is important for the empirical success of the model, nor have any greater impact on the estimated parameters. However, this result is most likely contingent upon that we do not include capacity utilization as an observable variable when estimating the model (since this is not available for the Euro area). Moreover, the working capital channel is not an effective channel to generate inflation persistence when subjecting the model to fit all the variation in the data and not just the dynamic effects of a monetary policy shock as in Christiano, Eichenbaum and Evans (2005).

We also conduct an extensive test for the role of various shocks included in the model. According to our estimated model, many shocks matter for the fluctuations in the 15 endogenous variables that we study. There is a substantial amount of internal propagation via the high substitution between foreign and domestic consumption goods which the data strongly prefer. Supply or technology shocks are about as important for output fluctuations as demand or non-technology shocks. For inflation, we find that markup shocks and inflation target shocks are most prominent, but there is a clear role for technology shocks as well. The real exchange rate in the model is mostly driven by import and export markup shocks.

The estimated model - although fitted to explain all the variation in the data and not only the dynamics of a monetary policy shock - have a monetary transmission mechanism well in line with those reported in identified VARs (see, e.g., Angeloni et al. (2003) for Euro area evidence) for standard variables like inflation, output, consumption and investment. For the real exchange rate, the estimated model implies a quick appreciation following an unexpected increase in the nominal interest rate. This finding is not in line with the results in the identified VAR literature which typically report a gradual appreciation, see, e.g., Eichenbaum and Evans (1995), and Faust and Rogers (2003). The fast response in our model is driven by the UIP condition in the model, and although the nominal frictions generate persistence in the real exchange rate, they cannot produce a hump-shaped response of the real exchange rate in the model. However, it should be kept in mind that the identification of the effects of policy shocks in VARs typically rest on a recursive ordering of variables, a requirement that is not fulfilled by the DSGE model used here. Therefore, strictly speaking, there is some uncertainty about what to make out of the the comparison of the model impulse responses versus those in VARs.

When we subject the estimated model to independent empirical validation methods, we find that the empirical performance is very good. In particular, the model can reproduce the joint inflation and real exchange rate dynamics, a task that has turned out to be difficult (see Bouakez (2004) for further discussion). However, one shortcoming of the model is that it overpredicts the persistence and volatility of exports relative to the data.

By and large, we think our paper has shown that it is possible to extend the benchmark closed economy model into an open economy setup and obtain an empirically plausible model to analyze open economy business cycles. We are also currently working on examining the forecasting properties of the estimated model with alternative best-practice models such as Bayesian VARs, random walks and various moving average type of models (ARIMA). Of particular interest is, of course, the forecasting properties of the model related to real exchange rates, export and import. However, there are a number of dimensions in which the model can be improved.

First, we assume that all agents in the economy have perfect information about all shocks hitting the economy. As recent work have shown, relaxing this assumption can generate interesting dynamics in the economy, see e.g. Collard and Dellas (2004) and Lippi and Neri (2003).

Second, the treatment of fiscal policy in the model is very simplistic. It would be of great interest to empirically test for the relevance of non-Ricardian households, and examine to what extent the introduction of government debt (i.e., adding fiscal policy rules) and government production would affect the empirical performance of the model. In addition, that would enable a study of the interaction of monetary and fiscal policy in an empirically reasonable model.

Third, there is no well-developed banking sector in the model as in for example Christiano, Motto and Rostagno (2003). An interesting extension would therefore be to test for the empirical relevance of the financial accelerator channel of monetary policy.

Finally, we have not analyzed optimal monetary policy in the context of the model. A full-blown welfare analysis of optimal policy is beyond the current scope of the paper and is something we leave for future work.

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Table 1: Prior and posterior distributions

Parameter		Prior distribution			With variable capital utilization $\sigma_a = 0.049$ Posterior distribution		No variable capital utilization $\sigma_a = 10^6$ Posterior distribution				
		type	mean*	std.dev. /df	mode	std. dev. (Hessian)	mode	std. dev. (Hessian)	mean	5%	95%
Calvo wages	ξ_w	beta	0.675	0.050	0.716	0.041	0.697	0.047	0.690	0.607	0.766
Calvo domestic prices	ξ_d	beta	0.675	0.050	0.895	0.014	0.883	0.015	0.891	0.862	0.921
Calvo import cons. prices	$\xi_{m,c}$	beta	0.500	0.100	0.523	0.047	0.463	0.059	0.444	0.345	0.540
Calvo import inv. prices	$\xi_{m,i}$	beta	0.500	0.100	0.743	0.036	0.740	0.040	0.721	0.641	0.792
Calvo export prices	ξ_x	beta	0.500	0.100	0.630	0.056	0.639	0.059	0.612	0.506	0.717
Calvo employment	ξ_e	beta	0.675	0.100	0.757	0.028	0.792	0.022	0.787	0.741	0.827
Indexation wages	κ_w	beta	0.500	0.150	0.453	0.148	0.516	0.160	0.497	0.258	0.739
Indexation domestic prices	κ_d	beta	0.500	0.150	0.173	0.059	0.212	0.066	0.217	0.095	0.362
Index. import cons. prices	$\kappa_{m,c}$	beta	0.500	0.150	0.128	0.054	0.161	0.074	0.220	0.084	0.418
Index. import inv. prices	$\kappa_{m,i}$	beta	0.500	0.150	0.192	0.082	0.187	0.079	0.231	0.098	0.405
Indexation export prices	κ_x	beta	0.500	0.150	0.148	0.070	0.139	0.072	0.185	0.069	0.347
Markup domestic	λ_d	inv. gamma	1.200	2	1.174	0.059	1.168	0.053	1.222	1.122	1.383
Markup imported cons.	$\lambda_{m,c}$	inv. gamma	1.200	2	1.636	0.071	1.619	0.063	1.633	1.526	1.751
Markup.imported invest.	$\lambda_{m,i}$	inv. gamma	1.200	2	1.209	0.076	1.226	0.088	1.275	1.146	1.467
Investment adj. cost	$\tilde{S}''$	normal	7.694	1.500	9.052	1.359	8.732	1.370	8.670	6.368	10.958
Habit formation	b	beta	0.650	0.100	0.694	0.043	0.690	0.048	0.708	0.608	0.842
Subst. elasticity invest.	η_i	inv. gamma	1.500	4	1.585	0.220	1.669	0.273	1.696	1.393	2.142
Subst. elasticity foreign	η_f	inv. gamma	1.500	4	1.400	0.078	1.460	0.098	1.486	1.340	1.674
Technology growth	μ_z	trunc. normal	1.006	0.0005	1.005	0.000	1.005	0.000	1.005	1.004	1.006
Capital income tax	τ_k	beta	0.120	0.050	0.220	0.040	0.137	0.042	0.135	0.072	0.200
Labour pay-roll tax	τ_w	beta	0.200	0.050	0.183	0.049	0.186	0.050	0.197	0.118	0.286
Risk premium	$\tilde{\phi}$	inv. gamma	0.010	2	0.131	0.044	0.145	0.047	0.252	0.139	0.407
Unit root tech. shock	ρ_{μ_z}	beta	0.850	0.100	0.753	0.107	0.723	0.106	0.698	0.526	0.852
Stationary tech. shock	ρ_ε	beta	0.850	0.100	0.935	0.021	0.909	0.030	0.886	0.810	0.939
Invest. spec. tech shock	ρ_Υ	beta	0.850	0.100	0.738	0.041	0.750	0.041	0.720	0.638	0.796
Asymmetric tech. shock	$\rho_{\tilde{z}^*}$	beta	0.850	0.100	0.992	0.003	0.993	0.002	0.992	0.986	0.995
Consumption pref. shock	ρ_{ζ_c}	beta	0.850	0.100	0.935	0.021	0.935	0.029	0.892	0.722	0.964
Labour supply shock	ρ_{ζ_h}	beta	0.850	0.100	0.646	0.057	0.675	0.062	0.676	0.565	0.774
Risk premium shock	$\rho_{\tilde{\phi}}$	beta	0.850	0.100	0.990	0.009	0.991	0.008	0.955	0.922	0.991
Imp. cons. markup shock	$\rho_{\lambda_{m,c}}$	beta	0.850	0.100	0.984	0.008	0.978	0.016	0.970	0.943	0.991
Imp. invest. markup shock	$\rho_{\lambda_{m,i}}$	beta	0.850	0.100	0.971	0.011	0.974	0.015	0.963	0.931	0.989
Export markup shock	ρ_{λ_x}	beta	0.850	0.100	0.895	0.042	0.894	0.045	0.886	0.789	0.961
Unit root tech. shock	σ_z	inv. gamma	0.200	2	0.122	0.023	0.130	0.025	0.137	0.099	0.185
Stationary tech. shock	σ_ε	inv. gamma	0.700	2	0.414	0.065	0.452	0.082	0.519	0.361	0.756
Invest. spec. tech. shock	σ_Υ	inv. gamma	0.200	2	0.397	0.046	0.424	0.046	0.469	0.389	0.561
Asymmetric tech. shock	$\sigma_{\tilde{z}^*}$	inv. gamma	0.400	2	0.200	0.030	0.203	0.031	0.217	0.166	0.276
Consumption pref. shock	σ_{ζ_c}	inv. gamma	0.200	2	0.132	0.025	0.151	0.031	0.157	0.108	0.224
Labour supply shock	σ_{ζ_h}	inv. gamma	0.200	2	0.094	0.014	0.095	0.015	0.098	0.075	0.128
Risk premium shock	$\sigma_{\tilde{\phi}}$	inv. gamma	0.050	2	0.123	0.023	0.130	0.023	0.183	0.128	0.246
Domestic markup shock	σ_λ	inv. gamma	0.300	2	0.133	0.013	0.130	0.012	0.132	0.111	0.157
Imp. cons. markup shock	$\sigma_{\lambda_{m,c}}$	inv. gamma	0.300	2	1.912	0.492	2.548	0.710	2.882	1.737	4.463
Imp. invest. markup shock	$\sigma_{\lambda_{m,i}}$	inv. gamma	0.300	2	0.281	0.068	0.292	0.079	0.354	0.218	0.550
Export markup shock	σ_{λ_x}	inv. gamma	0.300	2	1.028	0.210	0.977	0.214	1.124	0.772	1.604
Monetary policy shock	σ_R	inv. gamma	0.150	2	0.126	0.013	0.133	0.013	0.135	0.113	0.160
Inflation target shock	$\sigma_{\bar{\pi}^c}$	inv. gamma	0.050	2	0.036	0.009	0.044	0.012	0.053	0.032	0.081
Interest rate smoothing	ρ_R	beta	0.800	0.050	0.885	0.020	0.874	0.021	0.881	0.844	0.915
Inflation response	r_π	normal	1.700	0.100	1.615	0.103	1.710	0.067	1.730	1.577	1.876
Diff. infl response	$r_{\Delta\pi}$	normal	0.300	0.100	0.301	0.058	0.317	0.059	0.310	0.212	0.411
Real exch. rate response	r_x	normal	0.000	0.050	-0.010	0.007	-0.009	0.008	-0.009	-0.024	0.006
Output response	r_y	normal	0.125	0.050	0.123	0.032	0.078	0.028	0.104	0.051	0.168
Diff. output response	$r_{\Delta\pi}$	normal	0.0625	0.050	0.142	0.025	0.116	0.028	0.128	0.081	0.177
Log marginal likelihood					-1917.39		-1909.34				

*Note: For the inverse gamma distribution. the mode and the degrees of freedom are reported. Also. for the parameters $\lambda_d, \eta_i, \eta_f, \lambda_{m,c}, \lambda_{m,i}$ and μ_z the prior distributions are truncated at 1.

Table 2: Sensitivity analysis with respect to frictions

Parameter		Posterior mode									
		Bench-mark	No wage sticki-ness	No price sticki-ness	No habit persist-ence	No invest. adj. cost	LOP imports	LOP exports	No working capital channel	Persis-tent dom. markup shock	IID markup shocks
			$\xi_w = 0.1$	$\xi_d = 0.1$	$b = 0.1$	$\tilde{S}'' = 0.1$	$\xi_{m,c} = \xi_{m,i} = 0.2$	$\xi_x = 0.1$	$\nu = 0.01$	$\rho_{\lambda_d} > 0$	$\rho_{\lambda_d} = \rho_{\lambda_{mc}} = \rho_{\lambda_{mi}} = \rho_{\lambda_x} = 0$
Calvo wages	ξ_w	0.697		0.669	0.687	0.733	0.706	0.710	0.702	0.626	0.687
Calvo domestic prices	ξ_d	0.883	0.866		0.878	0.898	0.885	0.899	0.863	0.661	0.882
Calvo import cons. prices	$\xi_{m.c}$	0.463	0.463	0.464	0.405	0.468		0.466	0.454	0.523	0.899*
Calvo import inv. prices	$\xi_{m,i}$	0.740	0.706	0.733	0.696	0.458		0.762	0.742	0.714	0.912*
Calvo export prices	ξ_x	0.639	0.657	0.637	0.668	0.646	0.711		0.640	0.669	0.853*
Calvo employment	ξ_e	0.792	0.774	0.782	0.763	0.765	0.787	0.776	0.786	0.795	0.784
Indexation wages	κ_w	0.516	0.409	0.696	0.442	0.489	0.424	0.466	0.523	0.291	0.480
Indexation domestic prices	κ_d	0.212	0.197	0.617	0.195	0.192	0.223	0.196	0.228	0.171	0.188
Index. import cons. prices	$\kappa_{m,c}$	0.161	0.161	0.141	0.173	0.152	0.834	0.144	0.165	0.148	0.256
Index. import inv. prices	$\kappa_{m,i}$	0.187	0.190	0.203	0.181	0.130	0.594	0.170	0.184	0.200	0.830
Indexation export prices	κ_x	0.139	0.134	0.140	0.128	0.142	0.126	0.724	0.137	0.125	0.262
Markup domestic	λ_d	1.168	1.149	1.123	1.162	1.203	1.151	1.164	1.164	1.155	1.160
Markup imported cons.	$\lambda_{m.c}$	1.619	1.677	1.652	1.721	1.545	1.203	1.636	1.629	1.642	1.515
Markup.imported invest.	$\lambda_{m.i}$	1.226	1.280	1.268	1.250	1.218	1.850	1.178	1.227	1.255	1.160
Investment adj. cost	$\tilde{S}''$	8.732	8.920	8.691	9.091		6.737	8.249	8.784	7.143	9.499
Habit formation	b	0.690	0.669	0.611		0.660	0.916	0.752	0.688	0.614	0.647
Subst. elasticity invest.	η_i	1.669	1.678	1.601	1.751	2.823	3.394	1.494	1.660	1.616	1.405
Subst. elasticity foreign	η_f	1.460	1.470	1.481	1.462	1.460	1.443	1.375	1.460	1.577	1.356
Technology growth	μ_z	1.005	1.005	1.005	1.005	1.005	1.006	1.005	1.005	1.006	1.005
Capital income tax	τ_k	0.137	0.182	0.165	0.228	0.132	0.213	0.143	0.150	0.265	0.172
Labour pay-roll tax	τ_w	0.186	0.184	0.186	0.186	0.185	0.185	0.186	0.186	0.185	0.186
Risk premium	$\tilde{\phi}$	0.145	0.146	0.086	0.176	0.485	0.300	0.140	0.147	0.095	0.035
Unit root tech. shock	ρ_{μ_z}	0.723	0.610	0.611	0.609	0.748	0.809	0.636	0.716	0.792	0.741
Stationary tech. shock	ρ_{ε}	0.909	0.995	0.999	0.917	0.921	0.848	0.991	0.913	0.997	0.904
Invest. spec. tech shock	ρ_{Υ}	0.750	0.749	0.769	0.694	0.922	0.469	0.741	0.748	0.562	0.785
Asymmetric tech. shock	$\rho_{\tilde{z}*}$	0.993	0.993	0.994	0.994	0.995	0.907	0.994	0.993	0.953	0.990
Consumption pref. shock	ρ_{ζ_c}	0.935	0.894	0.987	0.959	0.944	0.496	0.791	0.938	0.992	0.911
Labour supply shock	ρ_{ζ_h}	0.675	0.933	0.471	0.637	0.686	0.689	0.718	0.657	0.536	0.656
Risk premium shock	$\rho_{\tilde{\phi}}$	0.991	0.991	0.987	0.993	0.957	0.955	0.992	0.991	0.991	0.920
Domestic markup shock	ρ_{λ_d}									0.995	
Imp. cons. markup shock	$\rho_{\lambda_{m,c}}$	0.978	0.979	0.986	0.989	0.959	0.978	0.938	0.982	0.975	
Imp. invest. markup shock	$\rho_{\lambda_{m,i}}$	0.974	0.976	0.969	0.969	0.980	0.989	0.982	0.973	0.990	
Export markup shock	ρ_{λ_x}	0.894	0.877	0.923	0.881	0.857	0.864	0.986	0.894	0.928	
Unit root tech. shock	σ_z	0.130	0.120	0.127	0.118	0.134	0.128	0.119	0.130	0.132	0.128
Stationary tech. shock	σ_{ε}	0.452	0.371	0.292	0.429	0.423	0.478	0.337	0.431	0.422	0.450
Invest. spec. tech. shock	σ_{Υ}	0.424	0.425	0.385	0.442	5.796	0.666	0.436	0.424	0.444	0.376
Asymmetric tech. shock	$\sigma_{\tilde{z}*}$	0.203	0.211	0.217	0.218	0.201	0.185	0.212	0.204	0.186	0.204
Consumption pref. shock	σ_{ζ_c}	0.151	0.150	0.207	0.730	0.150	0.121	0.137	0.151	0.155	0.163
Labour supply shock	σ_{ζ_h}	0.095	0.195	0.097	0.095	0.091	0.095	0.089	0.096	0.098	0.096
Risk premium shock	$\sigma_{\tilde{\phi}}$	0.130	0.129	0.121	0.137	0.229	0.171	0.122	0.128	0.122	0.344
Domestic markup shock	σ_{λ}	0.130	0.134	0.261	0.132	0.136	0.130	0.130	0.129	0.125	0.129
Imp. cons. markup shock	$\sigma_{\lambda_{m.c}}$	2.548	2.622	2.548	3.505	2.468	4.798	2.654	2.657	1.810	1.147
Imp. invest. markup shock	$\sigma_{\lambda_{m,i}}$	0.292	0.368	0.316	0.391	1.640	13.247	0.243	0.289	0.341	0.414
Export markup shock	σ_{λ_x}	0.977	0.922	0.938	0.885	0.988	0.783	13.836	0.973	0.789	1.272
Monetary policy shock	σ_R	0.133	0.134	0.144	0.142	0.150	0.115	0.126	0.133	0.144	0.130
Inflation target shock	$\sigma_{\bar{\pi}^c}$	0.044	0.048	0.041	0.037	0.036	0.039	0.047	0.043	0.041	0.049
Interest rate smoothing	ρ_R	0.874	0.834	0.805	0.813	0.865	0.877	0.889	0.869	0.824	0.851
Inflation response	r_{π}	1.710	1.704	1.746	1.657	1.753	1.703	1.722	1.700	1.660	1.697
Diff. infl response	$r_{\Delta\pi}$	0.317	0.368	0.365	0.403	0.349	0.345	0.282	0.327	0.384	0.304
Real exch. rate response	r_x	-0.009	-0.007	-0.007	-0.003	-0.018	-0.008	-0.008	-0.008	-0.008	0.003
Output response	r_v	0.078	0.058	-0.001	0.042	0.064	0.043	0.109	0.080	-0.030	0.056
Diff. output response	$r_{\Delta\pi}$	0.116	0.087	0.088	0.145	0.244	0.123	0.142	0.115	0.130	0.104
Log marginal likelihood		-1909.34	-1918.38	-1967.99	-1936.70	-1994.00	-1986.50	-1937.89	-1905.16	-1915.53	-1975.5

*Note: The same prior is used as for the domestic price stickiness parameter.

Table 3: Sensitivity with respect to shocks

Parameter		Posterior mode							
		Bench-mark	No varying inflation target	No technology shocks	No preference shocks	No domestic markup shock	No imported/ exported shocks	No risk premium + asymm. tech. shocks	No fiscal shocks
			$\sigma_{\bar{\pi}^c}$ = 0.0001	$\sigma_z = \sigma_\varepsilon = \sigma_{\mathrm{Y}} = 0$	$\sigma_{\zeta_c} = \sigma_{\zeta_h} = 0.01$	$\sigma_\lambda = 0$	$\sigma_{\lambda_{m,c}} = \sigma_{\lambda_{m,i}} = \sigma_{\lambda_x} = 0.3$	$\sigma_{\tilde{\phi}} = \sigma_{\tilde{z}^*} = 0$	
Calvo wages	ξ_w	0.697	0.711	0.684	0.810	0.698	0.709	0.695	0.708
Calvo domestic prices	ξ_d	0.883	0.882	0.926	0.930	0.843	0.893	0.867	0.887
Calvo import cons. prices	$\xi_{m,c}$	0.463	0.495	0.566	0.489	0.485	0.944	0.498	0.495
Calvo import inv. prices	$\xi_{m,i}$	0.740	0.721	0.682	0.604	0.742	0.980	0.755	0.735
Calvo export prices	ξ_x	0.639	0.638	0.690	0.675	0.643	0.942	0.607	0.619
Calvo employment	ξ_e	0.792	0.786	0.793	0.806	0.800	0.782	0.795	0.801
Indexation wages	κ_w	0.516	0.482	0.587	0.153	0.741	0.461	0.639	0.494
Indexation domestic prices	κ_d	0.212	0.246	0.956	0.952	0.092	0.167	0.329	0.207
Index. import cons. prices	$\kappa_{m,c}$	0.161	0.148	0.171	0.180	0.160	0.535	0.144	0.153
Index. import inv. prices	$\kappa_{m,i}$	0.187	0.202	0.274	0.262	0.200	0.711	0.182	0.192
Indexation export prices	κ_x	0.139	0.143	0.128	0.124	0.136	0.421	0.144	0.145
Markup domestic	λ_d	1.168	1.182	1.122	1.141	1.172	1.165	1.151	1.181
Markup imported cons.	$\lambda_{m,c}$	1.619	1.604	1.628	1.806	1.633	1.228	1.655	1.557
Markup.imported invest.	$\lambda_{m,i}$	1.226	1.240	1.198	1.646	1.237	1.309	1.195	1.272
Investment adj. cost	$\tilde{S}''$	8.732	8.763	1.985	7.850	9.346	9.197	9.014	8.679
Habit formation	b	0.690	0.680	0.674	0.673	0.717	0.619	0.747	0.731
Subst. elasticity invest.	η_i	1.669	1.708	2.525	1.610	1.665	1.380	1.622	1.587
Subst. elasticity foreign	η_f	1.460	1.459	1.415	1.557	1.448	4.593	1.505	1.440
Technology growth	μ_z	1.005	1.005	1.005	1.005	1.005	1.005	1.006	1.006
Capital income tax	τ_k	0.137	0.120	0.253	0.248	0.158	0.259	0.196	
Labour pay-roll tax	τ_w	0.186	0.185	0.186	0.186	0.186	0.188	0.187	
Risk premium	$\tilde{\phi}$	0.145	0.137	0.046	0.331	0.161	0.027	0.216	0.112
Unit root tech. shock	ρ_{μ_z}	0.723	0.793		0.829	0.680	0.729	0.830	0.829
Stationary tech. shock	ρ_ε	0.909	0.906		0.984	0.918	0.898	0.872	0.904
Invest. spec. tech shock	ρ_{Y}	0.750	0.748		0.695	0.751	0.652	0.729	0.763
Asymmetric tech. shock	$\rho_{\tilde{z}^*}$	0.993	0.994	0.994	0.930	0.993	0.995		0.993
Consumption pref. shock	ρ_{ζ_c}	0.935	0.937	0.989		0.972	0.944	0.979	0.924
Labour supply shock	ρ_{ζ_h}	0.675	0.696	0.624		0.632	0.607	0.708	0.697
Risk premium shock	$\rho_{\tilde{\phi}}$	0.991	0.991	0.927	0.941	0.991	0.927		0.991
Imp. cons. markup shock	$\rho_{\lambda_{m,c}}$	0.978	0.965	0.984	0.968	0.977		0.967	0.962
Imp. invest. markup shock	$\rho_{\lambda_{m,i}}$	0.974	0.983	0.974	0.985	0.966		0.991	0.981
Export markup shock	ρ_{λ_x}	0.894	0.894	0.833	0.881	0.893		0.920	0.905
Unit root tech. shock	σ_z	0.130	0.137		0.155	0.131	0.133	0.155	0.137
Stationary tech. shock	σ_ε	0.452	0.449		0.464	0.544	0.466	0.482	0.467
Invest. spec. tech. shock	σ_{Y}	0.424	0.419		0.425	0.420	0.465	0.476	0.426
Asymmetric tech. shock	$\sigma_{\tilde{z}^*}$	0.203	0.197	0.249	0.185	0.209	0.203		0.195
Consumption pref. shock	σ_{ζ_c}	0.151	0.149	0.223		0.155	0.170	0.158	0.136
Labour supply shock	σ_{ζ_h}	0.095	0.092	0.095		0.104	0.096	0.092	0.092
Risk premium shock	$\sigma_{\tilde{\phi}}$	0.130	0.133	0.156	0.213	0.131	0.346		0.129
Domestic markup shock	σ_λ	0.130	0.132	0.158	0.135		0.128	0.127	0.130
Imp. cons. markup shock	$\sigma_{\lambda_{m,c}}$	2.548	2.200	1.542	2.384	2.317		2.300	2.204
Imp. invest. markup shock	$\sigma_{\lambda_{m,i}}$	0.292	0.327	0.412	0.721	0.296		0.253	0.303
Export markup shock	σ_{λ_x}	0.977	0.979	0.849	0.807	0.965		1.066	1.055
Monetary policy shock	σ_R	0.133	0.136	0.135	0.130	0.134	0.120	0.129	0.137
Inflation target shock	$\sigma_{\bar{\pi}^c}$	0.044		0.207	0.150	0.043	0.047	0.070	0.042
Interest rate smoothing	ρ_R	0.874	0.867	0.890	0.871	0.863	0.860	0.884	0.883
Inflation response	r_π	1.710	1.745	1.725	1.592	1.671	1.664	1.619	1.712
Diff. infl response	$r_{\Delta\pi}$	0.317	0.327	0.258	0.310	0.360	0.347	0.275	0.294
Real exch. rate response	r_x	-0.009	-0.015	0.013	-0.004	-0.008	0.010	-0.018	-0.018
Output response	r_y	0.078	0.048	0.131	0.145	0.082	0.068	0.088	0.081
Diff. output response	$r_{\Delta\pi}$	0.116	0.143	0.168	0.143	0.075	0.134	0.132	0.127
Log marginal likelihood		-1909.34	-1908.58	-1992.90	-1949.38	-1910.94	-2038.19	-1931.29	-1914.81

Table 5: Variance decompositions. 5th median (bold) and 95th percentiles

1 quarter	Domestic inflation			Real exchange rate			Interest rate			Output			Exports			Imports		
Stationary technology	0.075	**0.114**	0.160	0.000	**0.004**	0.011	0.021	**0.038**	0.061	0.002	**0.014**	0.033	0.000	**0.003**	0.007	0.000	**0.003**	0.007
Unit root technology	0.026	**0.046**	0.090	0.004	**0.010**	0.020	0.002	**0.016**	0.051	0.057	**0.087**	0.135	0.020	**0.028**	0.039	0.014	**0.022**	0.036
Investment specific technology	0.002	**0.024**	0.059	0.071	**0.097**	0.123	0.074	**0.113**	0.150	0.169	**0.202**	0.239	0.051	**0.070**	0.091	0.201	**0.244**	0.290
Asymmetric technology	0.002	**0.004**	0.008	0.011	**0.014**	0.018	0.000	**0.001**	0.004	0.004	**0.006**	0.009	0.019	**0.027**	0.038	0.013	**0.018**	0.024
Consumtion preference	0.012	**0.037**	0.059	0.024	**0.038**	0.058	0.035	**0.066**	0.094	0.090	**0.124**	0.161	0.015	**0.025**	0.040	0.023	**0.033**	0.046
Labour supply	0.152	**0.201**	0.254	0.001	**0.010**	0.028	0.039	**0.070**	0.107	0.002	**0.023**	0.053	0.001	**0.005**	0.014	0.000	**0.003**	0.010
Risk premium	0.006	**0.013**	0.024	0.077	**0.098**	0.122	0.038	**0.052**	0.069	0.049	**0.063**	0.081	0.037	**0.051**	0.068	0.086	**0.112**	0.140
Domestic markup	0.238	**0.302**	0.381	0.007	**0.012**	0.017	0.061	**0.095**	0.131	0.030	**0.041**	0.053	0.004	**0.007**	0.010	0.030	**0.037**	0.047
Import consumption markup	0.008	**0.044**	0.085	0.229	**0.265**	0.304	0.029	**0.061**	0.091	0.002	**0.016**	0.044	0.128	**0.162**	0.195	0.212	**0.247**	0.285
Import investment markup	0.002	**0.022**	0.062	0.112	**0.146**	0.182	0.008	**0.038**	0.068	0.004	**0.027**	0.054	0.083	**0.105**	0.129	0.001	**0.014**	0.040
Export markup	0.001	**0.010**	0.028	0.072	**0.097**	0.127	0.003	**0.023**	0.046	0.053	**0.080**	0.106	0.284	**0.336**	0.405	0.083	**0.113**	0.146
Monetary policy	0.017	**0.037**	0.059	0.059	**0.071**	0.087	0.211	**0.274**	0.357	0.091	**0.118**	0.151	0.027	**0.038**	0.051	0.013	**0.027**	0.042
Inflation target	0.061	**0.100**	0.155	0.013	**0.021**	0.033	0.028	**0.048**	0.078	0.021	**0.036**	0.060	0.006	**0.010**	0.018	0.001	**0.004**	0.011
Fiscal variables	0.006	**0.012**	0.021	0.003	**0.005**	0.008	0.019	**0.031**	0.044	0.050	**0.057**	0.067	0.001	**0.003**	0.005	0.001	**0.002**	0.004
Foreign variables	0.005	**0.012**	0.021	0.086	**0.103**	0.123	0.044	**0.062**	0.084	0.074	**0.092**	0.113	0.095	**0.123**	0.153	0.083	**0.112**	0.142
4 quarters	Domestic inflation			Real exchange rate			Interest rate			Output			Exports			Imports		
Stationary technology	0.067	**0.115**	0.175	0.002	**0.011**	0.022	0.034	**0.062**	0.103	0.013	**0.035**	0.063	0.002	**0.007**	0.015	0.002	**0.006**	0.010
Unit root technology	0.040	**0.070**	0.137	0.000	**0.004**	0.014	0.008	**0.032**	0.096	0.072	**0.115**	0.184	0.022	**0.034**	0.051	0.033	**0.052**	0.081
Investment specific technology	0.004	**0.046**	0.101	0.104	**0.132**	0.162	0.110	**0.175**	0.241	0.202	**0.237**	0.281	0.071	**0.094**	0.120	0.197	**0.239**	0.285
Asymmetric technology	0.003	**0.007**	0.014	0.011	**0.015**	0.019	0.004	**0.007**	0.012	0.000	**0.002**	0.004	0.005	**0.008**	0.012	0.018	**0.025**	0.035
Consumtion preference	0.018	**0.053**	0.090	0.025	**0.041**	0.064	0.084	**0.129**	0.169	0.098	**0.129**	0.164	0.017	**0.029**	0.047	0.006	**0.019**	0.033
Labour supply	0.200	**0.269**	0.345	0.003	**0.020**	0.038	0.087	**0.134**	0.191	0.025	**0.068**	0.109	0.002	**0.014**	0.027	0.003	**0.010**	0.018
Risk premium	0.005	**0.015**	0.030	0.041	**0.055**	0.074	0.029	**0.043**	0.061	0.030	**0.040**	0.054	0.029	**0.039**	0.053	0.072	**0.100**	0.135
Domestic markup	0.012	**0.025**	0.039	0.004	**0.007**	0.011	0.012	**0.026**	0.044	0.017	**0.025**	0.037	0.003	**0.005**	0.008	0.000	**0.002**	0.005
Import consumption markup	0.017	**0.076**	0.139	0.259	**0.304**	0.353	0.002	**0.025**	0.070	0.002	**0.021**	0.049	0.156	**0.189**	0.227	0.148	**0.185**	0.224
Import investment markup	0.004	**0.037**	0.099	0.152	**0.189**	0.228	0.004	**0.038**	0.088	0.010	**0.035**	0.062	0.114	**0.141**	0.170	0.060	**0.097**	0.132
Export markup	0.001	**0.012**	0.041	0.075	**0.106**	0.141	0.019	**0.058**	0.088	0.057	**0.082**	0.108	0.283	**0.333**	0.394	0.108	**0.150**	0.196
Monetary policy	0.024	**0.055**	0.090	0.032	**0.042**	0.057	0.065	**0.103**	0.151	0.083	**0.108**	0.142	0.023	**0.032**	0.043	0.000	**0.005**	0.014
Inflation target	0.096	**0.156**	0.235	0.006	**0.011**	0.019	0.056	**0.092**	0.143	0.018	**0.031**	0.054	0.004	**0.008**	0.014	0.002	**0.006**	0.012
Fiscal variables	0.010	**0.019**	0.031	0.002	**0.003**	0.006	0.008	**0.015**	0.026	0.010	**0.015**	0.021	0.001	**0.003**	0.005	0.000	**0.001**	0.002
Foreign variables	0.005	**0.013**	0.024	0.037	**0.053**	0.072	0.025	**0.039**	0.057	0.031	**0.043**	0.057	0.044	**0.057**	0.072	0.067	**0.098**	0.130

Table 5 (cont.): Variance decompositions. 5th median (bold) and 95th percentiles

8 quarters	Domestic inflation			Real exchange rate			Interest rate			Output			Exports			Imports		
Stationary technology	0.021	**0.071**	0.136	0.007	**0.017**	0.031	0.032	**0.069**	0.126	0.027	**0.054**	0.093	0.005	**0.013**	0.024	0.000	**0.004**	0.010
Unit root technology	0.043	**0.075**	0.152	0.000	**0.003**	0.014	0.025	**0.054**	0.133	0.092	**0.150**	0.244	0.028	**0.047**	0.078	0.062	**0.101**	0.163
Investment specific technology	0.016	**0.089**	0.146	0.119	**0.148**	0.185	0.059	**0.137**	0.227	0.190	**0.240**	0.295	0.086	**0.113**	0.145	0.061	**0.120**	0.192
Asymmetric technology	0.003	**0.009**	0.017	0.012	**0.015**	0.020	0.004	**0.008**	0.015	0.000	**0.001**	0.002	0.006	**0.008**	0.012	0.025	**0.037**	0.054
Consumtion preference	0.017	**0.050**	0.099	0.016	**0.037**	0.065	0.098	**0.147**	0.198	0.079	**0.111**	0.153	0.014	**0.030**	0.052	0.004	**0.017**	0.035
Labour supply	0.137	**0.205**	0.285	0.019	**0.040**	0.060	0.108	**0.168**	0.240	0.074	**0.122**	0.169	0.014	**0.030**	0.046	0.001	**0.006**	0.019
Risk premium	0.000	**0.006**	0.022	0.003	**0.014**	0.034	0.001	**0.010**	0.027	0.002	**0.010**	0.020	0.007	**0.015**	0.029	0.026	**0.057**	0.110
Domestic markup	0.013	**0.025**	0.042	0.000	**0.002**	0.005	0.001	**0.007**	0.015	0.009	**0.015**	0.024	0.001	**0.002**	0.005	0.008	**0.012**	0.016
Import consumption markup	0.033	**0.106**	0.181	0.256	**0.308**	0.366	0.004	**0.041**	0.114	0.001	**0.013**	0.040	0.167	**0.208**	0.255	0.083	**0.121**	0.166
Import investment markup	0.005	**0.051**	0.127	0.200	**0.247**	0.294	0.005	**0.053**	0.129	0.050	**0.076**	0.107	0.152	**0.194**	0.239	0.162	**0.201**	0.241
Export markup	0.001	**0.011**	0.048	0.059	**0.093**	0.137	0.019	**0.052**	0.079	0.037	**0.058**	0.081	0.201	**0.283**	0.364	0.128	**0.185**	0.252
Monetary policy	0.020	**0.052**	0.095	0.015	**0.026**	0.040	0.021	**0.047**	0.078	0.057	**0.083**	0.121	0.014	**0.022**	0.034	0.024	**0.033**	0.045
Inflation target	0.113	**0.184**	0.281	0.002	**0.006**	0.012	0.082	**0.132**	0.203	0.010	**0.020**	0.040	0.001	**0.004**	0.010	0.008	**0.014**	0.025
Fiscal variables	0.013	**0.024**	0.037	0.001	**0.003**	0.006	0.006	**0.016**	0.029	0.007	**0.013**	0.020	0.001	**0.002**	0.005	0.001	**0.003**	0.005
Foreign variables	0.003	**0.009**	0.017	0.020	**0.030**	0.041	0.012	**0.024**	0.037	0.007	**0.014**	0.024	0.009	**0.018**	0.030	0.041	**0.068**	0.105

20 quarters	Domestic inflation			Real exchange rate			Interest rate			Output			Exports			Imports		
Stationary technology	0.001	**0.016**	0.073	0.006	**0.017**	0.036	0.005	**0.036**	0.101	0.018	**0.047**	0.091	0.005	**0.014**	0.030	0.009	**0.018**	0.031
Unit root technology	0.041	**0.072**	0.153	0.005	**0.012**	0.029	0.054	**0.092**	0.183	0.155	**0.244**	0.390	0.056	**0.097**	0.174	0.102	**0.171**	0.285
Investment specific technology	0.108	**0.174**	0.247	0.005	**0.039**	0.092	0.094	**0.154**	0.213	0.070	**0.129**	0.198	0.006	**0.037**	0.081	0.076	**0.133**	0.206
Asymmetric technology	0.008	**0.017**	0.030	0.014	**0.020**	0.029	0.004	**0.012**	0.024	0.003	**0.005**	0.009	0.011	**0.017**	0.025	0.036	**0.054**	0.080
Consumtion preference	0.016	**0.046**	0.108	0.007	**0.031**	0.072	0.043	**0.111**	0.183	0.002	**0.029**	0.108	0.006	**0.026**	0.061	0.018	**0.038**	0.061
Labour supply	0.004	**0.040**	0.103	0.025	**0.044**	0.071	0.053	**0.104**	0.174	0.079	**0.121**	0.179	0.020	**0.036**	0.060	0.030	**0.045**	0.065
Risk premium	0.001	**0.005**	0.014	0.011	**0.019**	0.029	0.002	**0.009**	0.018	0.002	**0.006**	0.015	0.008	**0.015**	0.023	0.012	**0.053**	0.083
Domestic markup	0.000	**0.003**	0.009	0.000	**0.001**	0.002	0.001	**0.003**	0.006	0.000	**0.002**	0.006	0.000	**0.001**	0.002	0.000	**0.001**	0.004
Import consumption markup	0.080	**0.180**	0.291	0.209	**0.328**	0.458	0.009	**0.080**	0.202	0.052	**0.099**	0.152	0.130	**0.224**	0.331	0.018	**0.090**	0.182
Import investment markup	0.013	**0.099**	0.204	0.267	**0.387**	0.501	0.006	**0.067**	0.228	0.128	**0.192**	0.261	0.201	**0.319**	0.434	0.081	**0.186**	0.288
Export markup	0.007	**0.022**	0.071	0.008	**0.041**	0.123	0.004	**0.022**	0.059	0.006	**0.029**	0.079	0.027	**0.138**	0.360	0.040	**0.106**	0.246
Monetary policy	0.001	**0.005**	0.032	0.003	**0.009**	0.022	0.001	**0.009**	0.021	0.012	**0.027**	0.057	0.003	**0.008**	0.019	0.001	**0.007**	0.016
Inflation target	0.139	**0.234**	0.368	0.000	**0.001**	0.004	0.128	**0.201**	0.305	0.000	**0.003**	0.009	0.000	**0.001**	0.004	0.001	**0.003**	0.007
Fiscal variables	0.016	**0.027**	0.038	0.003	**0.006**	0.009	0.014	**0.027**	0.041	0.010	**0.017**	0.025	0.002	**0.005**	0.008	0.002	**0.004**	0.006
Foreign variables	0.002	**0.006**	0.013	0.013	**0.020**	0.029	0.006	**0.014**	0.027	0.005	**0.009**	0.015	0.016	**0.023**	0.033	0.038	**0.059**	0.085

Figure 1: Data (bold) and one-sided predicted values (thin)

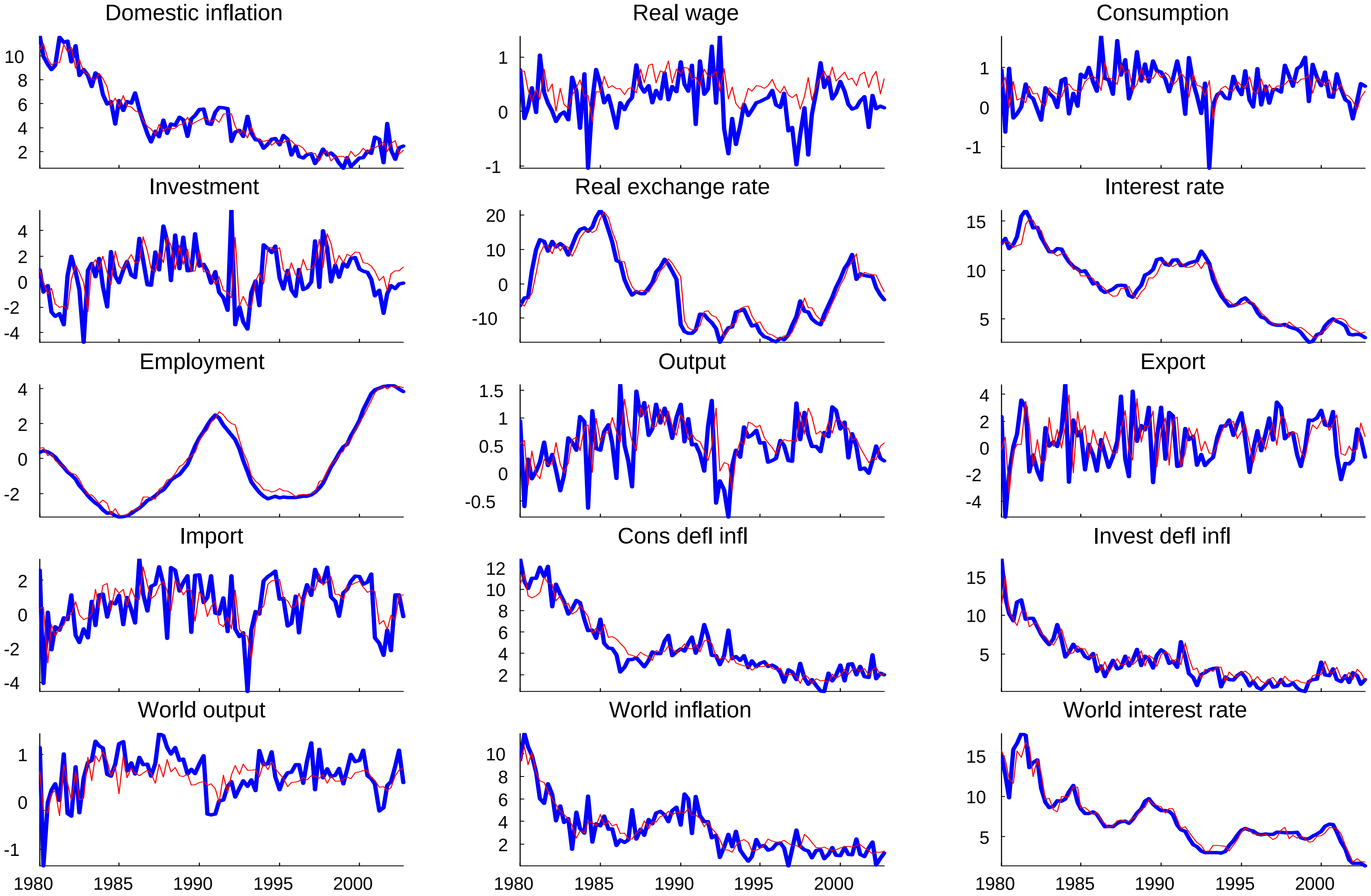


Figure 2a: Prior and posterior distributions, friction parameters

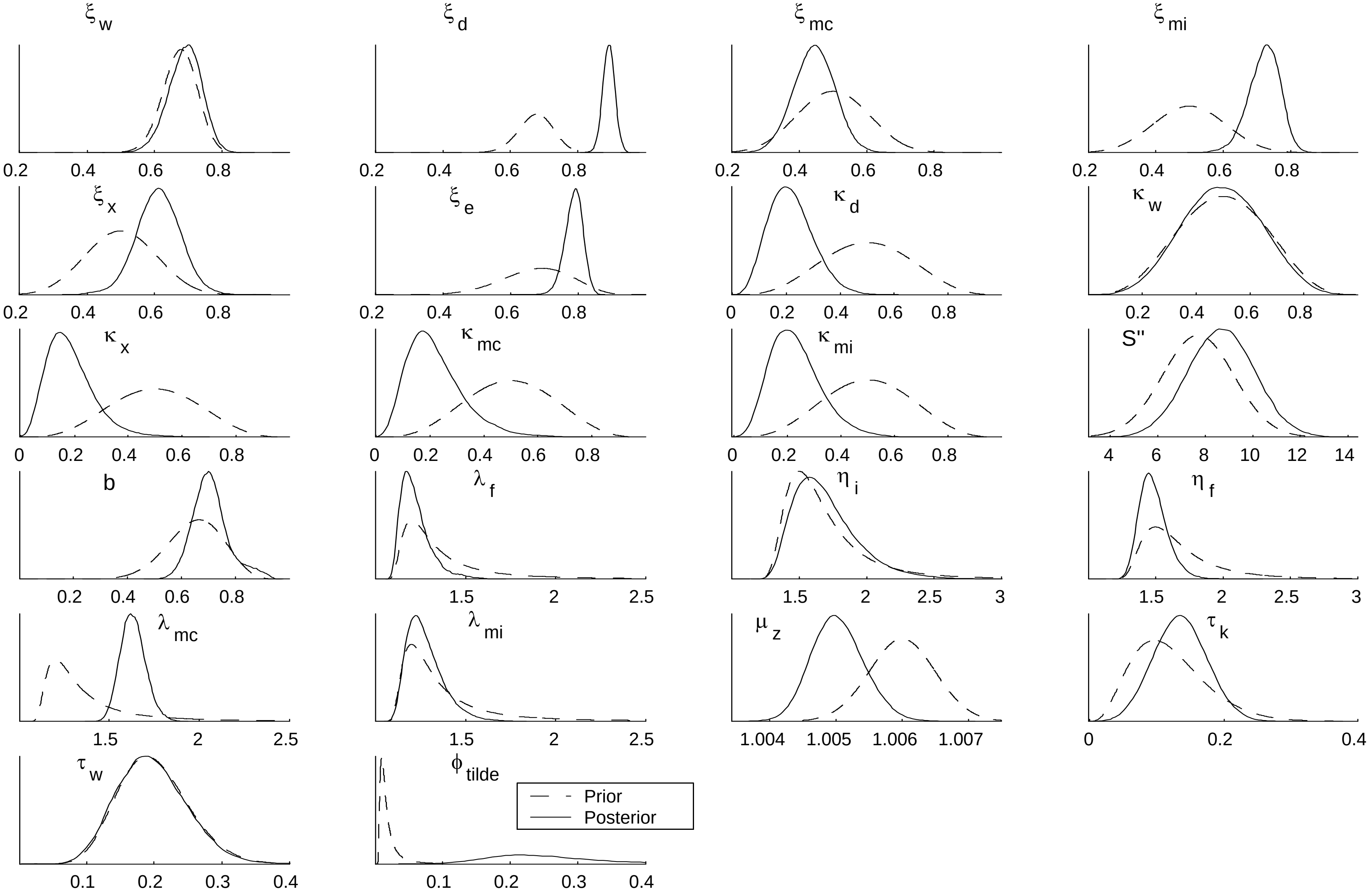


Figure 2b: Prior and posterior distributions, shock processes parameters

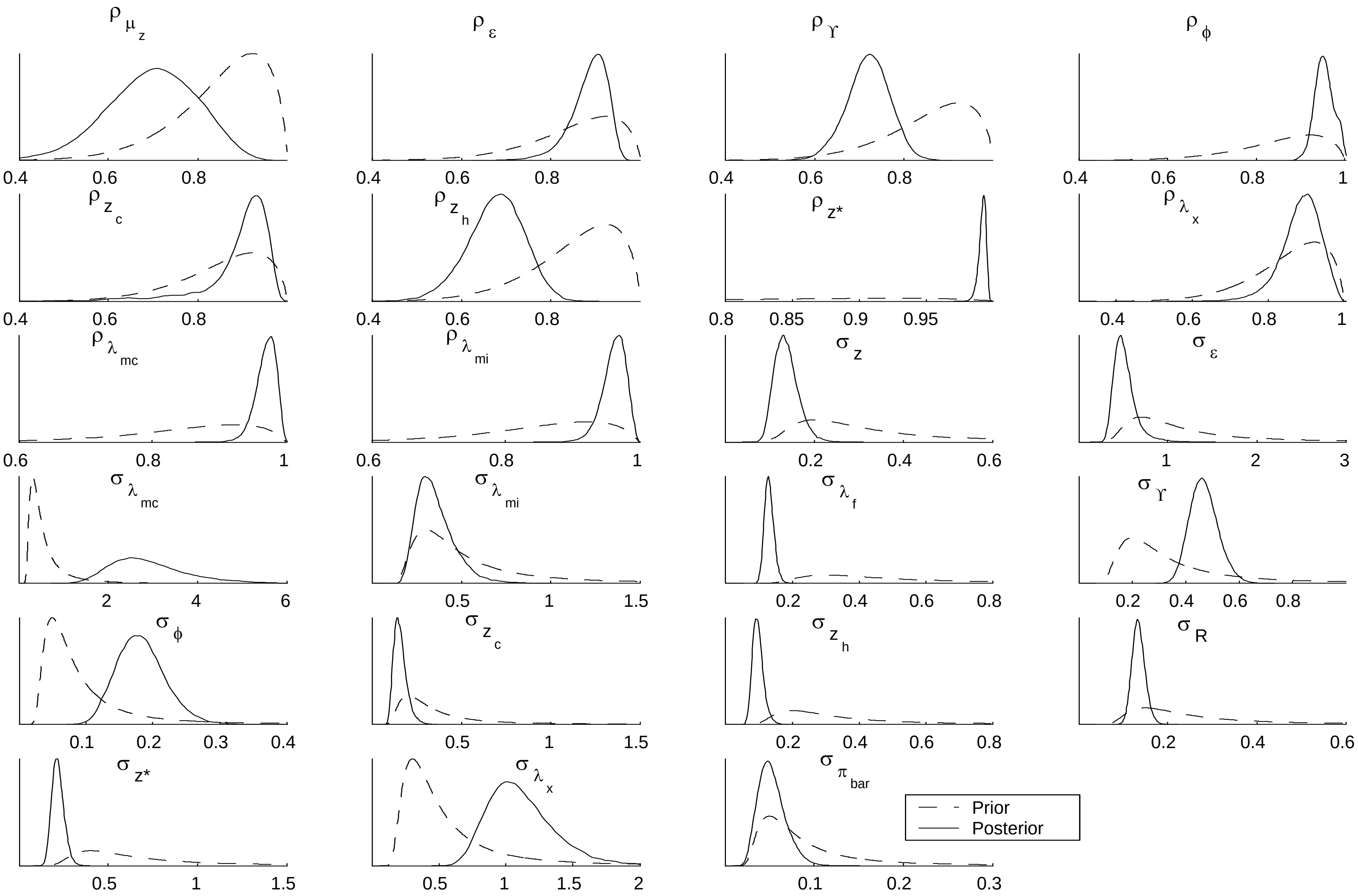


Figure 2c: Prior and posterior distributions, policy parameters

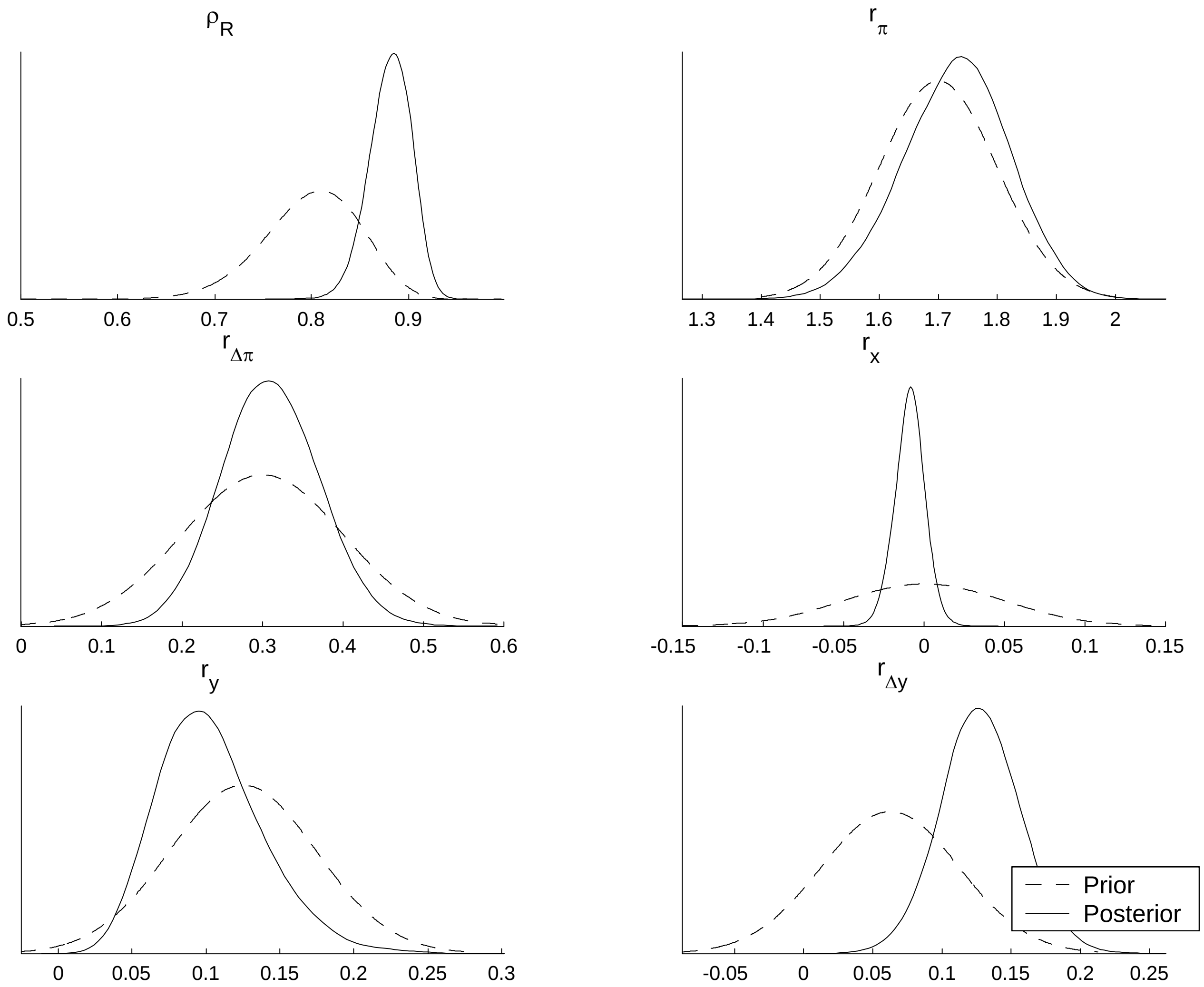


Figure 3: Smoothed (two-sided) estimates of the unobserved shocks

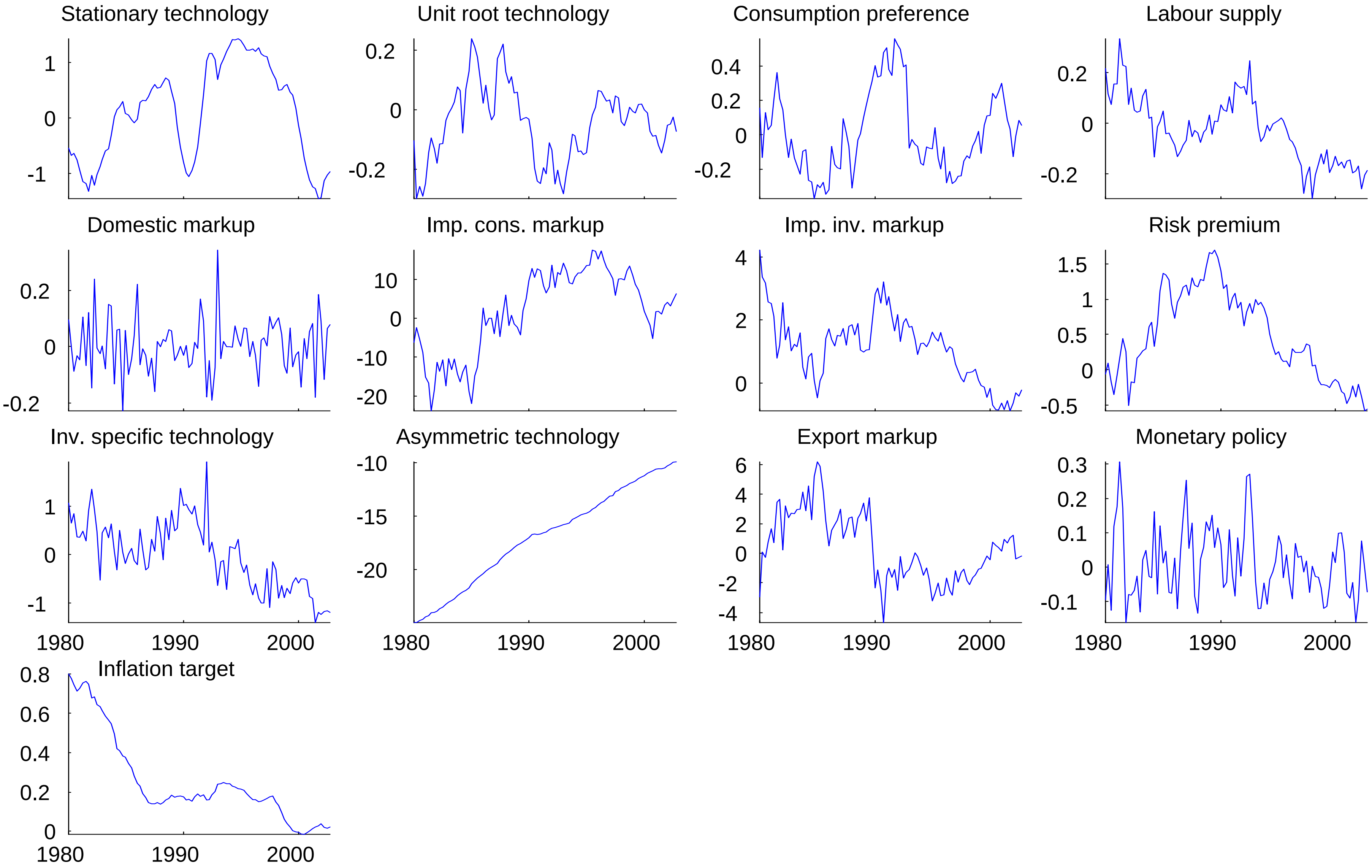
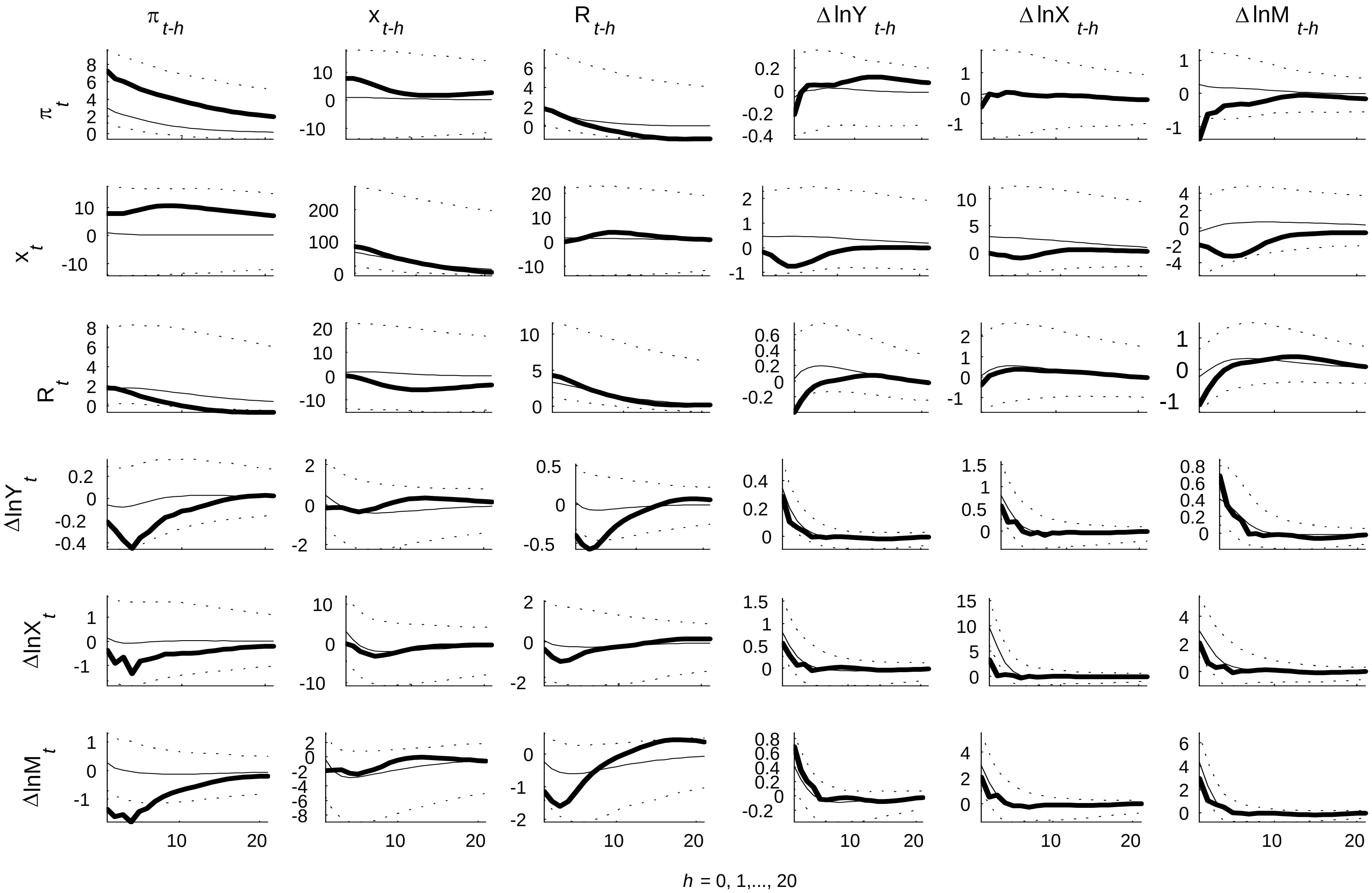
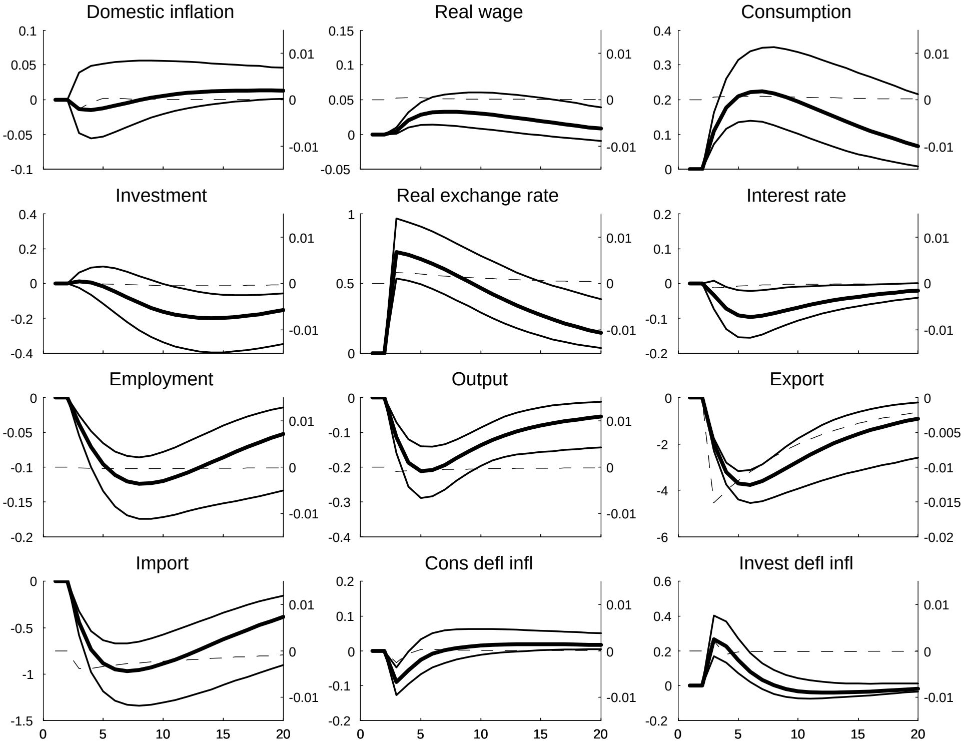


Figure 4: Autocovariance functions



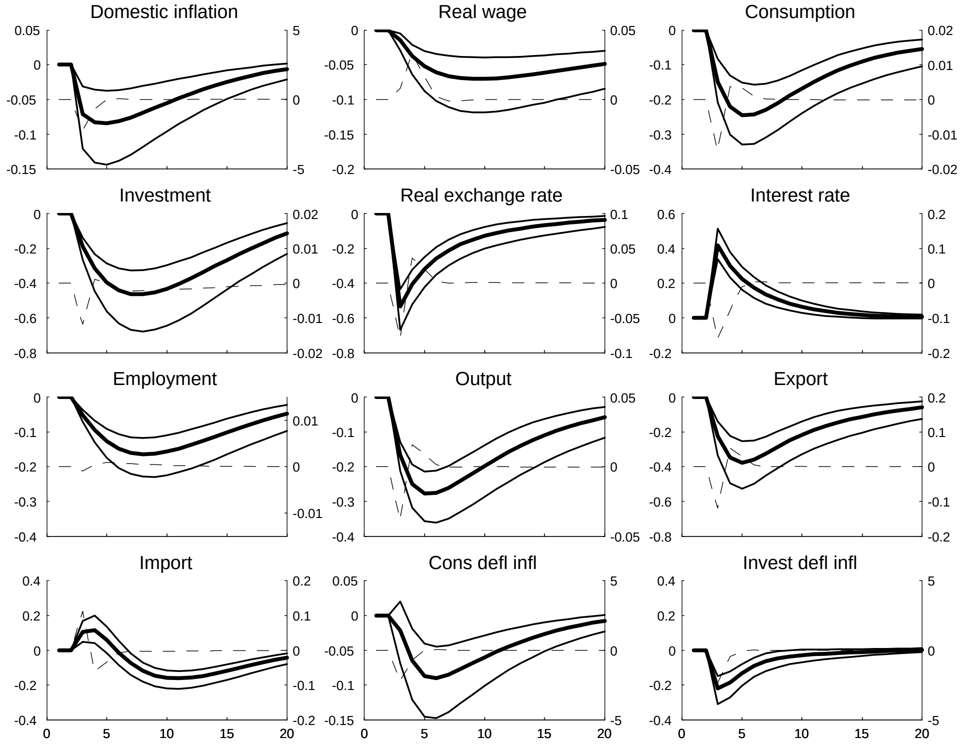
Note: VAR (thick), DSGE posterior median (thin) and DSGE 95% posterior probablity density (dashed).

Figure 5k: Impulse responses to an export markup shock



Note: Benchmark (solid, left axis) and flexible prices and wages (dashed, right axis).

Figure 5l: Impulse responses to a monetary policy shock



Note: Benchmark (solid, left axis) and flexible prices and wages (dashed, right axis).

Figure 6: Historical decompositions, data (thick) and model (thin)