An Estimated DSGE Model for the German Economy within the Euro Area[*]

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Abstract

This paper presents an estimated DSGE model for the European Monetary Union. Our approach, contrary to the previous studies, accounts for heterogeneity within the euro area. We advance the empirical literature by estimating an open-economy model with unfiltered data, which is a much more challenging task than a similar exercise done in the closed-economy framework. In the estimation we utilize disaggregated information, employing single country data, along with the aggregated EMU data by Fagan *et. al* (2001). We also contribute to the literature by proposing a strategy for consistent estimation of the currency union model, using information available prior to the adoption of the single currency and afterwards. This approach requires the determination of two separate data generating processes - here these are theoretical DSGE models - corresponding to both current and historical monetary regimes. We emphasize the use of regime-switching models in the DSGE framework (in our case the threshold is known exactly and the switch is permanent). The approach is illustrated by developing a simple two-region DSGE model, with a particular focus on analyzing the German economy within EMU, and its Bayesian estimation on the sample 1980:q1- 2003:q4. Moreover, the paper offers: (i) a robustness check of the estimation results with respect to the alternative data approaches and various restrictions imposed on the model's structure, (ii) assessments of the relative importance of various shocks and frictions for explaining the model dynamics and (iii) an evaluation of the model's empirical properties.

1 Introduction

The approach to macro-modeling has significantly changed during the last decade. The most recent developments include models with optimizing agents and the diffusion of numerical methods both at the level of solving the models and optimization algorithms. Indeed, it seems that even empirical researchers have abandoned the traditional Keynesian framework and large-scale stylized models in favor of theoretically grounded dynamic stochastic general equilibrium (DSGE) models.[1]

Our research, in line with the most recent literature, exploits all of these developments and applies them to a model for the European Monetary Union (EMU). The research may also be

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[1] One of the first empirical applications of the new, microfounded approach may be found in Black, Laxton, Rose and Tetlow (1995)

seen as an attempt to simultaneously estimate the system of linearized equations, contrary to the traditional "equation by equation" estimation.[2]

The vast majority of existing DSGE models for the euro area, treat this conglomerate as a single country. To estimate such models the aggregated Euro area data are used (see e.g. Fagan *et al.* (2001)). Since the "genuine" time series for the EMU are relatively short, the estimated models necessarily rely to a large extent on a sample period before the actual establishment of the monetary union. Thus, those models are estimated under implicit assumption that, even before establishment of the currency area, there was a common monetary policy in the European Union (see e.g. Smets and Wouters (2003a) or Adolfson *et al.* (2004)). That approach neglects interactions between the regions of the currency area, their structural heterogeneity and existence of diverse monetary policies and flexible exchange rates before 1999[3].

This paper presents an atempt to utilize the disaggregated information on the euro area along with the aggregated data by developing a DSGE model for a two-region monetary union.[4] We find significant structural heterogeneity between Germany and the rest of the EMU, which may justify the need to build such a two-region model[5]. Furthermore, we contribute to the literature by proposing a strategy for consistent estimation of this model, using the information available prior to the adoption of the single currency and afterwards. This approach requires determination of two separate theoretical DSGE models corresponding to both current and historical monetary regimes. These two models reflect our assumption that changes in the structure of the whole area are attributed solely to permanent switch to a new monetary regime. The model for the currency area is a restricted version of the New Open Economy Macroeconomics (NOEM) model. All structural parameters, except for the monetary policy rule parameters, are assumed to be constant over the period considered. The approach is illustrated by developing a simple DSGE model for the German economy within the euro area and its Bayesian estimation on the sample 1980:q1- 2003:q4.[6]

Several further aspects of our analysis are worth highlighting. First, we extend the benchmark closed economy model by Christiano, Eichenbaum and Evans (2001) and Smets and Wouters

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[2] Following recent developments in Bayesian estimation techniques (see, e.g., Geweke (1999) and Schorfheide (2000) (2003)), we estimate the model in its linearized form. In addition to our own codes we use modified codes by Michael Juillard, Frank Schorfheide, Cristopher Sims.

Very interesting and extensively documented example of micro founded modeling may be found in the article by the pioneer of the applied NOEM modelling Fabio Ghironi (2000). He develops the estimated NOEM model for the Canadian economy. The model is estimated "equation by equation". Nowadays, system estimation methodology is more common. One tends to use either generalized method of moments (GMM) or a wide range of maximum likelihood (ML) methods.

[3] We assume that the exchange rates in the EMU countries are flexible before the adoption of the euro. This assumption is not very restrictive for the period directly preceding EMU (the fluctuation of the European currencies was restricted to $\mp 15\%$). However, this is more crude for the period before 1992. The fluctuations of local currencies were then restricted to $\mp 2.5\%$.

[4] Tractability requires that the model is restricted to a two-region model. Such a framework may be useful for discussing issues pertaining to the links between two large blocs (here we concentrate on explaining the links between Germany and the rest of the euro area) but it can hardly be viewed as a realistic description of policy making in the euro area, currently made up of twelve countries. The modification of existing two-country models allows us to incorporate an arbitrarily large number of countries (see e.g. Gali and Monacelli (2004)). However, extending the analysis for a larger number of countries might lead to ignoring nominal and real rigidities and restricting the model parametrization.

[5] Overall, one should note that the model is initially constructed to illustrate the general approach to currency area modeling. Since we treat the rest of the euro area as a homogenous bloc, there is a lot of heterogeneity that is not captured by the model. Thus, the scope of our research is shifted to the German economy.

[6] An example of Bayesian estimation of a multi-country model is presented in Jondeau and Sahuc (2004). Their model is constructed to assess the problem of heterogeneity regarding the optimal monetary policy in the euro area. The scale of the model is rather limited. Moreover, they use only data before the adption of the euro to estimate the model.

(2003a) by incorporating currency union specific elements into it. Keeping our specification close to the standard closed economy DSGE models allows for more consistent cross-model comparison of the estimates. Note, though, that our model differs from the benchmark in several aspects. Apart from extending it to a two-country model, we enrich its stochastics, allowing for a balanced growth path as in Altig *et al.* (2003). We identify distinct permanent technology shocks for each region of the monetary union. These shocks are assumed to be cointegratd. Moreover, an additional shock accounting for asymmetries in technological progress across the regions is introduced. Including all these shocks allows us to integrate growth and business cycle theory. Thus, the model at the same time can match both low and high frequencies of the data.

Second, the paper examines the impact of introducing a single currency on the transmission of structural shocks. Overall, the qualitative results are in line with the existing evidence in both monetary union and in flexible exchange rate settings. However, the mechanics of each setting imply quantitative differences, which indicate the necessity of modeling each of the regimes with a separate DSGE model. Particularly in the monetary union setting, the terms-of-trade channel is not affected by the fluctuations of nominal exchange rate. In turn, in the DSGE with flexible exchange rate, the endogenously determined nominal exchange rate reduces (or amplifies) the impact of structural shocks. The interesting results related to the open economy aspects of the model are as follows: (i) our estimated DSGE model satisfactorily replicates cross-country correlations of real and nominal variables and (ii) contrary to some recent open economy studies, it generates significant international spillover effects.[7]

Third, we take advantage of the use of disaggregated information about the euro area. Thus, the model is estimated using simultaneously the seasonally adjusted German national accounts data (Volkswirtschaftliche Gesamtrechnung (VGR) database) and the aggregated data for the whole EMU (Area Wide Model (AWM) database). In the latter case the time series by Fagan *et al.* (2001) are disaggregated "inside" the model assuming constant weights for the German economy in the euro area, following the AWM methodology[8].

Fourth, to check the robustness of the estimates we report a comparison of alternative approaches with respect to the data used in the estimation procedure. Having a stochastic unit root in the model, it is straightforward to estimate the model on unfiltered data either using the first differences or data in levels[9]. But we also experiment with detrended data which are traditionally used as proxies for deviations of particular variables from the steady state (see Smets and Wouters (2003a) or Juillard, Pesenti, Laxton and Karam (2004)).[10] The necessity of matching lower frequency movements of the data implies that the estimates of shock persistence parameters are in general higher using raw data. This is a first indication that the endogenous propagation mechanisms are much weaker if we confront the data with the balanced growth hypothesis. The differences in the estimates of the deterministic part of the model are less articulated.

Fifth, to assess the reliability of the estimates and the impact of various restrictions on the system dynamics, we apply alternative model specifications. An interesting feature of this analysis is to evaluate to what extent frictions and shocks differ between open- and closed-economy settings. We find only slight discrepancies in the estimates of structural parameters using alternative (often nested) models. For the estimated open-economy model, we find that the importance of domestic shocks is significantly lower compared to the model estimated in the closed-economy framework.

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[7] See e.g. de Walque and Wouters (2004), Adjemian, Paries and Smets (2004)

[8] See the form of the vector of observed variables in the state space representation of the model in the section Data consideration .

[9] In the latter case it is necessary to use the Diffuse Kalman Filter (see Koopman and Durbin (2003)) for recursive computation of the likelihood.

[10] Note that the model estimated on filtered data does not contain the balanced growth mechanism.

Finally, the models examined here are compared regarding their predictive performance. Among other things, comparing the log marginal densities we find that the model constructed in a two-country framework with international trade and integrated financial markets can beat the model estimated on the same data set, but for a pooling of closed economies i.e. with countries closed to international trade and without integrated financial markets.[11]

To the best of our knowledge, this is the first attempt to estimate an open-economy DSGE model employing both the German and the aggregated euro area data[12]. We consider the model to be a major step forward in establishing a suitable framework for analyzing the German economy as a member state of the euro area.

The remainder of this paper is organized as follows. Section 2 presents the theoretical models for both flexible exchange rate and a common currency regimes. We recapitulate the model and present the solving method in section 3. In section 4 we discuss the data used in the estimation. Section 5 briefly shows the estimation methodology. In section 6 we present the empirical results. We extensively comment on the robustness of the results and critically compare different approaches. Section 7 summarizes the main findings and concludes.

2 The Model

2.1 An overview

The theoretical foundation of our model is inspired by a wide range of the New Open Economy Macroeconomics and Optimal Currency Area literature. The pioneering work laying out the general framework has been carried out by Obstfeld and Rogoff (1995). More closely related to our paper are articles by Kollmann (2001), Benigno (2001), Christiano, Eichenbaum and Evans (2001), Chari *et al.* (2002) and Duarte and Wolman (2004). We also build on the most recent empirical works and DSGE models for the euro area and the US economy (see Smets and Wouters (2003a, b), Bayoumi, Laxton and Pesenti (2004), Jondeau and Sahuc (2004) and Adolfson *et al.* (2004)). Following Smets and Wouters (2003a), we postulate that a major part of the stochastic volatility in the model is of a structural nature.

In this paper we refer to a currency area, which is defined as a group of regions that share the same currency. One currency means there is one central bank that is entitled to conduct monetary policy within this area. Relevant for our analysis is the simplest form of a currency area, a two-region area.

From now on, the world economy consists of two countries, Home (Germany) and Foreign country (the rest of the euro area). These two countries before forming the monetary union used to conduct independent monetary policies. Contrary to some recent studies (e.g. Benigno (2001)), we allow for differences in size, technologies and preferences between the countries[13]. In turn, restricting the analysis to the two-country framework, we abstract from the existence of "the rest of the world". This may be justified by a wide range of studies on the European Business Cycles. For example, Masson and Taylor (1993) indicate that all the EU-countries have a high degree of openness. Thus, it is necessary to model them in an open-economy framework. However, they

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[11] For this exercise we estimate both model on the sample prior to the EMU, i.e. 1980:q1-1998:q4.

[12] Prior attempts to model the German economy in closed economy DSGE frameworks are presented in Welz (2004), Kremer (2004), Kremer, Lombardo and Werner (2003).

[13] We assumed that households have a bias towards domestically produced goods, which results in deviation of the real exchange rate (or consumer price ratio in a model for monetary union) from purchasing power parity (PPP). For an earlier contribution see e.g. Benigno, Thoenissen (2003), Jondeau, Sahuc (2004)

also find that the European Union as a whole is a relatively closed economy, thus presenting the possibility of neglecting the links between European economies and the rest of the world in empirical modeling.

In order to account for the persistence observed in the actual data, we build on the literature recalled above and derive an optimization-based, open-economy model with nominal and real rigidities. We impose on households a cost of capital adjustment and restrict firms from changing their prices and employment in a framework *à la Calvo*. Each household is a monopoly supplier of differentiated labor services and sets its own nominal wage. The probability that the household is allowed to optimize the wage rate is determined exogenously. Furthermore, the statistical fit of the model to the data is improved by introducing an external habit formation into households' preferences (see McCallum and Nelson (1999)).

Since the aim of the paper is to present a prototype DSGE model for the monetary union, as well as advances towards a consistent approach to the estimation of such a model, we make a range of assumptions, which, without loss of generality, simplify the derivation of the model and its estimation. Among other things, we assume complete financial markets and perfect risk sharing in order to: (i) avoid the necessity of an explicit modeling of the nominal exchange rate prior to the adoption of the single currency, (ii) stationarize the real exchange rate and (iii) develop a genreal structure which is adequate for both monetary union as well as the flexible exchange rate regime[14]. We do not allow for price discrimination across markets (no pricing to market) and do not distinguish between tradable and non-tradable goods. These mechanisms could not improve the performance of the model, since we decide to fit our model to the data-set corresponding as close as possible to that used by Smets and Wouters (2003a), i.e. we use only one type of price measure in the economy - the GDP deflator[15]. Furthermore, we do not define typical open economy shocks (e.g. an uncovered interest parity shock), which might be helpful in explaining the asymmetric fluctuations across the countries prior to EMU.

Unless the general setting for the Foreign economy differs from the ones for the Home economy, we present only equations for the latter. In order to lighten the notation, if equations for both economies are presented, the Foreign economy variables are indexed with a star. Reviewing the model, we point to the differences between the setting for a currency area and the model with flexible exchange rate.

In each country modeled there are households, a government, two types of firms (intermediate-good and final-good producers) and distributors which transform the final good (output index) into differentiated consumption and investment goods. These goods are sold both to households domestically and abroad. Households own domestic firms and receive dividends paid by these firms. Labor and capital are assumed to be immobile internationally.

A following normalization is assumed throughout the paper. The population of the two countries is a continuum of agents distributed on the interval $[0, 1]$. The Home's (German) population is distributed on the interval $[0, n)$ and that of the rest of the euro area on the interval $[n, 1]$. Thus, the relative size of the Home economy is equal to n.

2.2 Firms

The economy of each country produces a single final good (an output index) and a continuum of intermediate goods indexed by z, where z is distributed over the unit interval (respectively over $[0, n)$ in the Home economy and $[n, 1]$ in the Foreign economy). The final-good sector is perfectly

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[14] Under incomplete financial markets e.g. portfolio adjustment costs are introduced to render the model stationary.

[15] For the discussion on the empirical relevance of pricing to market mechanism see e.g. Justiniano and Preston (2004).

competitive. In contrast, in the markets for intermediate goods there is monopolistic competition. Each intermediate good is produced by a single firm. Producers of intermediate goods use domestic physical capital and domestic labor as inputs. The final good is transformed into a consumption, a capital good and a public good. After differentiation (e.g. brand naming) it is the subject of trade between two countries.

2.2.1 The final-good sector

Final-good firms produce a homogenous good Y_t (resp. Y_t^* in the Foreign country) according to the Dixit-Stiglitz production function (Dixit and Stiglitz (1977)), using differentiated intermediate goods $Y_t(z)$:

$$Y_t = \left[\left(\frac{1}{n}\right)^{\frac{-\varepsilon_t^P}{1+\varepsilon_t^P}} \int_0^n Y_t(z)^{\frac{1}{1+\varepsilon_t^P}} dz \right]^{1+\varepsilon_t^P} \tag{1}$$

where $\varepsilon_t^P > 0$ is a stochastic parameter which determines the time-varying mark-up in the goods market. Following Smets and Wouters (2003a), a shock to this parameter could be interpreted as a cost-push shock to the inflation equation. We assume that the markup follows a white-noise process.

The production function above, exhibits diminishing marginal product, which causes firms to diversify and produce using all intermediate goods available. Y_t may be seen as a total demand for the intermediate goods produced in Home economy or supply of the final good.

The final-good producer minimizes her cost choosing the input $Y_t(z)$ given the input price $P_t(z)$ (price of the intermediate good z) subject to the production technology (1). The cost minimization condition yields:

$$Y_t(z) = \frac{1}{n} Y_t (\frac{P_t(z)}{P_t})^{-\frac{1+\varepsilon_t^P}{\varepsilon_t^P}} \tag{2}$$

which may be seen as an equation of total demand for intermediate good z.

The Lagrangian multiplier P_t from the above minimization problem is the cost-minimizing price of a unit of a final good basket. Solving we obtain:[16]

$$P_t = \left[\frac{1}{n} \int_0^n [P_t(z)]^{-1/\varepsilon_t^P} dz \right]^{-\varepsilon_t^P}$$

As the final-good sector is perfectly competitive, each firm takes the price of the final good P_t as given and equates its marginal cost to the price.

The domestic output index Y_t may be either sold to the domestic households, being used in the production of the final consumption or investment good, or it may be exported.

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[16] The symmetric results (the country size is $(1-n)$) hold for the Foreign economy.

2.2.2 Intermediate-good producers

Intermediate-good producers choose a price for their products based on the production technology and the total demand (2). Firms use both labor and capital bundles to produce according to the following Cobb-Douglas production function[17]:

$$Y_t(z) = A_t^{\alpha} \varepsilon_t^{Y} K_t^{1-\alpha}(z) L_t(z)^{\alpha} \tag{3}$$

where α denotes the share of labor in production, A_t is a unit root technology shock. ε_t^Y is a Kydland-Prescott type of covariance stationary technology shock[18]. $K_t(z)$ is a bundle of physical capital used by the firm at time t. Following Kollmann (2001) we denote $L_t(z)$ as an index of different types of labor used by the firm z. The amount of labor service utilized by firm z is then given by the following Dixit-Stiglitz aggregate:

$$L_t(z) = \left\{ \left(\frac{1}{n}\right)^{\frac{\varepsilon^w}{1+\varepsilon^w}} \int\limits_{h=0}^{n} l_t(h,z)^{1/(1+\varepsilon^w)} dh \right\}^{1+\varepsilon^w} \tag{4}$$

where $l_t(h,z)$ denotes the number of hours of type h labor used by the firm z. $(1+\varepsilon^w) > 1$ is a net wage markup. Further, the growth rate of technological progress is assumed to be a stationary process $(A_t/A_{t-1} \equiv \varepsilon_t^A)$:

$$\varepsilon_t^A = (1-\rho_A)\bar{\varepsilon}^A + \rho_A \varepsilon_{t-1}^A + u_t^A \tag{5}$$

Thus, ε_t^A may be seen as a shock to the growth rate of technology. The stationary technology shock is given by the following autoregressive process:[19]

$$\hat{\varepsilon}_t^Y = \rho_Y \hat{\varepsilon}_{t-1}^Y + u_t^Y \tag{6}$$

Because of the unit root in the technology process A_t, variables in the model evolve along the stochastic growth path. In order to calculate the steady state and solve the model in the log-linearized form we stationarize the variables, dividing them by the level of technology A_t, in Home and A_t^* in Foreign economy[20]. We assume that technology processes A_t and A_t^* are cointegrated. Recapitulating the model structure (see section Solving the model), we present the equations in stationarized variables.[21]

Firm z chooses production factors: a sequence of different types of labor $l_t(h,z)$ and capital bundle $K_t(z)$ to minimize the total cost of production, given by:

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[17] In the version of the model "without capital" the production function is assumed to be linear in labor: $Y_t(z) = A_t \varepsilon_t^Y L_t(z)$

[18] In a two-country setting we allow for correlation of the same type of structural shocks, i.e. technology shocks, investment shocks, labor supply shocks and preference shocks. For the shock identification details see the sections below.

[19] We assume that all strucural shocks play a role of shifters. Thus, $E(\varepsilon_t^Y) = 1 \Rightarrow \hat{\varepsilon}_t^Y \equiv \varepsilon_t^Y - 1$

[20] This property is convenient in forecasting. The growth rate of observed variable may be calculated from the stationarized variables as follows: $\log(\frac{X_t}{X_{t-1}}) = \log(\frac{\tilde{X}_t}{\tilde{X}_{t-1}} \frac{A_t}{A_{t-1}}) \Rightarrow \Delta \log X_t \approx \Delta \hat{x}_t + \hat{\varepsilon}_t^A + \log(\bar{\varepsilon}^A)$

[21] Note that $\tilde{K}_{t+1} = \frac{K_{t+1}}{A_t}$, because the capital stock at the begining of the period $t+1$ is determined in period t.

$$\min_{K_t(z),l_t(h)} Z_t^{nom} K_t(z) + \int\limits_{h=0}^{n} W_t^{nom}(h) l_t(h,z) dh \tag{7}$$

s.t.

$$Y_t(z) = A_t^{\alpha} \varepsilon_t^Y K_t^{1-\alpha}(z) \left[\left\{ \left(\frac{1}{n}\right)^{\varepsilon_t^w/(1+\varepsilon_t^w)} \int\limits_{h=0}^{n} l_t(h,z)^{1/(\varepsilon_t^w+1)} dh \right\}^{\varepsilon_t^w+1} \right]^{\alpha}$$

where Z_t^{nom}denotes a common nominal rental cost of capital faced by the firms in the Home country (Z_t^{*nom} in Foreign economy).

Cost minimization implies the following equation of the demand for labor of type $l_t(h,z)$:

$$l_t(h,z) = \frac{1}{n} L_t(z) \left[W_t^{nom}(h) / W_t^{nom} \right]^{-\frac{1+\varepsilon_t^w}{\varepsilon_t^w}} \tag{8}$$

The aggregated labor demand is given by:

$$L_t(z) = \frac{\alpha}{1-\alpha} Z_t^{nom} K_t(z) / (W_t^{nom}) \tag{9}$$

where $W_t^{nom}(h)$ represents the cost of hiring labor of type h. Further, an aggregated wage index (minimizing expenditures needed to purchase one unit of labor L_t) is given by:

$$W_t^{nom} = \left\{ \frac{1}{n} \int\limits_{h=0}^{n} W_t^{nom}(h)^{\frac{-1}{\varepsilon_t^w}} dh \right\}^{-\varepsilon_t^w} \tag{10}$$

Since all firms face the same prices for labor and capital inputs, cost minimization implies that the capital-labor ratio is the same for all firms (here in real terms):

$$\frac{W_t L_t}{Z_t K_t} = \frac{\alpha}{1-\alpha} \tag{11}$$

The firms' nominal marginal cost is then given by:

$$MC_t^{nom} = \frac{1}{\varepsilon_t^Y} \left[\frac{W_t^{nom}}{\alpha} \right]^{\alpha} \left[\frac{Z_t^{nom}}{(1-\alpha)} \right]^{1-\alpha} \tag{12}$$

2.2.3 Optimal price setting

Deriving the New Keynesian Phillips Curve we follow the methodology of Calvo (1983) as augmented in Smets and Wouters (2003a). We assume that intermediate-good producing firms set the prices in a staggered fashion. In each period with probability $(1-\theta^P)$ a firm may adjust its price $P_t(z)$ to the level at which it maximizes the discounted future profits. Thus, the average time between price changes equals $1/(1-\theta^P)$.

If we denote the nominal marginal cost as $MC_t^{nom} = P_t MC_t$ and set the firms' stochastic discount factor equal to $\beta^i \Lambda_{t,i} = \beta^i \frac{U_{C,t+i}}{U_{C,t}}$ (firms discount expected profits with the factor used by shareholder-households, see the section below) the profit maximization problem is given by:[22]

$$\max_{P_t(z)} \sum_{i=0}^{\infty} (\theta^P \beta)^i E_t \left[\Lambda_{t,i} \frac{P_t(z) - MC_{t+i}^{nom}}{P_{t+i}} Y_{t,t+i}(z) \right] \tag{13}$$

subject to the demand function (derived from the cost minimization of final-good producers):

$$Y_{t,t+i}(z) = \frac{1}{n} \left[\frac{P_t(z)}{P_{t+i}} \right]^{-\frac{1+\varepsilon_{t+i}^P}{\varepsilon_{t+i}^P}} Y_{t+i} \tag{14}$$

where $U_{C,t+i}$ is the household's marginal utility of consumption at time $t+i$.

All firms adjusting prices choose the same optimum (see e.g. Woodford (2003)). We suppress the firm-specific indexation (z) and simply denote the price chosen by $\bar{P}_t$.

Then, the first order condition from minimization of (13) subject to (14)is given by:

$$E_t \sum_{i=0}^{\infty} (\theta^P \beta)^i \Lambda_{t,i} \left[\frac{1+\varepsilon_{t+i}^P}{\varepsilon_{t+i}^P} \left(\frac{1}{P_{t+i}} \right)^{\frac{-1}{\varepsilon_{t+i}^P}} \bar{P}_t^{-\frac{1+\varepsilon_{t+i}^P}{\varepsilon_{t+i}^P}} Y_{t+i} \left(\frac{MC_{t+i}^{nom} - \bar{P}_t}{\bar{P}_t} \right) \right] = 0 \tag{15}$$

We assume that firms that are not allowed to optimally adjust their prices instead of fixing them with probability θ^P update them according to the formula: $P_t = \pi_{t-1}^{\gamma_p} P_{t-1}$, where γ_p is an indexation degree, π_{t-1} denotes inflation in the previous period. This yields the following equation for the price index:

$$P_t = [\theta^P \left((1+\pi_{t-1})^{\gamma_p} P_{t-1} \right)^{-\frac{1}{\varepsilon_t^P}} + (1-\theta^P) \bar{P}_t^{-\frac{1}{\varepsilon_t^P}}]^{-\varepsilon_t^P} \tag{16}$$

After log-linearization of the above equation and after substituing the equation (15), we obtain the following New Keynesian Phillips Curve *à la Smets and Wouters*:

$$\hat{\pi}_t = \frac{\beta}{1+\gamma_p} E_t \hat{\pi}_{t+1} + \frac{\gamma_p}{1+\gamma_p} \hat{\pi}_{t-1} + \frac{(1-\beta\theta^P)(1-\theta^P)}{(1+\gamma_p)\theta^P} (\hat{mc}_t + \hat{\varepsilon}_t^P) \tag{17}$$

The price determined in this way may be seen as an output index deflator. In the observed data we link it to the GDP deflator.

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[22] A firm allowed to change its price at the given period sets the price anticipating no possibility of price adjustment in the future.

2.2.4 Production of consumption and investment good

A final-consumption good is produced by a representative consumption-good distributor. This firm combines part of the domestic output index with imported goods to produce a final-consumption basket according to the Cobb-Douglas production function:

$$C_t(j) = \frac{C_{D,t}^{\omega_C}(j) M_{C,t}^{1-\omega_C}(j)}{\omega_C^{\omega_C}(1-\omega_C)^{(1-\omega_C)}} \tag{18}$$

where ω_C (resp. ω_C^*) is the share of domestically produced goods in the consumer basket (Armington (1969)). $C_{D,t}(j)$ and $M_{C,t}(j)$ denote the composites of a continuum of differentiated consumption goods, each supplied by a different firm located in Home (Foreign) economy which follows the CES function.

Given the decision on $C_t(j)$ (see below), household j will optimally allocate the expenditure on $C_{D,t}$ and $M_{C,t}$, by minimizing the total expenditure $P_{C,t}C_t(j)$ under the constraint given by (18). Note that we suppress the household-specific indexation due to the fact that households are homogeneous in each region.

$$\min_{C_{D,t}M_{C,t}} E_0 \sum_{t=0}^{\infty} \beta^{-t}(\frac{U_{C,t}}{U_{C,0}})(P_t C_{D,t} + P_t^* S_t M_{C,t}) + P_{C,t}\left[C_t - \frac{C_{D,t}^{\omega_C} M_{C,t}^{1-\omega_C}}{\omega_C^{\omega_C}(1-\omega_C)^{(1-\omega_C)}}\right]$$

where P_t, P_t^* are the price sub-indexes for home- (foreign-) produced goods, expressed in the domestic currency, $P_{C,t}$ may be interpreted as a consumption price index (shadow cost of producing an additional unit of a consumption good). S_t denotes the nominal exchange rate and is fixed in the model for the currency area.

Moreover, since the aggregator selling of the domestic output index behaves competitively in the product market, the law of one price (LOOP) holds for traded goods[23]. In particular, the export price index simply equals the domestic output price index.

The overall price index $P_{C,t}$, defined as the minimum expenditure required to purchase goods resulting in index C_t, is:

$$P_{C,t} = P_t^{\omega_C}\,(S_t P_t^*)^{(1-\omega_C)} \tag{19}$$

Defining the terms of trade (ratio of import to export prices) as $\mathcal{T}_t = \frac{P_t^* S_t}{P_t}$ and using the dynamic form of this definition: $\mathcal{T}_t - \mathcal{T}_{t-1} = \pi_t^* \frac{S_t}{S_{t-1}} - \pi_t$, we obtain the following equation for consumer price inflation:

$$\pi_{C,t} = \pi_t \left(\frac{\mathcal{T}_t}{\mathcal{T}_{t-1}}\right)^{(1-\omega_C)} \tag{20}$$

where $\pi_t = P_t/P_{t-1}$. Note that this equation does not explicitly contain the time-varying exchange rate. Thus, it also fits into the monetary union framework.

Symmetric results hold for the foreign economy. Investment good production is modeled in a very similar manner assuming preference parameters to be ω_I and ω_I^*, respectively.

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[23] Since we fit the model to the data including only the GDP deflators, the evidence that the law of one price holds in the euro area cannot be verified.

2.3 Households and preferences

A typical open economy is inhabited by a representative household who owns capital, which it rents to domestic firms and provides labor in exchange for wage income. It derives satisfaction from leisure and consuming commodities which are composites of domestically produced and imported goods (see section above). Each period the representative household decides what part of the income to spend on consumption and what to save, in effect to maximize its discounted utility given the budget constraint. We consider a cashless limit of a money in the utility function framework a la Woodford (2003). The preferences of the household are additively separable in consumption and labor effort.[24] The objective function for household j is given by:

$$\mathcal{U}_t(j) = E_0 \sum_{t=0}^{\infty} \beta^t [U_t(C_t(j)) - V_t(L_t(j))] \tag{21}$$

where $0 < \beta < 1$ is the discount factor, $C_t(j)$ is period t *per capita* consumption of the commodity bundle defined as in Obstfeld and Rogoff (1998). $L_t(j)$ is the labor effort (or "hours worked"). Let $l_t(h, j)$ denote the number of hours of type h labor. There exists a continuum of labor types, indexed for each country by $h \in [0, n]$, then the variable that appears in the utility is defined as: $L_t(j) = \int\limits_{h=0}^{n} l_t(h, j) dh$

The explicit form of the household's instantaneous utility assumed here is given by:

$$\mathcal{U}_t^{inst.}(j) = \left[\varepsilon_t^C \log(C_t(j) - H_t(j)) - \varepsilon_t^L A_L \frac{1}{1+\upsilon} (L_t(j))^{1+\upsilon} \right] \tag{22}$$

where $H_t(j) = \varkappa C_{t-1}$ is an external habit stock.[25] We introduce it into the model in order to obtain more realistic, hump-shaped responses of consumption to the changes in income (we made consumption more persistent). Furthermore, υ denotes the inverse of the elasticity of the labor effort with respect to the real wage. We follow e.g. Ireland (2002) and restrict the elasticity of intertemporal substitution of consumption to unity, which is also in line with the most recent estimates for the euro area. This restriction is necessary to ensure balanced growth in the model.[26] ε_t^C denotes an exogenous preference shock common to all households of a given country, ε_t^L is a labor supply shock.

The structure of financial markets is highly simplified in the model to be appropriate for the flexible and fixed exchange rate regime. We represent the asset structure in the economy, following Chari *et al.* (2002), by having state contingent one-period nominal bonds denominated in the home currency and traded both domestically and internationally. Then, the budget constraint of the consumer in the Home country may be written:

---

[24] We abstract from the real money balances in the utility function. If it enters additively into the utility function, money market equilibrium plays no role for the dynamics when the nominal interest rate is set to be the instrument of monetary policy.

[25] External habits are relative to past aggregate consumption (catching up with the Joneses, Abel (1990))

[26] This restriction applies for models with an instantaneous utility function that is additively separable in consumption and leisure.

$$[P_{C,t}C_t(j) + P_{I,t}I_t(j) + B_{t+1}(j)/R_t] \leq \left[\begin{array}{c} B_t(j) + \int\limits_{z=0}^{n} \int\limits_{h=0}^{n} W_t^{nom}(h) l_t(h,z) dh dz + \\ + Z_t^{nom} K_t(j) + \int\limits_{z=0}^{n} \Pi_t(z) dz + TAX_t(j) - TR_t(j) \end{array} \right] \tag{23}$$

where B_t denotes a one-period nominal bond. R_t is a gross nominal interest rate. Note that in the setting for monetary union completeness of financial markets assures that a riskless bond has the same price in both regions, implying $R_t = R_t^*$. $Z_t^{nom} K_t(j)$ denotes household's income from renting capital and $\int\limits_{h=0}^{n} W_t^{nom}(h) l_t(h,z) dh$ represents its total wage income. $\Pi_t(z)$ denotes the dividend from firm z, $TAX_t(z)$ is a lump sum tax paid by the household, $TR_t(z)$ are transfers to the household. We abstract from imposing on agents any costs of financial transactions (see e.g. Benigno (2000)).[27]

In each country households accumulate capital K_t and bear the costs of capital adjustment. The law of motion for capital owned by a household in Home country is given by:

$$K_{t+1}(j) = (1-\delta)K_t(j) + \varepsilon_t^I F(I_t(j), I(j)_{t-1}) \tag{24}$$

where $0 < \delta < 1$ is the physical depreciation rate of capital. We follow Christiano, Eichenbaum and Evans (2001) and assume that the function turning investment into physical capital has a form:

$$F(I_t(j), I_{t-1}(j)) = (1 - \tilde{S}(\frac{I_t(j)}{I_{t-1}(j)}))I_t(j) \tag{25}$$

(25) implies (see Adolfson *et al. (2004)*): $F_1(I_t(j), I_{t-1}(j)) = \frac{\partial F(I_t(j), I_{t-1}(j))}{\partial I_t(j)} = -\tilde{S}'(\frac{I_t(j)}{I_{t-1}(j)})(\frac{I_t(j)}{I_{t-1}(j)}) + (1 - \tilde{S}(\frac{I_t(j)}{I_{t-1}(j)}))$ $F_2(I_t(j), I_{t-1}(j)) = \frac{\partial F(I_t(j), I_{t-1}(j))}{\partial I_{t-1}(j)} = \tilde{S}'(\frac{I_t(j)}{I_{t-1}(j)})(\frac{I_t(j)}{I_{t-1}(j)})^2$.

On the balanced growth path the following expressions hold: $F_1(I,I) = -\tilde{S}'(\bar{\varepsilon}^A)\bar{\varepsilon}^A + (1 - S(\bar{\varepsilon}^A)) = 1$ and $F_2(I,I) = \tilde{S}'(\bar{\varepsilon}^A)\left(\bar{\varepsilon}^A\right)^2 = 0$[28]

---

[27] Imposing internationally incomplete markets is justified for multi-country models with countries that are not in a common currency area (e.g. models for the world economy).

[28] We have also experimented with an alternative setting adopting an explicit functional form for capital adjustment costs which is more common in the US literature (Pesenti (2002), Erceg, Guerrieri, Gust (2003)), transforming the original one to allow for balanced growth in the model: $K_{t+1}(j) = (1-\delta)K_t(j) + \Psi_t K_t(j)$, $\Psi_t = I_t(j)/K_t(j) - \frac{\phi_{I_1}}{2}(\frac{I_t(j)}{K_t(j)} - \varepsilon_t^I(\bar{\varepsilon}^A + \delta - 1))^2 - \frac{\phi_{I_2}}{2}(\frac{I_t(j)}{K_t(j)} - \frac{I_{t-1}}{K_{t-1}})^2$where $\phi_{I_1}, \phi_{I_2} \geq 0$, and $\bar{\varepsilon}^A$ is long-term productivity growth, ε_t^I is a temporary investment shock (an unexpected increase in the demand for investment is equivalent to the increase in the capital depreciation rate.

Contrary to Juillard *et al.* (2004), we find that the specification of capital adjustment *à la Christiano, Eichenbaum and Evans* implies a much higher marginal likelihood of the model (see section Results below). Thus, the choice of proper functional form is of great importance for model-based predictions.

2.3.1 Consumer's program

Summarizing, the intertemporal optimization problem of the representative household (Home) is given by:

$$
\begin{aligned}
\mathcal{L}_t(j) \;=\; & \varepsilon_t^C \log(C_t(j) - \varkappa C_{t-1}) - \varepsilon_t^L A_L \frac{1}{1+\upsilon} \left(L_t(j)\right)^{1+\upsilon} + \\
& +\lambda_t(j) \left[\begin{array}{c}
\int\limits_{z=0}^{n} \int\limits_{h=0}^{n} W_t^{nom}(h) l_t(h,z) dh dz + Z_t^{nom} K_t(j) + TR_t(j) + \\
+ \int\limits_{z=0}^{n} \Pi_t(z) dz - TAX_t(j) - P_{C,t} C_t(j) - P_{I,t} I_t(j) + B_{t+1}(j)/R_t - B_t(j) + \\
+ P_t Q_t(j) \left[-K_{t+1}(j) + (1-\delta) K_t(j) + \varepsilon_t^I F(I_t(j), I(j)_{t-1}) \right]
\end{array} \right]
\end{aligned}
$$

where λ_t, Q_t are multipliers associated with the budget constraint and the law of motion for capital, respectively (Q_t may be seen as the price of installed capital).

The following equations are the first order conditions (FOC) for the consumer optimization problem:

$$
\frac{1}{R_t} = \beta E_t \left[\frac{\varepsilon_{t+1}^C (C_t - \varkappa C_{t-1})}{\varepsilon_t^C (C_{t+1} - \varkappa C_t) \pi_{C,t+1}} \right] \tag{26}
$$

where $\pi_{C,t+1} = P_{C,t+1}/P_{C,t}$ denotes the gross rate of consumer price inflation .

$$
-\frac{P_{I,t}}{P_t} + Q_t \varepsilon_t^I F_1(I_t, I_{t-1}) + E_t\left(\frac{\pi_{t+1}}{R_t} Q_{t+1} \varepsilon_{t+1}^I F_2(I_{t+1}, I_t)\right) = 0 \tag{27}
$$

$$
-E_t\left(\frac{R_t}{\pi_{t+1}} Q_t\right) + E_t(Z_{t+1}) + E_t(Q_{t+1}(1-\delta)) = 0 \tag{28}
$$

Equation (26) is an Euler equation, (27) may be interpreted as investment demand, (28) determines the price of installed capital. The first order condition for the household's optimal choice of wage rate and labor effort is provided in the next subsection (Wage determination).

To render all variables stationary we divide real variables by the trend level of technology A_t (or multiply the Lagrange multipliers with the trend level of technology and the price level). The following holds: $\lambda_t = \frac{\tilde{\lambda}_t}{P_t A_t}$, where the tilde denotes the stationary variables. Equations in stationarized variables are listed in the section Summarizing and solving the model.

2.3.2 Wage determination

We decided to introduce wage rigidities into the model in order to dampen the response of marginal cost to structural shocks. In turn, a sluggish behavior of marginal cost allows a greater degree of endogenous price stickiness. Following Kollmann (2001), we assume that wages are modeled in a fashion *à la Calvo,* with random duration of wage contracts. The wage rate of a given labor type h can be changed (optimized) in any particular period with the probability $1 - \theta^w$. After a change at time t the new wage $\bar{W}_t(h)$ is in effect also in the forthcoming periods determining the labor effort in that periods. Having assumed that the household always meets the demand for labor at its chosen wage level, the following demand equation (from firms' optimization) applies:

$$
l_t(\bar{W}_t^{nom}(h)) = \frac{1}{n} \frac{\alpha}{1-\alpha} \left[\frac{\bar{W}_t^{nom}(h)}{W_t^{nom}} \right]^{-\frac{1+\varepsilon^w}{\varepsilon^w}} \frac{Z_t K_t(z)}{W_t^{nom}} \tag{29}
$$

Infinitesimally small changes in the chosen wage lead to the following changes in the demand for labor of type h

$$\frac{\partial l_t(\bar{W}_t^{nom}(h))}{\partial \bar{W}_t^{nom}(h)} = -\frac{1}{n}\frac{1+\varepsilon^w}{\varepsilon^w}\frac{\alpha}{1-\alpha}\left[\bar{W}_t^{nom}(h)\right]^{-\frac{1+2\varepsilon^w}{\varepsilon^w}} Z_t K_t(z) \left(W_t^{nom}\right)^{\frac{1}{\varepsilon^w}}$$

$$\int \frac{\partial l_t(\bar{W}_t^{nom}(h))}{\partial \bar{W}_t^{nom}(h)} dz = -\frac{1}{n}\frac{1+\varepsilon^w}{\varepsilon^w}\left[\bar{W}_t^{nom}(h)\right]^{-\frac{1+2\varepsilon^w}{\varepsilon^w}} \frac{\alpha}{1-\alpha} Z_t K_t \left(W_t^{nom}\right)^{\frac{1}{\varepsilon^w}}$$

and labor income from labor of type h

$$\int \frac{\partial (l_t(\bar{W}_t^{nom}(h))\bar{W}_t^{nom}(h))}{\partial \bar{W}_t^{nom}(h)} dz = -\frac{1}{n}\frac{1}{\varepsilon^w}\left[\bar{W}_t^{nom}(h)\right]^{-\frac{1+\varepsilon^w}{\varepsilon^w}} \frac{\alpha}{1-\alpha} Z_t K_t \left(W_t^{nom}\right)^{\frac{1}{\varepsilon^w}}$$

The optimal choice of wage $\bar{W}_t(h)$ should bring about a maximization of the expected life-time utility of a household (i.e. any changes in labor effort $l_t(h)$ affecting the wage income $l_t(\bar{W}_t(h))\bar{W}_t(h)$ should not imply any further improvement in the life-time utility as long as the wage rate $\bar{W}_t(h)$ holds).

Thus, the FOC with respect to the wage rate is then given by:

$$\sum_{i=0}^{\infty}(\beta\theta^w)^i E_t \left[\begin{array}{c} -\frac{U_{C,t+i}}{P_{C,t+i}}\frac{1}{\varepsilon^w}\left(\bar{W}_t^{nom}\right)^{-\frac{1+\varepsilon^w}{\varepsilon^w}} Z_{t+i}K_{t+i}\left(W_t^{nom}\right)^{\frac{1}{\varepsilon^w}} \\ -(\frac{1+\varepsilon^w}{\varepsilon^w})U_{L,t+i}\left[\bar{W}_t^{nom}(h)\right]^{-\frac{1+2\varepsilon^w}{\varepsilon^w}} Z_{t+i}K_{t+i}\left(W_{t+i}^{nom}\right)^{\frac{1}{\varepsilon^w}} \end{array} \right] = 0 \quad \Rightarrow$$

$$\bar{W}_t^{nom}(h) = (1+\varepsilon^w)\frac{\sum_{i=0}^{\infty}(\beta\theta^w)^i E_t\left[U_{L,t+i}Z_{t+i}K_{t+i}\left(W_{t+i}^{nom}\right)^{\frac{1}{\varepsilon^w}}\right]}{\sum_{i=0}^{\infty}(\beta\theta^w)^i E_t\left[\frac{U_{C,t+i}}{P_{C,t+i}}Z_{t+i}K_{t+i}\left(W_{t+i}^{nom}\right)^{\frac{1}{\varepsilon^w}}\right]} \tag{30}$$

Analogously to the price equation, the aggregate wage level is determined by[29]:

$$W_t^{nom} = [\theta^w (W_{t-1}^{nom})^{-\frac{1}{\varepsilon^w}} + (1-\theta^w)\left(\bar{W}_t^{nom}\right)^{-\frac{1}{\varepsilon^w}}]^{-\varepsilon^w} \tag{31}$$

Note that we defined the real wage as $W_t = W_t^{nom}/P_t$.

2.3.3 Real exchange rate and terms of trade

The main problem related to endogenizing the exchange rate mechanism in our DSGE models is to nest the fixed exchange rate regime in a more general structure, allowing us to model of economies that do not form part of the common currency area. To do this we do not refer explicitly to the nominal exchange rate S_t, which is fixed in a monetary union, but find a variable containing the whole information about it and being endogenously determined in both a DSGE model for the

---

[29] Note that when the wage is fully flexible the wage equation is standard $\varepsilon_t^C W_t/P_{C,t} = \varepsilon_t^L L_t^v (C_t - \varkappa C_{t-1})$. We use this specification when constructing alternative models.

currency area and a model with flexible exchange rate. These criteria are met by the real exchange rate and terms of trade.

Since the financial markets are complete and both Foreign and Home households trade in state contingent claims denominated in the home currency, the perfect risk sharing condition holds. Thus, in every state of the world the ratio of marginal utilities of per capita consumption across the countries is equated to the ratio of consumer price levels (or to the real exchange rate S_t^{real}):[30]

$$\frac{S_t P_{C,t}^*}{P_{C,t}} = S_t^{\text{real}} = \kappa \frac{\varepsilon_t^{C^*} U'(C_t^*)}{\varepsilon_t^C U'(C_t)} = \kappa \frac{\varepsilon_t^{C^*} (C_t^* - \varkappa^* C_{t-1}^*)^{-1^*}}{\varepsilon_t^C (C_t - \varkappa C_{t-1})^{-1}} \tag{32}$$

Equation (32) is derived from the set of optimality condition that characterize the optimal allocation of wealth among state contingent securities (the full derivation can be found in Chari *et al.* (2002)). As we see, using this condition is a way to endogenize and stationarize the real exchange rate. Furthermore, using the knowledge about the composition of the consumer basket (18), we may derive the relationship between the terms of trade $\mathcal{T}_t$ and the real exchange rate (Kollmann (2001), Devereux (2003)):

$$S_t^{\text{real}} = \frac{S_t P_{C,t}^*}{P_{C,t}} = \frac{(S_t P_t^*)^{(\omega_C + \omega_C^* - 1)}}{P_t^{(\omega_C + \omega_C^* - 1)}} = \mathcal{T}_t^{(\omega_C + \omega_C^* - 1)} \tag{33}$$

where ω_C, ω_C^* denote the share of domestically produced goods in the consumer basket in Home and Foreign economy respectively. Note that the real exchange rate S_t^{real} deviates from the purchasing power parity (PPP) rule due to different consumer preferences regarding consuming foreign and domestically produced goods (bias towards domestically produced goods).

Finally, we obtain the equation endogenizing the terms of trade in the two-country DSGE model with flexible exchange rate:[31]

$$\mathcal{T}_t = \kappa \left[\frac{\varepsilon_t^{C^*} (C_t^* - \varkappa^* C_{t-1}^*)^{-1^*}}{\varepsilon_t^C (C_t - \varkappa C_{t-1})^{-1}} \right]^{\frac{1}{(\omega_C + \omega_C^* - 1)}} \tag{34}$$

As mentioned above, under flexible exchange rate the nominal interest rates may differ across countries. Thus, to price riskless bonds one needs two separate Euler equations. The completeness of financial markets implies, however, that in the currency union the nominal interest rate is equalised across the countries at all times. Thus, only one arbitrarily chosen Euler equation is needed for pricing a riskless bond. The perfect risk sharing condition in a model with fixed exchange rate does not determine (endogenize) the nominal exchange rate anymore. This equation, however, still conditions the ratio of marginal utilities of consumption on the ratio of consumer prices restricting the consumption from diverging in the long run across countries:

$$\frac{P_{C,t}^*}{P_{C,t}} = \kappa \frac{\varepsilon_t^{C^*} (C_t^* - \varkappa^* C_{t-1}^*)^{-1^*}}{\varepsilon_t^C (C_t - \varkappa C_{t-1})^{-1}} = \mathcal{T}_t^{(\omega_C + \omega_C^* - 1)} \tag{35}$$

---

[30] $\kappa = P_0^* U_C(C_0)/(P_0 U_{C^*}(C_0^*)$ is a constant that depicts the initial condition.

[31] Note also that in the case of no preference bias ($\omega_C = 1 - \omega_C^*$) the perfect risk sharing assumption does not allow one to uniquely determine the terms of trade.

One should note that, contrary to the model with a flexible exchange rate arrangement, in the currency union the terms of trade are only an auxiliary variable which is determined uniquely given the ratio of Home and Foreign prices. However, to avoid a necessity of dealing with nonstationary variables ($P_{C,t}, P^*_{C,t}$), we introduce the terms of trade in the currency union DSGE using the following dynamic definition:

$$\mathcal{T}_t - \mathcal{T}_{t-1} = \pi^*_t - \pi_t \tag{36}$$

2.4 Fiscal authority

The role of a fiscal authority in the model is highly simplified. It co-creates demand but its spending rule is assumed to follow an autoregressive process. We assume that spending, financed by lump-sum taxes, falls solely on the final good G, which is entirely domestically produced, and that the price of government consumption coincides with the output deflator. The fiscal authority is not allowed to run budget deficits. Its budget constraint is thus given by:

$$P_t G_t + TR_t = TAX_t \tag{37}$$

The budget spending represents on average a constant part of output and evolves according to the following rule:

$$G_t = (1 - \rho_A)\bar{G} + \rho_G G_{t-1} + u^G_t \tag{38}$$

where u^G_t is i.i.d.

2.5 Market clearing conditions

The model is closed by imposing the following market-clearing conditions:

The final goods market (for consumption and investment goods) clears when the demand from the households ($C_{D,t}, I_{D,t}$), the government (G_t) and the foreign economy ($M^*_{C,t}, M^*_{I,t}$) can be met by the production of the intermediate domestic firms.

$$Y_t = C_{D,t} + M^*_{C,t} + I_{D,t} + M^*_{I,t} + G_t \tag{39}$$

Using the information about the domestically consumed and imported goods (from the optimization of the consumption good distributors), we may derive the following aggregated output equation:

$$\begin{aligned} Y_t \quad = \quad & \omega_C C_t T_t^{(1-\omega_C)} + \omega_I I_t T_t^{(1-\omega_I)} + G_t \\ & + \frac{(1-n)}{n}\left[(1-\omega^*_C)C^*_t T_t^{\omega^*_C} + (1-\omega^*_I)I^*_t T_t^{\omega^*_I}\right] \end{aligned} \tag{40}$$

We obtain the similar expression for the foreign country:

$$\begin{aligned} Y^*_t \quad = \quad & \frac{n}{n-1}\left[(1-\omega_C)C_t T_t^{\omega_C} + (1-\omega_I)I_t T_t^{\omega_I}\right] + \\ & + G^*_t + \omega^*_C C^*_t T_t^{(1-\omega^*_C)} + \omega^*_I I^*_t T_t^{(1-\omega^*_I)} \end{aligned} \tag{41}$$

Equilibria in the factor markets require that:

$$
\begin{aligned}
L_t &= \int\limits_{z=0}^{n} L_t(z)dz \\
L_t^* &= \int\limits_{z=n}^{1} L_t^*(z)dz
\end{aligned}
$$

$$
\begin{aligned}
K_t &= \int\limits_{z=0}^{n} K_t(z)dz \\
K_t^* &= \int\limits_{z=n}^{1} K_t^*(z)dz
\end{aligned}
$$

2.6 Monetary authority

Money balances are not explicitly referred to in our model. It is assumed that the central bank follows an interest rate rule. The authority supplies in each period the amount of money ΔM_t, but it does not affect the dynamics of the model. Money cancels out in the estimable version of the model.

The two-country currency union model is closed by a modified Taylor rule (1993) of the form:

$$\hat{r}_{EMU,t} = \rho_{R\_EMU}\hat{r}_{EMU,t-1} + (1-\rho_{R\_EMU})\left[\hat{\varepsilon}_t^{\pi} + \kappa_{\pi\_EMU}(\hat{\pi}_{C_{EMU},t-1} - \hat{\varepsilon}_t^{\pi}) + \kappa_{y\_EMU}(\hat{y}_{EMU,t-1})\right] + u_t^{R\_EMU} \tag{42}$$

The monetary authority is assumed to adjust the short-run interest rate in response to the deviations of euro area wide CPI inflation from the time-varying inflation target ε_t^{π} and output from its steady state.

Variables are expressed in log-deviations from steady state. We assume that there are two monetary shocks, one is a persistent shock to the inflation objective ε_t^{π} which is assumed to follow a first-order autoregressive process ($\varepsilon_t^{\pi} = \rho_{\pi}\varepsilon_{t-1}^{\pi} + u_t^{\pi}$), the other is a temporary euro area wide interest rate shock $u_t^{R\_EMU}$. For simplicity the inflation target is assumed to be common for the euro area countries also prior to the adoption of the euro (see below). This element proxies for monetary coordination prior to EMU. Further, $\hat{r}_{EMU,t}$ denotes the nominal interest rate in the euro area, $\hat{\pi}_{C_{EMU},t}$ is the inflation rate in the EMU (deviation from steady state inflation) and $\hat{y}_{EMU,t}$ denotes deviation of the Euro Area wide aggregated output from its steady state. Parameter ρ_{R_EMU} captures the degree of interest rate smoothing.

By definition, the consumer price inflation gap and output gap in the EMU are given by:

$$\hat{\pi}_{C_{EMU},t} = n\hat{\pi}_{C,t} + (1-n)\hat{\pi}_{C,t}^* \tag{43}$$

$$\hat{y}_{EMU,t} = n\hat{y}_t + (1-n)\hat{y}_t^* \tag{44}$$

In order to estimate the model on the time series containing the observations prior to EMU, we have to account for the heterogeneous monetary rules within the area. We assume that the monetary policy was conducted (on the single country level) by independent monetary authorities (in Germany and in the rest of the euro area):

$$\hat{r}_t = \rho_R \hat{r}_{t-1} + (1-\rho_R)\left[\varepsilon_t^{\pi} + \kappa_{\pi}(\hat{\pi}_{C,t-1} - \varepsilon_t^{\pi}) + \kappa_{\pi}(\hat{y}_{t-1})\right] + u_t^R \tag{45}$$

$$\hat{r}_t^* = \rho_R^* \hat{r}_{t-1}^* + (1-\rho_R^*)\left[\varepsilon_t^{\pi} + \kappa_{\pi}^*(\hat{\pi}_{C^*,t-1} - \varepsilon_t^{\pi}) + \kappa_{\pi}^*(\hat{y}_{t-1}^*)\right] + u_t^{R^*} \tag{46}$$

Thus, we decide to work with three interest rate shocks ($u_t^R, u_t^{R^*}, u_t^{R\text{-}EMU}$). The country-specific shocks are allowed to be cross-country correlated (the correlation coefficient is estimated). These shocks vanish after the adoption of the single currency. The area-wide shock, in turn, is set to zero prior to the adoption of the common currency. Similar monetary rules are used when constructing closed-economy models, obtained by a straightforward reduction of the two-country model.

3 Summarizing the model

Recapitulating, the model we have formed may be presented in terms of stationary variables.

The perfect risk sharing condition restricts the consumption from diverging across the countries and implicitly determine the varying nominal exchange rate (only in the DSGE model for countries not constituting the monetary union). Using the variables common for both DSGE models, the perfect risk sharing condition is expressed as follows:

$$\mathcal{T}_t^{(\omega_C + \omega_C^* - 1)} = \left(\varepsilon_t^Z\right)\left[\frac{\varepsilon_t^{C^*}(\tilde{C}_t - \varkappa \tilde{C}_{t-1}/\varepsilon_t^A)}{\varepsilon_t^C(\tilde{C}_t^* - \varkappa^* \tilde{C}_{t-1}^*/\varepsilon_t^{A^*})}\right] \tag{47}$$

Note that foreign trending variables have been scaled with the technical progress factor A_t^*. We assume, however, that in the long run, the growth rate of technology is equal across the euro area blocs, in line with the AWM methodology (see the section Data consideration). The ratio $\frac{A_t}{A_t^*} = \varepsilon_t^Z$ is assumed to be stationary and to measure the degree of asymmetry in the technological progress across the regions (see e.g. Adolfson *et al.* (2004))[32]. This asymmetric technology innovation follows an autoregressive process. Thus, the processes for technology are cointegrated and the growth in the rest of the euro area is determined endogenously, given the exogenously driven technology progress in the German economy and the process for the asymmetric shock:

$$\hat{\varepsilon}_t^{A^*} = \hat{\varepsilon}_t^A - \Delta\hat{\varepsilon}_t^Z \tag{48}$$

Note that the meaning of the asymmetric shock may be a little bit confusing. This shock does not accelerate the technological progress in the Home economy, it implies only the decrease (increase) in the technological progress in the Foreign economy relative to the Home economy. Therefore, the impact of this shock on output growth may be negative (positive) in both economies (e.g. lower

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[32] Assuming two different long run growth rates of technology in the model, technological progress in the rest of the euro area would be given by the following expression: $\hat{\varepsilon}_t^{A^*} = \hat{\varepsilon}_t^A - \Delta\hat{\varepsilon}_t^Z + \log(\bar{\varepsilon}^{A^*}) - \log(\bar{\varepsilon}^A)$, where $\bar{\varepsilon}^{A^*}$ is a long run growth rate of technology in the rest of the euro area.

demand in the rest of the euro area may adversely affect German exports). A negative asymmetric technology shock also results in a temporary lower level of technology in the euro area as a whole.

Our model does not explain a possible convergence in terms of per capita variables in Europe. Nevertheless, due to the included persistent asymmetric technology shock, wich is estimated to be highly persistent, the model allows for long-lasting differences in growth rates of real variables across the regions.[33]

For countries with independent monetary authorities we obtained the following Euler equations:

$$\frac{1}{R_t} = \beta E_t \left[\frac{\varepsilon^C_{t+1}(\tilde{C}_t - \varkappa \tilde{C}_{t-1}/\varepsilon^A_t)}{\varepsilon^C_t(\varepsilon^A_{t+1}\tilde{C}_{t+1} - \varkappa \tilde{C}_t)\pi_{C,t+1}} \right] \tag{49}$$

$$\frac{1}{R^*_t} = \beta E_t \left[\frac{\varepsilon^{C*}_{t+1}(\tilde{C}^*_t - \varkappa^* \tilde{C}^*_{t-1}/\varepsilon^{A*}_t)}{\varepsilon^{C*}_t(\varepsilon^{A*}_{t+1}\tilde{C}^*_{t+1} - \varkappa^* \tilde{C}^*_t)\pi^*_{C,t+1}} \right] \tag{50}$$

However, in the currency area setting, it is sufficient to use only one of them (the price of a riskless bond is the same in both countries) along with the perfect risk sharing condition to pin down the consumption and obtain a unique stable solution.

The model for the currency area is augmented with auxiliary equations defining the terms of trade:

$$\frac{\mathcal{T}_t}{\mathcal{T}_{t-1}} = \pi^*_t/\pi_t$$

and nominal interest rates:

$$R_t = R^*_t$$

Thus, the number of variables in both DSGE for monetary union and DSGE for a flexible exchange rate regime is the same (convenient for estimation).

The remaining equations are identical for a currency area and a two-country model with flexible prices. Below we present the conditions only for the Home country (the structure of the Foreign economy is symmetric).

From the household's decision problem we use a capital accumulation equation

$$\varepsilon^A_t K_{t+1} = (1-\delta)K_t + \varepsilon^I_t F(I_t, I_{t-1}, \varepsilon^A_t) \tag{51}$$

the equation defining price of installed capital (we use $\frac{\beta\lambda_{t+1}}{\lambda_t} = \frac{\pi_{t+1}}{R_t}$)

$$-E_t(\frac{R_t}{\pi_{t+1}}Q_t) + E_t(Z_{t+1}) + E_t(Q_{t+1}(1-\delta)) = 0 \tag{52}$$

the equation for investment demand (we use $\frac{P_{I,t}}{P_t} = \mathcal{T}_t^{(1-\omega^I)}$)

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[33] As an alternative one may determine two exogenously given technology processes in the EMU. Then, however, the ratio of ε^Z_t would be nonstationary and the model would have to be estimated with the Diffuse Kalman Filter.

$$-\mathcal{T}_t^{(1-\omega^I)} + Q_t \varepsilon_t^I F_1(I_t, I_{t-1}, \varepsilon_t^A) + E_t(\frac{\pi_{t+1}}{R_t} Q_{t+1} \varepsilon_{t+1}^I F_2(I_{t+1}, I_t, \varepsilon_{t+1}^A)) = 0 \tag{53}$$

The equations defining the optimal and aggregated wage are given by:

$$A_t \bar{W}_t^{nom}(h) = (1+\varepsilon^w) \frac{\sum\limits_{i=0}^{\infty} (\beta\theta^w)^i E_t \left[U_{L,t+i} Z_{t+i} A_{t+i-1} \tilde{K}_{t+i} \left(A_{t+i} \tilde{W}_{t+i}^{nom} \right)^{\frac{1}{\varepsilon^w}} \right]}{\sum\limits_{i=0}^{\infty} (\beta\theta^w)^i E_t \left[\frac{1}{P_{C,t+i}} \frac{1}{A_t \tilde{C}_{t+i} - \varkappa A_{t-1} \tilde{C}_{t+i-1}} Z_{t+i} A_{t+i-1} \tilde{K}_{t+i} \left(A_{t+i} \tilde{W}_{t+i}^{nom} \right)^{\frac{1}{\varepsilon^w}} \right]} \tag{54}$$

$$\varepsilon_t^A \tilde{W}_t^{nom} = [\theta(\tilde{W}_{t-1}^{nom})^{-\frac{1}{\varepsilon^w}} + (1-\theta) \left(\varepsilon_t^A \bar{W}_t^{nom} \right)^{-\frac{1}{\varepsilon^w}}]^{-\varepsilon^w} \tag{55}$$

Production technology in the intermediate sector is given by:

$$\tilde{Y}_t = \left(\varepsilon_t^A \right)^{\alpha-1} \varepsilon_t^Y \tilde{K}_t^{1-\alpha} {L_t}^{\alpha} \tag{56}$$

Cost optimization in the intermediate sector implies the following labor demand equation

$$L_t = \frac{\alpha}{1-\alpha} Z_t^{nom} \tilde{K}_t / (\tilde{W}_t^{nom} \varepsilon_t^A) \tag{57}$$

and marginal cost equation:

$$MC_t^{nom} = \frac{1}{\varepsilon_t^Y} \left[\frac{\tilde{W}_t^{nom}}{\alpha} \right]^{\alpha} \left[\frac{Z_t^{nom}}{(1-\alpha)} \right]^{1-\alpha} \tag{58}$$

We define a utility-based pricing kernel $\Lambda_{t,i} = \beta^i \frac{U_{C,t+i}}{U_{C,t}}$ and derive the optimal price in the intermediate sector:

$$E_t \sum_{i=0}^{\infty} (\theta^P \beta)^i \Lambda_{t,i} \left[\frac{1+\varepsilon_{t+i}^P}{\varepsilon_{t+i}^P} \left(\frac{1}{P_{t+i}} \right)^{\frac{-1}{\varepsilon_{t+i}^P}} \bar{P}_t^{-\frac{1+\varepsilon_{t+i}^P}{\varepsilon_{t+i}^P}} Y_{t+i} (\frac{MC_{t+i}^{nom} - \bar{P}_t}{\bar{P}_t}) \right] = 0 \tag{59}$$

The aggregated producer price index is given by:

$$P_t = [\theta^P \left((\pi_{t-1})^{\gamma_p} P_{t-1} \right)^{-\frac{1}{\varepsilon_t^P}} + (1-\theta^P) \bar{P}_t^{-\frac{1}{\varepsilon_t^P}}]^{-\varepsilon_t^P} \tag{60}$$

The consumer price index derived from the distributor optimization problem implies the following inflation equation:

$$\pi_{C,t} = \pi_t \left(\frac{\mathcal{T}_t}{\mathcal{T}_{t-1}} \right)^{(1-\omega_C)} \tag{61}$$

This equation allows for a perfect exchange rate pass through in the flexible exchange rate setting.

Finally, the aggregate demand in the Home country is as follows:

$$\begin{aligned} \varepsilon_t^Z \tilde{Y}_t &= \varepsilon_t^Z \omega_C \tilde{C}_t \mathcal{T}_t^{(1-\omega_C)} + \varepsilon_t^Z \omega_I \tilde{I}_t \mathcal{T}_t^{(1-\omega_I)} + \varepsilon_t^Z \tilde{G}_t \\ &\quad + \frac{(1-n)}{n} \left[(1-\omega_C^*) \tilde{C}_t^* \mathcal{T}_t^{\omega_C^*} + (1-\omega_I^*) \tilde{I}_t^* \mathcal{T}_t^{\omega_I^*} \right] \end{aligned} \tag{62}$$

We obtain the similar expression for the foreign country:

$$\begin{aligned} \left(\varepsilon_t^Z\right)^{-1} \tilde{Y}_t^* &= \frac{n}{n-1} \left[(1-\omega_C) \tilde{C}_t \mathcal{T}_t^{\omega_C} + (1-\omega_I) \tilde{I}_t \mathcal{T}_t^{\omega_I} \right] + \\ &\quad + \left(\varepsilon_t^Z\right)^{-1} \tilde{G}_t^* + \left(\varepsilon_t^Z\right)^{-1} \omega_C^* \tilde{C}_t^* \mathcal{T}_t^{(1-\omega_C^*)} + \left(\varepsilon_t^Z\right)^{-1} \omega_I^* \tilde{I}_t^* \mathcal{T}_t^{(1-\omega_I^*)} \end{aligned} \tag{63}$$

The model for a currency area is closed with a single Taylor-like monetary policy rule on the aggregated euro area variables, while the two-country model with flexible exchange rate regime is closed with two separate monetary feedback rules.

The stochastic behavior of the system is governed by eighteen exogenous structural shocks. A time-varying inflation target and twelve shocks arising from technology and preferences ($\varepsilon_t^\pi, \varepsilon_t^A, \varepsilon_t^Z, \varepsilon_t^Y, \varepsilon_t^{Y*}$, $\varepsilon_t^C, \varepsilon_t^{C*}, \varepsilon_t^I, \varepsilon_t^{I*}, \varepsilon_t^L, \varepsilon_t^{L*}, \varepsilon_t^G, \varepsilon_t^{G*}$) are assumed to follow first-order autoregressive processes. Two cost-push shocks are assumed to be i.i.d.. Monetary shocks, prior to the adoption of the single currency, are assumed to be cross-country correlated.

3.1 Solving the model

Having derived the first-order conditions and combined them with market-clearing conditions (see the sections above), we log-linearize each of the two models, for flexible and fixed exchange rates respectively, around the non-stochastic steady state. In the next step we put the models in a form of a Linear Rational Expectations (LRE) system (see e.g. Sims (2002)):

$$\Gamma_{0,t}(\theta) s_t = \Gamma_{1,t}(\theta) s_{t-1} + x(\theta) + \Psi_t(\theta) u_t + \Pi_t \eta_t \tag{64}$$

where s_t is a vector of the model variables, $x(\theta)$ is a vector containing constant terms, u_t is a vector of structural shocks, and η_t is a vector of rational expectations errors ($\eta_t = s_t - E_{t-1}(s_t)$). Matrices $\Gamma_{0,t}, \Gamma_{1,t}$, containing reduced-form parameters are in fact functions of deep (structural) parameters, stored in the vector θ. To solve the system it is necessary to determine η_t as a function of u_t such that s_t is stable.

Note that in order to account for a change in the data generating process resulting from the introduction of the single currency, we allow the matrices $\Gamma_{0,t}, \Gamma_{1,t}, \Psi_t, \Pi_t$ to be time-varying. To be more precise, reduced-form parameters are assumed to be constant within each of the two subsamples. For $t <$ 1999:1q the LRE system stands for the flexible exchange rate model, for $t \geq$ 1999:1q it stands for the common currency area. In turn, deep parameters, except for the parameters of monetary policy rule, are assumed to be time-invariant.

In order to produce one step forecasts, used to compute the log-likelihood (for details see the section Estimation) and determine the complete DGP, we have to solve (separately) two LRE systems [34]. To do this we use the algorithm by Sims (2002), which is applicable also to large scale models, in which matrix Γ_0 is often non-invertible (the algorithm uses QZ singular value decomposition).

In general, the solution of (64) may be written as follows:

$$s_t = G_t(\theta)x(\theta) + B_t(\theta)s_{t-1} \tag{65}$$

where the selection matrices $G_t(\theta)$, $B_t(\theta)$ are also threshold-dependent.

4 Data consideration

In the estimation, we use mostly the seasonally adjusted quarterly data from the AWM Database by Fagan *et al.* (2001) (update containing data from 1970:q1 to 2003:q4) and the German VGR data. In the case of the AWM data, the single country series are re-based to the same year (i.e. 1995) and then joined. The methodology of the AWM, the so called "index method" with fixed weights for each country (see Table 1), allows for a straightforward disaggregation of the data, for instance, into a data set for two regions given the data for a single country. The fixed weights applied when constructing the AWM data-set imply the same long-run growth rates of real variables across the euro area countries.

We also follow the AWM methodology constructing the time series for the unified Germany re-scaling data available only for West Germany by the ratio of the two series at the starting date of the post-unification series.

To estimate the baseline model, a two-country model with deterministic regime-switching containing real and nominal rigidities, we decide to match the following set of fourteen variables: GDP, consumption, investment, annualized GDP deflator, annualized nominal interest rate, real wage, total employment for Germany and the respective euro area wide aggregates. The model is estimated on the sample 1980:q1-2003:q4. We follow Smets and Wouters (2003a) and use the data from the 1970s as a training sample for initialization of the Kalman Filter.

In estimation we follow two alternative data approaches. The model is estimated: (i) employing the HP-filtered data and (ii) the log-differences calculated from the raw data in the presence of the unit root (comparison of the estimates is presented in the section Results below)[35]. The former approach is emphasized e.g. by Juillard, Pesenti, Laxton and Karam (2004). We follow their suggestion and eliminate the trend also in nominal variables by applying an HP filter with a smoothing parameter equal to 1000.[36] The DSGE model is estimated on the raw data for instance in Adolfson *et al.* (2004). Since there are long-lasting differences in the growth rates

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[34] Our approach to the DSGE model estimation may be easily augmented. It is possible to incorporate further regimes into the estimation procedure. In order to account for the fact that before 1992 the European currencies were pegged to the Deutsche Mark (the fluctuations were restricted to $\mp$ 2.5%) one may construct an additional DSGE model for that period. Thus, the monetary policy would be determined by the imperfect peg against the DM. Since the interest rate is assumed to be the instrument which is used to keep the nominal exchange constant up to an exogenous policy shock, the monetary policy rule in the rest of the euro area countries would be given by $\hat{r}_t^* = \hat{r}_t + u_t^{EMS}$. Thus, the interest rate would respond one-to-one to changes in the Bundesbank's monetary policy but it would also be affected by an exogenous shock.

[35] Using the growth rates of the observed macro variables may be useful for direct forecasting from the model. Nevertheless, model constructed on deviations may also be used as a forecating tool. In order to obtain a forecast of observed variables we have to use the following transformation:$\ln x_t = \hat{x}_t + \ln \bar{X}$, where $\bar{X}$ may be seen as a long-run trend in the data (HP trend). In order to obtain a forecast of the levels we should initially forecast the trend component of the time series.

[36] Smets and Wouters (2003a) remove the linear trend from the data.

of real variables across the regions, the implementation of the balanced growth mechanism into a two-country model poses some additional technical problems. This peculiar feature may be partially overcome by including an additional persistent technology shock standing for cross-region asymmetries (see the section above).[37] Nevertheless, periods during which the growth rates of real variables differ significantly within the region are still long enough to induce high persistence in the estimates of almost all structural shocks, in the model estimated on log-differences.

In order to estimate the model on raw data for inflation and the nominal interest rate (both have a downward trend starting in the 1980s), we allow for the time-varying inflation target (ε_t^{π}). This target follows an autoregressive process. Thus, our model is constructed to explain deviations from the inflation target ($\hat{\pi}_t - \hat{\varepsilon}_t^{\pi}$). Technically, including an autoregressive process for the inflation target is almost equivalent to the detrending of inflation and the nominal interest rate series outside the model.

As mentioned above, the model is estimated simultaneously on both single country data and the aggregated data for the whole euro area. In that case we use the original AWM time series which are disaggregated inside the model, assuming constant weights for the German economy in EMU. The corresponding vector of the observed variables in the state space representation of the model has the following form[38]:

$$\begin{bmatrix} \Delta \ln Y_t^{GER} \\ \Delta \ln Y_t^{EMU} \\ \Delta \ln C_t^{GER} \\ \Delta \ln C_t^{EMU} \\ \Delta \ln I_t^{GER} \\ \Delta \ln I_t^{EMU} \\ \Delta \log(W_t^{GER}/P_t^{GER}) \\ \Delta \log(W_t^{EMU}/P_t^{EMU}) \\ EM_t^{GER\_HP} \\ EM_t^{EMU\_HP} \\ 4\text{x}\Delta \ln P_t^{GER} \\ 4\text{x}\Delta \ln P_t^{EMU} \\ \ln R_t^{GER} \\ \ln R_t^{EMU} \end{bmatrix} = \begin{bmatrix} \hat{y}_t - \hat{y}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A \\ (1-n)(\hat{y}_t^* - \hat{y}_{t-1}^* + \ln(\bar{\varepsilon}^A) + \varepsilon_t^{A^*}) + n(\hat{y}_t - \hat{y}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A) \\ \hat{c}_t - \hat{c}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A \\ (1-n)(\hat{c}_t^* - \hat{c}_{t-1}^* + \ln(\bar{\varepsilon}^A) + \varepsilon_t^{A^*}) + n(\hat{c}_t - \hat{c}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A) \\ \hat{\imath}_t - \hat{\imath}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A \\ (1-n)(\hat{\imath}_t^* - \hat{\imath}_{t-1}^* + \ln(\bar{\varepsilon}^A) + \varepsilon_t^{A^*}) + n(\hat{\imath}_t - \hat{\imath}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A) \\ \hat{w}_t - \hat{w}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A \\ (1-n)(\hat{w}_t^* - \hat{w}_{t-1}^* + \ln(\bar{\varepsilon}^A) + \varepsilon_t^{A^*}) + n(\hat{w}_t - \hat{w}_{t-1} + \ln(\bar{\varepsilon}^A) + \varepsilon_t^A) \\ \hat{e}m_t \\ n\ \hat{e}m_t + (1-n)\hat{e}m_t^* \\ 4\text{x}(\hat{\pi}_t + \bar{\pi}) \\ 4\text{x}(\hat{r}_t^{EMU} + \bar{R}) \\ 4\text{x}(\hat{r}_t + \bar{R}) \\ 4\text{x}(n\hat{\pi}_t + (1-n)\hat{\pi}_t^* + \bar{\pi}) \end{bmatrix}$$

Since there is no official euro area-wide data for the "hours worked", denoted in our model by L_t,(or $\hat{l}_t$ as log-deviations), we use available data on employment. Employment time series are, however, more persistent compared to the "hours worked". Therefore we follow Smets' and Wouters' framework assuming that only $1-\theta^L$ fraction of firms may adjust the employment EM_t (or $\widehat{em}_t$ in log -deviations) to the preferred level at each date. The aggregated employment equation is then given by:

$$\Delta\widehat{em}_t = \beta E_t \Delta\widehat{em}_{t+1} + \frac{(1-\theta^L)(1-\beta\theta^L)}{\theta^L}(\hat{l}_t - \widehat{em}_t)$$

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[37] Note that introducing two differnt long-run technology growth rates would not be fully in line with the AWM methodology.

[38] The vector of observed variables in the model estimated on HP-filtered data has the following form:$[\ln Y_t^{GER\_HP}, \ln Y_t^{EMU\_HP}, \ln C_t^{GER\_HP}, \ln C_t^{EMU\_HP}, \ln I_t^{GER\_HP}, \ln I_t^{EMU\_HP}, \pi_t^{GER\_HP}, \pi_t^{EMU\_HP}, \ln(1+R_t)^{GER\_HP}, \ln(1+R_t)^{EMU\_HP}, \ln(W_t/P_t)^{GER\_HP}, \ln(W_t/P_t)^{EMU\_HP}, \ln EM^{GER\_HP}, \ln EM_t{}^{EMU\_HP}]' = [\hat{y}_t, n\hat{y}_t + (1-n)\hat{y}_t^*, \hat{c}_t, n\hat{c}_t + (1-n)\hat{c}_t^*, \hat{\imath}_t, n\hat{\imath}_t + (1-n)\hat{\imath}_t^*, 4\text{x}\hat{\pi}_t, 4\text{x}n\hat{\pi}_t + 4\text{x}(1-n)\hat{\pi}_t^*, 4\text{x}\hat{r}_t, 4\text{x}n\hat{r}_t + 4\text{x}(1-n)\hat{r}_t^*, \hat{w}_t, n\hat{w}_t + (1-n)\hat{w}_t^*, \widehat{em}_t, n\widehat{em}_t + (1-\hat{n})\widehat{em}_t^*]'$.

	EU 12
Belgium	0.036
Germany	0.283
Spain	0.111
France	0.201
Ireland	0.019
Italy	0.195
Luxembourg	0.003
Netherlands	0.060
Austria	0.030
Portugal	0.024
Finland	0.017
Greece	0.025

Table 1: Weights used in aggregation

The framework presented above allows for a model-consistent choice of time series used in estimation and simultaneously improving model fit to the data. Contrary to Adolfson *et al.* (2004) our functional form for the consumption good production function does not necessitate redefining the variables in the linearized version of the model in order to match the observed data.

5 Estimation

Recent advances in estimation methods, especially applying Bayesian techniques, have made it feasible to estimate even large-scale DSGE models. In this paper we follow Schorfheide (2000), (2003) and Lubik and Schorfheide (2002) and apply a two-step estimation procedure involving calibration and Bayesian Maximum Likelihood methods.

An advantage of the method applied here is twofold: on the one hand, the system of linearized equations is estimated simultanously and on the other hand, the Bayesian analysis allows us to formally incorporate uncertainty and prior information regarding the parameterization of the model.[39] The same exercise is much more difficult in the GMM setup. However, it should be underlined that the choice of the prior is of the highest importance because it might significantly affect the estimates. For example, Onatski and Williams (2004) limit the prior information assuming the uniform distribution of the parameters over a bounded range. Hence, they simply maximize the likelihood over the bounded space. Their procedure seems to be very attractive as an alternative to the approach advocated by e.g. Smets and Wouters (2003a, b). A potential drawback of the method, as we see it, is that when applying uniform priors the probability that a number of estimates will be on boundaries is much higher. The results in Onatski and Williams (2004) seem to confirm our point. Their estimates of consumption habit, fixed cost of production, Calvo parameter in the employment equation, response to a lagged inflation in the monetary feedback rule, inverse of elasticity of labor supply, and capital utilization cost may be seen as corner solutions of optimization problem.

Because of the problems listed above, the sensitivity analysis of the results might be seen as a complementary part of the method. In larger DSGE models, which group our model also belongs to, the sensitivity analysis might be problematic due to a large number of parameters. In this paper we conduct the sensitivity analysis by employing alternative data sets in the estimation and estimating a range of nested models (see the section Results).[40]

With the prior specified (for details see section below), we turn to the estimation of the model. The principle of the approach is straightforward: we look for a parameter vector which maximizes the posterior mode, given our prior and the likelihood based on the data.

By Bayes theorem the posterior density $p(\theta|Y)$ is related to the prior and the likelihood as follows:

$$p(\theta|Y) = \frac{p(Y|\theta)p(\theta)}{p(Y)} \propto p(Y|\theta)p(\theta) = L(\theta|Y)p(\theta) \tag{66}$$

where $p(\theta)$ denotes the prior density of the estimated parameter, $p(\theta|Y)$ is the posterior probability of the parameter, $L(\theta|Y)$ is the likelihood of the data Y and $p(Y) = \int p(Y|\theta)p(\theta)d\theta$ is the unconditional data density (as it does not depend on the unknown parameter it may be treated as a proportionality factor and may be neglected in the estimation). At this point, the difference between non-Bayesian likelihood methods and the Bayesian approach is visible. Beside using the information contained in the full distribution $p(\theta, Y)$ we utilize additional information contained in the prior density.

Assuming that priors are independently distributed, the logarithm of the posterior may be calculated as follows (N is the number of estimated parameters):

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[39] For instance, Linde (2002) also argues by means of Monte Carlo simulations that the Full Information Maximum Likelihood approach improves the estimation result considerably in comparison with single-equation methods even if the model and the policy rule are misspecified.

[40] For alternative methods of sensitivity analysis see e.g. Ratto at al. (2005).

$$\ln(p(\theta|Y)) = \ln(L(\theta|Y)) + \sum_{i=1}^{N} \ln(p(\theta_i)) \tag{67}$$

Thus, the computation of the posterior is twofold, (i) the value of the data log-likelihood is computed and (ii) the values for priors are assigned. The value of the log-likelihood has to be computed recursively on the whole sample containing information of the both monetary regimes. For this purpose, the solution of the linearized DSGE model is to be written in a state space form:[41]

$$\begin{array}{rl} \begin{array}{r} s_t = A_1(\theta)s_{t-1} + x(\theta) + R_1(\theta)u_t \\ y_t^{obs1} = G_1(\theta)x(\theta) + B_1(\theta)s_t \end{array} & u_t \sim N(0, Q_1) \text{ for } t < T^* \\ \\ \begin{array}{r} s_t = A_2(\theta)s_{t-1} + x(\theta) + R_2(\theta)u_t \\ y_t^{obs2} = G_2(\theta)x(\theta) + B_2(\theta)s_t \end{array} & u_t \sim N(0, Q_2) \text{ for } t \geq T^* \end{array} \tag{68}$$

where T^* denotes the point of transition to the new regime. y_t^{obs} is a vector of observable variables. Its size is threshold-dependent. s_t may, in turn, contain unobservable elements. x is a vector of predetermined variables, the common rate of technology growth, steady state inflation and the steady state nominal interest rate, in our model. Note that it is necessary to solve two models, one for the flexible exchange rate regime and one for monetary union, on an adequate subsample. The reduced-form matrices $A_1, A_2, R_1, R_2, G_1, G_2$ are constant within the subsamples.

For convenience, the size of the state-variable vector s_t is set to be the same in the both regimes. We added auxiliary equations for interest rates $\hat{r}_t = \hat{r}_t^* = \hat{r}_{EMU,t}$ and the equation defining terms of trade $\hat{t}_t$ in the DSGE for the monetary union. Since there is only a single nominal interest rate in the EMU, we redefine the selection matrix B_2 to reduce the size of the vector of observables in the setting for the monetary union. y_t^{obs2} contains one less variable compared to the flexible exchange rate regime.[42]

Due to the unobserved variables in the vector s_t of the state space representation (and the scale of the maximization problem), the likelihood function, given the initial values for the structural parameter vector θ_0, has to be computed recursively taking into account the regime switch:

$$\ln(L) = -\frac{T}{2}\ln(2\pi) - \frac{1}{2}\left(\sum_{t=1}^{T^*-1} \ln|F_{1,t}| + \sum_{t=T^*}^{T} \ln|F_{2,t}|\right) + \frac{1}{2}\left(\sum_{t=1}^{T^*-1} \ln(v_{1,t}' F_{1,t} v_{1,t}) + \sum_{t=T^*}^{T} \ln(v_{2,t}' F_{2,t} v_{2,t})\right) \tag{69}$$

where $F_{1,t}$, $F_{2,t}$ are forecast-error covariance matrices in the particular regimes:

$$F_{1,t} = B_1 P_{1,t|t-1} B_1' \text{ for } t < T^*$$

$$F_{2,t} = B_2 P_{2,t|t-1} B_2' \text{ for } t \geq T^*$$

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[41] Note that our approach to estimation is a little bit "automatical". To extend the estimation sample and to fit the model to the data prior to EMU, we assume that the switch to the new monetary regime has not been anticipated by the household, which might be at odds with the empirical evidence.

[42] Extending the vector of observables in the DSGE model for monetary union with local interest rate would imply singularities in the forecast-error-matrix in the Kalman Filter.

$v_{1,t}$, $v_{2,t}$ are forecast errors:

$$v_{1,t} = y_t^{obs1} - y_{t|t-1}^{obs1} \text{ for } t < T^*$$

$$v_{2,t} = y_t^{obs2} - y_{t|t-1}^{obs2} \text{ for } t \geq T^*$$

Note that the vectors $v_{1,t}$ and $v_{2,t}$ differ in size. $y_{t|t-1}^{obs1}$, $y_{t|t-1}^{obs2}$ are one-step forecasts of observables. The model-consistent one step forecast for the weighted average of local nominal interest rates $n\hat{r}_{T^*|T^*-1} + (1-n)\hat{r}^*_{T^*|T^*-1}$ (conditional on the information prior to the adoption of the euro) is used to compute the forecast error for the observed common nominal interest rate ($v_{r_{EMU},2,T^*} = \hat{r}_{EMU,T^*} - \left[n\hat{r}_{T^*|T^*-1} + (1-n)\hat{r}^*_{T^*|T^*-1}\right]$) at the point of transition to the new regime T^*.

The state covariance matrices for the respective regimes $P_{1,t|t-1}$, $P_{2,t|t-1}$ are calculated as follows:

$$P_{1,t|t-1} = A_1 P_{1,t-1} A_1' + R_1 Q_1 R_1' \text{ for } t < T^*$$

$$P_{2,t|t-1} = A_2 P_{2,t-1} A_2' + R_2 Q_2 R_2' \text{ for } t \geq T^*$$

where $P_{1,t-1}$, $P_{2,t-1}$ are updating state variance-covariance matrices.

At the point of transition T^* the matrix $P_{2,T^*|T^*-1}$ is obtained using the updating matrix P_{1,T^*-1} from the previous regime as an initial value for the Kalman Filter on the new DGP:

$$P_{2,T^*|T^*-1} = A_2 P_{1,T^*-1} A_2' + R_2 Q_2 R_2'$$

Similarly, the one-step conditional forecast of the state vector $s_{T^*|T^*-1}$ is based on s_{T^*-1}. For further details of Kalman Filter see e.g. Hamilton (1994).

Having computed the likelihood of the data, the prior distributions are assigned to all parameters of the model. The posterior distribution (67) is maximized numerically. In order to tackle the problem of local optima often faced in numerical optimization, firstly, we applied a random search algorithm over the bounded parameter space. To determine the boundaries we used the results from one-country model estimation as well as those from other studies. Further, starting with the parameter values obtained in the former step (initial values for which the posterior takes the highest values), we use the CSMINWEL, numerical optimization routine developed by Sims (2002), to locally maximize the posterior. Our approach is similar to that described in Onatski and Williams (2004)[43].

Note that indeterminate models are ruled out during the estimation procedure (see Blanchard and Kahn (1980) or Klein (2000)).[44]

In the second stage of the estimation procedure, the posterior mode (the outcome of the numerical optimization) is used as a starting point for the Metropolis-Hasting (MH) algorithm. The

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[43] Onatski and Williams (2004) used a genetic algorithm initialized on the draws from the prior distribution.

[44] The likelihood function is maximized under the constraint that the parameter vector θ does not yield multiple stable solutions. In this case the numeric maximization of the likelihood function might be corrupted by the impossibility to 'wander' through the indeterminacy region even when the maximum is beyond that region: that is, it is more likely to end up in a local maximum. Thus, starting with parameter values which are supported by data (i.e. estimates from one country model) may improve the quality of estimation (Kremer, Lombardo and Werner (2003)). We suppose, however, that in the case of larger models it is much more efficient to work with random search algorithms.

proposal distribution is taken to be the multivariate normal density centered at the previous draw with a covariance matrix proportional to the inverse Hessian (calculated numerically) at the posterior mode (see e.g. Schorfheide (2000) and Geweke (1999) for details).

$$\theta_1|\theta_0\tilde{}N\left(\theta_0,\sum(\theta_0)\right) \tag{70}$$

where θ_0 is the posterior mode and $\sum(\theta_0)$ denotes the inverse Hessian evaluated at the posterior mode.

The proposed values of parameters are accepted with the probability:

$$\min\left[\frac{p(\theta_1|Y)}{p(\theta_0|Y)},1\right] \tag{71}$$

If the proposal is accepted the parameter is set to θ_1.The parameters $\theta_{i+1}|\theta_i$ are generated in the same fashion. The sequence of posterior draws $\theta_0,\theta_1,...,\theta_n$ should converge to the posterior distribution. We use the posterior distribution obtained in this manner for the computation of the posterior mean of the parameters, their confidence intervals as well as confidence intervals for the IRFs and simulated second moments of the variables.

5.1 Calibrated parameters and specification of the priors

A DSGE model often faces the problem of parameter identification, due to the fact that detrended and seasonally adjusted time series may contain little information about the parameter of interest. In general, in small scale models the identification issue may be resolved by careful inspection of single equation. In turn, in larger models we have no possibility of telling *ex ante* which parameters are identifiable. Because of this we follow the DSGE literature and calibrate the values for the discount factor, physical depreciation rate of capital and the share of capital in the production function.

The discount factor (β) is fixed in our model at 0.998. Along with the estimated steady-state inflation and long-run growth rate of technology, it implies the annualized steady-state nominal interest rate ($\bar{R}=\frac{\bar{\pi}\bar{\varepsilon}^A}{\beta}$) equal to about 5%. The value for the physical depreciation rate of capital is calibrated to 0.02.[45] The share of capital input in the production function is fixed at 0.3.

Another reason for fixing parameters is the fact that certain parameters affect only the steady state and therefore cannot be estimated on log-differences or detrended data. Therefore, we calibrate the whole set of parameters using the simple arithmetic means of the raw data as estimates. In the two-country model the relative country size parameter n is set to 0.283, which corresponds to the weight assigned to the German economy in the AWM database. The ratio of the per capita GDP in the rest of the euro area to the per capita GDP in Germany is estimated at 0.8. The share of consumption, investment and government consumption in the GDP in the rest of the euro area and Germany is set respectively to: $\frac{C}{Y}=0.57$, $\frac{C^*}{Y^*}=0.57$, $\frac{I}{Y}=0.23$, $\frac{I^*}{Y^*}=0.21$, $\frac{G}{Y}=0.20$, $\frac{G^*}{Y^*}=0.21$, which reflects the simple mean in the 1980:q1-2003:q4 sample.

The Bayesian approach to the DSGE model estimation allows us to use the prior information from other macro as well as micro studies in a formalized way. The locations of the prior distributions for parameters which we estimate in a two- and one-country models to a large extent

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[45] Incorporating fixed parameters in our estimation procedure is consistent with the Bayesian approach and may be seen as an introduction of a very strict prior. This mixed approach (calibration combined with estimation) produces under regularity conditions, asymptotically consistent estimates (Canova 2004).

correspond to those in Smets and Wouters (2003a) and Altig *et al.* (2003) and to the recent studies for the euro area and the German economy (Jandeau and Sahuc (2004), Welz (2004), Adolfson *et al.* (2004)). Note, however, that contrary to e.g. Smets and Wouters (2003a) we do not normalize structural shocks (or use the reduced form of them), which results in much different priors and estimates of the shock volatilities in our model.

Selecting the prior distributions, we follow the standard procedure, assuming inverse gamma distribution for the parameters bounded to be positive (e.g. standard deviations of shocks), beta distribution for parameters bounded between zero and one (e.g. parameters of the shocks persistence ρ, Calvo stickiness parameters θ^P, θ^L, θ^W, indexation parameters γ, habit persistence parameter $\varkappa$) and normal distribution for the remaining parameters.

We are aware of the recent critique of imposing tight priors (see e.g. Onatski and Williams (2004)). Nevertheless, we think that the growing body of empirical literature delivers more information regarding possible estimates of structural parameters. This also allows for a more accurate selection of the form of prior distributions. Limiting the prior distribution class to solely uniform distribution may be too parsimonious.

As a mean of the prior for the technology growth rate $\bar{\varepsilon}^A$ we set 1.004, which implies an annual growth rate of about 1.6%. Note that the parameter $\bar{\varepsilon}^A$ which we refer to in the model as a steady state growth rate of technological progress is more or less a mixture of population growth and technological progress because we work with the data in levels, and not in per capita terms. The standard deviation of the asymmetric technology shock ε_t^Z is set to 0.6. This number is estimated from the first-order autoregression on the cumulated differences in GDP growth rates in the rest of the euro area and Germany (see Adolfson *et al.* (2004)). The persistence parameter of the asymmetric technology shock is set to 0.9. The mean of the prior for the steady state rate of inflation (applies only to the model estimated on raw data) is set at 2% (annualized).

Finally, in order to improve the data fit of the model we estimate shares of domestic goods in consumption and investment basket. The Means of the priors for these parameters are set respectively to: $\omega_C = 0.55, \omega_C^* = 0.85, \omega_I = 0.4, \omega_I^* = 0.7$, which roughly corresponds to the values in Jondeau and Sahuc (2004)[46].

Structural parameters are assumed to be constant on the estimation sample. Switching to the new monetary regime (new data generating process) affects only the parameters in the monetary feedback rule and monetary shocks. These parameters are allowed to vary between the two regimes.

A detailed description of the prior distribution for all estimated models can be found in Tables 4 to 6.

6 Results

In this section the results, including parameter estimates, impulse response functions (IRF) and unconditional second moments replicated by the model are discussed. A lot of research seems to suggest that results from estimated DSGE models are very sensitive to even slight changes in the model structure or depend on the data used in the estimation. To investigate wheter this is the case in our model, we check the robustness of the estimates by performing a straightforward twofold exercise. First, we estimate the baseline model, a two-region model with variable capital stock and integrated good and financial markets, on the two alternative data sets: (i) confronting the data with the balanced growth hypothesis, i.e. estimating the model on log-differences of the raw data and (ii) employing the HP-filtered time series. Second, we compare the estimates from the

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[46] Since we do not treat trade inside the rest of the euroarea in terms of exports and imports, the share of domestically consumed goods is much higher compared to the German economy.

baseline model with those obtained for a range of nested models, including the model with fixed capital stock, the model without international trade (ω_C, ω_I restricted to unity), the model with imposed structural homogeneity of the both regions and the model with flexible wages. These nested models are also used to examine the implication of structural differences for the system dynamics. In particular, we compare dynamics of the model estimated in the closed-economy framework with that estimated using the open-economy framework. Moreover, we show the differences in mechanics between the monetary union and the flexible exchange rate regime simulating both models with set of parameters obtained while estimating the baseline model, a model with two data generating processes, over the sample 1980:q1 - 2003:q4. Finally, the results are compared with those obtained in the most recent studies on the German and European economies.

6.1 Posterior estimates of the parameters

The complete set of estimation results is reported in Tables 4 to 11. These tables show the mode of all parameters along with the approximate posterior standard deviation obtained from the inverse Hessian at the posterior mode. In addition, we present the 5th and 95th percentiles of the posterior distribution (obtained after 100,000 draws).

The posterior distributions of the estimated parameters, reported along with the imposed priors, indicate that vast majority of the estimates is data, not solely prior, driven.[47] This may be seen as the simplest robustness test for the results. Despite the assignment of no correlation across the prior distributions, many of the estimates obtained from posterior maximization exhibit non-zero correlation. Due to this as well as due to the fact that the set of parameters being calibrated differs across the studies, it is difficult to compare the results directly with those from other studies.

In what follows we concentrate on the point estimates of parameters. First, we discuss the estimates of the interest rate rule in the EMU. These estimates imply that in the long run the response of nominal interest rate to inflation is greater than one (1.59), in line with the Taylor rule. The assumption of a common inflation target in the EMU implies slightly higher estimates of the interest rate smoothing parameters (0.90) compared to the model estimated on the HP-detrended data and without a time-varying inflation target. Note that the estimates of the Taylor rule for the EMU are prior driven. To estimate the interest rate rule for the EMU we effectively use only information contained in the twenty most recent observations (see the form of the log-likelihood function above), therefore weight of the prior information for these parameters is much higher compared to the remaining parameters which are estimated on the whole sample. However, this should not be seen as a drawback of the whole approach. The estimates obtained for the Taylor rules prior to the adoption of the euro as well as those obtained in the closed-economy setting are data driven and in line with the literature.

Although we have selected the same priors for both regions, we find evidence of heterogeneity, in terms of structural parameters, between Germany and the rest of the euro area. This hypothesis is tested empirically (see the section Empirical performance of the model). Particularly, the parameter standing for the capital adjustment cost is much higher for the rest of the euro area. The degree of wage stickiness is slightly lower in the German economy (baseline model). The Calvo price stickiness parameters (θ^P), in turn, are estimated to be almost equal for the both regions and imply an average price contract duration of above 16 quarters (this result is common for all models considered here). This result is, however, at odds with microeconomic surveys that indicate that the price stickiness is no higher than 6-12 months (see e.g. de Walque, Smets and Wouters (2004)). A particularly interesting result in Table 8 is that the use of HP-detrended data in the estimation

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[47] The plots of prior and posteror distributions as well as MCMC convergence statistics are provided in a separate technical appendix (available upon request).

does not lead to significantly lower estimates of the price stickiness. Our estimates of the Calvo parameter are higher than those obtained by Smets and Wouters (2003a) or Adolfson *et al.* (2004), but close to those in Onatski and Williams (2004). Note that the evidence of implausibly high estimates of the Calvo parameter in the German economy is common to other studies (see e.g. in Kremer, Lombardo and Werner (2003)). Those authors decide, however, to fix the Calvo parameter at the level consistent with the microevidence. This does not seem to be supported by the data and results in a significant deterioration of the marginal likelihood of the model.

One possible explanation for implausibly high estimates of the Calvo parameters may be related to the assumption of a white-noise price markup shock. De Walque, Smets and Wouters (2004) indicate that including in their model a persistent markup shock reduces estimated degree of price stickiness to 0.73. Nevertheless, the assumption that markup shocks follow an autoregressive process may create identification problems for other structural shocks. Also the introduction of firm specific capital into a DSGE model may reduce the degree of price stickiness. Technically, the reduced-form parameter at the marginal cost is then multiplied by an additional term standing for real rigidities. All these findings should apply also to our models.

The estimates of the price indexation parameter (γ) indicate that the German firms weaker link their prices to inflation in the past. The implied weights of lagged inflation in the New Keynesian Phillips Curve are equal to 0.24 and 0.36 respectively (our Phillips Curve is slightly more backwardlooking than one in e.g. Smets and Wouters (2003a)). The estimates obtained in the closed-economy framework and those from the models without capital roughly correspond to those for the baseline model.

The habit persistence estimates we obtain for both economies (0.68 for Germany and 0.80 for the rest of the eur area obtained for the baseline model estimated on the log-differences and 0.62 and 0.78 respectively for the baseline model estimated on the HP-filtered data) differ only slightly from those obtained by Jondeau and Sahuc (2004) for their multi-country euro area model estimated on the filtered data (0.57 for Germany, 0.73 for France and 0.84 for Italy).

As mentioned above, in order to improve the data fit of the model the share of domestic goods in the consumption and investment basket is estimated. In general, the estimates are in line with the values calibrated by Jondeau and Sahuc (2004). Note that the priors assigned to the share of domestic consumption goods are quite tight. With the uniformly distributed prior these parameters approach the implausibly high values of 0.9 and 0.95 respectively.

The estimates of structural parameters for the baseline two-country model are by and large simillar to the the estimates obtained for each bloc using a closed-economy framework or using more restrictive specifications (e.g. the model with a fixed capital stock or the model with flexible wages, see Tables 7 to 11). There are however few exceptions. Estimate of capital adjustment cost in the rest of the EMU obtained in the closed economy framework is significantly lower than the etimate from the benchmark model (it lies outside the 90% confidence interval, constructed from the posterior distribution). Fixing the capital stock in the model implies e.g. significantly higher estimates of wage stickiness for both regions. Potential sources of these discrepancies may be different assumptions regarding the processes for technological progress and the inflation target. We investigate the impact of the long run restrictions imposed on the model by estimating the benchmark model with detrended data. Overall, the results obtained from the model estimated on the HP-filtered data suggest that estimates of the deterministic part are quite immune to data transformations. We find, however, few exceptions, especially in the estimates of monetary policy rule. This might result from our quite restrictive assumption regarding the common steady state inflation and the common inflation target in the euro area prior to EMU. This assumption is not verified by the data while using the detrended data in the estimation.

As is usually the case in DSGE models, the data are quite informative about the persistence and volatility of shocks. Indeed, the patterns of prior and posterior distributions are relatively distinct. However, the cross-model comparisons indicate that estimates of the stochastic part might depend more on the model structure (see Tables 9 to 10).

For the baseline model persistent shocks are estimated to have an autoregressive parameter between 0.31, for the preference shock in the German economy, and 0.99 for the government spending shock in the rest of the euro area. In the closed-economy model the general pattern of shocks is similar to the baseline model. There are, however, some important quantitative differences. The persistence and volatility of a shock to the growth rate of technology is slightly higher than that for the baseline model. Because of the permanent impact of this shock on levels of real variables, the implications of higher persistence and volatility estimates are very severe for model stochastics.

Note that the assumption of balanced growth is not verifiable empirically when we employ the detrended data in the estimation. Therefore, we remove the permanent technology shock and the asymmetric technology shock from the model estimated on the filtered data. In turn, employing the log-differences in the estimation means that the model has to explain the longlasting differences in the growth rates of real variables. This implies that besides the permanent nature of the unit root technology shock remaining structural shocks are likewise very persistent (for further discussion see the section Smoothed estimates of shocks). Highly persistent shocks may be an indication of a weak endogenous propagation mechanism of the balanced growth DSGE models. The estimated persistence of shocks decreases if we allow for two different long run growth rates of technology in the euro area, which is not in line with the AWM methodology, or use the detrended series for real wages[48]. Despite all probles which apear while estimating the models on raw data, it seems that the future of estimated DSGE models strongly depends on their ability not only to reproduce the short run fluctuations but also to integrate the aspects of economic growth.

Commenting on the estimates of the stochastic part of DSGE models, we should underline that there is no consensus in the literature. Note that many authors normalize structural shocks (see Smets and Wouters (2003a, b)), which reduces their volatilities, but also poses some problems in cross-study comparisons[49]. The lack of a consensus regarding the estimates of model stochastics may also be attributed to the fact that the estimates seem to be strongly affected by choice of measurement errors, if one decides to estimate the volatility of these errors, and by even slight changes in the model structure.[50] The differences also result from the problems with the identification of structural shocks. In particular, we estimate the DSGE model without a time-varying wage markup, contrary to Smets and Wouters (2003a, b). Allowing for this shock, along with the labor supply shock, we find that the estimates corresponding to both of them are not stable numerically. The reason for this is that in the log-linearized version of the model both shocks appear exclusively in the wage-setting equation. Therefore, even if the former is assumed to be i.i.d. and the latter to follow an autoregressive process, the numerical optimization procedure has a hard time to distinguish them.

Notwithstanding this, we find some similarities in the results across studies: (i) the majority of structural shocks have a very high persistence (above 0.85), which is partially attributed to the absence of some important shocks in the specification of the model (e.g. open-economy shocks) (ii) the asymmetric technology shock is estimated to be very persistent, due to the long-lasting differences in technology growth rates across the regions (see the smoothed estimates of structural shocks) (iii) estimates of stationary technology shocks and monetary shocks coincide across the

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[48] Note that during the last 20 years the annualized growth rate of real wages in Europe was on average 0.8 percentage point lower than the growth rate of GDP.

[49] This may also have an impact on the numerical optimization procedure, making the model less nonlinear. However, not all shocks could be normalized in a two-country framework.

[50] The evidence is presented e.g. in Kremer, Lombardo and Werner (2003) or Boivin and Giannoni (2005))

studies (none of the authors normalize them) (iv) the volatilities of structural shocks estimated in the open-economy framework are in general lower than those obtained in the closed-economy framework, which may be seen as an indication in favor of an open economy specification.

Finally, we find that the estimated cross-region correlations of structural shocks roughly correspond to those in Jondeau and Sahuc (2004). The cross-country correlation between preference shocks and labor supply shocks is estimated to be 0.49 and 0.29 respectively. Our estimated model also captures the correlation of monetary shocks prior to the establishing of EMU (0.43). These results may be only to some extent seen as an evidence of the European integration or common European business cycles.

To summarize, the estimates of structural parameters across the nested models do not differ dramatically, contrary to the model stochastics which is more model-dependent. This finding has not been, however, explicitly pointed out in the literature before.

6.2 Smoothed estimates of shocks

Figure 3 plots the Kalman-smoothed time series for structural shocks. Note that some of the cross-country differences in the pace of economic growth are captured by including the asymmetric technology shock. This shock has a downward slope in the most recent period which is caused by an on average lower economic growth in the German economy compared to the rest of the euro area. Moreover, the differences in growth rates of real variables are explained by highly autocorrelated domestic shocks. Note that e.g. labor supply shocks, whose role is dominant in explaining the volatility of real wages, are estimated to be highly persistent. The smoothed series for these shocks follow a downward path to capture an on average lower growth of real wages compared to the remaining real variables over the period considered. It also seems that some of the relations stipulated by the model may not be constant over time in the data employed in the estimation (e.g. the share of consumption and investment in GDP). For this reason, e.g. the government spending shock exhibits a downward trend. Additionally, in the case of the German economy, the behavior of shocks is strongly affected by the unification process (or by the poor quality of statistical data at the beginning of the 1990s).

6.3 Variance decomposition and impulse responses

Tables 13 to 15 report the contribution of each structural shock to the variability in real GDP, consumption, investment, employment, inflation and nominal interest rate in Germany and the rest of the euro area. These statistics are calculated for the baseline model, after transition to the common currency area.[51] Table 16 reports the variance decomposition obtained for the German economy using the closed-economy framework. Figures 4 to 18 report the impulse responses to one-standard deviation of structural shocks. The shocks are orthogonalized because of the assigned non-zero cross-country correlation. Note that for the real variables effects of the shocks refer to the levels, defined as $\hat{y}_t + \log(A_t)$, where $\hat{y}_t$ is a detrended real variable and A_t is a level of technology evolving according to the following unit root process: $\log(A_t) = \log(A_{t-1}) + \varepsilon_t^A$.

A comparison across Tables 13 to 16 shows that in both open and closed-economy settings the volatility of the levels of real variables is explained by demand shocks in the short run and supply shocks in the long run. The contribution of the preference shock is higher in the Home economy. In turn, the investment shock is more important for the variability of the Foreign economy aggregates. In line with other DSGE studies, variability of the nominal interest rate is mostly caused by the

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[51] Due to large scale of the model, for presentation purposes we limit the number of variables for which we report the IRF's and variance decomposition.

demand shocks and innovations in the inflation target. We also find a significant contribution of a unit root technology shock. The variability of inflation is mainly determined by markup and preference shocks as well as innovations to the inflation target. The role of the interest rate shock is insignificant in the long run. The most important sources of GDP variability (in all our models) are productivity and preference shocks followed by investment shocks. These findings are similar to those in the literature (see e.g. Altig *et al.* (2003)).

Tables 13 to 15 report the percentage of variability attributed to the common shocks (i.e. the asymmetric technology shock, the unit root technology shock, the interest rate shock and the inflation target shock), domestic shocks and foreign shocks. Contrary to some most recent open-economy studies (see e.g. Adjemian, Paries and Smets (2004)), we find significant spillover effect from the Foreign economy. However, part of this effect may be attributed not only to non-zero correlations between closed-economy shocks but also to the quite tight priors assigned to international trade[52]. After 20 quarters, spillovers from foreign shocks account for over 40% of employment and inflation fluctuations and from 1 to 10% of the variability in the levels of real variables. Note that the contribution of foreign shocks is the highest over the medium term. Closed-economy shocks originating from the German economy account for about 6% of nominal interest rate variability compared to about 25% caused by the Foreign economy shocks. This may be particularly attributed to the preference bias and to imperfect measure of the area wide inflation, both in the real world and in the model. Almost 70% of the variability of area wide nominal interest rate is caused in the long run by common shocks. Fluctuations in the terms of trade are explained by the asymmetric technology shock (20% in the long run) and the closed-economy shocks (stationary technology shock, markup shocks and labor supply shocks).

The contribution of the permanent technology shock to the variability of real variables is similar in both regions of the currency area. In the closed-economy framework the role of this shock seems to be overestimated. We can attribute this phenomenon to much more parsimonious stochastics of the closed-economy framework.

Figures 4 to 18 report the sequence of impulse response functions (IRF). On each subplot we present a comparison of responses of the German and the rest of the euro area aggregates to a particular orthogonalized shock obtained for the baseline model before EMU and afterwards. Figures 15 to 18 report a comparison of the IRFs of Home economy variables across alternative settings. The graphs plot the mean response together with the 90 per cent confidence interval.[53]

Overall, the qualitative results have a rather intuitive explanation and coincide with those obtained in other studies for the auro area or Germany. Nevertheless, the cross model comparison shows significant quantitative differences. Indeed, it seems that the stochastics of the model is strictly setting-dependent.

Below we describe the main characteristics of transmission mechanisms at work in our baseline currency union model. One should note that such reasoning entails a considerable simplification, because, given the general equilibrium nature of the model, described events happen simultaneously.

Responses to the stationary technology shock, standing for changes in the level of technology, differ slightly from those obtained from the standard RBC model. These differences may be attributed to the high degree of price stickiness in our estimated model. Nominal rigidities cause the immediate supply effect to be very limited. Furthermore, a given level of productivity can now be reached using fewer resources due to a higher level of technology. It causes labor as well as capital demand to fall, supporting the results by Gali (1999). Also investment and capital supply

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[52] Note that the convention is to calibrate the shares of domestic goods in the consumption and investment basket (see e.g. Jondeau and Sahuc (2004)).

[53] The bootstrapped confidence intervals for the baseline model are calculated for a selection of 1000 parameters from the posterior sample of 100,000.

drop below the balanced growth path. In the short run, lower demand may outweight the positive supply effect, additionally limiting the increase of aggregated output. However, after some time, this shock expands production and lowers marginal costs implying a fall in prices and real wages. Investment rises after initial drop due to higher expected returns from capital. Due to the habit formation, consumption rises more slowly compared to the standard RBC models. The impact of the stationary technology shock on the terms of trade is positive. The movement in relative prices favors the goods produced in the Home economy. Shocks to the level of technology have been estimated to have a low correlation across the two countries, which amplifies their effects. Note that low or negative cross-country correlation of the stationary technology shocks may also be attributed to the assumed cointegration of the unit root technology shocks in the euro area. Thus, the short run supply shocks are obligated to explain some of the asymmetric developments in the area.

The reaction of the economies to the shock to the growth rate of technology is also in line with the theoretical literature. Higher expected future growth stimulates the demand side of the economy resulting in higher prices and interest rate hikes. Our quite high estimate of the persistence of the permanent technology shock implies that it is more profitable for individuals to adjust their investment and work effort more gradually, because it takes some time before the labor and capital input become more productive. In the case of imposed no persistence, this shock causes an immediate rise in employment, because the production input is at its highest productivity immediately after the shock (see e.g. Linde 2004). Note that employment in both economies rises after a positive shock to the growth rate of technology, supporting the results reported e.g. by Altig (2003) for the US economy.

The investment-specific shock affects cost of investment. Thus, firms invest more and increase their capital stock. Effect of this shock is positive on output and, after an initial drop, it has also a positive impact on consumption.

Turning to the dynamic effects of an unanticipated temporary increase in nominal interest rate, we see that after 12-16 quarters all variables return to their steady state, which is in line with the estimates from the VAR studies. Consumption declines because of the monetary contraction. Lower consumption implies lower output and lower employment. Decreased labor demand brings about the reduction in real wages. Note that the response of the Home variables to the common interest rate shock has a higher amplitude which should be attributed to the parametrization of the model and especially to the relative size of both economies. However, in the real world the rest of the EMU is a conglomerate of heterogeneous economies and thus the volatility at a single country level should be even higher than that estimated for the German economy. Note also that the common interest rate shock has a non-zero effect on the relative prices which may be explained by the home bias in households' preferences.

As mentioned above, we do not define typical open-economy shocks, except for the asymmetric technology shock.[54] The reason for this is that the only open-economy shock affecting the monetary union would originate from the rest of the world, whose existence is neglected in our model. Nevertheless, there are many interesting issues related to the responses of the both economies to the foreign originating shocks. In traditional open-economy models, the IRFs are strongly asymmetric in the Home and Foreign economy respectively. In our model, the assumption of a single monetary policy, bias in preferences and real and nominal rigidities make the IRFs less asymmetric. Allowing for cross-country correlation of structural shocks, we obtain an amplification of spillover effect. Significant spillovers in the euro area suggest that there may be a welfare gain to a common

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[54] For example, Adjemian, Paries and Smets (2004) introduce the uncovered interest parity shock in their DSGE model for the US and euro area. This shock is not fully structural in nature and should be seen rather as a measurement error.

monetary policy for the whole area.

There are some important differences in the model mechanics using the flexible exchange rate and the currency union setting which suggest it is sufficient to build a separate model for each of the regimes. Particularly, in the monetary union the terms of trade channel is no longer affected by the nominal exchange rate. In turn, in the flexible exchange rate DSGE the endogenously determined nominal exchange rate may reduce (or amplify) the impact of structural shocks, depending on their nature. The effects of structural shocks on the common nominal interest rate are much more limited in the setting for a currency union. We also find significant differences in the transmission of preference and stationary technology shocks after transition to the currency union. Finally, in the monetary union, asymmetric technology shock is no longer accommodated by the country-specific monetary policy and flexible exchange rate. By construction, the common monetary policy rule does not account for offsetting the asymmetric developments in the euro area. The observation from the first years of EMU seem to confirm this finding.

6.4 Empirical performance of the model

In this section we briefly examine the empirical performance of our baseline model. Firstly we conduct a visual analysis of the in-sample fit of the model. Further, we compare the predictive abilities of the baseline model to the model with imposed structural homogeneity between the both regions [55]. The fullblown analysis of forecasting performance of the model is to be presented in a companion paper. Finally, the statistics replicated by the model are compared with those in the actual data.

In Figures 1 and 2 we report the Kalman filtered one-side estimates of the observed variables, computed using the posterior mode of θ. These, de facto one-step in-sample forecasts are presented along with the actual variables. Figure 1 presents the fitted values for the model estimated on the HP-filtered data. In turn, in Figure 2 the fitted values for the baseline model estimated on log-differences are plotted. As is evident from the figures, the in-sample fit is satisfactory in both cases. However, the model estimated on log-differences seems to have a hard time fitting the decrease in the real wage in the most recent period.

A natural method to assess the empirical validity of the linearized DSGE model is to compare the marginal likelihood of the model with other available linear models (DSGE models or perhaps an even larger class of non-structural linear reduced-form models). The post-sample information about the DSGE model parameters is summarized in the marginal posterior density of θ, given by:

$$p(Y|M_i) = \int p(Y|\theta, M_i)p(\theta|M_i)d\theta \tag{72}$$

where $p(\theta|M_i)$ denotes the prior density for the model M_i, $p(Y|\theta, M_i)$ stands for data density of the model given the parameters θ. The approach is discussed in detail, for example, in Geweke (1999).

To test the null hypothesis that the structural homogeneity holds across the euro area regions, we estimate the baseline model restricting the structural parameters to be the same in the both regions.[56] This hypothesis seems to be rejected by the data (see Table 2).

Furthermore, our simple two-country model with international trade and integrated financial markets is compared with the model estimated on the same data set but with countries closed

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[55] Note that number of observed variables used to estimate our baseline model is threshold-dependent. Thus, it is problematic to compare its predictive density with standard BVAR models.

[56] We allow for stochastic heterogeneity and different composition of consumption and investment baskets across the regions.

	Marginal likelihood (Estimation sample 1980:q1-2003:q4)
Baseline model (log-differences)	-1264
Model with imposed structural homogeneity (log-differences)	-1322

Table 2: Model comparisons - structural heterogeneity

	Marginal likelihood (Estimation sample 1980:q1-1998:q4)
Two-country model with international trade (HP-filtered data)	–980
Pooling of closed economies estimated on the sample (HP-filtered data)	-1001
Two-country model with international trade (log-differences)	-1100
Pooling of closed economies estimated on the sample (log-differences)	-1121

Table 3: Model comparisons - closed- vs. open economy framework

to international trade and without integrated financial markets. Thus, the latter model collapses to a pooling of closed economies. In this exercise both models are estimated on sample 1980:q1-1998:q4. Although the open-economy mechanisms in our models are very stylized, the model with open-economy features beats, in terms of marginal density, the closed economy models.

In addition, Tables 17 to 20 report the comparison of the unconditional second moments replicated by the baseline DSGE model to those calculated from the data. By and large, we see that the statistics replicated by the model and the data compare very well, giving additional credibility to the estimated DSGE model. The point estimates of volatilities of growth rates of GDP ($\Delta \ln Y_t^{GER}$, $\Delta \ln Y_t^{EMU}$), Consumption ($\Delta \ln C_t^{GER}$, $\Delta \ln C_t^{EMU}$) and Investment ($\Delta \ln I_t^{GER}$, $\Delta \ln I_t^{EMU}$) as well as those of GDP deflators ($\Delta \ln P_t^{GER}$, $\Delta \ln P_t^{EMU}$) almost coincide with the data. Note that the model underestimates the volatility of the nominal interest rate ($\ln R_t^{GER}$, $\ln R_t^{EMU}$) and overestimates the volatility of employment ($EM_t^{GER\_HP}$, $EM_t^{EMU\_HP}$). The cross-variables correlations replicated by the model are very close to those in the data. Our model has no problem with replicating high correlations between consumption and GDP growth rates and low correlations between real variables and nominal interest rates. Also correlations between area wide aggregates and the German variables are replicated satisfactorily.

7 Conclusions and direction of further research

The main objective of this research was to present an approach to the consistent estimation of a DSGE model for a currency area. This approach was illustrated by developing and estimating a simple prototype model for Germany within the European Monetary Union.

Our open-economy model was estimated simultaneously on the unfiltered data for Germany and the euro area using Bayesian methods. Employing raw data in the estimation allows for direct forecasting from the model. Due to the use of the multi-country framework, as well as disaggregated information on the euro area the model provides additional insights for forecasting the aggregated euro area series and analyze the interactions within the euro area. Overall, we consider the estimation to be satisfactory. However, the scale of the optimization problem (to estimate the model, we must maximize the posterior over 65 parameters, which is a challenging numerical task) causes the procedure to settle into local maxima for a range of starting values. Using the random search algorithm for initial values helps to tackle this problem. Moreover, the robustness of the estimates was checked by estimating the baseline model on filtered data.

By and large, the results are in line with those of Welz (2004), Smets and Wouters (2003a), Jondeau and Sahuc (2004) obtained respectively either on the German data or the aggregated euro area data. The differences are most significant for estimates of persistence and volatility of structural shocks. The comparison across the DSGE literature indicate that these estimates are often not well identified and not stable numerically. Indeed, it seems that some shocks capture volatility which might not be considered as structural. Thus, their meaning is likewise much wider than anticipated by the theoretical model. Furthermore, we found that the permanent technology shock, is, at least in our models, a kind of "ignorance measure" and its importance for the volatility of the variables increases with more parsimonious specification of the stochastic part. The estimates of structural parameters obtained from nested models do not differ dramatically from those from the baseline model. The estimates of the stochastic part is strongly affected by applying alternative data sets in the estimation.

Notwithstanding this, the open-economy model which we have constructed is favored by the data over a pooling of closed-economy models. In addition in our model the estimated spillovers of domestic shocks to the foreign economy are much higher compared with the estimated open-economy models for the US and the euro area. Moreover, contrary to closed economy studies, the model allows for consistent analysis of the interactions between Germany and the rest of the monetary union.

We see some possibilities of improving the performance of our quite stylized two-region model along with the existing literature. For instance, introducing a pricing-to-market mechanism might allow for augmenting the list of observed variables to include the consumer price inflation. The DSGE model prior to the adoption of the common currency might also be estimated using the information contained in the nominal exchange rate. Finally, a simple deterministic regime-switching approach to the estimation presented in this paper (we assumed the existence of only two monetary regimes) may be easily augmented by further regimes (e.g. by the DSGE model with a pegged exchange rate which would correspond to the period of the ERM-I).

Note that our approach does not account for the fact that agents perfectly foresaw the transition to EMU (the date of adoption of the single currency was announced in December 1994). Implementing this mechanism into our model would allow to use its structure to analyze the accession of further countries to the EMU (given the announced date of accession). We leave it for future research.

We are also currently working on examining the forecasting properties of the estimated two-region model. We compare the forecasts from this model with forecasts from a one-region model in the spirit of Smets and Wouters (2003a) as well as with alternative VAR models.

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Parameter	Prior distribution			Two-country model with capital		Posterior distribution		
	Type	Mean	Std error	mode	std error	mean	5%	95%
growth rate of techn.$\bar{\varepsilon}^A$	normal	1.004	0.002	1.0039	0.001	1.0041	1.0025	1.0057
steady state inflation $\bar{\pi}$	normal	1.005	0.003	1.0049	0.0017	1.0053	1.0025	1.0079
interest rate smoothing ρ_{R_EMU}	beta	0.8	0.1	0.908	0.029	0.874	0.802	0.937
interest rate smoothing ρ_R	beta	0.8	0.1	0.838	0.027	0.827	0.792	0.873
interest rate smoothing ρ_R^*	beta	0.8	0.1	0.906	0.014	0.905	0.877	0.929
inflation response κ_{π_EMU}	normal	1.6	0.1	1.593	0.097	1.574	1.430	1.727
inflation response κ_π	normal	1.6	0.1	1.542	0.102	1.535	1.354	1.724
inflation response κ_π^*	normal	1.6	0.1	1.491	0.102	1.480	1.344	1.651
output response κ_{y_EMU}	normal	0.2	0.05	0.205	0.041	0.222	0.149	0.307
output response κ_y	normal	0.2	0.05	0.205	0.045	0.224	0.143	0.296
output response κ_y^*	normal	0.2	0.05	0.301	0.041	0.288	0.220	0.366
habit formation $\varkappa$	beta	0.7	0.1	0.682	0.082	0.570	0.348	0.780
habit formation $\varkappa^*$	beta	0.7	0.1	0.809	0.054	0.719	0.536	0.909
inverse elast. of lab. υ	normal	2.0	0.4	1.80	0.21	1.76	1.45	2.09
inverse elast. of lab. υ^*	normal	2.0	0.4	1.80	0.21	1.81	1.49	2.13
share of dom consum. ω_C	beta	0.6	0.05	0.696	0.036	0.675	0.617	0.729
share of dom consum. ω_C^*	beta	0.8	0.05	0.877	0.027	0.854	0.790	0.916
share of dom invest. ω_I	beta	0.5	0.05	0.500	0.036	0.486	0.430	0.552
share of dom invest. ω_I^*	beta	0.7	0.05	0.675	0.037	0.681	0.622	0.745
capital adj. cost S''	normal	4.0	1.5	2.42	0.63	3.11	1.61	4.88
capital adj. cost $S^{*\prime\prime}$	normal	4.0	1.5	5.15	1.11	5.96	4.11	7.68
Calvo employment θ^L	beta	0.5	0.15	0.771	0.022	0.764	0.722	0.802
Calvo employment θ^{L^*}	beta	0.5	0.15	0.876	0.016	0.874	0.853	0.896
Calvo wages θ^w	beta	0.7	0.1	0.854	0.035	0.857	0.804	0.919
Calvo wages θ^{w^*}	beta	0.7	0.1	0.924	0.024	0.924	0.894	0.951
Calvo prices θ^P	beta	0.7	0.1	0.960	0.006	0.957	0.948	0.968
Calvo prices θ^{P^*}	beta	0.7	0.1	0.960	0.004	0.962	0.954	0.969
indexation prices γ	beta	0.7	0.15	0.322	0.086	0.320	0.176	0.466
indexation prices γ^*	beta	0.7	0.15	0.552	0.075	0.587	0.473	0.679

Table 4: Estimation results, structural parameters

	Prior distribution					Posterior distribution		
	type	mean	std. error	mode	std. error	mean	5%	95%
unit root tech. shock ρ_A	beta	0.85	0.1	0.930	0.026	0.772	0.584	0.953
asymmetric technology shock ρ_Z	beta	0.9	0.05	0.993	0.003	0.988	0.979	0.998
stationary tech. shock ρ_Y	beta	0.85	0.1	0.891	0.030	0.864	0.814	0.918
stationary tech. shock ρ_Y^*	beta	0.85	0.1	0.901	0.045	0.901	0.847	0.964
preference shock ρ_C	beta	0.85	0.1	0.435	0.134	0.647	0.409	0.915
preference shock ρ_C^*	beta	0.85	0.1	0.455	0.138	0.659	0.369	0.935
labor supply shock ρ_L	beta	0.85	0.1	0.901	0.037	0.885	0.881	0.954
labor supply shock ρ_L^*	beta	0.85	0.1	0.805	0.068	0.763	0.671	0.869
investment shock ρ_I	beta	0.85	0.1	0.319	0.081	0.396	0.221	0.563
investment shock ρ_I^*	beta	0.85	0.1	0.679	0.071	0.652	0.543	0.769
government spending shock ρ_G	beta	0.85	0.1	0.919	0.031	0.866	0.675	0.975
government spending shock ρ_G^*	beta	0.85	0.1	0.992	0.003	0.993	0.988	0.997

Table 5: Estimation results, persistence parameters

	Prior distribution					Posterior distribution		
	type	mean	df/std. error	mode	std error	mean	5%	95%
unit root technology shock	inv. gamma	0.5	2	0.15	0.03	0.33	0.12	0.52
stationary technology shock	inv. gamma	0.3	2	1.16	0.18	1.26	0.92	1.6
stationary technology shock*	inv. gamma	0.3	2	1.23	0.35	1.30	0.82	1.77
preference shock	inv. gamma	2	2	2.25	0.60	1.94	0.90	3.19
preference shock*	inv. gamma	2	2	2.64	0.71	2.57	0.79	4.98
labor supply shock	inv. gamma	5	2	5.28	1.17	5.74	3.42	8.13
labor supply shock*	inv. gamma	5	2	15.03	4.23	15.7	10.7	20.6
investment shock	inv. gamma	5	2	5.73	1.46	6.84	3.75	10.4
investment shock*	inv. gamma	5	2	5.71	1.37	6.93	4.53	9.00
asymmetric technology shock	inv. gamma	0.6	2	0.795	0.08	0.82	0.66	0.95
government spending shock	inv. gamma	1	2	2.21	0.25	2.22	1.75	2.75
government spending shock*	inv. gamma	1	2	1.58	0.17	1.76	1.48	2.04
monetary shock EMU	inv. gamma	0.6	2	0.12	0.02	0.12	0.08	0.15
monetary shock	inv. gamma	0.6	2	0.13	0.01	0.14	0.12	0.16
monetary shock*	inv. gamma	0.3	2	0.17	0.01	0.17	0.15	0.19
price markup	inv. gamma	0.1	2	0.16	0.02	0.17	0.15	0.20
price markup*	inv. gamma	0.1	2	0.21	0.02	0.21	0.18	0.23
inflation target	inv. gamma	0.05	2	0.13	0.04	0.12	0.05	0.20
Corr. tech stationary shock	normal	0.2	0.4	-0.20	0.11	-0.15	-0.34	0.05
Corr. preference shock	normal	0.2	0.4	0.49	0.09	0.45	0.23	.66
Corr. labor supply shock	normal	0.2	0.4	0.29	0.09	0.27	0.13	0.43
Corr. investment shock	normal	0.2	0.4	-0.14	0.10	-0.22	-0.38	0.00
Corr. monetary shock	normal	0.2	0.4	0.44	0.12	0.46	0.29	0.64
Corr. gov. spending shock	normal	0.2	0.4	0.32	0.17	0.18	-0.13	0.48

Table 6: Estimation results, structural shocks

	Estimation period 1980:1-2003:4			Estimation period 1980:1-1998:4	
	baseline		without capital	baseline	closed economies
Parameter	HP-filtered data	log-differences			
growth rate of techn.$\bar{\varepsilon}^A$	-	1.0039	1.0036	1.0045	1.0045
		[1.0025, 1.0057]	[1.0016, 1.0070]	[1.0037, 1.0055]	[1.0033, 1.0056]
steady state inflation $\bar{\pi}$	-	1.0049	1.0034	1.0058	1.0061
		[1.0025, 1.0079]	[1.0019, 1.0069]	[1.0037, 1.0089]	[1.0039, 1.008]
steady state inflation $\bar{\pi}^*$	-	-	-	-	1.0053
					[1.0014, 1.0092]
interest rate smoothing ρ_{R_EMU}	0.841	0.908	0.833	-	-
	[0.741, 0.887]	[0.802, 0.937]	[0.740, 0.948]		
inflation response κ_{π_EMU}	1.578	1.593	1.579	-	-
	[1.397, 1.791]	[1.432, 1.721]	[1.396, 1.714]		
output response κ_{y_EMU}	0.191	0.205	0.252	-	-
	[0.128, 0.257]	[0.147, 0.309]	[0.183, 0.314]		
interest rate smoothing ρ_R	0.836	0.838	0.786	0.819	0.864
	[0.764, 0.885]	[0.791, 0.873]	[0.790, 0.882]	[0.794, 0.877]	[0.784, 0.881]
inflation response κ_π	1.422	1.542	1.598	1.512	1.683
	[1.274, 1.601]	[1.354, 1.724]	[1.481, 1.753]	[1.174, 1.757]	[1.437, 2.031]
output response κ_y	0.177	0.205	0.118	0.205	0.245
	[0.111, 0.255]	[0.143, 0.296]	[0.118, 0.241]	[0.193, 0.291]	[0.180, 0.318]
interest rate smoothing ρ_R^*	0.839	0.906	0.889	0.886	0.901
	[0.782, 0.879]	[0.877, 0.929]	[0.870, 0.924]	[0.869, 0.911]	[0.876, 0.928]
inflation response κ_π^*	1.418	1.491	1.533	1.369	1.455
	[1.272, 1.577]	[1.334, 1.651]	[1.231, 1.559]	[1.183, 1.536]	[1.300, 1.611]
output response κ_y^*	0.179	0.301	0.292	0.288	0.271
	[0.103, 0.244]	[0.220, 0.367]	[0.244, 0.367]	[0.231, 0.299]	[0.211, 0.336]
capital adj. cost S''	3.06	2.42	-	1.86	1.90
	[2.10, 4.70]	[1.61, 4.88]		[1.06, 2.89]	[1.39, 4.26]
capital adj. cost $S^{*\prime\prime}$	4.92	5.15	-	4.01	3.70
	[3.53, 6.74]	[4.11, 7.68]		[3.84, 7.27]	[2.81, 5.98]
inv. labor supply υ	1.88	1.80	1.95	1.82	1.85
	[1.62, 2.19]	[1.45, 2.10]	[1.63, 2.21]	[1.52, 1.96]	[1.54, 2.17]
inv. labor supply υ^*	1.79	1.80	1.82	1.79	1.77

Table 7: Comparison of the estimates, structural parameters

	Estimation period 1980:1-2003:4			Estimation period 1980:1-1998:4	
	baseline		without capital	baseline	closed economies
Parameter	HP-filtered data		log-differences		
Calvo empl. θ^L	0.759	0.771	0.653	0.758	0.768
	[0.725, 0.795]	[0.722, 0.822]	[0.600, 0.698]	[0.750, 0.804]	[0.719, 0.796]
Calvo empl. θ^{L^*}	0.841	0.876	0.831	0.844	0.859
	[821, 0.863]	[0.853, 0.895]	[0.810, 0.876]	[0.829, 0.869]	[0.839, 0.893]
Calvo wages θ^w	0.835	0.854	0.801	0.856	0.854
	[0.803, 0.901]	[0.804, 0.919]	[0.738, 0.834]	[0.839, 0.907]	[0.808, 0.901]
Calvo wages θ^{w^*}	0.914	0.924	0.872	0.867	0.875
	[887, 0.963]	[0.897, 0.951]	[915, 0.967]	[0.855, 0.912]	[0.835, 0.924]
Calvo prices θ^P	0.973	0.960	0.969	0.951	0.962
	[0.956, 0.986]	[0.948, 0.969]	[0.956, 0.976]	[0.945, 0.959]	[0.945, 0.969]
Calvo prices θ^{P^*}	0.948	0.960	0.963	0.943	0.942
	[0.912, 0.969]	[0.954, 0.969]	[0.958, 0.974]	[0.936, 0.950]	[0.936, 0.955]
indexation prices γ	0.344	0.322	0.801	0.345	0.499
	[0.210, 0.505]	[0.176, 0.466]	[0.204, 0.486]	[0.285, 0.447]	[0.301, 0.640]
indexation prices γ^*	0.303	0.552	0.875	0.433	0.491
	[0.198, 0.422]	[0.473, 0.679]	[0.481, 0.437]	[0.251, 0.442]	[0.392, 0.646]
habit formation $\varkappa$	0.625	0.682	0.482	0.422	0.578
	[0.453, 0.803]	[0.348, 0.779]	[0.435, 0.646]	[0.462, 0.637]	[0.360, 0.715]
habit formation $\varkappa^*$	0.779	0.809	0.633	0.544	0.795
	[0.707, 0.866]	[0.536, 0.910]	[0.614, 0.864]	[0.555, 0.647]	[0.702, 0.855]
share of dom. goods in consum.ω_C	0.749	0.696	0.695	0.678	1 (fixed)
	[0.703, 0.803]	[0.671, 0.728]	[0.629, 0.746]	[0.643, 0.707]	
share of dom. goods in consum. ω_C^*	0.914	0.877	0.889	0.825	1 (fixed)
	[0.872, 0.945]	[0.790, 0.916]	[0.826, 0.905]	[0.792, 0.890]	
share of dom. goods in invest. ω_I	0.529	0.500	-	0.486	1 (fixed)
	[0.464, 0.590]	[0.430, 0.552]		[0.465, 0.538]	
share of dom. goods in invest. ω_I^*	0.731	0.675	-	0.672	1 (fixed)
	[0.651, 0.777]	[0.621, 0.746]		[0.592, 0.760]	

Table 8: Comparison of the estimates, structural parameters - continued

	Estimation period 1980:1-2003:4			Estimation period 1980:1-1998:4	
	baseline		without capital	baseline model	closed economies
Parameter	HP-filtered data		log-differences		
unit root tech. shock ρ_A	-	0.930	0.86	0.871	0.936
		[0.584, 0.953]	[0.888, 0.969]	[0.746, 0.932]	[0.813, 0.948]
unit root tech. shock ρ_A^*	-	-	-	-	0.747
					[0.610, 0.867]
asymmetric technology shock ρ_Z	-	0.993	0.987	0.989	-
		[0.979,0.998]	[0.962, 0.999]	[0.983, 0.998]	
stationary tech. shock ρ_Y	0.884	0.891	0.981	0.856	0.895
	[0.767, 0.945]	[0.812, 0.918]	[0.874, 0.963]	[0.787, 0.906]	[0.819, 0.933]
stationary tech. shock ρ_Y^*	0.828	0.901	0.955	0.909	0.916
	[0.644, 0.899]	[0.847, 0.964]	[0.931, 0.985]	[0.856, 0.953]	[0.854, 0.941]
preference shock ρ_C	0.603	0.435	0.883	0.780	0.487
	[0.381, 0.766]	[0.401, 0.965]	[0.792, 0.946]	[0.486, 0.807]	[0.407, 0.923]
preference shock ρ_C^*	0.469	0.455	0.875	0.873	0.483
	[0.329, 0.605]	[0.370, 0.916]	[0.347, 0.865]	[0.800, 0.911]	[0.338, 0.727]
labor supply shock ρ_L	0.218	0.901	0.934	0.843	0.779
	[0.132, 0.357]	[0.811, 0.955]	[0.903, 0.969]	[0.717, 0.887]	[0.675, 0.873]
labor supply shock ρ_L^*	0.374	0.805	0.902	0.818	0.835
	[0.246, 0.604]	[0.671, 0.859]	[0.647, 0.879]	[0.732, 0.895]	[0.746, 0.910]
investment shock ρ_I	0.321	0.319	-	0.301	0.242
	[0.201, 0.459]	[0.221, 0.563]		[0.193, 0.362]	[0.151, 0.355]
investment shock ρ_I^*	0.399	0.679	-	0.491	0.340
	[0.265, 0.494]	[0.543, 0.750]		[0.338, 0.520]	[0.234, 0.515]
government spending shock ρ_G	0.771	0.919	0.861	0.907	0.925
	[0.716, 0.828]	[0.676, 0.976]	[0.819, 0.950]	[0.853, 0.959]	[0.894, 0.967]
government spending shock ρ_G^*	0.844	0.992	0.991	0.992	0.994
	[0.780, 0.910]	[0.988, 0.999]	[0.969, 0.999]	[0.992, 0.998]	[0.992, 0.998]

Table 9: Comparison of the estimates, persistence parameters

	Estimation period 1980:1-2003:4			Estimation period 1980:1-1998:4	
Parameter	baseline		without capital	baseline	closed economies
	HP-filtered data	log-differences			
unit root technology shock	-	0.15	0.21	0.23	0.18
		[0.12, 0.52]	[0.12, 0.23]	[0.16, 0.31]	[0.16, 0.30]
unit root technology shock*	-	-	-	-	0.21
					[0.14, 0.35]
asymmetric technology shock	-	0.79	0.80	0.81	-
		[0.66, 0.96]	[0.61, 0.86]	[0.72, 1.03]	
stationary technology shock	1.06	1.16	0.91	1.22	1.12
	[0.88, 1.49]	[0.92, 1.60]	[0.72, 1.10]	[1.20, 1.63]	[0.89, 1.47]
stationary technology shock*	1.12	1.23	0.99	0.98	1.08
	[0.87, 1.69]	[0.83, 1.77]	[0.59, 1.43]	[0.85, 1.52]	[0.86, 1.81]
preference shock	2.30	2.25	1.56	1.06	1.60
	[1.45, 3.55]	[0.91, 0.320]	[1.02, 1.86]	[1.07, 1.72]	[0.78, 2.66]
preference shock*	2.70	2.64	1.77	0.83	2.71
	[1.95, 3.84]	[0.80, 4.99]	[1.29, 3.38]	[0.78, 1.02]	[1.76, 3.49]
labor supply shock	4.97	5.28	3.89	5.49	5.53
	[3.95, 7.90]	[3.40, 8.13]	[2.61, 4.38]	[4.92, 7.82]	[3.87, 7.31]
labor supply shock*	7.48	15.03	9.28	9.27	9.57
	[4.99, 15.66]	[10.70, 20.60]	[12.03, 26.5]	[8.03, 13.1]	[6.76, 13.0]
investment shock	7.29	5.73	-	4.71	5.23
	[5.02, 11.44]	[3.75, 10,42]		[2.63, 7.39]	[4.42, 11.3]
investment shock*	7.20	5.71	-	5.62	5.87
	[4.94, 10.32]	[4.54, 9.00]		[5.58, 10.2]	[4.32, 9.45]
government spending shock	3.11	2.21	2.12	2.52	2.83
	[2.79, 3.59]	[1.75, 2.75]	[1.84, 2.49]	[2.14, 2.88]	[2.52, 3.32]
government spending shock*	1.67	1.58	1.48	1.80	1.90
	[1.54, 1.95]	[1.49, 2.05]	[1.26, 1.75]	[1.54, 2.15]	[1.67, 2.16]
monetary shock EMU	0.10	0.12	0.10	-	-
	[0.07, 0.13]	[0.08, 0.16]	[0.07, 0.13]		
monetary shock	0.15	0.13	0.14	0.13	0.13
	[0.13, 0.18]	[0.11, 0.16]	[0.12, 0.16]	[0.11, 0.16]	[0.12, 0.15]
monetary shock*	0.16	0.17	0.17	0.16	0.17
	[0.15, 0.20]	[0.15, 0.19]	[0.15, 0.20]	[0.14, 0.19]	[0.14, 0.19]
price markup	0.15	0.16	0.16	0.16	0.15
	[0.13, 0.18]	[0.15, 0.20]	[0.14, 0.18]	[0.13, 0.18]	[0.13, 0.20]
price markup*	0.22	0.21	0.21	0.20	0.21
	[0.19, 0.25]	[0.18, 0.24]	[0.19, 0.25]	[0.19, 0.27]	[0.18, 0.25]
inflation target	-	0.13	0.02	0.08	0.02
		[0.05, 0.20]	[0.09, 0.23]	[0.07, 0.15]	[0.01, 0.07]
inflation target*	-	-	-	-	0.02
					[0.01, 0.05]

Table 10: Comparison of the estimates, structural shocks

	Estimation period 1980:1-2003:4			Estimation period 1980:1-1998:4	
Parameter	baseline		without capital	baseline	closed economies
	HP-filtered data	log-differences			
Corr. tech stationary shock	-0.23	-0.20	-0.24	-0.15	0 (fixed)
	[-0.39, -0.08]	[-0.34, 0.05]	[-0.30, 0.00]	[-0.30, 0.00]	
Corr. preference shock	0.59	0.49	0.58	0.41	0 (fixed)
	[0.43, 0.68]	[0.23, 0.66]	[0.30, 0.70]	[0.28, 0.65]	
Corr. labor supply shock	0.14	0.29	0.15	0.22	0 (fixed)
	[-0.04, 0.25]	[0.14, 0.43]	[0.10, 0.41]	[0.11, 0.38]	
Corr. investment shock	-0.06	-0.14	-	-0.24	0 (fixed)
	[-0.20, 0.09]	[-0.39, 0.0]		[-0.43, -0.04]	
Corr.monetary shock	0.37	0.44	0.45	0.42	0 (fixed)
	[0.16, 0.55]	[0.29, 0.64]	[0.24, 0.64]	[0.20, 0.61]	
Corr. gov. spending shock	-0.17	0.32	0.47	0.33	0 (fixed)
	[-0.32, 0.02]	[-0.14, -0.48]	[0.25, 0.66]	[0.15, 0.49]	

Table 11: Comparison of the estimates, cross-country correlations of structural shocks

		Models				
Parameter	baseline	I	II	III	IV	V
interest rate smoothing ρ_{R_EMU}	0.908				0.865	0.961
interest rate smoothing ρ_R	0.838	0.813	0.886	0.8699		
interest rate smoothing ρ_R^*	0.906					
output response κ_{y_EMU}	0.205				0.099	0.19
output response κ_y	0.205		0.440	0.3241		
output response κ_y^*	0.301					
inflation response κ_{π_EMU}	1.593				1.689	1.684
inflation response κ_π	1.542		1.501	1.0429		
inflation response κ_π^*	1.491					
investment adj. cost S''^{EMU}					6.77	7.94
investment adj. cost S''	2.42					
investment adj. cost $S^{*\prime\prime}$	5.15					
inverse elasticity of labor supply υ^{EMU}						
inverse elasticity of labor supply υ	1.80				2.40	
inverse elasticity of labor supply υ^*	1.80					
habit formation $\varkappa^{EMU}$					0.573	0.763
habit formation $\varkappa$	0.682		0.565			
habit formation $\varkappa^*$	0.809					
Calvo employment θ^{L_EMU}					0.759	0.599
Calvo employment θ^L	0.771					
Calvo employment θ^{L^*}	0.876					
Calvo wages θ^{w_EMU}					0.703	0.653
Calvo wages θ^w	0.854					
Calvo wages θ^{w^*}	0.924					
Calvo prices θ^{P_EMU}					0.908	0.933
Calvo prices θ^P	0.960		0.860	0.9223		
Calvo prices θ^{P^*}	0.960					
indexation prices γ^{EMU}					0.496	0.469
indexation prices γ	0.322	0.126	0.238	0.285		
indexation prices γ^*	0.552					
steady state growth rate of technology $\bar{\varepsilon}^A$	1.0039					1.006

Table 12: Comparison of estimates. Note: I - one-country model for the German economy, estimation period from 1980 to 1999 (Kremer, Lombardo and Werner (2003)), II - Multi-country model, estimation period from 1980 to 1999 (Jondeau and Sahuc, III - one-country model for the German economy, estimation period from 1980 to 1999 (Welz (2004)), IV - model on the aggregated euro area data (Adolfsson et al. (2004)), V - model on aggregated euro area data (Smets and Wouters (2003a)).

	Output					Consumption					Investment				
Shocks	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	0.1	0.1	0.0	0.5	1.3	0.0	0.0	0.2	0.9	0.6	2.8	4.5	6.2	3.6	4.0
stationary techn.*	0.3	0.5	0.4	0.2	0.5	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.2	0.9	1.3
preference shock	15.6	9.7	1.4	0.1	0.0	66.1	46.3	13.6	0.1	0.0	0.1	0.2	0.5	0.6	0.1
preference shock*	0.1	0.0	0.1	0.3	0.0	0.2	0.3	0.6	0.5	0.0	0.3	0.5	1.0	1.0	0.2
labor supply	0.4	0.5	0.2	0.1	0.7	0.0	0.1	0.5	1.9	0.6	2.5	4.1	5.6	3.0	1.5
labor supply*	0.5	0.8	0.8	0.3	0.9	0.0	0.0	0.2	0.9	0.1	0.0	0.0	0.4	1.8	2.3
gov. spending	27.5	10.7	3.1	0.4	0.0	0.6	1.0	1.7	2.0	0.7	0.0	0.0	0.0	0.1	0.4
gov. spending*	1.3	2.1	2.7	2.1	0.2	1.5	2.4	3.9	3.9	1.8	1.5	2.8	5.0	6.6	0.7
interest rate shock	8.9	12.7	12.0	3.6	0.0	6.0	7.9	7.8	1.9	0.1	6.2	9.4	11.1	4.1	1.9
investment shock	7.6	4.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	70.0	48.1	15.1	0.0	4.0
investment shock*	6.6	7.4	3.9	0.0	0.4	0.5	0.9	1.3	0.6	0.3	0.8	1.5	2.8	2.9	1.7
unit root techn.	18.4	32.1	50.7	73.2	93.1	19.5	32.0	56.1	75.0	90.6	5.6	10.4	20.5	37.9	77.1
asymmetric techn.	4.4	7.5	11.0	10.6	1.3	3.0	4.9	8.4	8.5	3.7	5.2	9.7	18.4	25.5	2.1
price markup	2.4	3.0	2.8	1.6	0.1	0.2	0.4	0.8	0.7	0.2	0.6	1.1	1.8	1.9	0.0
price markup*	0.9	0.6	0.2	0.5	0.8	0.0	0.0	0.1	0.1	0.4	0.1	0.2	0.1	0.5	2.5
inflation target	4.9	7.9	9.8	6.4	0.6	2.5	3.7	4.7	2.4	0.8	4.4	7.4	11.3	9.7	0.1
Domestic shocks	53.6	28.5	8.4	2.7	2.1	66.8	47.8	16.9	5.6	2.2	76.0	58.0	29.2	9.2	10.0
Foreign shocks	9.8	11.4	8.1	3.4	2.8	2.2	3.7	6.3	6.6	2.6	2.7	5.0	9.5	13.7	8.7
Common shocks	36.6	60.2	83.5	93.9	95.1	31.0	48.5	76.9	87.8	95.2	21.3	36.9	61.3	77.1	81.3
	Real wage					GDP deflator					Employment				
Shocks	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	20.3	19.0	16.3	10.8	0.0	2.1	13.2	13.7	5.2	1.0	53.3	47.8	38.6	22.5	1.6
stationary techn.*	0.0	0.0	0.1	0.1	0.7	0.4	2.9	4.6	6.6	12.2	0.4	0.5	0.6	1.1	9.6
preference shock	0.7	1.0	0.8	0.1	0.0	0.0	0.1	0.1	0.0	0.1	2.5	2.0	0.9	0.0	0.0
preference shock*	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.2	0.3
labor supply	62.2	60.1	54.9	43.6	6.3	2.4	17.0	23.8	19.0	2.5	0.0	0.0	0.0	1.4	15.8
labor supply*	0.0	0.1	0.1	0.1	1.2	0.7	5.0	8.2	11.6	21.3	0.7	0.8	1.1	1.9	17.5
gov. spending	1.6	1.4	0.9	0.4	0.0	0.0	0.1	0.1	0.0	0.4	4.9	4.2	3.1	1.8	0.1
gov. spending*	0.5	0.7	1.1	1.8	0.9	0.3	2.2	3.3	3.6	3.1	1.6	1.9	2.5	3.1	0.1
interest rate shock	2.4	3.3	4.6	4.4	0.0	0.1	0.9	1.1	0.4	0.1	6.7	7.6	8.2	5.2	1.1
investment shock	0.6	0.5	0.2	0.0	0.1	0.0	0.2	0.5	0.5	0.0	0.2	0.1	0.1	1.2	0.6
investment shock*	0.0	0.2	0.5	0.4	0.0	0.0	0.1	0.3	1.1	5.1	2.9	3.0	2.5	0.6	3.1
unit root techn.	4.6	6.8	12.0	25.8	83.3	1.2	8.7	13.5	16.2	17.4	11.4	13.7	18.4	28.4	37.7
asymmetric techn.	1.1	1.7	3.2	6.2	3.7	0.4	2.9	4.2	3.5	0.0	6.9	8.5	11.6	16.8	2.5
price markup	4.6	3.2	2.2	1.8	0.5	90.0	29.5	0.3	1.4	0.3	2.0	2.3	2.7	3.0	0.4
price markup*	0.1	0.1	0.1	0.2	1.7	0.2	1.5	2.4	3.2	2.4	0.5	0.6	0.7	2.0	6.9
inflation target	1.2	1.8	2.9	4.2	1.6	2.2	15.7	23.9	27.6	34.0	6.0	7.1	9.1	10.9	2.8
Domestic shocks	90.0	85.2	75.4	56.7	6.9	94.5	60.2	38.5	26.2	4.3	62.9	56.3	45.4	29.9	18.5
Foreign shocks	0.7	1.1	1.9	2.6	4.4	1.6	11.7	18.8	26.0	44.3	6.1	6.8	7.4	8.8	37.4
Common shocks	9.3	13.7	22.7	40.7	88.6	3.9	28.1	42.7	47.8	51.4	31.0	36.9	47.2	61.3	44.1

Table 13: Variance decomposition, model for monetary union - Home economy

	Output					Consumption					Investment				
Shocks	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	0.1	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.9	0.1
stationary techn.*	0.2	0.1	0.0	0.7	0.9	0.0	0.0	0.4	2.0	1.5	1.5	1.7	2.1	1.7	0.6
preference shock	7.1	4.4	0.8	0.0	0.0	16.4	12.2	4.6	0.2	0.0	0.1	0.1	0.3	0.6	0.0
preference shock*	10.5	7.4	2.0	0.0	0.0	55.9	43.4	18.8	1.6	0.0	0.0	0.1	0.1	0.4	0.0
labor supply	0.3	0.4	0.2	0.0	0.1	0.0	0.0	0.2	0.7	0.2	0.1	0.1	0.1	0.0	0.1
labor supply*	0.4	0.3	0.0	1.0	1.7	0.0	0.1	0.6	3.4	2.7	2.7	3.2	4.3	4.1	1.4
gov. spending	1.1	0.2	0.0	0.0	0.0	0.4	0.7	1.3	1.5	0.5	0.1	0.2	0.4	0.9	0.0
gov. spending*	13.8	4.3	1.0	0.3	0.2	1.2	2.0	3.6	4.4	2.9	0.0	0.0	0.0	0.1	0.1
interest rate shock	7.3	9.6	8.7	2.8	0.0	4.8	6.4	6.9	2.5	0.0	3.1	3.6	4.7	4.8	0.1
investment shock	1.5	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	1.9	0.8	0.7
investment shock*	12.8	13.7	8.2	1.1	0.0	0.4	0.6	0.9	0.2	1.3	83.4	78.9	66.7	26.4	9.3
unit root techn.	17.1	28.2	43.7	63.3	84.4	15.8	25.9	46.8	65.9	80.0	2.2	3.3	7.1	31.3	76.8
asymmetric techn.	20.0	18.9	20.9	22.2	12.1	2.5	4.3	8.3	11.7	9.9	0.9	1.3	3.0	11.2	9.4
price markup	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
price markup*	3.3	5.5	6.9	3.8	0.0	0.3	1.2	3.4	3.1	0.2	1.5	2.2	4.0	6.9	0.0
inflation target	4.3	6.3	7.4	4.7	0.4	2.1	3.1	4.2	2.7	0.6	2.3	3.0	4.9	9.9	1.3
Foreign shocks	10.3	5.7	1.2	0.3	0.2	16.9	13.0	6.1	2.4	0.9	2.6	2.7	3.0	3.1	0.9
Domestic shocks	41.0	31.3	18.1	6.7	2.9	57.9	47.3	27.7	14.8	8.6	89.0	86.1	77.3	39.7	11.5
Common shocks	48.7	63.0	80.8	93.0	96.9	25.2	39.7	66.3	82.9	90.5	8.5	11.3	19.8	57.2	87.7
	Real wage					GDP deflator					Employment				
Shocks	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.2	0.0	1.0	1.4	1.2	0.9	0.5	0.1
stationary techn.*	4.1	4.4	4.8	5.2	1.2	1.3	8.3	24.6	20.2	4.1	59.7	55.4	47.0	30.0	1.5
preference shock	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.6	0.3	0.0	0.0
preference shock*	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	1.5	1.4	0.9	0.3	0.0
labor supply	7.7	7.8	7.6	7.0	1.6	0.3	1.8	6.5	7.3	5.7	0.0	0.0	0.0	0.2	1.0
labor supply*	84.1	83.5	80.9	72.4	14.5	1.8	11.9	41.0	40.0	6.5	1.3	1.7	3.2	9.3	28.0
gov. spending	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.3
gov. spending*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	3.2	2.1	1.9	1.7	1.8	3.1
interest rate shock	0.3	0.5	0.9	1.4	0.3	0.0	0.2	0.7	0.5	0.1	5.1	5.5	5.7	3.7	0.1
investment shock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
investment shock*	0.0	0.0	0.1	0.1	0.2	0.1	0.8	3.2	5.4	6.9	0.4	0.3	0.0	1.5	6.8
unit root techn.	0.7	1.1	2.4	8.3	68.1	0.1	0.8	3.0	5.1	22.9	16.2	18.9	24.5	35.8	54.0
asymmetric techn.	0.4	0.0	0.1	1.4	10.7	0.1	0.6	1.5	1.1	0.9	0.0	0.0	0.3	1.3	1.2
price markup	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.0	0.0	0.0	0.1	0.2
price markup*	2.1	2.0	2.1	2.7	1.4	95.7	72.1	6.4	2.2	2.5	4.9	5.6	6.6	6.1	0.3
inflation target	0.2	0.3	0.6	1.3	1.8	0.5	3.3	12.3	17.5	45.4	6.5	7.4	8.9	9.7	3.3
Foreign shocks	7.9	8.0	7.9	7.2	1.7	0.3	2.0	7.0	7.6	7.4	2.3	1.9	1.3	0.8	1.6
Domestic shocks	90.4	90.1	88.1	80.4	17.3	99.0	93.2	75.5	68.3	23.3	69.9	66.3	59.4	48.8	39.7
Common shocks	1.6	2.0	4.0	12.4	81.0	0.7	4.8	17.5	24.1	69.3	27.8	31.8	39.3	50.4	58.7

Table 14: Variance decomposition, model for monetary union - Foreign economy

	Terms of trade					Common nominal interest rate				
Shocks	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	0.9	2.2	5.8	11.6	10.6	0.0	0.0	0.2	0.6	0.0
stationary techn.*	0.4	1.2	4.6	12.5	16.7	0.0	0.2	3.9	15.5	7.4
preference shock	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.5	1.8	0.1
preference shock*	0.0	0.0	0.0	0.1	0.1	0.0	0.1	1.0	1.5	0.1
labor supply	0.2	0.4	0.8	1.3	1.0	0.0	0.1	2.3	10.3	4.8
labor supply*	0.5	1.5	6.5	20.8	31.2	0.0	0.3	6.0	27.4	14.0
gov. spending	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.4	0.4	0.0
gov. spending*	0.1	0.2	0.5	1.1	2.1	0.0	0.0	0.1	0.1	1.0
interest rate shock	0.0	0.0	0.0	0.0	0.1	99.6	88.7	54.4	5.4	0.0
investment shock	0.0	0.1	0.2	0.6	1.3	0.0	0.0	0.3	0.1	0.1
investment shock*	0.0	0.1	0.6	2.3	7.0	0.0	0.1	1.1	2.1	3.5
unit root techn.	0.1	0.3	0.6	1.2	1.7	0.0	0.2	3.6	21.5	49.0
asymmetric techn.	0.4	1.1	3.4	9.1	21.3	0.0	0.4	1.8	1.3	0.0
price markup	30.1	22.7	14.3	6.5	1.4	0.0	0.6	0.9	0.1	0.0
price markup*	67.2	70.1	62.6	32.8	5.4	0.0	8.6	22.6	5.1	0.3
inflation target	0.1	0.1	0.1	0.0	0.1	0.4	0.5	0.0	6.7	19.7
Home Economy shocks	31.3	25.4	21.1	20.1	14.4	0.0	1.0	5.5	13.2	5.0
Foreign economy shocks	68.2	73.2	74.8	69.6	62.4	0.0	9.3	34.7	51.8	26.2
Common shocks	0.6	1.4	4.1	10.3	23.2	100.0	89.7	59.8	35.0	68.8

Table 15: Variance decomposition, model for monetary union

	Output					Consumption					Investment				
	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	0.2	0.1	0.0	0.1	0.0	0.1	0.2	0.5	0.8	0.0	2.7	2.7	1.9	0.2	0.0
preference shock	2.3	1.5	0.4	0.0	0.0	9.1	7.7	4.9	1.1	0.0	1.0	1.4	2.4	2.6	0.0
labor supply	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.4	0.4	0.4	0.1	0.0
gov. spending	3.7	0.7	0.0	0.0	0.0	0.5	0.6	0.7	0.5	0.1	0.4	0.6	0.9	1.0	0.0
interest rate shock	25.1	20.9	11.0	0.8	0.0	17.7	13.3	5.8	0.3	0.1	37.2	36.1	25.7	3.4	0.3
investment shock	2.3	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.8	6.7	0.8	0.1	0.0
unit root techn.	59.9	66.7	78.9	96.9	99.9	70.5	74.9	84.4	96.5	99.6	21.7	27.6	40.9	82.7	99.3
price markup	3.6	6.3	6.9	1.1	0.0	0.7	2.1	2.8	0.4	0.1	12.6	17.4	19.1	4.9	0.2
inflation target	0.0	0.0	0.0	0.0	0.0	1.4	1.3	0.9	0.3	0.2	6.1	7.1	7.9	5.2	0.2
	Real wage					GDP deflator					Nominal interest rate				
	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y	1Q	2Q	1Y	2Y	5Y
stationary techn.	19.5	15.1	10.0	4.6	0.1	0.4	3.0	12.0	7.7	1.0	0.0	0.1	2.0	5.1	0.6
preference shock	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.1	0.9	1.3	0.2
labor supply	13.2	10.1	6.8	3.4	0.1	0.1	0.4	1.9	1.4	0.2	0.0	0.0	0.3	0.9	0.1
gov. spending	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.5	0.4	0.1
interest rate shock	16.4	17.7	15.6	6.6	0.0	0.0	0.3	1.2	0.2	0.2	99.8	83.6	38.6	0.1	0.1
investment shock	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.1	0.0
unit root techn.	34.9	42.3	54.0	77.4	99.5	1.5	12.5	64.3	79.3	89.0	0.0	1.2	26.3	87.9	96.0
price markup	13.2	12.0	10.9	6.0	0.0	97.7	81.6	10.2	0.1	0.1	0.0	14.7	31.0	1.1	0.1
inflation target	1.7	2.1	2.4	2.1	0.3	0.3	2.0	10.1	10.9	9.2	0.2	0.2	0.1	3.1	2.7
	Employment														
	1Q	2Q	1Y	2Y	5Y										
stationary techn.	28.3	24.3	19.4	12.4	0.7										
preference shock	1.2	1.1	0.8	0.3	0.2										
labor supply	0.0	0.0	0.0	0.1	0.2										
gov. spending	0.6	0.4	0.2	0.1	0.2										
interest rate shock	17.2	16.7	13.5	3.8	0.7										
investment shock	0.2	0.1	0.0	0.1	0.1										
unit root techn.	41.3	44.9	52.6	74.5	96.5										
price markup	7.2	8.2	8.7	4.0	0.6										
inflation target	4.0	4.4	4.9	4.7	0.9										

Table 16: Variance decomposition, closed-economy model

Variable	Data:1980:q1-2003:q4	Model for monetary union	Model with flex. exch. rate
$\Delta \ln C_t^{GER}$	0.76	1.01	0.94
$\Delta \ln C_t^{EMU}$	0.53	0.75	0.72
$\Delta \ln I_t^{GER}$	2.74	3.91	3.41
$\Delta \ln I_t^{EMU}$	1.40	2.36	2.05
$\Delta \ln(W_t^{GER}/P_t^{GER})$	0.66	1.03	0.93
$\Delta \ln(W_t^{EMU}/P_t^{EMU})$	0.45	0.96	0.92
$\Delta \ln Y_t^{GER}$	0.73	0.98	0.86
$\Delta \ln Y_t^{EMU}$	0.51	0.84	0.74
$\mathrm{EM}_t^{GER\_HP}$	1.54	4.07	3.33
$\mathrm{EM}_t^{EMU\_HP}$	0.59	2.91	2.80
$4\mathrm{x}\Delta \ln P_t^{GER}$	1.40	1.68	1.77
$4\mathrm{x}\Delta \ln P_t^{EMU}$	2.86	1.89	1.99
$\ln R_t^{GER}$	2.36	1.88	2.08
$\ln R_t^{EMU}$	3.36	1.88	2.22

Table 17: Uncondtitional second moments in the euro area and in the estimated DSGE model, standard deviations

$\Delta \ln C_t^{GER}$	1													
$\Delta \ln C_t^{EMU}$	0.81	1												
$\Delta \ln I_t^{GER}$	0.31	0.26	1											
$\Delta \ln I_t^{EMU}$	0.40	0.51	0.50	1										
$\Delta \ln(W_t^{GER}/P_t^{GER})$	0.51	0.43	0.22	0.36	1									
$\Delta \ln(W_t^{EMU}/P_t^{EMU})$	0.28	0.27	0.02	0.29	0.52	1								
$\Delta \ln Y_t^{GER}$	0.59	0.51	0.58	0.64	0.51	0.25	1							
$\Delta \ln Y_t^{EMU}$	0.50	0.67	0.50	0.79	0.40	0.28	0.79	1						
$\mathrm{EM}_t^{GER\_HP}$	0.11	0.02	-0.13	-0.13	0.44	0.33	0.11	-0.07	1					
$\mathrm{EM}_t^{EMU\_HP}$	0.12	0.03	-0.15	-0.14	0.44	0.34	0.09	-0.09	0.93	1				
$4\mathrm{x}\Delta \ln P_t^{GER}$	-0.22	-0.26	-0.14	-0.29	-0.06	0.02	-0.17	-0.25	0.43	0.38	1			
$4\mathrm{x}\Delta \ln P_t^{EMU}$	-0.10	-0.15	-0.14	-0.24	0.04	0.05	-0.11	-0.16	0.23	0.27	0.71	1		
$\ln R_t^{GER}$	-0.05	-0.18	-0.16	-0.31	0.13	0.18	-0.04	-0.23	0.59	0.54	0.81	0.72	1	
$\ln R_t^{EMU}$	0.02	-0.11	-0.07	-0.22	0.14	0.16	0.01	-0.13	0.30	0.30	0.76	0.87	0.87	1

Table 18: Uncondtitional second moments in the Euro Area, correlations

$\Delta \ln C_t^{GER}$	1													
$\Delta \ln C_t^{EMU}$	0.84	1												
$\Delta \ln I_t^{GER}$	0.32	0.33	1											
$\Delta \ln I_t^{EMU}$	0.24	0.28	0.47	1										
$\Delta \ln(W_t^{GER}/P_t^{GER})$	0.23	0.29	0.49	0.39	1									
$\Delta \ln(W_t^{EMU}/P_t^{EMU})$	0.12	0.19	0.18	0.37	0.58	1								
$\Delta \ln Y_t^{GER}$	0.67	0.64	0.57	0.66	0.45	0.31	1							
$\Delta \ln Y_t^{EMU}$	0.63	0.74	0.50	0.74	0.44	0.34	0.87	1						
$\mathrm{EM}_t^{GER\_HP}$	0.13	0.25	0.09	0.13	0.41	0.28	0.16	0.25	1					
$\mathrm{EM}_t^{EMU\_HP}$	0.14	0.23	0.02	0.13	0.32	0.39	0.19	0.25	0.70	1				
$4\mathrm{x}\Delta \ln P_t^{GER}$	0.10	0.15	0.08	0.11	0.28	0.23	0.10	0.18	0.57	0.38	1			
$4\mathrm{x}\Delta \ln P_t^{EMU}$	0.05	0.01	-0.01	-0.01	0.19	0.20	0.14	0.01	0.35	0.32	0.69	1		
$\ln R_t^{GER}$	0.02	0.00	-0.10	-0.15	0.02	-0.01	-0.03	-0.05	0.43	0.42	0.57	0.55	1	
$\ln R_t^{EMU}$	0.02	0.00	-0.10	-0.15	0.02	-0.01	-0.03	-0.05	0.43	0.42	0.57	0.55	1	1

Table 19: Uncondtitional second moments in the estimated DSGE model for currency area, correlations

$\Delta \ln C_t^{GER}$	1													
$\Delta \ln C_t^{EMU}$	0.82	1												
$\Delta \ln I_t^{GER}$	0.18	0.23	1											
$\Delta \ln I_t^{EMU}$	0.09	0.13	0.33	1										
$\Delta \ln(W_t^{GER}/P_t^{GER})$	0.15	0.20	0.40	0.30	1									
$\Delta \ln(W_t^{EMU}/P_t^{EMU})$	0.06	0.12	0.10	0.33	0.54	1								
$\Delta \ln Y_t^{GER}$	0.56	0.54	0.35	0.53	0.37	0.27	1							
$\Delta \ln Y_t^{EMU}$	0.56	0.70	0.38	0.65	0.35	0.28	0.77	1						
$\mathrm{EM}_t^{GER\_HP}$	0.15	0.25	0.12	0.13	0.37	0.28	0.21	0.27	1					
$\mathrm{EM}_t^{EMU\_HP}$	0.17	0.25	0.05	0.16	0.32	0.36	0.24	0.29	0.76	1				
$4\mathrm{x}\Delta \ln P_t^{GER}$	0.07	0.11	0.07	0.09	0.24	0.18	0.08	0.15	0.54	0.38	1			
$4\mathrm{x}\Delta \ln P_t^{EMU}$	0.03	0.01	-0.03	0.03	0.15	0.19	0.10	0.04	0.26	0.31	0.37	1		
$\ln R_t^{GER}$	0.04	0.07	-0.06	-0.05	0.07	0.10	-0.02	0.05	0.60	0.54	0.66	0.33	1	
$\ln R_t^{EMU}$	0.04	0.03	-0.04	-0.06	0.11	0.07	0.03	0.03	0.44	0.48	0.36	0.67	0.69	1

Table 20: Uncondtitional second moments in the estimated DSGE model with flexible exchange rate, correlations

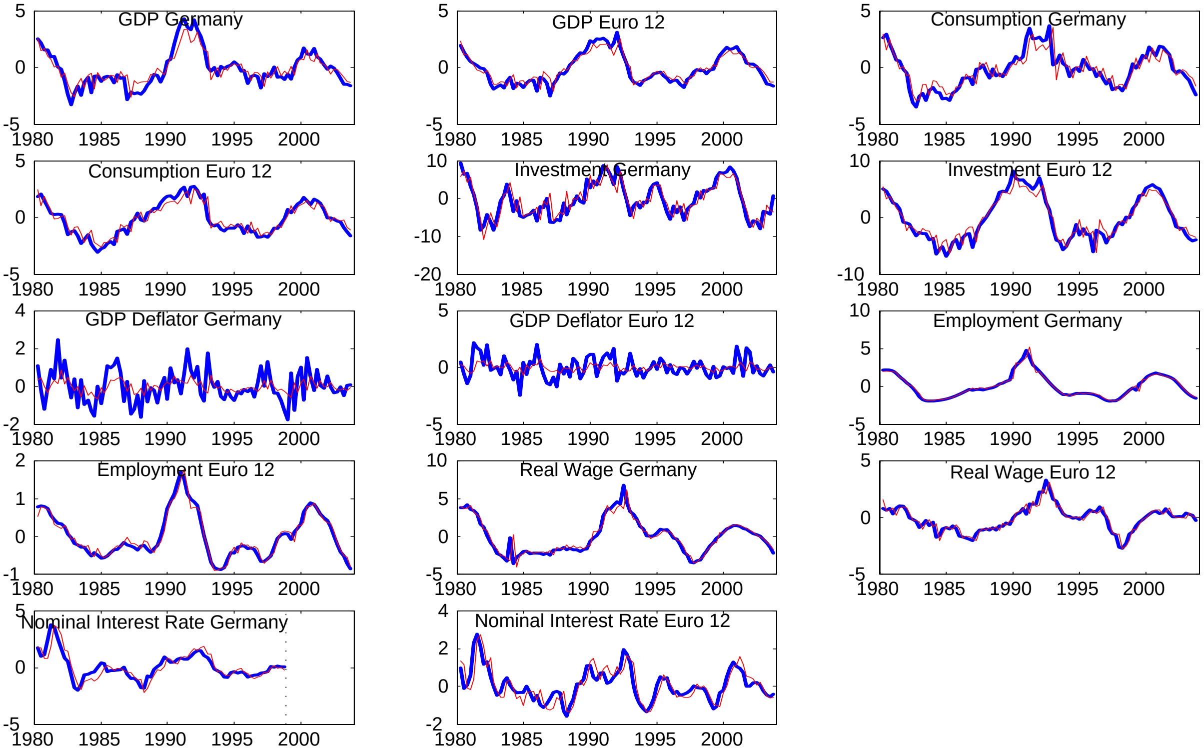

Figure 1: Observed data and one-step forecasts, model estimated on HP-filtered data

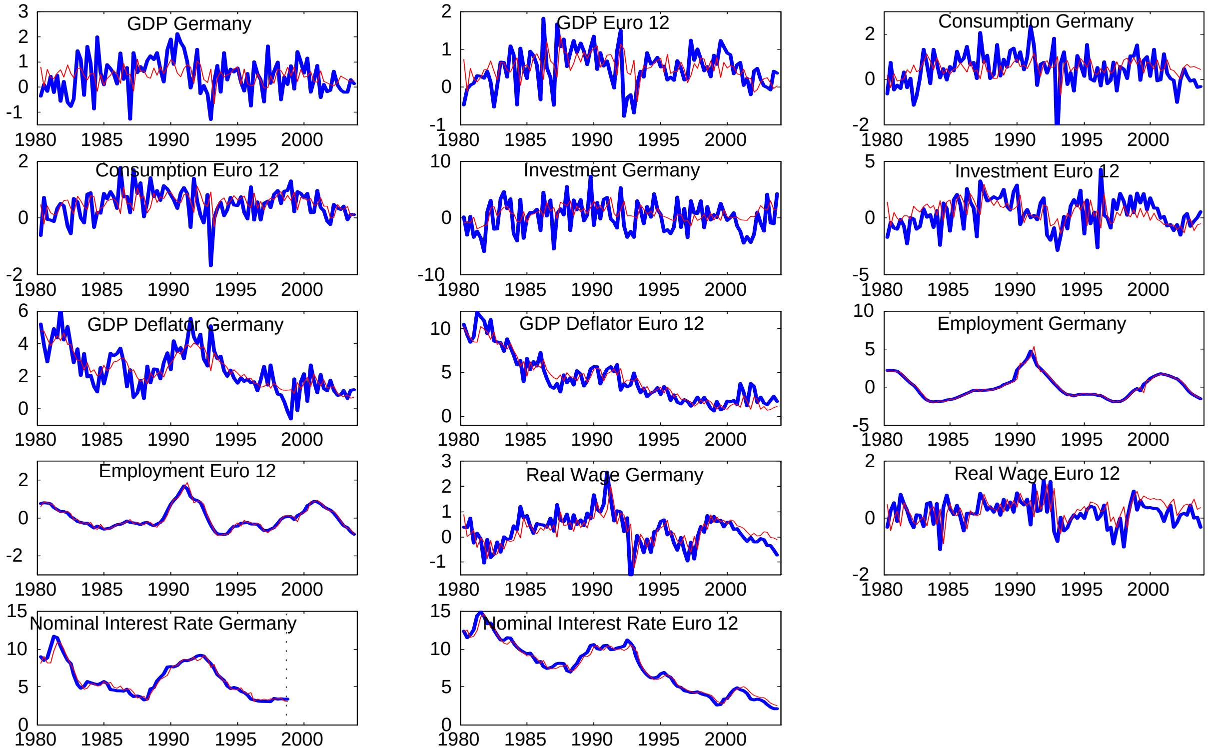

Figure 2: Observed data and one-step forecasts, model estimated on log-differences

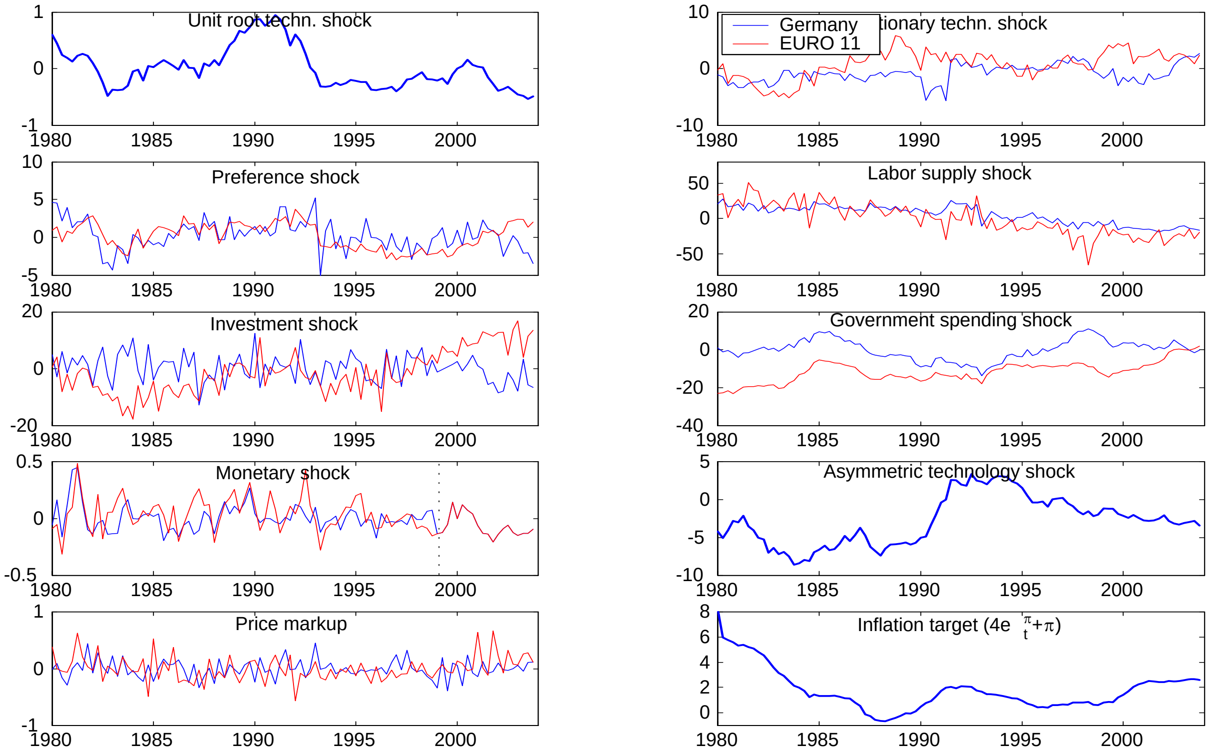

Figure 3: Smoothed estimated of structural shocks

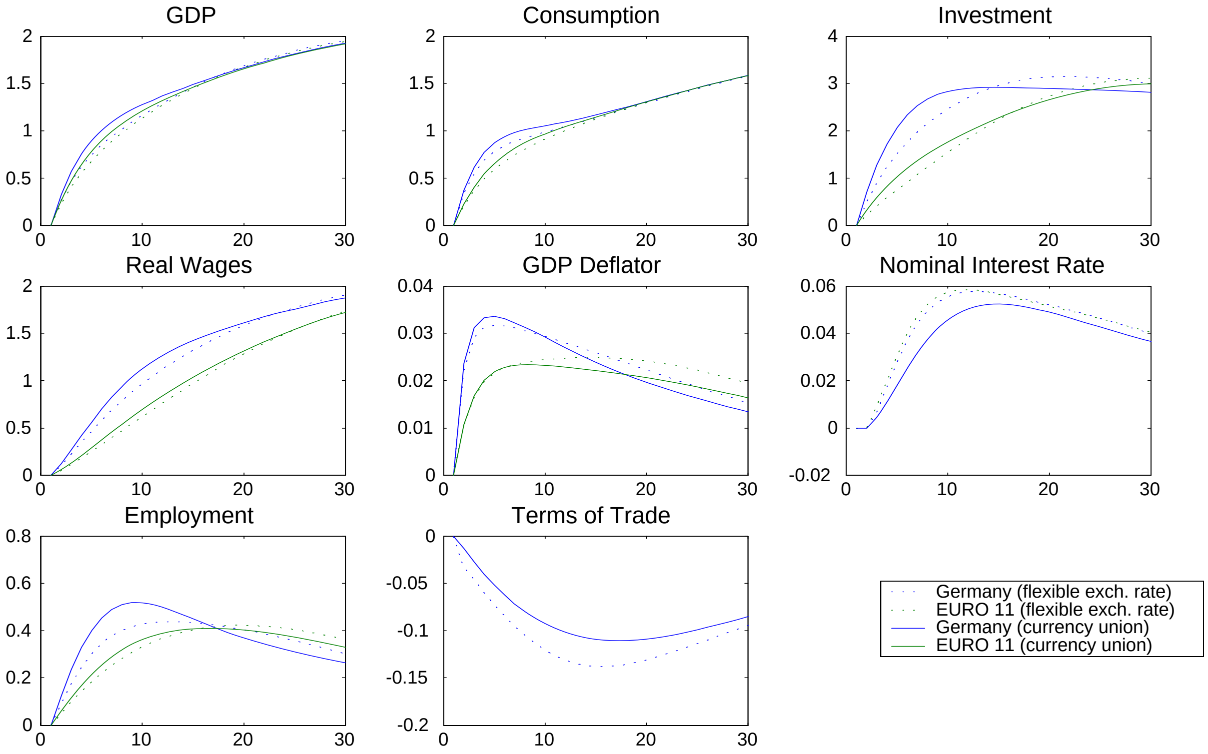

Figure 4: Response to an orthogonalized unit root technology shock

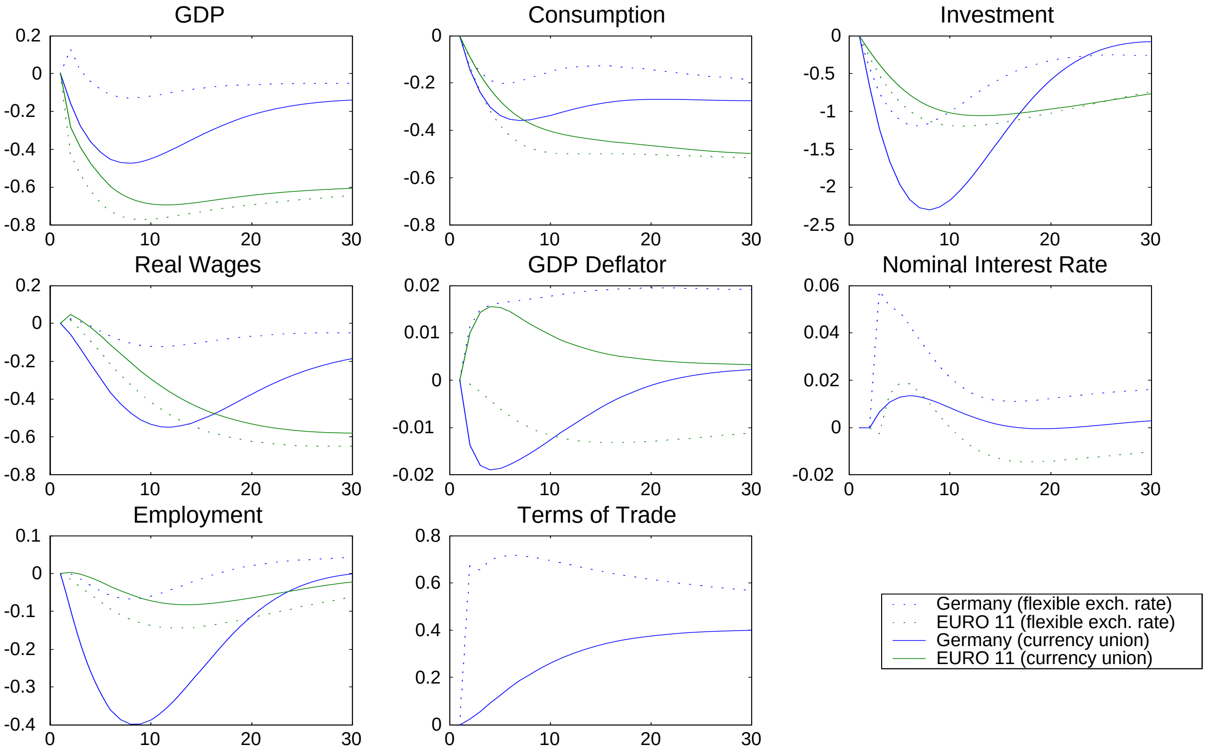

Figure 5: Response to an asymmetric technology shock

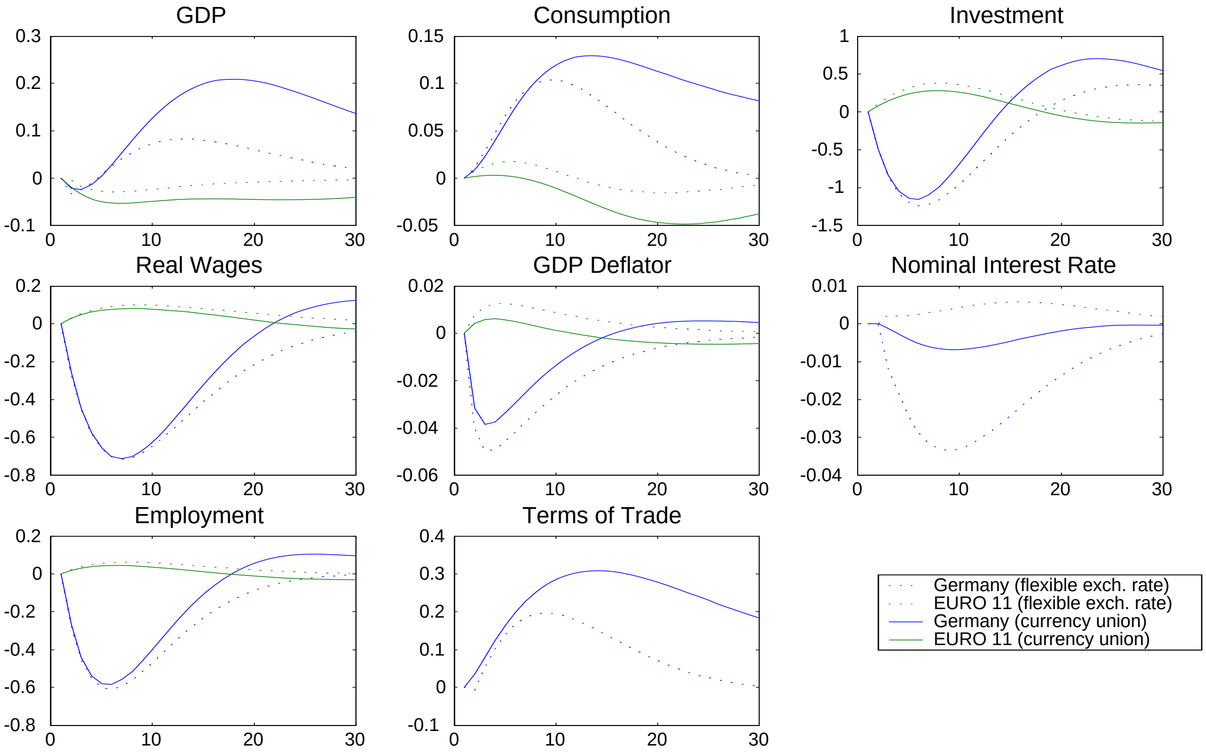

Figure 6: Response to an orthogonalized stationary technology shock hitting the Home economy

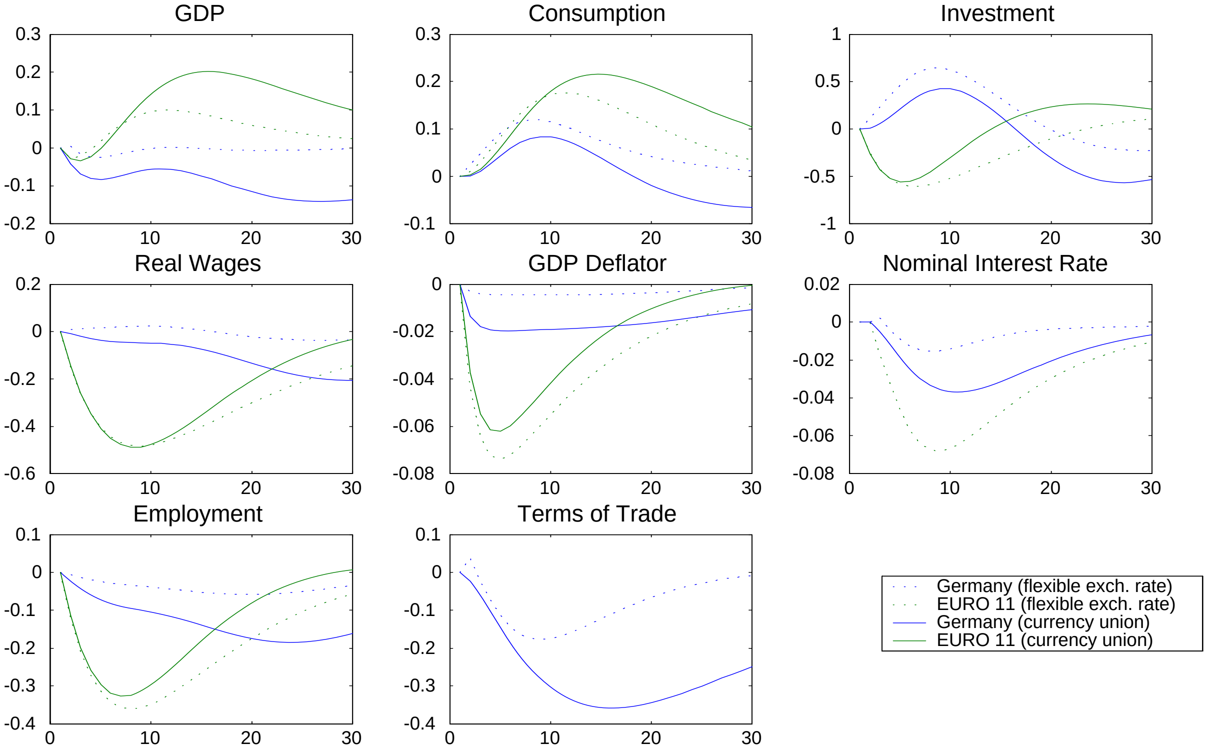

Figure 7: Response to an orthogonalized stationary technology shock hitting the Foreign economy

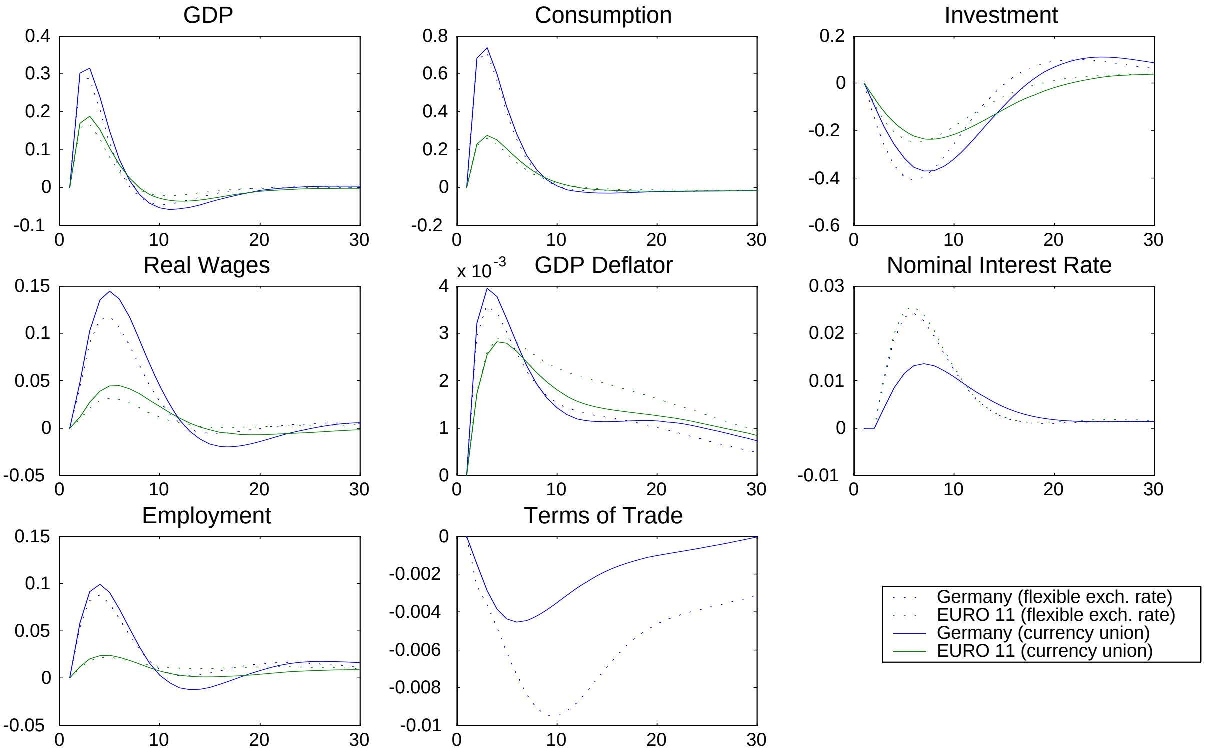

Figure 8: Response to an orthogonalized preference shock hitting the Home economy

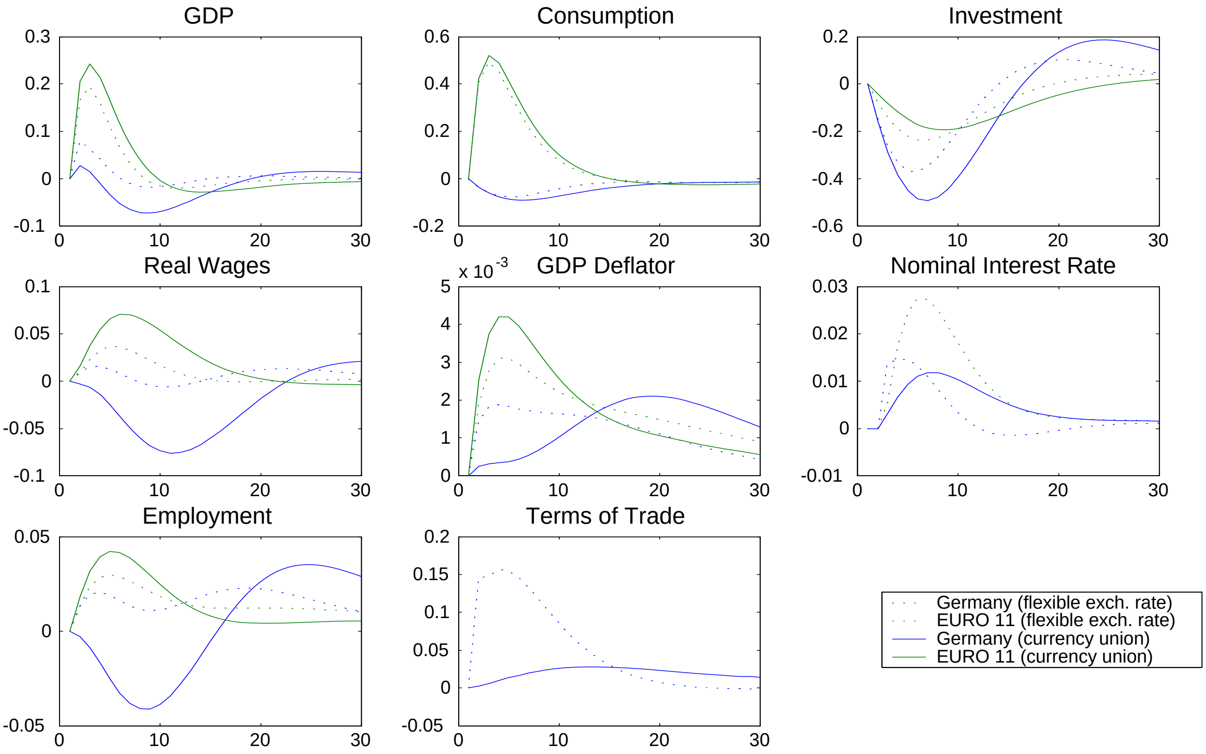

Figure 9: Response to an orthogonalized preference shock hitting the Foreign economy

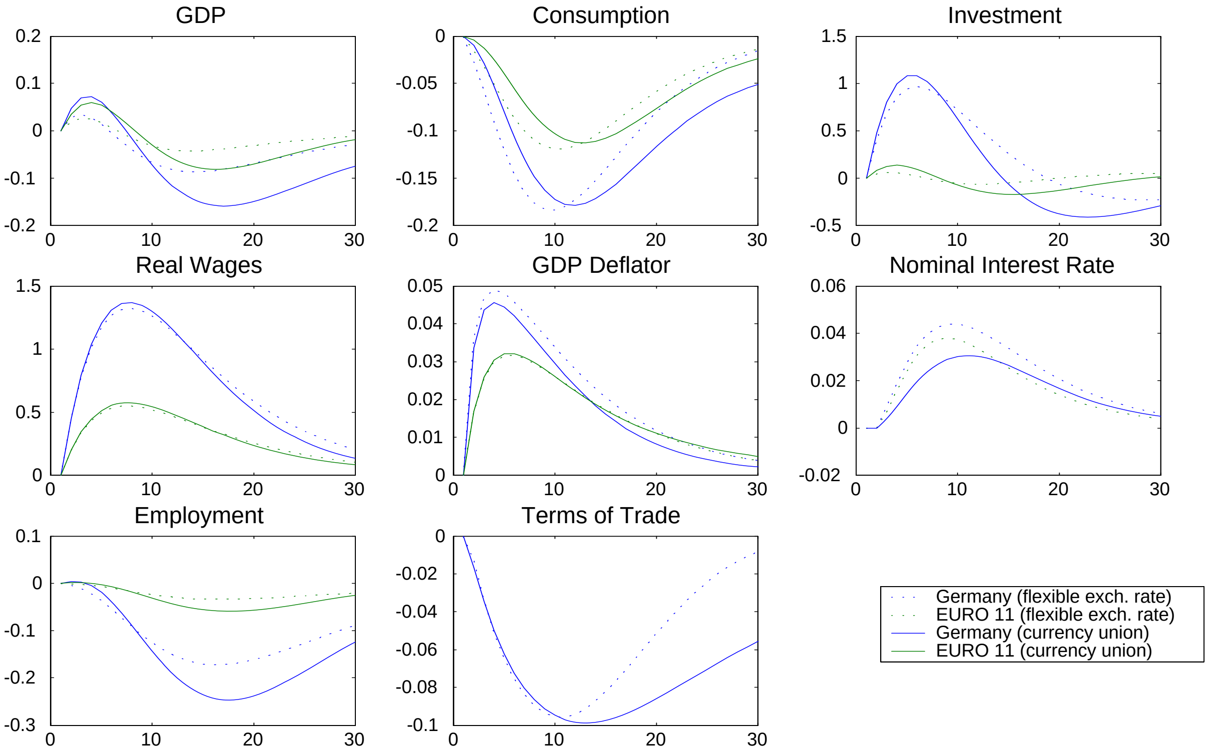

Figure 10: Response to an orthogonalized negative labor supply shock hitting the Home economy

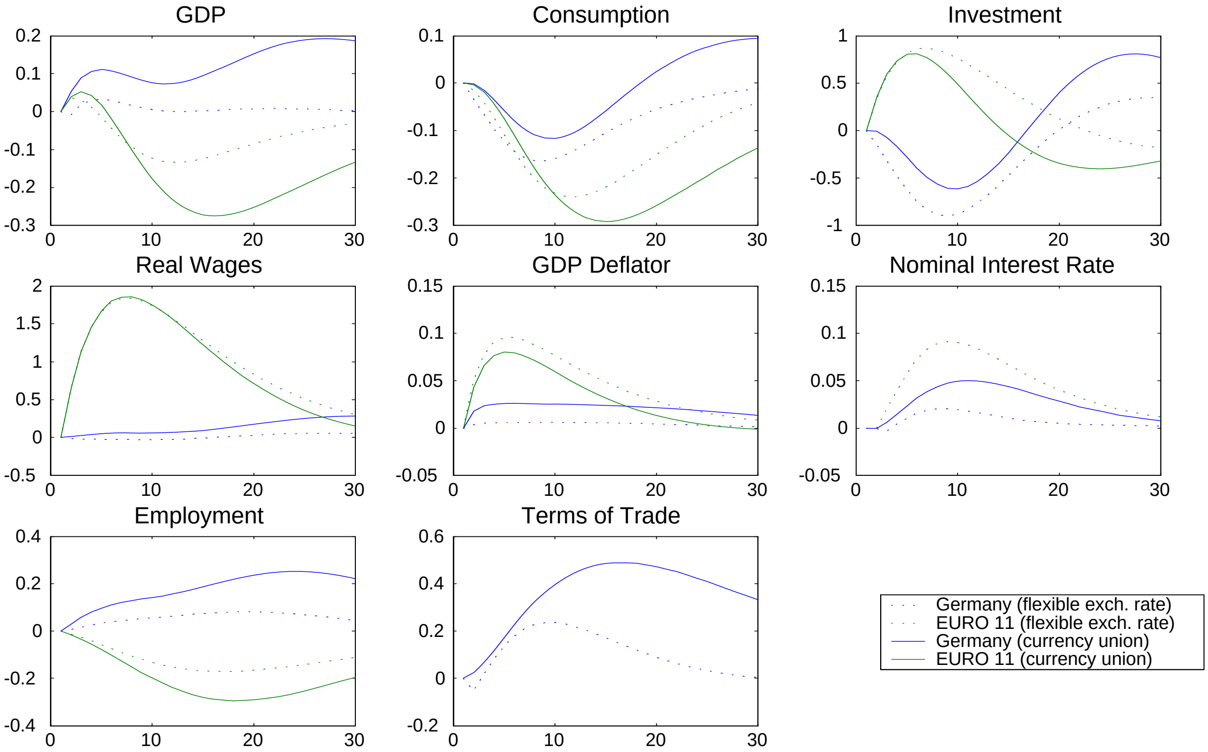

Figure 11: Response to an orthogonalized, negative labor supply shock hitting the Foreign economy

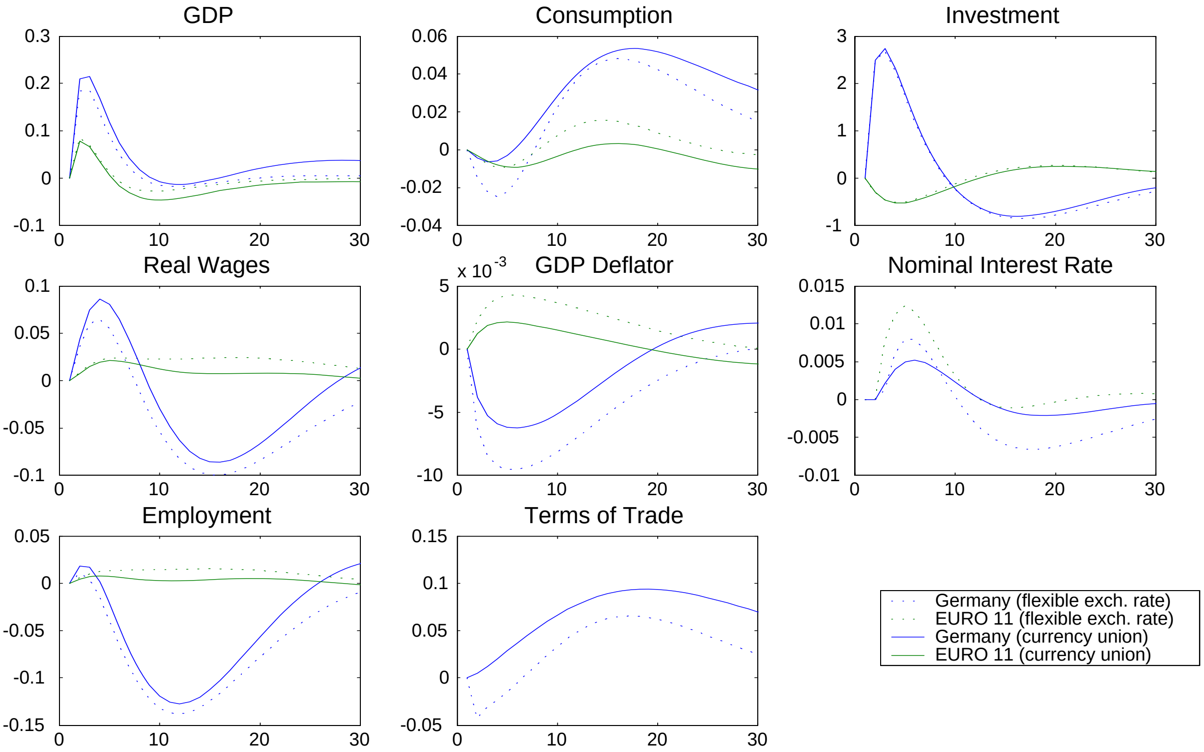

Figure 12: Response to an orthogonalized investment specific shock hitting the Home economy

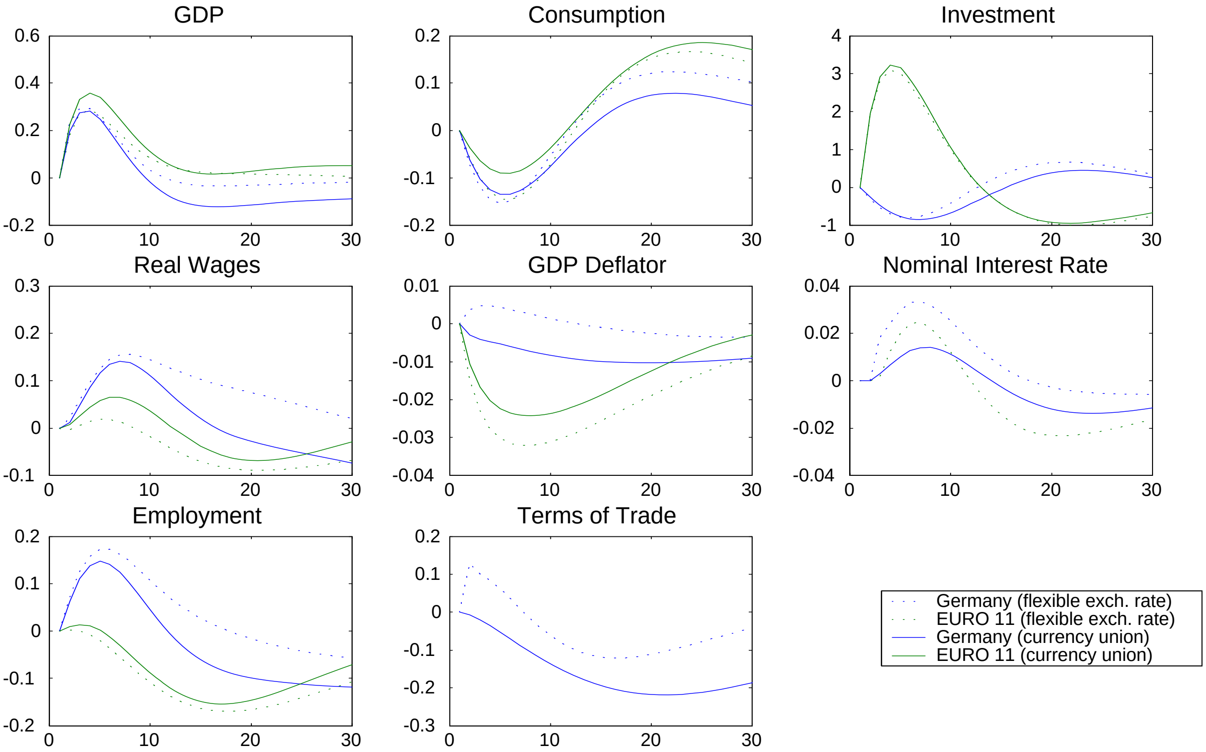

Figure 13: Response to an orthogonalized investment specific shock hitting the Foreign economy

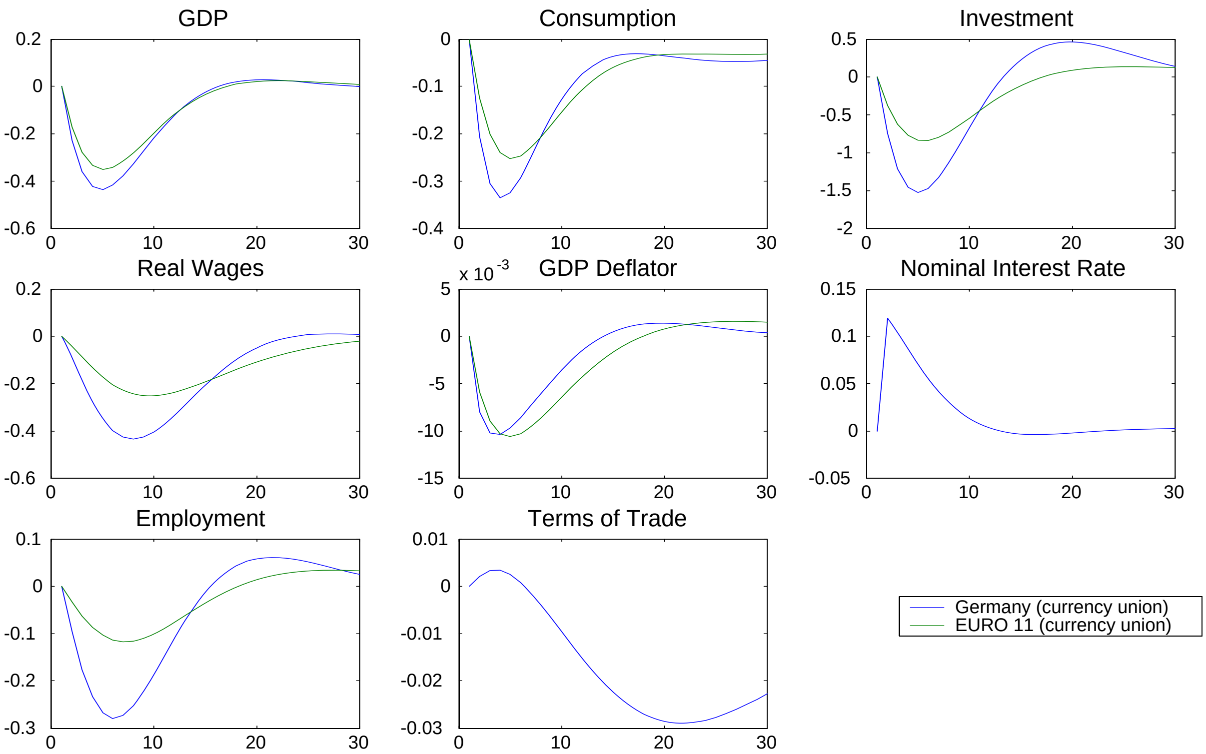

Figure 14: Response to a common interest rate shock

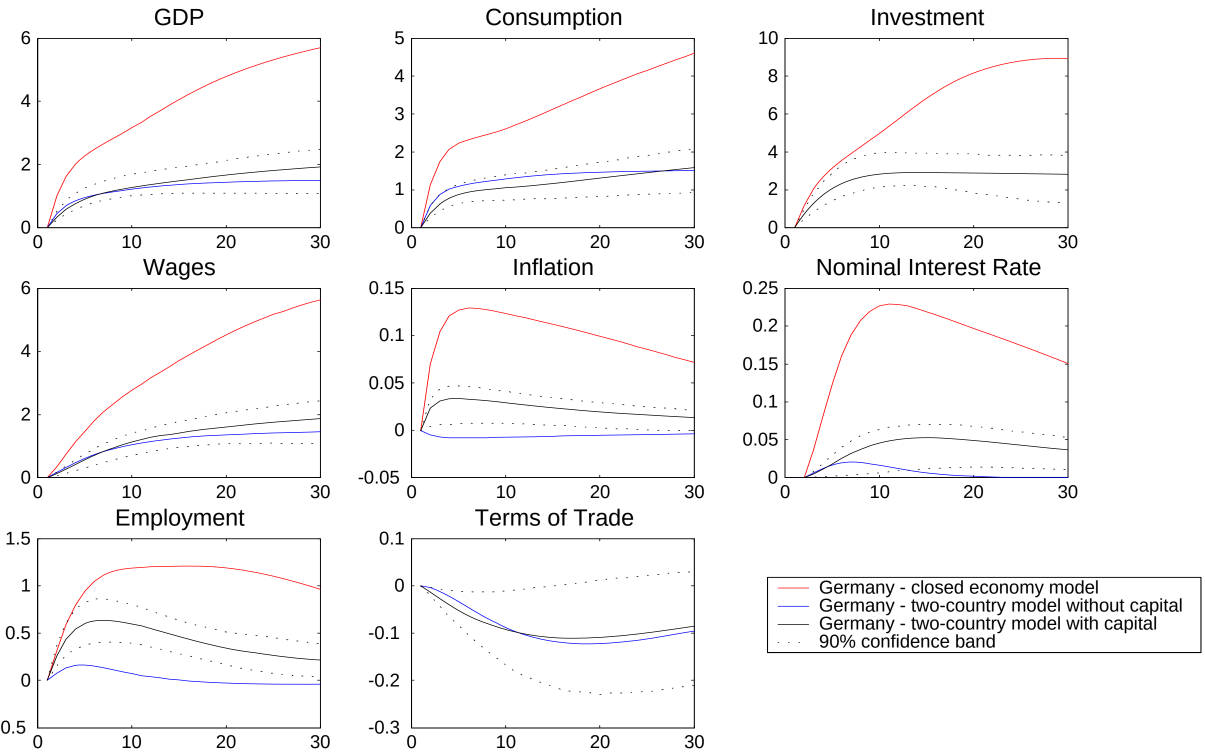

Figure 15: Response to an orthogonalized stationary technology shock hitting the Home economy

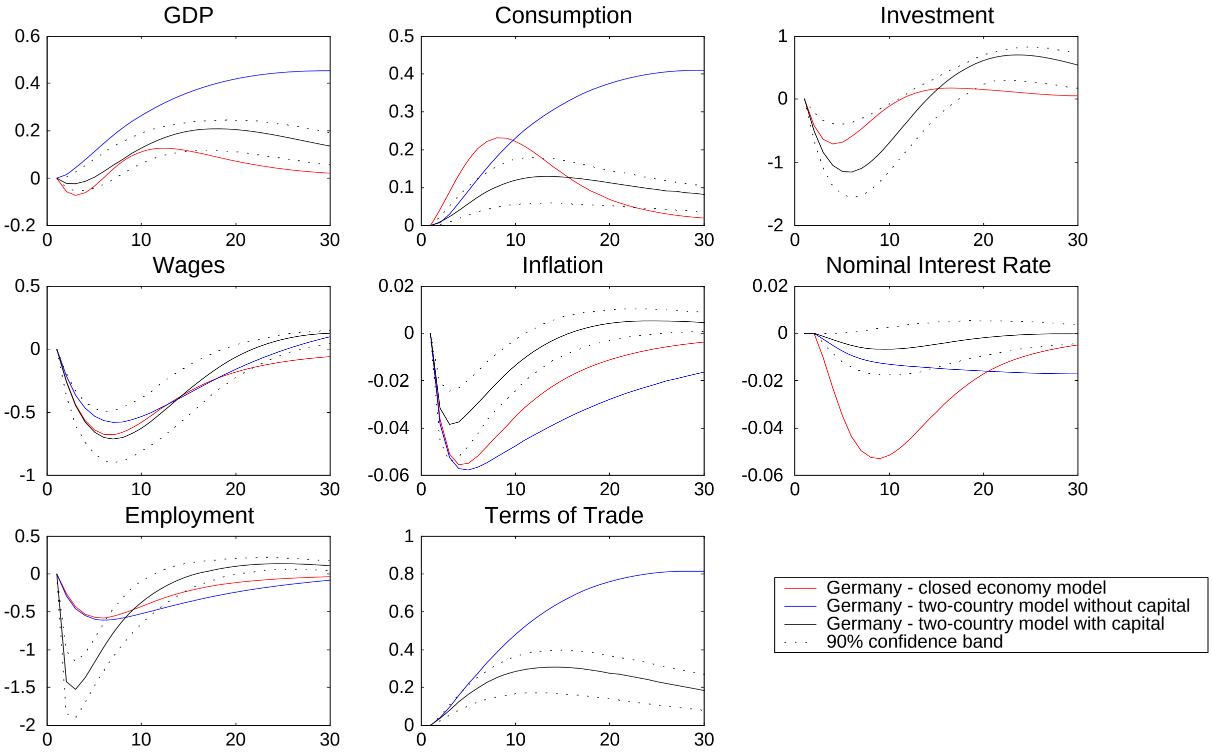

Figure 16: Response to an orthogonalized stationary technology shock hitting the Home economy

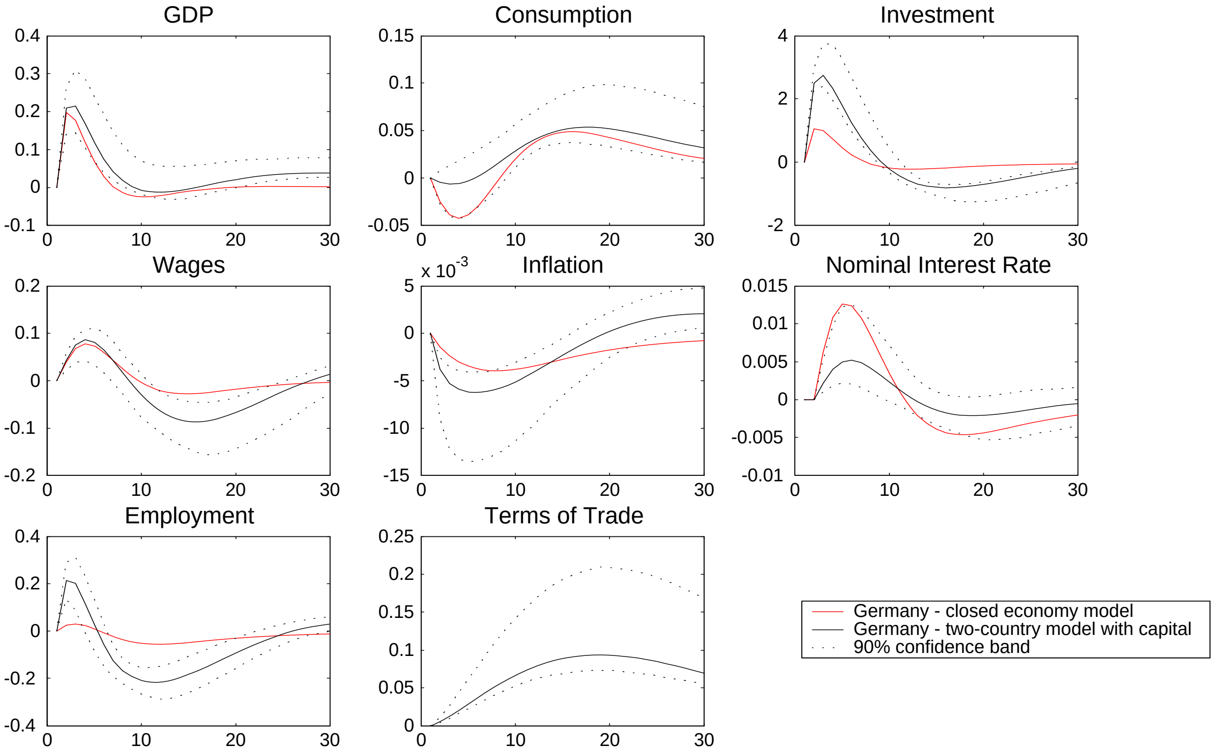

Figure 17: Response to an orthogonalized investment specific shock hitting the Home economy

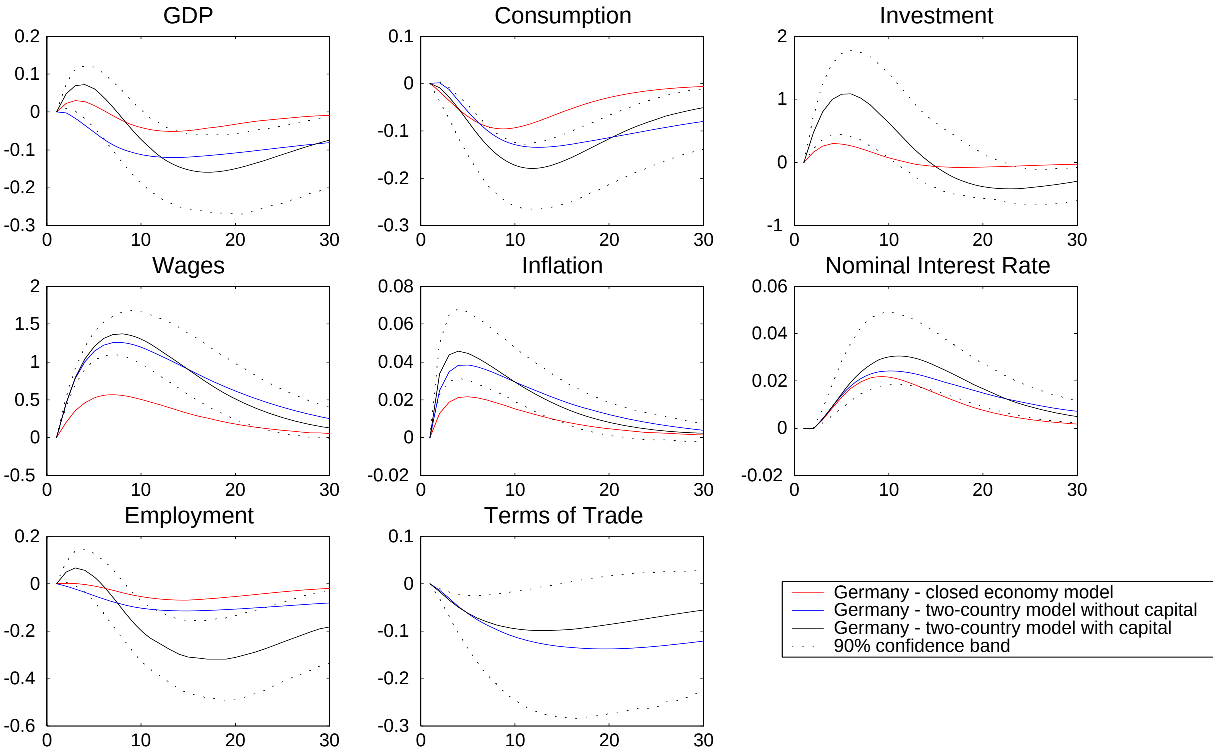

Figure 18: Response to an orthogonalized preference shock hitting the Home economy