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An Estimated Two-Country DSGE Model of Austria and the Euro Area*

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Abstract

We present a two-country New Open Economy Macro model of the Austrian economy within the European Union's Economic & Monetary Union (EMU). The model includes both nominal and real frictions that have proven to be important in matching business cycle facts, and that allows for an investigation of the effects and cross-country transmission of a number of structural shocks: shocks to technologies, shocks to preferences, cost-push type shocks and policy shocks. The model is estimated using Bayesian methods on quarterly data covering the period of 1976:Q1-2005:Q1. In addition to the assessment of the relative importance of various shocks, the model also allows to investigate effects of the monetary regime switch with the final stage of the EMU and investigates in how far this has altered macroeconomic transmission. We find that Austria's economy appears to react stronger to demand shocks, while in the rest of the Euro Area supply shocks have a stronger impact. Comparing the estimations on pre-EMU and EMU subsamples we find that the contribution of (rest of the) Euro Area shocks to Austria's business cycle fluctuations has increased significantly.

JEL classification: E4, E5, F4;
Keywords: EMU, DSGE modelling, Bayesian Estimation;

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1 Introduction

This paper develops a dynamic stochastic general equilibrium (DSGE) model in the style of New Keynesian/ New Open Economy Macroeconomics for the small open economy of Austria as a member of the European Economic and Monetary Union (EMU). The model is then estimated using Bayesian methods on quarterly data covering the period of 1975:Q1-2005Q1.

Recent years have seen considerable advances in estimation of large scale DSGE models. These models are rich in structure, in the sense that they derive macroeconomic relationships explicitly from underlying microeconomic foundations: intertemporally optimizing households and firms aim to maximize their life-time utility or profits. They also include a number of frictions to account for the empirical evidence that prices and wages adjust sluggishly to supply and demand shocks. In addition to nominal rigidities also real frictions are typically included, such as costs of adjusting the capital stock or habit persistence in consumption. Including these frictions, the model allows an interpretation of macroeconomic fluctuations as agents' optimal responses to demand and supply shocks in various markets. As such, microfounded DSGE models have become increasingly popular as a framework to conduct policy analysis and have recently also started to emerge as a tool for forecasting (see, for example, Smets & Wouters (2004), Del Negro et al. (2007)).

Bayesian estimation techniques have become particularly popular in quantitative macromodels. Among the pioneers in this field are the works of Geweke (1999), Schorfheide (2000) and Lubik & Schorfheide (2007). Smets & Wouters (2003*a*) develop a New Keynesian model, close in spirit to Christiano et al. (2001) - which has become a benchmark closed economy model of the monetary macroeconomics transmission mechanism - , and estimate it on a Euro Area dataset (the Area Wide Model dataset developed by Fagan et al. (2001)).

They show that their DSGE model can in fact provide a satisfactory representation of the main macroeconomic aggregates in the Euro Area.

This paper presents a two country (region) model in which the focus of the numerical simulations and econometric estimations is on Austria as a small open economy and member of the EMU. Similar to the model of Smets & Wouters (2003*a*) we consider shocks to production technologies and preferences, as well as "cost-push" shocks and policy shocks. Shocks may originate in either of both regions, that is, they may be specific to the Austrian economy or be Euro Area wide shocks. The shocks to production technologies and preferences include productivity shocks, shocks to labor supply, shocks to households' discount factor, and shocks to investment adjustment costs. Cost-push shocks may stem from temporary changes in the markups charged in either the goods or labor markets. The policy shocks considered are monetary and fiscal shocks.

We choose to employ a two country setup, despite the fact that Austria only forms a small part of the Euro Area and we could, alternatively, have constructed a small open economy model. The two country setup allows us, however, to maintain the full set and interpretation of structural shocks also in the Euro Area, and allows us to investigate transmission of each of these shocks to the Austrian economy. In addition, in this way we keep our specifications close to the standard closed economy DSGE models, which allows for more consistent cross-model comparisons of the estimates. Also, we make full use of the available data by using the two country setup: we employ the synthetic Euro Area data by Fagan et al. (2001) together with national accounts data for Austria from the Austrian Institute of Economic Research.

This setup allows an investigation of the sources of business cycle movements and an assessment of the relative importance of various shocks and frictions for explaining the model's dynamics. For the Austrian economy it can also give an indication about how strongly shocks from the Euro Area are transmitted. Not surprisingly, we find few signs of transmission from shocks originating in Austria to the Euro Area, or at least of small quantitative importance. In addressing these issues, this paper fills an important gap in the literature for the Austrian economy. Leitner (2007) gives a characterization of the Austrian business cycle stylized facts. However, relatively little research has been undertaken on business cycle modelling or shock transmission for the Austrian economy. To our knowledge, this paper presents the first estimated DSGE model for the Austrian economy.

As in Pytlarczyk (2005), we argue that a model estimated over the entire period that data are available (in our case 1976Q2:2005Q1) should take account of the regime switch in monetary policy that took place with the third and final stage of the EMU at the beginning of 1999. Otherwise the model might become misspecified because of the implicit assumption that, even before establishment of the currency area, there was a common monetary policy. We address this issue by estimating two versions of our two country model. A version that allows for two separate monetary policy authorities that is estimated over the period of 1976Q2:1998Q4, and a version of the two countries forming a currency union, which is estimated on the data after the start of the EMU, 1999Q1:2005Q1. Finally, we also consider an estimation procedure in which we use the entire time series of 1976Q2:2005Q1 in which we allow for the change in the monetary regime but restrict all other (all regime-invariant) parameters to be constant over the entire period. In addition to questions about the sources of business cycle movements and the relative importance of shocks the model may therefore be able to address the effects of the monetary policy regime switch to a common monetary policy from 1999 on.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 summarizes briefly the log-linearized equilibrium conditions from which a solution to the Rational Expectations system is derived. Section 4 discusses some properties of the data and some issues of data measurement. Section 5 discusses the subset of calibrated model parameters and the choice of priors on the estimated parameters. We also discuss the procedure for the estimation over the entire sample including the monetary regime switch. Section 6 presents and discusses the results: we provide the posterior distributions of the estimated parameters. We compare the estimation results from maximum likelihood with those from Bayesian estimation. In addition, we compare the results obtained from estimation over the pre-EMU and EMU subsamples. We then disucss results from the model's forecast error variance decompositions and and derive impulse response functions from the structural shocks. Finally, section 7 concludes.

2 The Model

The theoretical model world consists of two countries/ regions, Home (Austria) and Foreign (the rest of the Euro Area).[1] Home is populated over a continuum of $[0, n)$, while Foreign is populated over $[n, 1]$. Each of the two regions specializes in the production of a region-specific good, that comes in many varieties. Households derive utility from current and past consumption and leisure. They are also the owners of the economy's capital stock, and supply capital services and differentiated types of labor input to the firms. As is customary in the literature, we assume that there are a number of frictions in the model, both real and nominal. We impose costs of capital adjustment and habit formation. We also assume that there is some degree of stickiness in firms' setting of prices and in households' setting of wages, modelled after the framework of Calvo. Before the introduction of a common currency, the two countries are assumed to conduct their own independent monetary policies. After the onset of the final stage of the Economic and Monetary Union in 1999, the two regions are modelled as a currency union, in which monetary policy is conducted by a sole authority, the European Central Bank. In the following, we will lay out the problem of domestic agents, with an understanding that, unless stated otherwise, the foreign economy is characterized by an equivalent set of equations. We denote foreign variables with an asterisk.

[1] Masson & Taylor (1993) find that the European Union as a whole is a relatively closed area.

2.1 Consumer Behavior

In the domestic economy, there is a continuum of households indicated by index j, and populated over the interval $[0, n)$. Households aim to maximize discounted expected lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t \left(C_t \left(j \right) - H_t \left(j \right); l_t \left(j \right) \right) \tag{1}$$

where β is the discount factor and the instantaneous utility function is a function of the households' current aggregate consumption, $C_t(j)$, relative to a habit level $H_t(j)$, and of labor, $l_t(j)$.

We assume that individual j's aggregate (private) consumption consists of a bundle of domestic and foreign goods, denoted C_H and C_F, according to a constant elasticity of substitution (CES) index[2]:

$$C_t \left(j \right) = \left[\gamma_c^{\frac{1}{\epsilon}} C_{H,t}^{\frac{\epsilon-1}{\epsilon}} \left(j \right) + \left(1 - \gamma_c \right)^{\frac{1}{\epsilon}} C_{F,t}^{\frac{\epsilon-1}{\epsilon}} \left(j \right) \right]^{\frac{\epsilon}{\epsilon-1}} \tag{2}$$

Domestic and foreign goods come in many varieties and are, again, aggregated according to a CES function:

$$C_{H,t} \left(j \right) = \left[\left(\frac{1}{n} \right)^{\frac{1}{\theta}} \int_0^n c_t(h, j)^{\frac{\theta-1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}} \tag{3}$$

$$C_{F,t} \left(j \right) = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\theta}} \int_n^1 c_t(f, j)^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}} \tag{4}$$

[2] In reality, consumption baskets also contain a large fraction of non-tradable goods. To keep the model simple, we however abstract from explicitly modelling non-tradable goods. Nontradable consumption is implicitly reflected by a higher parameter weight on own consumption goods relative to a model in which nontradables are explicitly modelled.

Parameter ϵ denotes the elasticity of substitution between the domestic and foreign produced good, while parameter θ denotes the elasticity of substitution among (domestic and foreign) varieties. The foreign country's aggregate consumption is given by a similar CES index, for which, however, we allow for different weights on the domestic and foreign good and for a different elasticity of substitution.[3]

Investment of household j is modelled in a similar way, that is, it consists of domestic and foreign varieties according to a CES function:

$$X_t(j) = \left[\gamma_x^{\frac{1}{\epsilon}} X_{H,t}^{\frac{\epsilon-1}{\epsilon}}(j) + (1-\gamma_x)^{\frac{1}{\epsilon}} X_{F,t}^{\frac{\epsilon-1}{\epsilon}}(j)\right]^{\frac{\epsilon}{\epsilon-1}} \tag{5}$$

$$X_{H,t}(j) = \left[(\frac{1}{n})^{\frac{1}{\theta}} \int_0^n x_t(h,j)^{\frac{\theta-1}{\theta}} dh\right]^{\frac{\theta}{\theta-1}} \tag{6}$$

$$X_{F,t}(j) = \left[(\frac{1}{1-n})^{\frac{1}{\theta}} \int_n^1 x_t(f,j)^{\frac{\theta-1}{\theta}} df\right]^{\frac{\theta}{\theta-1}} \tag{7}$$

The household's utility function is assumed to be separable in consumption and leisure:

$$U_t = \varepsilon_t^C \left\{ \frac{(C_t(j) - H_t(j))^{1-\sigma_c}}{1-\sigma_c} - \varepsilon_t^L \frac{l_t(j)^{1+\sigma_l}}{1+\sigma_l} \right\} \tag{8}$$

Households derive utility from consumption $C_t(j)$, relative to an external habit variable, H_t, and derive disutility from supplying a differentiated type of labor, $l_t(j)$. The fact that each household supplies a differentiated kind of labor means that households have monopoly power over the it. σ_c denotes the coefficient of relative risk aversion or the

[3] That is, the foreign aggregate consumption index, for foreign household j^*, is given by:

$$C_t^*(j^*) = \left[\gamma_c^{*\frac{1}{\epsilon^*}} C_{H,t}^{*\frac{\epsilon^*-1}{\epsilon^*}}(j^*) + (1-\gamma_c^*)^{\frac{1}{\epsilon}} C_{F,t}^{*\frac{\epsilon^*-1}{\epsilon^*}}(j^*)\right]^{\frac{\epsilon^*}{\epsilon^*-1}}$$

inverse of the intertemporal elasticity of substitution. σ_l represents the inverse of the elasticity of work effort with respect to the real wage. The form of the utility function in equation (8) also contains two kinds of preference shocks: ε^C represents a shock to the discount rate that affects households' intertemporal substitution, and ε^L represents a shock to the labor supply. Both shocks have mean equal to 1 and are assumed to follow a first-order autoregressive process with an i.i.d.-normal error term.

The external habit stock $H_t(j)$ is a function of past aggregate consumption:

$$H_t(j) = hC_{t-1} \tag{9}$$

The structure of financial markets is highly simplified in the model. We assume that there are complete asset markets. Specifically, we assume that residents of each country can purchase state-contingent nominal bonds, denominated in the foreign currency. We can then write the budget constraint of domestic household j as:

$$\sum_{s^{t+1}} P_B\left(s^{t+1}, s^t\right) B_{H,t}\left(s^{t+1}, j\right) + S_t \sum_{s^{t+1}} P_B^*\left(s^{t+1}, s^t\right) B_{F,t}\left(j, s^{t+1}\right) + P_{X,t}X(j) + P_tC_t(j) = \tag{10}$$

$$\left[B_{H,t}(j) + S_tB_{F,t}(j) + \int_0^n W_t^{nom}(h,j)l_t(j)dh + R_t^{k\ nom}K_t(j) + \frac{1}{n}\int_0^n \phi_t(h,j)dh + TR_t(j) - TAX_t(j)\right]$$

Here, B_H (respectively, B_H) are domestic-currency (foreign-currency) denominated contingent claims, whose prices at time t are $P_B\left(s^{t+1}, s^t\right)$ (respectively, $P_B^*\left(s^{t+1}, s^t\right)$), where s^t represents the state at time t. S_t denotes the nominal exchange rate (domestic currency per unit of foreign currency). $X_t(j)$ denotes investment, $R_t^{k\ nom}K_t(j)$ is the household's income from renting capital, $\int_0^n W_t^{nom}(h,j)l_t(j)dh$ its total wage income, and $\frac{1}{n}\int_0^n \phi_t(h,j)dh$

denotes income from the household's share in firms' profits. $TAX_t(j)$ is a lump-sum tax paid by the household and $TR_t(j)$ are government transfers to the household.

In each country households accumulate capital $K_t(j)$, which is subject to capital adjustment cost, and follows the following law of motion:

$$K_t(j) = (1-\delta) K_{t-1}(j) + \varepsilon_t^X F(X_t(j), X_{t-1}(j)) \tag{11}$$

where $F(X_t(j), X_{t-1}(j))$ is a function turning investment into physical capital. We adopt the specification of Christiano et al. (2001) and assume that

$$F(X_t(j), X_{t-1}(j)) = \left(1 - \Phi\left(\frac{X_t(j)}{X_{t-1}(j)}\right)\right) X_t(j) \tag{12}$$

where the function $\Phi(\cdot)$ has the following properties at steady state: $\Phi(1) = \Phi'(1) = 0$ and $\Phi''(1) > 0$. Note that in the log-linearized model only the parameter Φ'' is identified. Equation (12) implies the following derivatives of the capital adjustment cost function with respect to the first and second argument:

$$\begin{aligned} F_1(X_t(j), X_{t-1}(j)) &= -\Phi'\left(\frac{X_t(j)}{X_{t-1}(j)}\right)\left(\frac{X_t(j)}{X_{t-1}(j)}\right) + \left(1 - \Phi\left(\frac{X_t(j)}{X_{t-1}(j)}\right)\right) \\ F_2(X_t(j), X_{t-1}(j)) &= \Phi'\left(\frac{X_t(j)}{X_{t-1}(j)}\right)\left(\frac{X_t(j)}{X_{t-1}(j)}\right)^2 \end{aligned} \tag{13}$$

2.1.1 Intratemporal Allocation

Household j minimizes, each period, its consumption expenditure $\int_0^n p_t(h)c_t(h,j)dh + \int_n^1 p_t(f)c_t(f,j)dj$ subject to $C_t = 1$. We denote with P_t the Lagrange multiplier to that problem. This gives the following optimal demand functions:

$$c_t(h,j) = \frac{1}{n}\left(\frac{p_t(h)}{P_{H,t}}\right)^{-\theta} C_{H,t} = \frac{\gamma_c}{n}\left(\frac{p_t(h)}{P_{H,t}}\right)^{-\theta}\left(\frac{P_{H,t}}{P_t}\right)^{-\epsilon} C_t(j) \tag{14}$$

$$c_t(f,j) = \frac{1}{1-n}\left(\frac{p_t(f)}{P_{F,t}}\right)^{-\theta} C_{F,t}(j) = \frac{(1-\gamma_c)}{1-n}\left(\frac{p_t(f)}{P_{F,t}}\right)^{-\theta}\left(\frac{P_{F,t}}{P_t}\right)^{-\epsilon} C_t(j) \tag{15}$$

The corresponding optimal CES price indices are given by:

$$P_{H,t} = \left[\frac{1}{n}\int_0^n p_t(h)^{1-\theta} dh\right]^{\frac{1}{1-\theta}} \tag{16}$$

$$P_{F,t} = \left[\frac{1}{1-n}\int_n^1 p_t(f)^{1-\theta} df\right]^{\frac{1}{1-\theta}} \tag{17}$$

$$P_t = \left[\gamma_c P_{H,t}^{1-\epsilon} + (1-\gamma_c) P_{F,t}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{18}$$

The investment demand functions and the price of investment goods[4] are given by:

$$x_t(h,j) = \frac{1}{n}\left(\frac{p_t(h)}{P_{H,t}}\right)^{-\theta} X_{H,t} = \frac{\gamma_x}{n}\left(\frac{p_t(h)}{P_{H,t}}\right)^{-\theta}\left(\frac{P_{H,t}}{P_{X,t}}\right)^{-\epsilon} X_t(j) \tag{19}$$

$$x_t(f,j) = \frac{1}{1-n}\left(\frac{p_t(f)}{P_{F,t}}\right)^{-\theta} X_{F,t}(j) = \frac{(1-\gamma_x)}{1-n}\left(\frac{p_t(f)}{P_{F,t}}\right)^{-\theta}\left(\frac{P_{F,t}}{P_{X,t}}\right)^{-\epsilon} X_t(j) \tag{20}$$

$$P_{X,t} = \left[\gamma_x P_{H,t}^{1-\epsilon} + (1-\gamma_x) P_{F,t}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{21}$$

[4]Note that the price for investment goods, $P_{X,t}$, may differ from the consumer price index, P_t, as the weights that determine the composition between domestic and foreign goods may differ.

2.1.2 Consumption and Saving Behavior

The consumer maximizes the objective function (8) subject to equations (10) and (11). Denote by λ_t^j the households Lagrange multiplier on the budget constraint and by Q_t the households constraint on the law of motion of the capital stock . The first order conditions with respect to consumption and the holdings of domestic and foreign-currency denominated state-contingent securities, give:

$$\lambda_t = \varepsilon_t^C \left(C_t(j) - H_t\right)^{-\sigma_c} \tag{22}$$

$$1 = \beta E_t \left\{ \frac{\lambda_{t+1}(j)}{\lambda_t(j)} \frac{P_t}{P_{t+1}} (1 + i_t) \right\} \tag{23}$$

$$1 = \beta E_t \left\{ \frac{\lambda_{t+1}(j)}{\lambda_t(j)} \frac{S_{t+1}}{S_t} \frac{P_t}{P_{t+1}} (1 + i_t^*) \right\} \tag{24}$$

where i_t (i_t^*) denotes the domestic (foreign) net nominal interest rate, which is given by $(1 + i_t) = \sum_{s^{t+1}} P_B\left(s^{t+1}, s^t\right)$ and $(1 + i_t^*) = \sum_{s^{t+1}} P_B^*\left(s^{t+1}, s^t\right)$ respectively.

The household's first order conditions with respect to investment, the capital stock, and the multiplier on the capital law of motion are:

$$1 = Q_t(j)\varepsilon_t^X F_1\left(X_t(j), X_{t-1}(j)\right) + \beta E_t \left\{ \begin{array}{c} \frac{\varepsilon_{t+1}^C (C_{t+1}(j) - H_{t+1})^{-\sigma_c}}{\varepsilon_t^C (C_t(j) - H_t)^{-\sigma_c}} \\ \frac{P_{t+1}^X}{P_{t+1}} \frac{P_t}{P_t^X} Q_{t+1}(j) \varepsilon_{t+1}^X F_2\left(X_{t+1}(j), X_t(j)\right) \end{array} \right\} \tag{25}$$

$$Q_t(j) \frac{P_t^X}{P_t} = \beta E_t \left\{ \begin{array}{c} \frac{\varepsilon_{t+1}^C (C_{t+1}(j) - H_{t+1})^{-\sigma_c}}{\varepsilon_t^C (C_t(j) - H_t)^{-\sigma_c}} \\ \left[\frac{P_{t+1}^X}{P_{t+1}} Q_{t+1}(j) (1 - \delta) + \frac{R_{t+1}^{k\ nom}}{P_{t+1}} \right] \end{array} \right\} \tag{26}$$

$$K_t(j) = (1 - \delta) K_{t-1}(j) + \varepsilon_t^X F\left(X_t(j), X_{t-1}(j)\right) \tag{27}$$

2.1.3 Labor Supply Decision and Wage Setting Equation

Each household j provides a differentiated type of labor services to firms, acting as a price-setter in the labor market. Following, Kollmann (2001), Erceg et al. (2000), Smets & Wouters (2003*a*), we assume that wages can only be optimally adjusted after some random 'wage-change signal' is received. The probability that household j can change its nominal wage in period t is constant and equal to $1-\xi_w$. A household that receives such a signal will set a new nominal wage to maximize expected utility subject to the firm's demand for labor of household j, given by equation (33).

The maximization problem of those households that reoptimize, results in the following markup equation for the optimal nominal wage, $W_t^{nom,o}(j)$, of household j:

$$W_t^{nom,o}(j) = \left\{ \frac{\lambda_w}{\lambda_w - 1} \frac{\sum_{k=t}^{\infty} (\beta\xi_w)^k E_t \left\{ \varepsilon_{l,t+k} \left[\left(W_{t+k}^{nom}\right)^{\lambda_w(1+\sigma_l)} L_{t+k}^{(1+\sigma_l)} \right] \right\}}{\sum_{k=t}^{\infty} (\beta\xi_w)^k E_t \left\{ \left[\left(W_{t+k}^{nom}\right)^{\lambda_w} L_{t+k} \right] \left(C_{t+k}^i - H_{t+k}\right)^{-\sigma_c} P_{t+k}^{-1} \right\}} \right\}^{\frac{1}{1+\lambda_w\sigma_l}} \tag{28}$$

Parameter λ_w is the elasticity of substitution among differentiated labor types. We define parameter μ_w as the wage markup, that is $1+\mu_w = \frac{\lambda_w}{\lambda_w-1}$. We allow for shocks to the wage markup, which are assumed to be i.i.d. normal around a constant, $\mu_{w,t} = \mu_w + u_{\mu_w,t}$. As in the case of price setting, we allow for partial indexation of wages, for those households that are not allowed to optimally reset their wage rate in period t. More formally, the wages of households that cannot reoptimize adjust according to:

$$W_t^{nom} = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1}^{nom} \tag{29}$$

From the equilibrium price indices, equation (34), and the optimal wage setting relation (28) and from equation (29), we can derive the law of motion of the aggregate wage index:

$$\left(W_t^{nom}\right)^{1-\lambda_w} = \xi_w \left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1}^{nom}\right)^{1-\lambda_w} + \left(1-\xi_w\right)\left(W_t^{nom,o}\left(j\right)\right)^{1-\lambda_w} \tag{30}$$

2.2 Firm Behavior

Firms in the domestic economy specialize in the production of a country specific good that comes in many varieties. The firm producing variety h has access to the following Cobb-Douglas production function:

$$y_t\left(h\right) = F\left(K_{t-1}\left(h\right), L_t\left(h\right)\right) = A_t K_{t-1}\left(h\right)^{\alpha} L_t\left(h\right)^{1-\alpha} \tag{31}$$

where A_t denotes total factor productivity, $K_t\left(h\right)$ denotes the capital stock that is used in firm h's production and $L_t\left(h\right)$ denotes an index of different types of labor services. It rents the capital stock and differentiated types of labor from households. The firm behaves as a monopolistic competitor and sets prices $p_t\left(h\right)$ and $p_t^*\left(h\right)$ in the local and foreign market to maximize profits, taking as given households' demand for that good. Demand for the domestic good is given by domestic households' demand for the domestic consumption and investment goods, $y_t^D\left(h\right)$, by foreign households' demand for domestic consumption and investment goods, $y_t^{D*}\left(h\right)$, and by the domestic country's government expenditure, which is assumed to fall on domestic goods entirely. [5]

[5] Similarly, we assume that foreign government consumption falls entirely on foreign goods. The domestic and foreign demand for the h good is formally given by:

$$y_t^D\left(h\right) = \int_0^n c_t\left(h,j\right)dj + \int_0^n x_t\left(h,j\right)dj + \int_0^n G_t\left(j\right)dj$$

$$y_t^{D*}\left(h\right) = \int_n^1 c_t^*\left(h,j\right)dj^* + \int_n^1 x_t^*\left(h,j^*\right)dj^* + \int_n^1 G_t^*\left(j^*\right)dj^*$$

2.2.1 Producer's Optimal Choice for Labor Types

We assume that the labor services supplied by households come in different types. The continuum of labor types is defined as the Dixit-Stiglitz index:

$$L_t\left(h\right) = \left[\left(\frac{1}{n}\right)^{\frac{1}{\lambda_w}} \int_0^n l_t(h,j)^{\frac{\lambda_w - 1}{\lambda_w}} dh\right]^{\frac{\lambda_w}{\lambda_w - 1}} \tag{32}$$

Optimal labor demand of type j and the aggregate nominal wage index are given by:

$$l_t\left(h,j\right) = \frac{1}{n}\left(\frac{W_t^{nom}\left(j\right)}{W_t^{nom}}\right)^{-\lambda_w} L_t(h) \tag{33}$$

$$W_t^{nom} = \left[\frac{1}{n}\int_0^n W_t^{nom}(j)^{1-\lambda_w} dj\right]^{\frac{1}{1-\lambda_w}} \tag{34}$$

The firm's problem can be decomposed into a cost minimization problem and a profit maximization problem:

2.2.2 Producer as a Cost Minimizer

Cost minimization gives firm h's optimal capital-labor ratio, which will be identical across all domestic intermediate good producers, and therefore coincides with the aggregate capital-labor ratio:

$$\frac{1-\alpha}{\alpha} = \frac{W_t^{nom} L_t\left(h\right)}{R_t^{k,nom} K_{t-1}\left(h\right)} \tag{35}$$

where $R_t^{k,nom}$ is the (nominal) rental rate of capital. Marginal costs of firm h are also the same for all domestic intermediate producing firms, i.e. $MC_t^{nom}(h) = MC_t^{nom}$, and are given by:

$$MC_t^{nom} = \frac{1}{A_t} \frac{\left(R_t^{k,nom}\right)^{\alpha} \left(W_t^{nom}\right)^{1-\alpha}}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}} \tag{36}$$

2.2.3 Producer as a Profit Maximizer

We assume that each domestic intermediate firm h has market power in the market for its own good and maximizes expected profits using a discount rate (from period t to $t+k$) $\beta^k \Lambda_{t,t+k}$, where $\Lambda_{t,t+k} = \frac{U_{C,t+k}}{U_{C,t}} \frac{P_t}{P_{t+k}}$. Firm h takes as given the demand for its goods (as given by the expressions in footnote 5) and serves the whole market. Firms are not allowed to change their price every period, but cannot change their price unless they receive a 'price-change signal'. The probability that a given price can be reoptimized at period t is assumed to be constant and equal to ξ_P. Whenever the firm is not allowed to reset its price contract, the firm's price is automatically increased according to the following formula :

$$P_{H,t} = P_{H,t-1} \pi_{H,t-1}^{\gamma_p} \tag{37}$$

where $\pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$ and γ_p denotes a parameter measuring the degree of indexation.

Under sticky prices according to the Calvo mechanism and assuming producer currency price setting, the firm maximization problem is:

$$\underset{p_t(h), p_t^*(h)}{max} E_t \sum_{k=t}^{\infty} (\beta \xi_P)^k \Lambda_{t,t+k} \left\{ \begin{array}{c} \left[\frac{p_t(h)}{P_{H,t+k}} - \frac{MC_t^{nom}}{P_{H,t+k}}\right] y_{t+k}^{D}(h) + \\ + \left[\frac{S_{t+k} p_t^*(h)}{P_{H,t+k}^*} - \frac{MC_{t\pm k}^{nom}}{P_{H,t+k}^*}\right] y_{t+k}^{D*}(h) \end{array} \right\} \tag{38}$$

The first order condition to the above maximization problem gives the following equation for the optimal price, $p_t^o(h)$:

$$p_t^o(h) = \frac{\theta}{(\theta-1)} \frac{\sum\limits_{k=t}^{\infty} (\beta\xi_P)^k E_t \left\{ \Lambda_{t,t+k} P_{H,t+k}^{1-\theta} Y_{H,t+k}^D MC_{t+k}^{nom} \right\}}{\sum\limits_{k=t}^{\infty} (\beta\xi_P)^k E_t \left\{ \Lambda_{t,t+k} P_{H,t+k}^{1-\theta} Y_{H,t+k}^D \right\}} \tag{39}$$

Similarly to the Calvo wage setting we allow for an i.i.d. price markup shock given by $\mu_{P,t} = \mu_P + u_{\mu_P,t}$, where $1 + \mu_w = \frac{\theta}{(\theta-1)}$ and μ_P denotes the markup of prices over future marginal costs.

Under producer currency price setting, the law of one price holds at the individual good level, and the price in the foreign market is given by $S_t p_t^{o*}(h) = p_t^o(h)$.[6] From the equilibrium price indices, equation (16), and the optimal price setting relation (39) and from equation (37), we can derive how prices in the domestic intermediate sector evolve over time:

$$P_{H,t}^{1-\theta} = \xi_P \left(P_{H,t-1} \pi_{H,t-1}^{\gamma_p} \right)^{1-\theta} + (1-\xi_P)\, p_t^o(h) \tag{40}$$

2.3 Monetary and Fiscal Policy

The monetary authority is assumed to apply an interest-feedback rule. The domestic and foreign monetary authorities set an interest rate in order to target inflation and the output gap according to a Taylor rule. We assume that before the onset of the monetary union

[6]Note that when prices are flexible equation (39) reduces to the standard expression of the price as a markup over current marginal costs:

$$p_t(h) = \frac{\theta}{(1-\theta)} MC_t^{nom}(h)$$

the central banks of both regions could act independently. For the Austrian economy this assumption is likely to exaggerate the degree of independence in its monetary policy decisions, since from the early 1980s on it closely pegged the Austrian Schilling to the Deutschmark. The monetary policy rules in the domestic and foreign economy are:

$$\frac{1+i_t}{1+\bar{i}} = \left[\frac{1+i_{t-1}}{1+\bar{i}}\right]^{\rho_i} \left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\rho_\pi} \left(\frac{Y_t}{\overline{Y}}\right)^{\rho_Y}\right]^{1-\rho_i} e^{u_{i,t}} \tag{41}$$

$$\frac{1+i^*_t}{1+\overline{i^*}} = \left[\frac{1+i^*_{t-1}}{1+\overline{i^*}}\right]^{\rho^*_i} \left[\left(\frac{\pi^*_t}{\overline{\pi^*}}\right)^{\rho^*_\pi} \left(\frac{Y^*_t}{\overline{Y^*}}\right)^{\rho^*_Y}\right]^{1-\rho^*_i} e^{u^*_{i,t}} \tag{42}$$

where $u_{i,t}$ and u_{i*} denote a domestic or foreign monetary policy shock. After the final stage of the EMU in 1999, monetary policy in the currency union is set by a sole authority which applies the following rule:

$$\frac{1+i^{emu}_t}{1+\overline{i^{emu}}} = \left[\frac{1+i^{emu}_{t-1}}{1+\overline{i^{emu}}}\right]^{\rho^{emu}_i} \left[\left(\frac{\pi^{emu}_t}{\overline{\pi^{emu}}}\right)^{\rho^{emu}_\pi} \left(\frac{Y^{emu}_t}{\overline{Y^{emu}}}\right)^{\rho^{emu}_Y}\right]^{1-\rho^{emu}_i} e^{u^{emu}_{i,t}} \tag{43}$$

The role of fiscal policy in the model is highly simplified. Government spending is assumed to be financed by lump-sum taxes. The government is not allowed to run budget deficits, and its budget constraint therefore is [7]:

$$P_t G_t + TR_t = TAX_t \tag{44}$$

$$P^*_t G^*_t + TR^*_t = TAX^*_t \tag{45}$$

[7]This proposed rule for the public sector is clearly much stricter than the one implied by the Stability and Growth pact. Ratto et al. (2007) propose a model in which European fiscal policy issues are more specifically addressed.

2.4 Other Equilibrium Conditions

Equilibrium in the factor markets requires:

$$L_t = \int_0^n L_t(h)\, dh = \int_0^n \int_0^n l_t(h, j)\, dh dj \tag{46}$$

$$L_t^* = \int_n^1 L_t^*(f)\, df = \int_n^1 \int_n^1 l_t^*(f, j^*)\, df dj^* \tag{47}$$

$$K_t = \int_0^n K_t(h)\, dh \tag{48}$$

$$K_t^* = \int_n^1 K_t^*(f)\, df \tag{49}$$

The countries' resource constraints hold:

$$Y_t = (C_{H,t} + X_{H,t}) + \frac{1-n}{n}\left(C_{H,t}^* + X_{H,t}^*\right) + G_t \tag{50}$$

$$Y_t^* = \frac{n}{(1-n)}(C_{F,t} + X_{F,t}) + \left(C_{F,t}^* + X_{F,t}^*\right) + G_t^* \tag{51}$$

2.4.1 Exogenous Processes

This section summarizes the shock processes of our model economy: the model of the flexible exchange rate regime includes 16 exogenous shock variables, the currency union model features a total of 15 shock variables. We model productivity, A (A^*), government expenditures, G (G^*), consumption preference shocks, ϵ^C (ϵ^{C*}), labor supply shocks, ϵ^L (ϵ^{L*}), and investment shocks, ϵ^X (ϵ^{X*}) as autoregressive processes, with persistence parameters ρ_j and and with zero mean disturbances (u_j) whose standard deviation is σ_j, for $j = A, A^*, G, G^*, \epsilon^C, \epsilon^{C*}, \epsilon^L, \epsilon^{L*}, \epsilon^X, \epsilon^{X*}$.

$$\begin{aligned}
A_t &= \rho_A A_{t-1} + u_{A,t} \qquad (52)\\
A^*_t &= \rho^*_A A^*_{t-1} + u^*_{A,t}\\
G_t &= \rho_G G_{t-1} + u_{G,t}\\
G^*_t &= \rho^*_G G^*_{t-1} + u^*_{G,t}\\
\varepsilon^C_t &= \rho_c \varepsilon^C_{t-1} + u_{C,t}\\
\varepsilon^{C*}_t &= \rho_c \varepsilon^{C*}_{t-1} + u^*_{C,t}\\
\varepsilon^L_t &= \rho_L \varepsilon^L_{t-1} + u_{L,t}\\
\varepsilon^{L*}_t &= \rho_L \varepsilon^{L*}_{t-1} + u^*_{L,t}\\
\varepsilon^X_t &= \rho_X \varepsilon^X_{t-1} + u_{X,t}\\
\varepsilon^{X*}_t &= \rho_X \varepsilon^{X*}_{t-1} + u^*_{X,t}
\end{aligned}$$

In addition to the shocks of autoregressive nature, the model features a number of i.i.d. independent shocks: the shocks to price and wage setting, as well as to the monetary policy rules, with mean zero disturbances and and respective standard deviations of $\sigma_{\mu_{P,t}}$, $\sigma^*_{\mu_{P,t}}$,$\sigma_{\mu_{w,t}}$,$\sigma^*_{\mu_{w,t}}$, and σ_i,σ^*_i, or σ^{emu}_i respectively.

To proceed, the model is transformed such that all variables are in aggregate (per capita) terms. Also, we define inflation rates $\pi_t = \frac{P_t}{P_{t-1}}$, $\pi^*_t = \frac{P^*_t}{P^*_{t-1}}$, the rate of nominal depreciation $\Delta_t = \frac{S_t}{S_{t-1}}$, the real exchange rate $RER_t = \frac{S_t P^*_t}{P_t}$, and the terms of trade $TOT_t = \frac{P_{F,t}}{S_z P^*_{H,t}}$. All other domestic nominal variables are normalized by the domestic CPI, all other foreign nominal variables are normalized by the foreign CPI, i.e., we denote: $p_H = \frac{P_H}{P}$, $p_F = \frac{P_F}{P}$, $p_X = \frac{P_X}{P}$, $p^*_H = \frac{P^*_H}{P^*}$, $p^*_F = \frac{P^*_F}{P^*}$, $p^*_X = \frac{P^*_X}{P^*}$, $MC = \frac{MC^{nom}}{P}$, $W = \frac{W^{nom}}{P}$, $R^K = \frac{R^{K,nom}}{P}$.

The model, such transformed, can then be log-linearized around the non-stochastic steady state and solved by any of the many readily available algorithms for solving linear rational expectation models in order to study the model's dynamics.

3 The Log-Linearized Model

This section turns to briefly summarizing the model's equations in log-linear form. Throughout the paper, a variable with a hat denotes log-linearized variables, i.e. $\widehat{Z}_t = \frac{dZ_t}{Z}$. The first set of equations we lay out holds for the domestic and foreign country. We present, again, only the equations for the domestic country with an understanding that an equivalent set of log-linearized equilibrium conditions hold in the foreign economy.

The *consumption Euler equation* is given by:

$$\widehat{C}_t = \frac{h}{1+h}\widehat{C}_{t-1} + \frac{1}{1+h}E_t\widehat{C}_{t+1} - \frac{1-h}{\sigma_c(1+h)}\left(\beta\widehat{(1+i_t)} - E_t\pi_{t+1} + E_t\widehat{\varepsilon}^C_{t+1} - \widehat{\varepsilon}^C_t\right) \quad (53)$$

Relative to the standard consumption Euler equation under constant relative risk aversion preferences, the inclusion of habit persistence makes current consumption dependent on a weighted average of past and expected future consumption which tends to reduce the impact of the real interest on consumption for any given elasticity of substitution.

The *investment equation* is given by:

$$0 = \left(\widehat{Q}_t + \widehat{\varepsilon}^X_t\right) - \widetilde{S}''(1)\left(\widehat{X}_t - \widehat{X}_{t-1}\right) + \beta\widetilde{S}''(1)\left(\widehat{X}_{t+1} - \widehat{X}_t\right) \quad (54)$$

where, as in Smets & Wouters (2003*a*), the presence of the capital adjustment cost helps in capturing the hump-shaped behavior of investment in response to various shocks, including monetary policy shocks.

The *capital Euler equation* is given by:

$$\left(\widehat{Q}_t + \widehat{p}_t^X\right) = \left[\beta\left(1-\delta\right)\left(\begin{array}{c} \widehat{Q}_{t+1} + \widehat{p}_{t+1}^X + \widehat{\varepsilon}_{t+1}^C - \widehat{\varepsilon}_t^C + \\ \frac{-\sigma_c}{(1-h)}\widehat{C}_{t+1} + \frac{\sigma_c(1+h)}{(1-h)}\widehat{C}_t - \frac{\sigma_c h}{(1-h)}\widehat{C}_{t-1} \end{array}\right) + \left(1-\beta\left(1-\delta\right)\right)\widehat{R}_{t+1}^k\right] \tag{55}$$

The log-linear form of the *capital law of motion* reads:

$$\widehat{K}_t = \left(1-\delta\right)\widehat{K}_{t-1} + \delta\widehat{\varepsilon}_t^X + \delta\widehat{X}_t \tag{56}$$

The *inflation equation* is given by:

$$\widehat{\pi}_{H,t} = \left[\frac{\left(1-\xi_P\right)\left(1-\beta\xi_P\right)}{\xi_P}\left(\widehat{MC}_t - \widehat{p}_{H,t} + u_t^{\mu_P}\right) + \beta E_t\widehat{\pi}_{H,t+1} - \beta\xi_P\gamma_P\widehat{\pi}_{H,t} + \gamma_P\widehat{\pi}_{H,t-1}\right] \tag{57}$$

Due to the inclusion of partial price indexation, the above equation is a more general specification of the New-Keynesian Phillips curve, in which current inflation depends not only on future expected inflation but also on past inflation, in addition of (current) real marginal costs. When $\gamma_P = 0$, equation (57) reduces to the more standard, purely forward-looking Phillips curve. As is typical in this setup, the elasticity of inflation with respect to changes in marginal costs depends mainly on the degree of price stickiness, ξ_P.

In a similar manner, the *Wage Phillips curve*, including partial wage indexation, is given by:

$$\widehat{W}_t\left(1+\beta\right) = \left[\begin{array}{c} \frac{(1-\beta\xi_w)1-\xi_w}{(1+\lambda_w\sigma_L)\xi_w}\left(\sigma_l\widehat{L}_t + \widehat{\varepsilon}_t^L + \frac{\sigma}{1-h}\left(\widehat{C}_t - h\widehat{C}_{t-1}\right) - \widehat{W}_t + u_t^{\mu_w}\right) + \\ \beta E_t\widehat{\pi}_{t+1} - \widehat{\pi}_t + \beta E_t\widehat{W}_{t+1} + \widehat{W}_{t-1} + \gamma_w\widehat{\pi}_{t-1} - \beta\xi_w\gamma_w\widehat{\pi}_t \end{array}\right] \tag{58}$$

The log-linear versions of the *production function*, firms' *optimal factor input ratio*, and *real marginal costs* are given by:

$$\widehat{Y}_t = \widehat{A}_t + \alpha \widehat{K}_{t-1} + (1-\alpha)\,\widehat{L}_t \tag{59}$$

$$\widehat{W}_t + \widehat{L}_t = \widehat{R}^k_t + \ \widehat{K}_{t-1} \tag{60}$$

$$\widehat{MC}_t = \alpha \widehat{R}^k_t + (1-\alpha)\,\widehat{W}_t - \widehat{A}_t \tag{61}$$

Following Smets & Wouters (2003a), we introduce employment in our model, for which a similar Calvo type mechanism is used as for price and wage setting. We assume that at any given period only a constant fraction, ξ_E, of firms is able to adjust employment to its desired total labor input, and therefore employment responds more slowly to macroeconomic shocks than total hours worked. We include employment in our model, since, for the Euro Area, as well as for Austria, time series on aggregate hours worked are not available on a quarterly basis. The Calvo mechanism for adjustments in employment leads to the following auxiliary equation for *employment*:

$$\Delta\widehat{empl}_t = \frac{(1-\xi_E)\,(1-\beta\xi_E)}{\xi_E}\left(\widehat{L}_t - \widehat{empl}_t\right) + \beta\Delta\widehat{empl}_{t+1} \tag{62}$$

While for the above equations a similar set of equilibrium conditions hold for the foreign economy, we now discuss the assumptions on monetary policy and then turn to the set of equilibrium conditions common to both countries.

Monetary policy is given by the log-linear versions of the Taylor rules given in equation (41) and (42) for the policy regime before 1999, and by equation (43) after the onset of the EMU:

$$(\widehat{1+i_t}) = \rho_i(\widehat{1+i_{t-1}}) + (1-\rho_i)\left[\rho_\pi\left(\widehat{\pi}_t - \overline{\pi}\right) + \rho_Y\left(\widehat{Y}_t - \overline{Y}\right)\right] + u_{i,t} \tag{63}$$

$$\widehat{(1+i_t^*)} = \rho_i^* \widehat{(1+i_{t-1}^*)} + (1-\rho_i^*)\left[\rho_\pi^*\left(\widehat{\pi}_t^* - \overline{\pi}^*\right) + \rho_Y^*\left(\widehat{Y}_t^* - \overline{Y}^*\right)\right] + u_{i,t}^* \tag{64}$$

$$\widehat{(1+i_t^{emu})} = \rho_i^{emu} \widehat{(1+i_{t-1}^{emu})} + (1-\rho_i^{emu})\left[\rho_\pi^{emu}\left(\widehat{\pi}_t^{emu} - \overline{\pi}^{emu}\right) + \rho_Y^{emu}\left(\widehat{Y}_t^{emu} - \overline{Y}^{emu}\right)\right] + u_{i,t}^{emu} \tag{65}$$

From domestic and foreign households' first order condition with respect to foreign-currency denominated Arrow-Debreu-securities we can derive an equation relating the change in the real exchange rate to the change in foreign's marginal utility relative to home's change in marginal utility. Iterating backwards, we arrive at the risk sharing equation (under complete markets) which links the (level of) the real exchange rate to (the level of) the ratio of marginal utilities[8]. In log-linear form, the expression for the real exchange rate is given by the log-linearizing the *risk sharing equation*:

$$\widehat{RER}_t = \left[\widehat{\varepsilon}_t^{*C} - \widehat{\varepsilon}_t^{C} - \frac{\sigma_c}{(1-h)}\left(\widehat{C}_t^* - h\widehat{C}_{t-1}^*\right) + \sigma_c \frac{\sigma_c}{(1-h)}\left(\widehat{C}_t - h\widehat{C}_{t-1}\right)\right] \tag{66}$$

Under the flexible exchange rate regime, the nominal exchange rate is given by the following dynamic definition of the rate of (nominal) *depreciation*:

[8] Formally, from the domestic and foreign FOCs w.r.t foreign-currency denominated Arrow-Debreu-securities:

$$1 = \beta E_t \left\{ \frac{U_{C,t+1}}{U_{C,t}} \frac{S_{t+1}}{S_t} \frac{P_t}{P_{t+1}} (1+i_t^*) \right\} \quad \text{and} \quad 1 = \beta E_t \left\{ \frac{U_{C,t+1}^*}{U_{C,t}^*} \frac{P_t^*}{P_{t+1}^*} (1+i_t^*) \right\}$$

from which:

$$\frac{RER_{t+1}}{RER_t} = \frac{U_{C,t+1}^*/U_{C,t}^*}{U_{C,t+1}/U_{C,t}}$$

Iterating back to 0 gives:

$$RER_t = \kappa \frac{U_{C,t}^*}{U_{C,t}}$$

where κ is a constant depending on initial conditions.

$$\Delta_t = \widehat{RER}_t - \widehat{RER}_{t-1} + \widehat{\pi}_t - \widehat{\pi}_t^* \tag{67}$$

For the currency union regime, when exchange rates are fixed the above equation reduces to:

$$\widehat{RER}_t - \widehat{RER}_{t-1} = \widehat{\pi}_t^* - \widehat{\pi}_t \tag{68}$$

The *good markets clearing* in the domestic and foreign economy is given by:

$$\begin{aligned} \widehat{Y}_t \;&=\; \frac{G}{Y}\widehat{G}_t + p_H^{-\epsilon}\gamma_c \frac{C}{Y}\left(\widehat{C}_t - \epsilon\widehat{p}_{H,t}\right) + \\ &+\left(\frac{p_H}{p_X}\right)^{-\epsilon}\gamma_x \frac{X}{Y}\left(\widehat{X}_t + \epsilon\widehat{p}_{X,t} - \epsilon\widehat{p}_{H,t}\right) + \\ &+\frac{1-n}{n} p_H^{*-\epsilon}\gamma_c^* \frac{Y^*}{Y}\frac{C^*}{Y^*}\left(\widehat{C}_t^* - \epsilon\widehat{p}_{H,t}^*\right) + \\ &+\frac{1-n}{n}\left(\frac{p_H^*}{p_X^*}\right)^{-\epsilon}\gamma_x^* \frac{Y^*}{Y}\frac{X^*}{Y^*}\left(\widehat{X}_t^* + \epsilon\widehat{p}_{X,t}^* - \epsilon\widehat{p}_{H,t}^*\right) \end{aligned} \tag{69}$$

$$\begin{aligned} \widehat{Y}_t^* \;&=\; \frac{G^*}{Y^*}\widehat{G}_t^* + \frac{n}{1-n} p_F^{-\epsilon}\left(1-\gamma_c\right)\frac{C}{Y}\frac{Y}{Y^*}\left(\widehat{C}_t - \epsilon\widehat{p}_{F,t}\right) + \\ &+\frac{n}{1-n}\left(\frac{p_F}{p_X}\right)^{-\epsilon}\left(1-\gamma_x\right)\frac{X}{Y}\frac{Y}{Y^*}\left(\widehat{X}_t + \epsilon\widehat{p}_t^X - \epsilon\widehat{p}_{F,t}\right) + \\ &+p_F^{*-\epsilon}\left(1-\gamma_c^*\right)\frac{C^*}{Y^*}\left(\widehat{C}_t^* - \epsilon\widehat{p}_{F,t}^*\right) + \\ &+\left(\frac{p_F^*}{p_X^*}\right)^{-\epsilon}\left(1-\gamma_x^*\right)\frac{X^*}{Y^*}\left(\widehat{X}_t^* + \epsilon\widehat{p}_t^{X*} - \epsilon\widehat{p}_{F,t}^*\right) \end{aligned} \tag{70}$$

4 Data and Measurement Issues

4.1 Data

To estimate the model we use quarterly Euro area data from the AWM (Area Wide Model) database by Fagan et al. (2001), in its most recent update[9], and quarterly Austrian national accounts data from the Austrian Institute of Economic Research (WIFO, own calculations). The time period covered is 1976:Q1-2005:Q1. To estimate the baseline model we decide to match a set of fourteen variables: for both Austria and the Euro Area aggregates we use time series for GDP, consumption, investment, employment, real wages, inflation, and the nominal interest rate. In the case of the AWM data, time series series of 12 individual countries are re-based to the same year and then weighted (with fixed weights) and joined, which creates synthetic Euro data. The countries included in the AWM dataset and their respective weights (in parenthesis) are Austria (0.030), Belgium (0.036), Finland (0.017), France (0.201), Germany (0.283), Greece (0.025), Ireland (0.019), Italy (0.195), Luxembourg (0.003), the Netherlands (0.060), Portugal (0.024) and Spain (0.111).

Figure 1 gives a graphical representation of the times series used in the estimation. The time series are depicted in terms of deviations from trend, as obtained by applying the Hodrik-Prescott Filter with smoothing parameter $\lambda = 1600$. Also, Table 1 presents stylized business cycle facts for the Austrian economy and the aggregated Euro Area data of the Area Wide Model, derived from the HP-filtered data. For the Euro Area, as it is typical for developed economies, consumption is slightly less volatile than output (0.97 times as volatile, over the entire sample, 1976:Q1-2005:Q1), while investment is several times more volatile than output (2.67 times as volatile, over the entire sample). Comparing the pre-EMU and the EMU subsamples we can observe that the volatility of consumption and investment has decreased in the latter sample. For the Austrian economy similar stylized facts are presented. We again find a substantially higher standard deviation of investment relative to output (2.92 over the entire sample), but a consumption volatility that is about

[9]The updated AWM database starts in 1970q1 (for most variables) and is available until 2005q4.

as high as those of output (to be precise, even 1.01 times that of output). Surprisingly, the Austrian consumption volatility (relative to output) as well as the investment volatility increases in the EMU subsample relative to the pre-EMU subsample. Likely reasons for this finding are issues of data measurement rather than an economic meaning and are related to revisions of Austria's National Accounts data in order to comply to the universal guidelines of the System of National Accounts (SNA 1995). In particular, only crude revisions have been made for the time series before 1995.[10]

4.2 Measurement Issues

When estimating the parameters of a stylized model it is of great importance that any variable that is carried in the model corresponds as closely as possible to the respective observed variable, that is, to what is captured by the variable in the data. In the following we denote observed variables with a $\widetilde{}$. There are a number of differences between data and model which need to be considered:

First, we follow Adolfson et al. (2007) to describe how consumption, investment and output should be measured in order to correspond to the data, and write the real GDP identity as:

$$Y_t = \widetilde{C}_t + \widetilde{X}_t + \widetilde{G}_t + \widetilde{EXP}_t - \widetilde{IMP}_t \tag{71}$$

where we have that:

$$\begin{aligned} \widetilde{C}_t &= C_{H,t} + C_{F,t} \\ \widetilde{X}_t &= X_{H,t} + X_{F,t} \\ \widetilde{EXP}_t &= C^*_{H,t} + X^*_{H,t} \\ \widetilde{IMP}_t &= C_{F,t} + X_{F,t} \end{aligned} \tag{72}$$

[10]We thank Marcus Scheiblecker (WIFO) for providing us with the revised data back to 1976.

In the theoretical model, the above equation (equation (71)) corresponds to the aggregate production resource constraint. In the model the aggregate resource constraint is given by equation (50), which we rearrange such as to link it to equation (71):

$$Y_t = (C_{H,t} + C_{F,t}) + (X_{H,t} + X_{F,t}) + G_t + \frac{1-n}{n}\left(C^*_{H,t} + X^*_{H,t}\right) - (C_{F,t} + X_{F,t}) \tag{73}$$

Comparing the GDP identity from the data (equation (71)) with the above equation we can see that, for example, consumption as defined in the model (which is given by a CES index over domestic and foreign goods, as given by equation (2)) does not measure the same as observed variable $\widetilde{C}_t$, which is the sum of domestic and foreign goods. For matching the model most closely with the data, we should therefore define a new variable, $\widetilde{C}_t = C_{H,t} + C_{F,t}$, in our model. Observed investment, $\widetilde{X}_t$, needs to be similarly introduced in the model.

Second, observed inflation and nominal interest rates data are usually reported in annualized terms, while in the model they are treated as quarterly variables. We therefore introduce annualized inflation and nominal interest rate in the model and declare them observed variables.

Third, we need to create variables in the model that correspond to Euro Area data, of which Austrian data form part of (although a small one). Since in the model the Home economy represents Austria and the Foreign economy 'the rest of the European Monetary Union' we need to take a country size-weighted average of domestic and foreign variables as observed variables corresponding to the Euro area time series.

The vector of observed variables can then be summarized (in log-linear terms) as:

$$
\begin{bmatrix}
\widetilde{Y}_t^{HP,\,AUT} \\
\widetilde{C}_t^{HP,\,AUT} \\
\widetilde{X}_t^{HP,\,AUT} \\
\widetilde{empl}_t^{HP,\,AUT} \\
\widetilde{W}_t^{HP,\,AUT} \\
\widetilde{\pi}_t^{HP,\,AUT} \\
\widetilde{i}_t^{HP,\,AUT} \\
\widetilde{Y}_t^{HP,\,EA} \\
\widetilde{C}_t^{HP,\,EA} \\
\widetilde{X}_t^{HP,\,EA} \\
\widetilde{empl}_t^{HP,\,EA} \\
\widetilde{W}_t^{HP,\,EA} \\
\widetilde{\pi}_t^{HP,\,EA} \\
\widetilde{i}_t^{HP,\,EA}
\end{bmatrix}
=
\begin{bmatrix}
\widehat{Y}_t \\
\frac{C_H}{C_H+C_F}\widehat{C}_{H,t} + \frac{C_F}{C_H+C_F}\widehat{C}_{F,t} \\
\frac{X_H}{X_H+X_F}\widehat{X}_{H,t} + \frac{X_F}{X_H+X_F}\widehat{X}_{F,t} \\
\widehat{empl}_t \\
\widehat{W}_t \\
\widehat{\pi}_t \\
4\widehat{i}_t \\
n\widehat{Y}_t + (1-n)\,\widehat{Y}_t^* \\
n\left[\frac{C_H}{C_H+C_F}\widehat{C}_{H,t} + \frac{C_F}{C_H+C_F}\widehat{C}_{F,t}\right] + (1-n)\left[\frac{C_H^*}{C_H^*+C_F^*}\widehat{C}_{H,t}^* + \frac{C_F^*}{C_H^*+C_F^*}\widehat{C}_{F,t}^*\right] \\
n\left[\frac{X_H}{X_H+X_F}\widehat{X}_{H,t} + \frac{X_F}{X_H+X_F}\widehat{X}_{F,t}\right] + (1-n)\left[\frac{X_H^*}{X_H^*+X_F^*}\widehat{X}_{H,t}^* + \frac{X_F^*}{X_H^*+X_F^*}\widehat{X}_{F,t}^*\right] \\
n\widehat{empl}_t + (1-n)\,\widehat{empl}_t^* \\
n\widehat{W}_t + (1-n)\,\widehat{W}_t^* \\
n\widehat{\pi}_t + (1-n)\,\widehat{\pi}_t^* \\
4\left(n\widehat{\imath}_t + (1-n)\,\widehat{\imath}_t^*\right)
\end{bmatrix}
\tag{74}
$$

where AUT and EA stand for 'Austria' and 'Euro Area' respectively. We will from now on refer to the vector in equation (74) as the vector of observed variables, $\mathbb{V}$.

5 Estimation

Many advances have been made in recent years in estimating DSGE models, partly shifting emphasis in quantitative macroeconomics from calibration exercises to directly estimating the parameters of a structural model and letting the data speak. In particular, Bayesian estimation and evaluation techniques have been particularly successful in estimation of not only small DSGE models but also medium to large-scale models, such as the generation of New Keynesian models. The estimation procedure is built around a likelihood function that is derived from the DSGE model. A variety of numerical techniques are available to solve linearized rational expectations systems. Examples are the algorithms developed by Blanchard & Kahn (1980), King (1998), Uhlig (1999), Klein (2000), Christiano (2002) and Sims (2002).[11] In the context of likelihood-based DSGE model estimation, linear approximation methods are very popular because they lead to a state-space representation of the DSGE model that can be analyzed with the Kalman filter. Together with the specification of a prior distribution (for all parameters of interest) the state-space representation can be translated to form the posterior distribution. The principle of Bayesian estimation is then to look for a parameter which maximizes the posterior, given the prior and the likelihood based on the data. Denote with ω the vector of parameters to be estimated and by $\mathbb{V}$ the data. In particular, according to Bayes' theorem, the posterior density $p(\omega|\mathbb{V})$ is related to the prior and the likelihood as follows:

$$p(\omega|\mathbb{V}) = \frac{p(\mathbb{V}|\omega)\, p(\omega)}{p(\mathbb{V})} \propto p(\mathbb{V}|\omega)\, p(\omega) = L(\omega|\mathbb{V})\, p(\omega) \tag{75}$$

where $p(\omega)$ is the prior density of the parameter vector, $L(\omega|\mathbb{V})$ is the likelihood of the data and $p(\mathbb{V}) = \int p(\mathbb{V}|\omega)\, p(\omega)\, d\omega$ is the unconditional data density, which, since it does not depend on the parameter vector to be estimated, can be treated as a proportionality factor and accordingly can be disregarded in the estimation process. Assuming independently distributed priors, the logarithm of the posterior is given by the sum of the log likelihood of the data and the sum of the logarithms of the prior distributions:

$$\ln(p(\omega|\mathbb{V})) = \ln(L(\omega|\mathbb{V})) + \sum_{\iota=1}^{N} \ln(p(\omega_i)) \tag{76}$$

The latter term can be directly calculated from the specified prior distributions of the estimated parameters. For the computation of the log likelihood of the data the Kalman filter is applied to the DSGE model solution (the state-state representation) for the number of periods, T, provided by the data $\mathbb{V}$.

[11] In particular, we make use of Klein's (2000) Matlab file 'solab.m'.

In the estimation of the model for the pre-EMU subsample (1976Q2: 1998Q4) the number of quarters $T_1 = 91$, in the estimation of the model for the EMU subsample (1999Q1: 2005Q1) $T_2 = 28$. In the estimation process over the entire sample period (for 1976Q2: 2005Q1, and with $T = T_1 + T_2 = 119$) the log likelihood can be derived as the sum of the log likelihood of the model for the pre-EMU subsample (for $T_1 = 91$ periods) and the log likelihood of the model for the EMU subsample (with $T_2 = 28$), each using the respective state-space representation of either the pre-EMU or the EMU DSGE model solutions. In the joint estimation all parameters other than those related to the monetary policy regime switch are restricted to be constant over the two subsamples. The so computed posterior distribution is then maximized to find the mode of the estimated parameters. Standard errors of these estimates can be derived from the diagonal elements of the inverse of the Hessian, and help to give an indication about the significance of these parameter estimates.

Once the mode of the posterior is found this way, one can use an approximation around the mode to generate a (large) sample of Markov-Chain Monte Carlo (MCMC) draws and characterize the shape of the posterior distribution, from which inference can be drawn. We make use of the Metropolis-Hastings algorithm which belongs to the class of acceptance-rejection algorithms, where proposal draws are taken from a generating density, and the draws are either accepted or rejected based on a certain acceptance probability.[12]

5.1 Calibrated Parameters

We follow the convention in the literature and choose to keep a number of parameters fixed throughout the estimation procedure. Most of these parameters can be related to the steady state values of the observed variables in the model and are calibrated to reflect certain long run features of the data. In our stationary model, estimated on HP-filtered data, we set the discount factor β equal to 0.988 which implies a steady state real interest

[12] It is a 'Markov-Chain' Monte Carlo algorithm because each proposal is drawn from a density that depends only on the previous draw.

rate of approximately 5% annually. To match the sample mean of the investment-output and the labor income-output ratios, the depreciation rate δ is set to 0.02, and the share of capital in the production function, α, is set to 1/3. We follow Smets & Wouters (2003*b*) in setting the markup power in wage setting, $1 + \mu_w$, equal to 1.5. We calibrate the weight of domestic and foreign consumption goods in their respective overall (aggregate) consumption index (parameters γ_C and γ_C^*) by making use of the measures of imports in private consumption from the GTAP database (2001). For Austria this implies a weight of 0.896 on its own goods (γ_C) and for the rest of the Euro Area the weight on its own goods is 0.997 ($1 - \gamma_C^*$). For simplicity, we assume that the weights in the respective investment CES indices are the same. Finally, country size n is taken to be 0.031, which corresponds to Austria's weight in the construction of the AWM database.[13]

5.2 Specification of Prior Distributions of Estimated Parameters

In selecting the prior distributions for the parameters to be estimated we are guided by the conventions in the literature. For parameters that are bounded to be positive (such as the standard deviations of the shocks) we assume inverse gamma distributions; beta distributions are chosen for parameters bounded between zero and one (e.g. parameters like those of shock persistence, the parameters in the Calvo wage and price setting, as well as for price and wage indexation). For the remaining parameters, a normal distribution is assumed. The choice the prior means and standard deviations of our estimated parameters is led by a range of previous studies on calibration and estimation exercises in New Keynesian open economy models. Table 2 provides a detailed description of the prior distributions used in the estimation on HP-filtered data.

[13] The weights are based on constant GDP at market prices (PPP) for the EU-11 for 1995.

6 Results

6.1 Parameter Estimates and Posterior Distributions

The complete set of parameter estimates is summarized in Tables 2 to 7. Tables 2 to 4 present our results from the estimation over the entire sample of 1999Q1:2005Q1, as outlined in section 5. Parameter results are given from estimation by maximum likelihood (column 'Maximized Posterior') and from Bayesian estimation. For the parameter estimates from the maximum likelihood estimation, we report the respective modes of the maximized posterior distribution together with standard errors, as derived from the diagonal elements of the inverse Hessian. The last two columns of Tables 2 to 4 present the results from the Bayesian estimation: we report the mean and standard deviations obtained from the posterior distribution that was generated by means of the Metropolis Hastings Markov-Chain Monte Carlo algorithm.[14]

Tables 5 to 7 compare the estimation results (from maximum likelihood) over different subsamples, Parameter estimates are given for the estimation of the pre-EMU subsample (1976Q2:1998Q4), the EMU subsample (1976Q2:2005Q1) as well as for the entire sample period (1999Q1:2005Q1).

The estimates reported are Table 2 (and Table 5 for the subsample comparison) presents the estimates of all structural parameters, Table 3 (Table 6) presents the estimated shock persistences and Table 4 (Table 7) presents the estimated standard deviations of the respective shocks. We will focus, in our exposition, on the Bayesian estimation results from the estimation over the entire period.

The estimates of the utility parameters for the Euro Area fall well into the region of values typically found for these parameters. The coefficient of relative risk aversion of 1.36 implies an elasticity of intertemporal substitution of 0.74, labor utility parameter, σ_L^*, implies an elasticity of work effort with respect to the real wage of about 2/3. For Austria

[14] The MCMC algorithm was run with 50000 draws.

this elasticity is estimated slightly higher, with the mode being $\sigma_L = 1.29$, yet the standard error obtained are relatively large. The coefficient of relative risk aversion for Austria is, with $\sigma = 0.77$ ($\sigma = 0.85$ in the maximum likelihood estimation) rather low; inspection of the estimation results from the pre-EMU and the EMU sample (Table 5) shows that this result comes from the time series from 1999 on. Habit parameters are estimated, with relatively small standard errors to be 0.74 in Austria and 0.24 in the Euro Area. The elasticity between domestic and foreign goods in consumption and investment, ϵ and ϵ^* is found to be 1.19 and 1.20 respectively, indicating that goods produced in Austria and the rest of the Euro Area are perceived as substitutes.

The estimates obtained for the Calvo parameters suggest that nominal rigidities play a significant role in both the Euro Area as well as in Austria. The parameters on rigidities in price setting, ξ_P and ξ_P^*, are 0.82 and 0.78, for the Calvo parameters in employment adjustment similarly high values are found, i.e. $\xi_{empl} = 0.68$ and $\xi_{empl}^* = 0.79$. The estimates of the Calvo wage setting parameters on the other hand is lower, with $\xi_w = 0.49$ and $\xi_w^* = 0.36$. Price and wage indexation also appears to be very relevant, only the price indexation parameter for the Euro Area is found to be somewhat lower.

We now turn to the parameter estimates related to the monetary policy rules, that is, on the parameters of the estimated Taylor rules. For the estimates over the entire period we find that the parameter on the lagged interest rate has decreased for the period of the EMU relative to the time before the monetary union. We find $\rho_i^{emu} = 0.69$, while before it was for the aggregation of later Euro Area countries (exclusive of Austria) $\rho_i^* = 0.84$. This also means that the weight on inflation in the Taylor rule has, as would be expected, increased in importance with the onset of the monetary union, despite the fact that parameter $\rho_\pi^{emu} = 1.40$ is lower than $\rho_\pi^* = 1.70$. The weight of inflation in the Taylor rule is however correctly measured by $(1 - \rho_i^*)\rho_\pi^*$ or $(1 - \rho_i^{emu})\rho_\pi^{emu}$, which respectively are 0.27 and 0.43. We also find that the weight on deviations of output from its long run value has increased from $(1 - \rho_i^*)\rho_Y^* = 0.04$ to $(1 - \rho_i^{emu})\rho_Y^{emu} = 0.12$, which is somewhat surprising since the sole target of the European Central Bank is on inflation (and not the output gap).

Table 3 presents the estimates for the persistence parameters. Most of the shock persistences are found to be very high, typically close to around 0.8. Exceptions are, in particular, the persistence of the investment shock in the rest of the Euro Area, and, to a lesser degree, also the investment shock in Austria. The standard errors of all estimates of persistence parameters are typically small, indicating high significance of the estimates.

Table 4 summarizes the results on the shock parameters. This gives a first indication on what shocks seem to drive the cyclical variations in our macroeconomic time series. The shocks estimated to have the highest standard deviations are investment shocks (particularly in the rest of the Euro Area, with 5.73%, in Austria only to a lesser degree, with 2.35%), markup shocks in price setting (5.52% in Austria and 3.63% in the rest of the Euro Area), as well as labor supply shocks (4.97% in Austria and 2.75% in the rest of the Euro Area). For Austria, the standard deviation of government expenditure shocks is also estimated to be relatively high, $\sigma_G = 2.71$.

In Figures 2 to 4 we also give a graphical representation of our parameter estimates and plot the prior and posterior distributions for the structural, persistence and shock parameters (from the estimation over the entire sample period). The prior distribution is given by the dashed pink line, the asymptotic posterior as obtained from maximum likelihood is given by the solid cyan line, while the histogram displays the MCMC results.

6.2 Variance Decompositions and Impulse Responses

We now turn to the results from the model, once parameters are set at their modes, as obtained from maximizing the posterior over the entire sample period. We use the estimated DSGE model to analyze the contribution of the various structural shocks to the business cycle developments in Austria and the rest of the Euro Area and to analyze the impulse responses from these shocks.

Forecast error variance decompositions are used to study the relative importance of each of the structural shocks for the variability of our observed variables. Table 8 and

9 report these contributions for the Euro Area and for the Austrian economy, for several time horizons. Interest focuses on the short run variation (one quarter ahead), on variation at business cycle frequencies (one year and $2\frac{1}{2}$ years ahead) and at long run variation (25 years ahead).

Table 8 presents the variance decompositions for Euro Area observed variables. The numbers shown in Tables 8 and 9 are the percent contributions of the various shocks to the overall variability of the respective variables. Beyond the very short-term horizon variations in (the rest of the) Euro Area output (Y) seems to be driven largely by labor supply shocks and productivity shocks. In the very short run also investment, government and consumption preference shocks have a significant effect on output. Price and wage markup shocks do not seem to influence output variability a lot. The second column of Table 5 suggest that fluctuations in Euro Area consumption (C) are due to consumption preference shocks, especially at shorter horizons, while their importance decreases over time. The second major contributor of consumption fluctuations is the labor supply shock, with increasing importance at longer time horizons. Euro Area investment (X) is driven mostly by the investment shock in shorter horizons, while at longer horizons the labor supply shock and the technology shock increase in importance. The largest amount of employment ($EMPL$) variability comes from the labor supply shock, whose contribution is high already at short horizons and even intensifies at longer horizons. Real wage (W) variations are driven also largely by the labor supply shock and, in particular, wage markup shocks can essentially not contribute to explaining wage variability. This may indicate that the model has an identification difficulty. Indeed, the labor supply shock and the wage markup shock enter in the same equation of our theoretical model (the Calvo wage setting equation) and with the same sign, suggesting that part of what could have been captured by the wage markup shock is contained already in the labor supply shock. Variations in Euro Area inflation (π) are driven mostly by price markup and productivity shocks. Interest rates (i) fluctuate because of monetary policy shocks in the short horizon, in the longer horizons investment shocks also are a relevant contributor. As a general result - as becomes clear from inspecting Table 8 - shocks originating from Austria largely leave the Euro Area variables unaffected.

Table 9 turns to the variance decompositions for Austrian observed variables, again for short, medium and long-term horizons. We now observe much larger spillovers from the (rest of the) Euro Area to the Austrian economy. Inspecting the variance decompositions for the estimation on the two subsamples (not specifically reported in the Tables), we find that these spillovers stem from the later subsample - in the estimation on the pre-EMU subsample, we find very small contributions of Euro Area shocks on Austrian variables. Also in the estimation over the entire period, however, the own (i.e. Austrian) shock disturbances remain the major sources for variations in all Austrian observed variables. For Austrian output variations we obtain a similar picture as for the Euro Area counterpart. In the very short run output fluctuations seem to be demand driven, with government and investment shocks being the main sources of output fluctuations. At horizons from one year onwards supply side shocks dominate, in particular, productivity and labor supply shocks. The role of these supply side shocks increases as the time horizon increases. Austrian consumption and investment are driven largely by the consumption preference shock and the investment shock respectively. Employment variations are driven by a multitude of shocks at the very short run; government shocks, investment and productivity shocks explain a significant amount. At longer horizons the importance is being shifted to the labor supply shock as the driving source. Real wage fluctuations come from a whole variety of shocks. While the labor supply shock is the most importance source, it is less so than in the Euro Area, and, in particular, different to the case of the Euro, it looses importance for longer horizons. Austrian inflation rates are mostly determined by price markup shocks, and, to a lesser degree also by productivity shocks.

Figures 5 to 20 report impulse responses of each of the structural shocks on the major economic variables of interest. We plot responses for Austria (bold blue line) and for the rest of the Euro Area (thin pink line) for two cases: 1) for the case of the pre-EMU model, where we derive impulse responses from the flexible exchange rate model (represented by the solid lines, labelled 'flex. ER' in the legend to the figures), and 2) for the case of the EMU, where we derive the responses from the model model of the currency union (dashed lines, labelled 'CU' in the legend). The parameters are set to the estimation results as obtained from the posterior distribution (from the estimation over the entire period, 1976Q2: 2005Q1). That is, all parameters apart from those relating to monetary policy regimes are equal in the impulse response functions derived from the flexible exchange rate model and the currency union model. This makes possible a direct comparison of the responses and enables a first judgement on the effects of the monetary regime switch. The size of the shocks considered is 1 % throughout, apart for the monetary policy shocks where we consider a shock in the size of 10 basis points.

Figure 5 presents the responses to a 1% increase in Austrian productivity. Output in the Austrian economy increases in response to the temporarily higher productivity, and together with it we observe an increase in both Austrian consumption and investment (and, as a result, the capital stock). The responses on these real variables are however much smaller than those that would be obtained from a real business cycle (RBC) type model. In particular, the nominal rigidities present in our richer model seem to dampen the immediate supply effects of productivity shocks, since prices can be adjusted only gradually. Also, the fall in employment is in contrast to the predictions of a standard RBC model, but similar results have been found in other studies where nominal rigidities are included. Gal (1999) find that the fall in employment is consistent with estimated impulse responses of identified productivity shock (for the United States), and also Smets & Wouters (2003*b*) obtain similar results. As can be seen from Figure 5 the shock in the Austrian economy does not have any quantitative impact on the rest of the Euro Area, simply because it is too small a fraction of the aggregate of countries considered - this confirms the findings of the forecast error variance decomposition. If the origin of the technology shock is, instead, the rest of the Euro Area, we can observe that the shock is transmitted to the Austrian economy quite strongly. These responses are depicted in Figure 6. In response to the (rest of) Euro Area technology shock we observe, in a similar pattern to Figure 5, the Euro Area output, consumption and investment increase, while Euro Area employment falls. We observe that Austria also benefits from the temporarily higher (rest of) Euro Area technology level; the level of Austrian output, consumption and investment also picks up, the correlation (conditional on the productivity shock) appears to be higher for the currency union model.

Figure 7 depicts the responses to a positive shock to labor supply, that temporarily disturbs the labor-leisure relationship and makes it more attractive for households to work harder. It can be seen that the responses are similar to the previous supply side shock (productivity), in that it leads to a temporary increase in output, consumption and investment. Contrary to the productivity shock however, it also leads to an increase in hours worked (and therefore employment). We find, like Smets & Wouters (2003*b*), that this leads to a significant drop in the real wage rate, that, in turn, leads to a fall in the marginal costs and a fall in inflation. These qualitative responses are the same for both Austria and the rest of the Euro Area. We see that labor supply shocks originating in the Euro Area, again, spill over to Austria, in particular under the scenario of the currency union.

Figures 9 and 10 turn to the responses of a negative shock to the markup in wage setting, that is, a temporary decrease of the wage markup. As can be seen, the responses of essentially all macroeconomic variables is the same as under the labor supply shock. This makes clearer as to why the model has difficulties to disentangle the relative contributions of these two shocks in the estimation, as indicated in the discussion of the forecast error variance decompositions.

The impact of a price markup shock that temporarily decreases the price setting markup is shown in Figures 11 and 12. The decrease in the distortion from monopolistic competition and stimulates higher input in production and leads to higher output, consumption, and investment. As prices are sticky, the response takes time however, and is small quantitatively.

Figures 13 and 14 provide responses to the first of our demand shock we discuss, the consumption preference shock, that temporarily makes current consumption more attractive relative to future consumption. As a result consumption increases significantly and, to some degree also output (on impact). These increases are accompanied by a large crowding-out effect on investment.

We consider a positive investment shock in Figures 15 and 16. The temporary reduction in the cost of installing capital leads to an investment boom which translates into an increase also in output and employment, but has only a smaller and negative (impact) effect on consumption.

Figures 17 and 18 look at government expenditure shocks. While output increases as a result of the temporarily higher demand falling on the own country's goods, we find strong evidence of crowding-out effects on both (private) consumption and investment. When the government expenditure shock originates in the rest of the Euro Area (Figure 18), we can observe that the increase in Euro Area government spending crowds out not only Euro Area's but also Austria's consumption and investment. In addition, it decreases Austria's employment and therefore output. The negative transmission of the Euro Area government expenditure shock is stronger under the currency union regime.

Finally, Figures 19 and 20 turn to an investigation of the monetary policy shocks. We show responses to a positive monetary shock, that is, to a shock that temporarily reduces the nominal interest rate. Figure 19 depicts the case of an Austrian monetary policy shock for the pre-EMU regime; after 1999 it forms part of the currency union and cannot set its own monetary policy anymore. As has been stated previously, it is true that also before the start of the monetary union Austria has been pegging the Schilling closely to the Deutschmark, and was not entirely free in its monetary policy decisions. The differences in the transmission of the rest of the Euro Area countries' monetary policy shock to Austria before EMU and in the EMU - as given by a comparison between the responses of the flexible exchange rate and the currency union model for Austria, shown in Figure 20 - should therefore be interpreted with caution. It should be clear that these differences might be overstated or at least constitute the maximal level of monetary independence before 1999. As can be observed, the responses of Austrian and Euro Area variables in response to the Euro Area monetary shock are very similar qualitatively, and help explain the higher correlation among Euro Area and Austrian variables found in the EMU subsample of the data.

7 Conclusions

In this paper we have developed a two region model of the Austrian economy within the European Union's Economic and Monetary Union. The model is estimated using Bayesian methods on quarterly data covering the period of 1976:Q1-2005:Q1.

This has allowed us to assess the relative importance for the Austrian economy of various shocks originating either at home or abroad. We find that, at short horizons, Austrian variables appear to be much more driven by demand shocks while - in comparison - in the rest of the Euro Area supply shocks have a stronger impact on Euro Area variables. This holds particularly true for output. In addition, we find that in both regions consumption is influenced very much by consumption preference shocks, while investment variations stem largely from temporary variations in investment efficiency. Labor supply shocks contribute a lot to both employment and real wage variations, while inflation rates are driven mostly by variations in price markups.

We also investigate effects of the monetary regime switch with the final stage of the European Economic and Monetary Union and investigate in how far this has altered macroeconomic transmission. From the impulse responses, by comparing the flexible exchange rate model (pre-EMU) with the currency union model (EMU), we find that the the transmission of shocks originating in the rest of the Euro Area is stronger under the monetary union. This, in most cases, translates into a stronger comovement of Austrian with the respective Euro Area variables and helps in explaining the observed increase - from the pre-EMU to EMU sample - of the correlations found in the data.

8 Tables

Table 1: Business Cycle Facts for Austria and Euro Area, HP-filtered data

	standard deviation			standard deviation rel. to output		
AUSTRIA	Entire Period	pre-EMU	EMU	Entire Period	pre-EMU	EMU
output	0.86	0.85	0.69	1.00	1.00	1.00
consumption	0.86	0.82	0.87	1.01	0.97	1.25
investment	2.51	2.36	2.74	2.92	2.79	3.94
employment	0.54	0.59	0.21	0.63	0.69	0.30
real wage	0.86	0.91	0.39	1.01	1.07	0.56
nom. int. rate	1.06	1.17	0.61	1.24	1.38	0.87
consumer prices	0.58	0.62	0.21	0.67	0.73	0.31
EURO AREA						
output	0.86	0.89	0.74	1.00	1.00	1.00
consumption	0.84	0.88	0.53	0.97	0.99	0.71
investment	2.31	2.38	1.54	2.67	2.68	2.07
employment	0.65	0.70	0.48	0.75	0.78	0.64
real wage	0.84	0.94	0.27	0.97	1.06	0.36
nom. int. rate	0.95	1.02	0.61	1.10	1.15	0.82
consumer prices	0.64	0.70	0.31	0.74	0.78	0.42

correlations (Austrian with Euro Area Variable)			
	Entire Period	pre-EMU	EMU
output	0.67	0.64	0.79
consumption	0.24	0.09	0.78
investment	0.56	0.50	0.75
employment	0.46	0.42	0.17
real wage	0.06	0.07	−0.06
nom. int. rate	0.70	0.67	1.00
consumer prices	0.71	0.78	−0.31

Table 2: Structural Parameters, Prior and Posterior Distributions

			Prior distribution			Maximized Post.		Bayesian Est.	
Parameter		domain	density	mean	st.err.	mode	st.err.	mean	st.dev.
Cons. utility	σ	$\mathbb{R}$	normal	1.50	0.50	0.86	0.18	0.77	0.17
Cons. utility	σ^*	$\mathbb{R}$	normal	1.50	0.50	1.53	0.13	1.36	0.20
Labor utility	σ_N	$\mathbb{R}$	normal	1.75	0.50	2.04	1.01	1.29	0.29
Labor utility	σ_N^*	$\mathbb{R}$	normal	1.75	0.50	1.74	0.44	1.51	0.42
Habit param.	h	$[0,1)$	beta	0.50	0.15	0.67	0.03	0.74	0.07
Habit param.	h^*	$[0,1)$	beta	0.50	0.15	0.18	0.03	0.24	0.06
Elast. of subst.	ϵ	$\mathbb{R}$	normal	1.10	0.25	1.20	0.20	1.19	0.20
Elast. of subst.	ϵ^*	$\mathbb{R}$	normal	1.10	0.25	1.09	0.07	1.20	0.24
Calvo prices	ξ_P	$[0,1)$	beta	0.60	0.15	0.75	0.01	0.82	0.01
Calvo prices	ξ_P^*	$[0,1)$	beta	0.60	0.15	0.77	0.00	0.78	0.01
Calvo wages	ξ_w	$[0,1)$	beta	0.60	0.15	0.34	0.02	0.49	0.04
Calvo wages	ξ_w^*	$[0,1)$	beta	0.60	0.15	0.35	0.01	0.36	0.03
Calvo empl.,	ξ_N	$[0,1)$	beta	0.60	0.15	0.59	0.01	0.68	0.02
Calvo empl.,	ξ_N^*	$[0,1)$	beta	0.60	0.15	0.79	0.00	0.79	0.01
Indexation	γ_p	$[0,1)$	beta	0.60	0.15	0.62	0.02	0.57	0.08
Indexation	γ_p^*	$[0,1)$	beta	0.60	0.15	0.17	0.01	0.25	0.07
Indexation	γ_w	$[0,1)$	beta	0.60	0.15	0.54	0.04	0.49	0.16
Indexation	γ_w^*	$[0,1)$	beta	0.60	0.15	0.65	0.03	0.63	0.12
Cap. Adj. Costs	ϕ_k	$\mathbb{R}$	normal	2.00	1.00	0.61	0.12	0.87	0.18
Cap. Adj. Costs	ϕ_k^*	$\mathbb{R}$	normal	2.00	1.00	1.16	1.56	1.56	0.29
Taylor rule	ρ_i	$[0,1)$	beta	0.80	0.14	0.62	0.00	0.63	0.04
Taylor rule	ρ_i^*	$[0,1)$	beta	0.80	0.14	0.91	0.02	0.84	0.09
Taylor rule	ρ_i^{emu}	$[0,1)$	beta	0.80	0.14	0.69	0.00	0.69	0.02
Taylor rule	ρ_π	$\mathbb{R}$	normal	1.70	0.15	1.86	0.02	1.84	0.12
Taylor rule	ρ_π^*	$\mathbb{R}$	normal	1.70	0.15	1.70	0.03	1.70	0.13
Taylor rule	ρ_π^{emu}	$\mathbb{R}$	normal	1.70	0.15	1.42	0.02	1.40	0.09
Taylor rule	ρ_Y	$\mathbb{R}$	normal	0.20	0.10	0.39	0.01	0.36	0.05
Taylor rule	ρ_Y^*	$\mathbb{R}$	normal	0.20	0.10	0.20	0.01	0.24	0.08
Taylor rule	ρ_Y^{emu}	$\mathbb{R}$	normal	0.20	0.10	0.43	0.01	0.38	0.05

Table 3: Persistence Parameters, Prior and Posterior Distributions

			Prior distribution			Maximized Post.		Bayesian Est.	
Parameter		domain	density	mean	st.err.	mode	st.err.	mean	st.dev.
Technology shock	ρ_Z	$[0,1)$	beta	0.80	0.14	0.70	0.00	0.69	0.05
Technology shock	ρ_{Z^*}	$[0,1)$	beta	0.80	0.14	0.55	0.03	0.55	0.08
Preference shock	ρ_C	$[0,1)$	beta	0.80	0.14	0.78	0.01	0.73	0.04
Preference shock	ρ_{C^*}	$[0,1)$	beta	0.80	0.14	0.67	0.00	0.66	0.05
Government shock	ρ_G	$[0,1)$	beta	0.80	0.14	0.85	0.00	0.85	0.04
Government shock	ρ_{G^*}	$[0,1)$	beta	0.80	0.14	0.83	0.01	0.78	0.05
Labor supply shock	ρ_N	$[0,1)$	beta	0.80	0.14	0.79	0.01	0.66	0.08
Labor supply shock	ρ_{N^*}	$[0,1)$	beta	0.80	0.14	0.90	0.00	0.87	0.03
Investment shock	ρ_X	$[0,1)$	beta	0.80	0.14	0.55	0.01	0.54	0.05
Investment shock	ρ_{X^*}	$[0,1)$	beta	0.80	0.14	0.36	0.03	0.33	0.03

Table 4: Persistence Parameters, Prior and Posterior Distributions

			Prior distribution			Maximized Post.		Bayesian Est.	
Parameter		domain	density	mean	st.err.	mode	st.err.	mean	st.dev.
Technology shock	σ_Z	$\mathbb{R}^+$	inv.gamma	0.60	2.00	0.82	0.03	1.15	0.14
Technology shock	σ_{Z^*}	$\mathbb{R}^+$	inv.gamma	0.60	2.00	1.66	0.28	1.78	0.37
Preference shock	σ_C	$\mathbb{R}^+$	inv.gamma	1.50	2.00	0.98	0.01	1.19	0.13
Preference shock	σ_{C^*}	$\mathbb{R}^+$	inv.gamma	1.50	2.00	1.30	0.08	1.29	0.17
Government shock	σ_G	$\mathbb{R}^+$	inv.gamma	1.50	2.00	2.56	0.04	2.71	0.21
Government shock	σ_{G^*}	$\mathbb{R}^+$	inv.gamma	1.50	2.00	1.67	0.02	1.82	0.16
Labor supply shock	σ_N	$\mathbb{R}^+$	inv.gamma	2.00	2.00	3.00	1.44	4.97	0.90
Labor supply shock	σ_{N^*}	$\mathbb{R}^+$	inv.gamma	2.00	2.00	2.70	0.43	2.75	0.69
Investment shock	σ_X	$\mathbb{R}^+$	inv.gamma	2.00	2.00	1.91	1.04	2.35	0.41
Investment shock	σ_{X^*}	$\mathbb{R}^+$	inv.gamma	2.00	2.00	4.00	17.75	5.73	1.15
Price markup shock	σ_{μ_P}	$\mathbb{R}^+$	inv.gamma	1.00	2.00	3.00	2.75	5.52	0.69
Price markup shock	$\sigma_{\mu_P^*}$	$\mathbb{R}^+$	inv.gamma	1.00	2.00	3.00	3.20	3.63	0.50
Wage markup shock	σ_{μ_W}	$\mathbb{R}^+$	inv.gamma	0.25	2.00	0.08	0.00	0.10	0.04
Wage markup shock	$\sigma_{\mu_W^*}$	$\mathbb{R}^+$	inv.gamma	0.25	2.00	0.08	0.00	0.14	0.06

Table 5: Structural Parameters, pre-EMU and EMU Comparison, Estimated Maximum Posterior

			Prior distribution			Posterior distribution					
						pre-EMU		EMU		Entire Period	
Parameter		domain	density	mean	std	mode	st.err.	mode	st.err.	mode	st.err.
Cons. utility	σ	$\mathbb{R}$	normal	1.50	0.50	1.07	0.04	0.65	0.08	0.86	0.18
Cons. utility	σ^*	$\mathbb{R}$	normal	1.50	0.50	1.52	0.25	1.43	0.16	1.53	0.13
Labor utility	σ_N	$\mathbb{R}$	normal	1.75	0.50	2.28	0.65	1.38	0.33	2.04	1.01
Labor utility	σ_N^*	$\mathbb{R}$	normal	1.75	0.50	2.05	0.56	1.68	0.28	1.74	0.44
Habit param.	h	$[0,1)$	beta	0.50	0.15	0.56	0.01	0.79	0.01	0.67	0.03
Habit param.	h^*	$[0,1)$	beta	0.50	0.15	0.21	0.01	0.31	0.01	0.18	0.03
Elast. of subst.	ϵ	$\mathbb{R}$	normal	1.10	0.25	1.10	0.18	1.13	0.05	1.20	0.20
Elast. of subst.	ϵ^*	$\mathbb{R}$	normal	1.10	0.25	1.07	0.08	1.13	0.05	1.09	0.07
Calvo prices	ξ_P	$[0,1)$	beta	0.60	0.15	0.75	0.01	0.77	0.01	0.75	0.01
Calvo prices	ξ_P^*	$[0,1)$	beta	0.60	0.15	0.76	0.01	0.69	0.00	0.77	0.00
Calvo wages	ξ_w	$[0,1)$	beta	0.60	0.15	0.30	0.01	0.53	0.02	0.34	0.02
Calvo wages	ξ_w^*	$[0,1)$	beta	0.60	0.15	0.32	0.02	0.25	0.01	0.35	0.01
Calvo empl.,	ξ_N	$[0,1)$	beta	0.60	0.15	0.57	0.00	0.68	0.01	0.59	0.01
Calvo empl.,	ξ_N^*	$[0,1)$	beta	0.60	0.15	0.79	0.00	0.65	0.00	0.79	0.00
Indexation	γ_p	$[0,1)$	beta	0.60	0.15	0.57	0.02	0.70	0.02	0.62	0.02
Indexation	γ_p^*	$[0,1)$	beta	0.60	0.15	0.19	0.01	0.30	0.01	0.17	0.01
Indexation	γ_w	$[0,1)$	beta	0.60	0.15	0.61	0.03	0.55	0.03	0.54	0.04
Indexation	γ_w^*	$[0,1)$	beta	0.60	0.15	0.71	0.03	0.52	0.04	0.65	0.03
Cap. Adj. Costs	ϕ_k	$\mathbb{R}$	normal	2.00	1.00	0.50	0.07	0.61	0.24	0.61	0.12
Cap. Adj. Costs	ϕ_k^*	$\mathbb{R}$	normal	2.00	1.00	1.12	0.71	0.95	0.47	1.16	1.56
Taylor rule	ρ_i	$[0,1)$	beta	0.80	0.14	0.58	0.01	–	–	0.62	0.00
Taylor rule	ρ_i^*	$[0,1)$	beta	0.80	0.14	0.70	0.01	–	–	0.91	0.02
Taylor rule	ρ_i^{emu}	$[0,1)$	beta	0.80	0.14	–	–	0.76	0.00	0.69	0.00
Taylor rule	ρ_π	$\mathbb{R}$	normal	1.70	0.15	1.85	0.03	–	–	1.86	0.02
Taylor rule	ρ_π^*	$\mathbb{R}$	normal	1.70	0.15	1.52	0.06	–	–	1.70	0.03
Taylor rule	ρ_π^{emu}	$\mathbb{R}$	normal	1.70	0.15	–	–	1.43	0.05	1.42	0.02
Taylor rule	ρ_Y	$\mathbb{R}$	normal	0.20	0.10	0.42	0.01	–	–	0.39	0.01
Taylor rule	ρ_Y^*	$\mathbb{R}$	normal	0.20	0.10	0.34	0.01	–	–	0.20	0.01
Taylor rule	ρ_Y^{emu}	$\mathbb{R}$	normal	0.20	0.10	–	–	0.41	0.01	0.43	0.01

Table 6: Persistence Parameters, pre-EMU and EMU Comparison, Estimated Maximum Posterior

			Prior distribution			Posterior distribution					
						pre-EMU		EMU		Entire Period	
Parameter		domain	density	mean	std	mode	st.err.	mode	st.err.	mode	st.err.
Technology shock	ρ_Z	$[0,1)$	beta	0.80	0.14	0.73	0.01	0.77	0.01	0.70	0.00
Technology shock	ρ_{Z^*}	$[0,1)$	beta	0.80	0.14	0.60	0.02	0.76	0.03	0.55	0.03
Preference shock	ρ_C	$[0,1)$	beta	0.80	0.14	0.76	0.00	0.88	0.01	0.78	0.01
Preference shock	ρ_{C^*}	$[0,1)$	beta	0.80	0.14	0.64	0.04	0.80	0.01	0.67	0.00
Government shock	ρ_G	$[0,1)$	beta	0.80	0.14	0.90	0.00	0.78	0.01	0.85	0.00
Government shock	ρ_{G^*}	$[0,1)$	beta	0.80	0.14	0.93	0.01	0.77	0.01	0.83	0.01
Labor supply shock	ρ_N	$[0,1)$	beta	0.80	0.14	0.83	0.01	0.72	0.01	0.79	0.01
Labor supply shock	ρ_{N^*}	$[0,1)$	beta	0.80	0.14	0.91	0.00	0.96	0.00	0.90	0.00
Investment shock	ρ_X	$[0,1)$	beta	0.80	0.14	0.59	0.01	0.62	0.01	0.55	0.01
Investment shock	ρ_{X^*}	$[0,1)$	beta	0.80	0.14	0.39	0.05	0.78	0.04	0.36	0.03

Table 7: Shock Parameters, pre-EMU and EMU Comparison, Estimated Maximum Posterior

			Prior distribution			Posterior distribution					
						pre-EMU		EMU		Entire Period	
Parameter		domain	density	mean	d.f.	mode	st.err.	mode	st.err.	mode	st.err.
Technology shock	σ_Z	$\mathbb{R}^+$	inv.gamma	0.60	2.00	0.77	0.02	0.65	0.04	0.82	0.03
Technology shock	σ_{Z^*}	$\mathbb{R}^+$	inv.gamma	0.60	2.00	1.56	0.18	0.54	0.04	1.66	0.28
Preference shock	σ_C	$\mathbb{R}^+$	inv.gamma	1.50	2.00	0.93	0.02	0.62	0.05	0.98	0.01
Preference shock	σ_{C^*}	$\mathbb{R}^+$	inv.gamma	1.50	2.00	1.50	0.16	0.81	0.05	1.30	0.08
Government shock	σ_G	$\mathbb{R}^+$	inv.gamma	1.50	2.00	2.58	0.08	2.22	0.24	2.56	0.04
Government shock	σ_{G^*}	$\mathbb{R}^+$	inv.gamma	1.50	2.00	1.61	0.02	1.27	0.06	1.67	0.02
Labor supply shock	σ_N	$\mathbb{R}^+$	inv.gamma	2.00	2.00	2.97	1.26	2.75	1.23	3.00	1.44
Labor supply shock	σ_{N^*}	$\mathbb{R}^+$	inv.gamma	2.00	2.00	2.82	0.45	1.35	0.25	2.70	0.43
Investment shock	σ_X	$\mathbb{R}^+$	inv.gamma	2.00	2.00	1.44	0.42	1.64	1.02	1.91	1.04
Investment shock	σ_{X^*}	$\mathbb{R}^+$	inv.gamma	2.00	2.00	4.00	15.69	0.63	0.16	4.00	17.75
Price markup shock	σ_{μ_P}	$\mathbb{R}^+$	inv.gamma	1.00	2.00	3.00	2.57	3.00	4.14	3.00	2.75
Price markup shock	$\sigma_{\mu_P^*}$	$\mathbb{R}^+$	inv.gamma	1.00	2.00	3.00	5.83	1.14	0.11	3.00	3.20
Wage markup shock	σ_{μ_W}	$\mathbb{R}^+$	inv.gamma	0.25	2.00	0.08	0.00	0.08	0.00	0.08	0.00
Wage markup shock	$\sigma_{\mu_W^*}$	$\mathbb{R}^+$	inv.gamma	0.25	2.00	0.08	0.00	0.08	0.00	0.08	0.00

Table 8: Forecast Error Variance Decomposition, Euro Area

	Y	C	X	$EMPL$	W	π	i
Shock							
t=1							
u_i^*	0.0646	0.0590	0.0277	0.0193	0.0420	0.0481	0.2222
u_A	0.0001	0.0000	0.0002	0.0010	0.0000	0.0002	0.0000
u_A^*	0.1457	0.0862	0.1032	0.2499	0.0865	0.3625	0.1326
u_C	0.0001	0.0004	0.0000	0.0001	0.0001	0.0001	0.0000
u_C^*	0.1555	0.6464	0.0292	0.0112	0.1662	0.0673	0.1645
u_G	0.0008	0.0000	0.0000	0.0015	0.0001	0.0001	0.0000
u_G^*	0.1932	0.0307	0.0136	0.0454	0.0133	0.0267	0.1172
u_N	0.0000	0.0000	0.0001	0.0008	0.0005	0.0001	0.0000
u_N^*	0.1683	0.1201	0.0986	0.5832	0.4630	0.0771	0.0051
u_X	0.0006	0.0000	0.0017	0.0014	0.0001	0.0001	0.0000
u_X^*	0.2119	0.0084	0.6966	0.0650	0.0458	0.0680	0.1871
u_{μ_P}	0.0001	0.0000	0.0001	0.0004	0.0003	0.0003	0.0000
$u_{\mu_P}^*$	0.0592	0.0489	0.0291	0.0208	0.1816	0.3495	0.1713
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000
t=4							
u_i^*	0.0284	0.0300	0.0159	0.0086	0.0536	0.0820	0.1030
u_A	0.0003	0.0001	0.0004	0.0001	0.0001	0.0002	0.0000
u_A^*	0.2366	0.1414	0.1882	0.0438	0.0389	0.3084	0.1730
u_C	0.0000	0.0007	0.0002	0.0000	0.0001	0.0002	0.0000
u_C^*	0.0442	0.4265	0.0646	0.0017	0.1448	0.0879	0.1760
u_G	0.0002	0.0001	0.0001	0.0004	0.0001	0.0001	0.0000
u_G^*	0.0643	0.0470	0.0319	0.0236	0.0121	0.0411	0.1182
u_N	0.0003	0.0001	0.0003	0.0012	0.0004	0.0001	0.0000
u_N^*	0.4627	0.3130	0.3372	0.8746	0.5701	0.1102	0.0329
u_X	0.0003	0.0000	0.0009	0.0005	0.0001	0.0001	0.0000
u_X^*	0.1294	0.0112	0.3392	0.0338	0.0852	0.1091	0.3067
u_{μ_P}	0.0001	0.0000	0.0001	0.0002	0.0002	0.0003	0.0000
$u_{\mu_P}^*$	0.0330	0.0298	0.0209	0.0115	0.0942	0.2604	0.0900
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000

Table 8, Cont.: Forecast Error Variance Decomposition, Euro Area

	Y	C	X	$EMPL$	W	π	i
Shock							
t=10							
u_i^*	0.0142	0.0204	0.0081	0.0025	0.0482	0.0796	0.0982
u_A	0.0003	0.0002	0.0003	0.0000	0.0002	0.0002	0.0000
u_A^*	0.1538	0.1089	0.1340	0.0105	0.0958	0.3239	0.1685
u_C	0.0000	0.0006	0.0003	0.0000	0.0001	0.0002	0.0000
u_C^*	0.0307	0.2934	0.0590	0.0023	0.1212	0.0853	0.1700
u_G	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0000
u_G^*	0.0321	0.0501	0.0380	0.0105	0.0115	0.0406	0.1255
u_N	0.0003	0.0002	0.0003	0.0007	0.0003	0.0001	0.0000
u_N^*	0.6805	0.4854	0.5740	0.9594	0.5427	0.1124	0.0354
u_X	0.0002	0.0001	0.0005	0.0001	0.0001	0.0002	0.0000
u_X^*	0.0710	0.0203	0.1744	0.0101	0.0959	0.1064	0.3159
u_{μ_P}	0.0000	0.0000	0.0000	0.0001	0.0002	0.0003	0.0000
$u_{\mu_P}^*$	0.0167	0.0203	0.0110	0.0036	0.0837	0.2506	0.0866
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
t=100							
u_i^*	0.0103	0.0103	0.0071	0.0017	0.0379	0.0772	0.0831
u_A	0.0002	0.0001	0.0002	0.0000	0.0001	0.0002	0.0000
u_A^*	0.1143	0.0717	0.1169	0.0095	0.0908	0.3160	0.1517
u_C	0.0000	0.0004	0.0003	0.0000	0.0001	0.0002	0.0000
u_C^*	0.0246	0.1506	0.0519	0.0027	0.1040	0.0837	0.1485
u_G	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0000
u_G^*	0.0251	0.0392	0.0355	0.0100	0.0190	0.0410	0.1133
u_N	0.0002	0.0002	0.0003	0.0005	0.0002	0.0001	0.0000
u_N^*	0.7564	0.6722	0.6253	0.9621	0.5831	0.1307	0.1440
u_X	0.0001	0.0001	0.0004	0.0001	0.0001	0.0002	0.0000
u_X^*	0.0565	0.0444	0.1525	0.0108	0.0984	0.1074	0.2857
u_{μ_P}	0.0000	0.0000	0.0000	0.0000	0.0002	0.0003	0.0000
$u_{\mu_P}^*$	0.0122	0.0106	0.0096	0.0025	0.0658	0.2428	0.0735
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000

Table 9: Forecast Error Variance Decomposition, Austria

	Y	C	X	$EMPL$	W	π
Shock						
t=1						
u_i^*	0.0377	0.0658	0.0251	0.0256	0.0310	0.0630
u_A	0.0525	0.0134	0.0612	0.1901	0.0236	0.1964
u_A^*	0.0062	0.0212	0.0100	0.0055	0.0085	0.0053
u_C	0.0375	0.7589	0.0074	0.0180	0.1164	0.0771
u_C^*	0.0039	0.0176	0.0096	0.0045	0.0053	0.0014
u_G	0.4687	0.0055	0.0044	0.2685	0.0891	0.0810
u_G^*	0.0094	0.0172	0.0098	0.0095	0.0089	0.0002
u_N	0.0238	0.0052	0.0297	0.1407	0.3916	0.0757
u_N^*	0.0272	0.0556	0.0295	0.0256	0.0366	0.0294
u_X	0.2784	0.0033	0.7648	0.2376	0.0885	0.0480
u_X^*	0.0006	0.0034	0.0043	0.0017	0.0005	0.0244
u_{μ_P}	0.0537	0.0262	0.0431	0.0728	0.1986	0.3864
$u_{\mu_P}^*$	0.0002	0.0067	0.0011	0.0000	0.0010	0.0117
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t=4						
u_i^*	0.0212	0.0262	0.0087	0.0139	0.0268	0.1029
u_A	0.2589	0.0813	0.1743	0.0504	0.0593	0.1599
u_A^*	0.0049	0.0143	0.0052	0.0038	0.0076	0.0056
u_C	0.0193	0.6390	0.0826	0.0072	0.1116	0.1095
u_C^*	0.0041	0.0118	0.0062	0.0044	0.0062	0.0071
u_G	0.1868	0.0537	0.0512	0.1470	0.0591	0.0920
u_G^*	0.0078	0.0106	0.0063	0.0090	0.0110	0.0021
u_N	0.1894	0.0530	0.1329	0.4762	0.3559	0.0914
u_N^*	0.0222	0.0458	0.0188	0.0202	0.0487	0.0543
u_X	0.2136	0.0240	0.4727	0.1832	0.1042	0.0507
u_X^*	0.0021	0.0032	0.0046	0.0033	0.0007	0.0757
u_{μ_P}	0.0697	0.0352	0.0361	0.0813	0.2083	0.2421
$u_{\mu_P}^*$	0.0001	0.0018	0.0003	0.0000	0.0004	0.0068
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 9, Cont.: Forecast Error Variance Decomposition, Austria

	Y	C	X	$EMPL$	W	π
Shock						
t=10						
u_i^*	0.0158	0.0159	0.0072	0.0087	0.0239	0.0819
u_A	0.2740	0.1105	0.1687	0.0403	0.1452	0.1670
u_A^*	0.0036	0.0093	0.0037	0.0022	0.0069	0.0061
u_C	0.0342	0.5061	0.1565	0.0156	0.0997	0.1050
u_C^*	0.0030	0.0084	0.0043	0.0026	0.0060	0.0113
u_G	0.1318	0.1249	0.0843	0.0901	0.0584	0.0885
u_G^*	0.0058	0.0079	0.0047	0.0060	0.0110	0.0128
u_N	0.3022	0.1209	0.1849	0.6633	0.3125	0.0895
u_N^*	0.0159	0.0372	0.0133	0.0118	0.0459	0.0463
u_X	0.1615	0.0327	0.3415	0.1072	0.1012	0.1050
u_X^*	0.0019	0.0022	0.0038	0.0026	0.0008	0.0770
u_{μ_P}	0.0501	0.0230	0.0269	0.0495	0.1880	0.2041
$u_{\mu_P}^*$	0.0001	0.0011	0.0003	0.0001	0.0004	0.0056
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t=100						
u_i^*	0.0144	0.0095	0.0068	0.0082	0.0198	0.0768
u_A	0.2537	0.1000	0.1636	0.0413	0.1280	0.1579
u_A^*	0.0051	0.0121	0.0046	0.0029	0.0117	0.0093
u_C	0.0426	0.3290	0.1550	0.0186	0.0935	0.0994
u_C^*	0.0041	0.0104	0.0044	0.0028	0.0092	0.0123
u_G	0.1227	0.1291	0.0831	0.0932	0.0555	0.0837
u_G^*	0.0073	0.0119	0.0049	0.0063	0.0149	0.0145
u_N	0.2976	0.1406	0.1807	0.6456	0.2642	0.0851
u_N^*	0.0419	0.1291	0.0283	0.0209	0.1340	0.0839
u_X	0.1610	0.1048	0.3356	0.1085	0.1066	0.1006
u_X^*	0.0040	0.0080	0.0072	0.0048	0.0083	0.0800
u_{μ_P}	0.0454	0.0147	0.0255	0.0468	0.1537	0.1912
$u_{\mu_P}^*$	0.0002	0.0009	0.0003	0.0001	0.0006	0.0055
u_{μ_w}	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
$u_{\mu_w}^*$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

9 Figures

Figure 1: HP-filtered Data for Austria and Euro Area

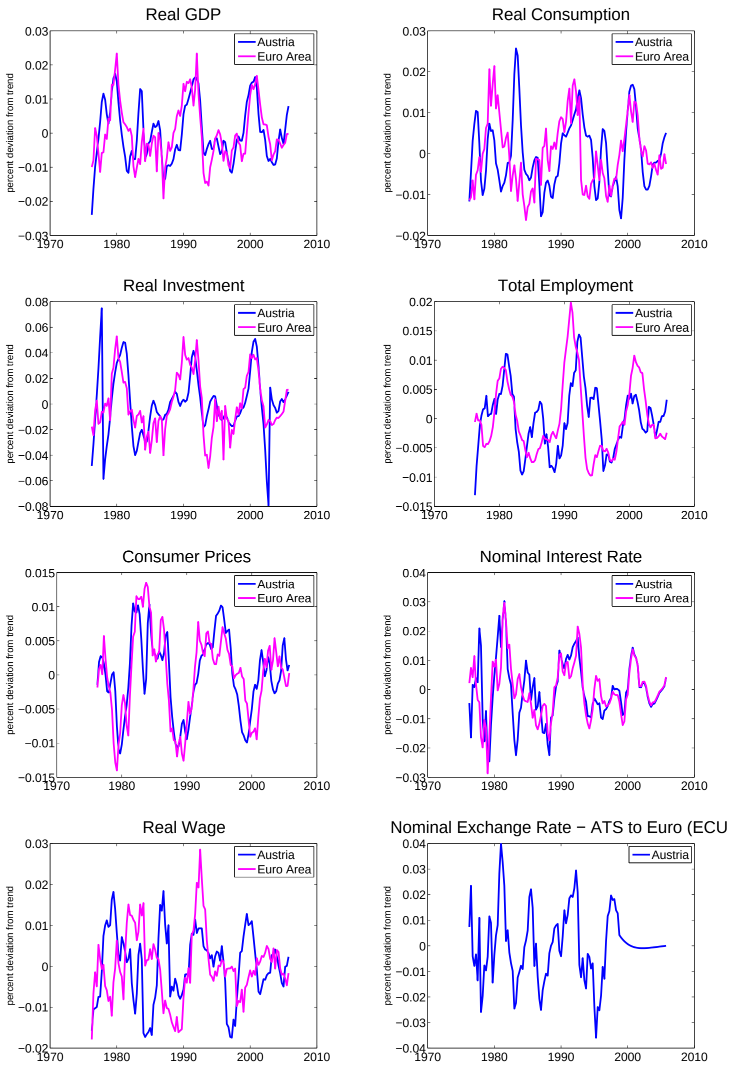


Figure 2: Prior and Posterior Distributions, Structural Parameters

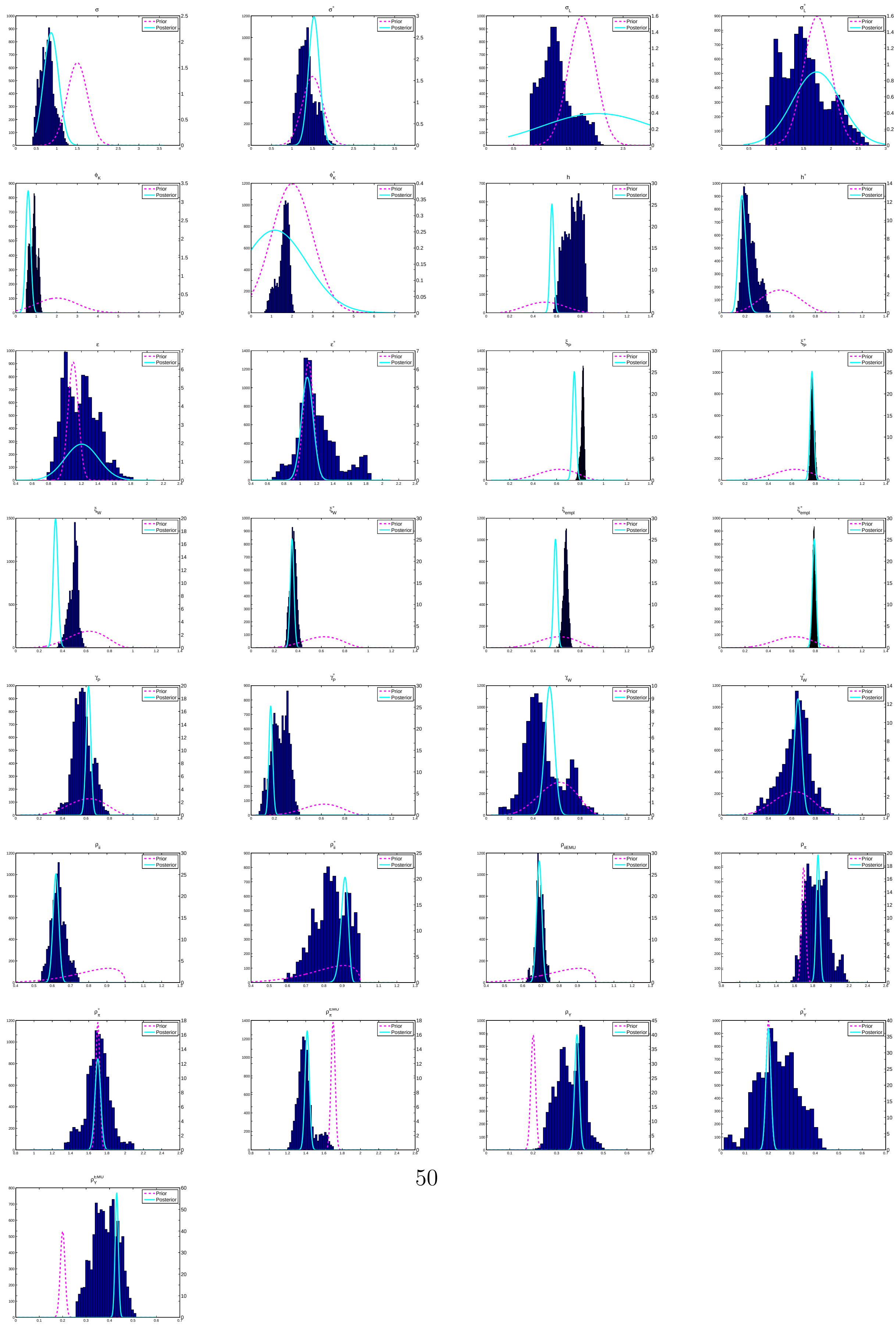


Figure 3: Prior and Posterior Distributions, Persistence Parameters

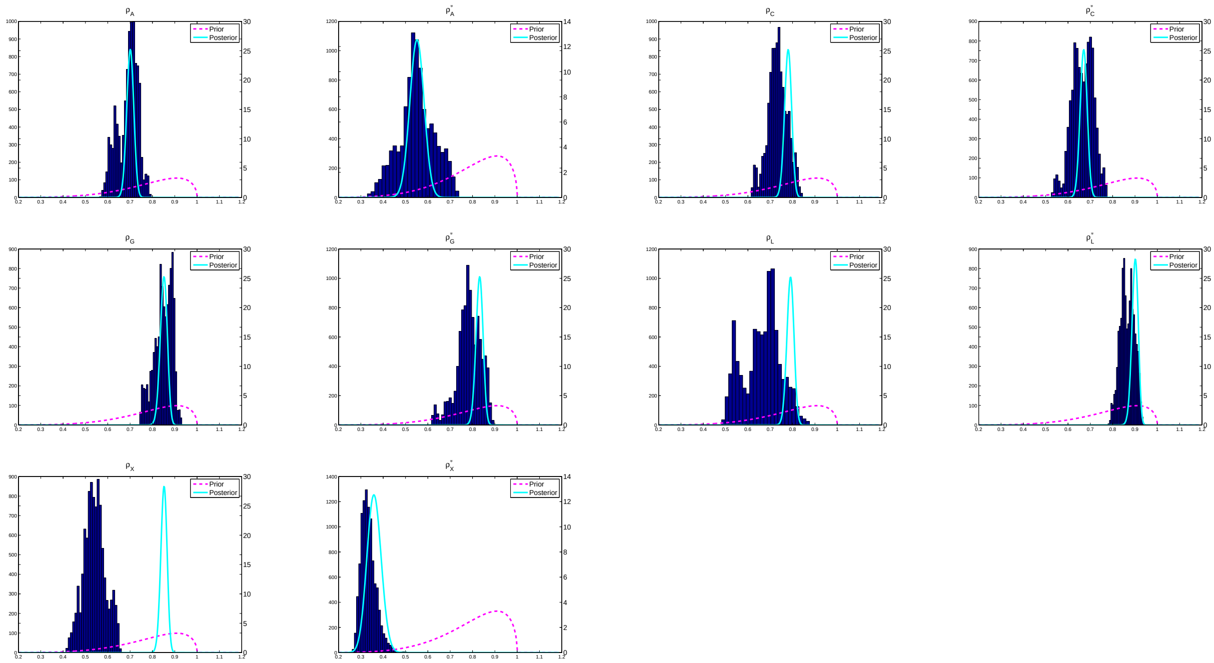


Figure 4: Prior and Posterior Distributions, Shock Parameters

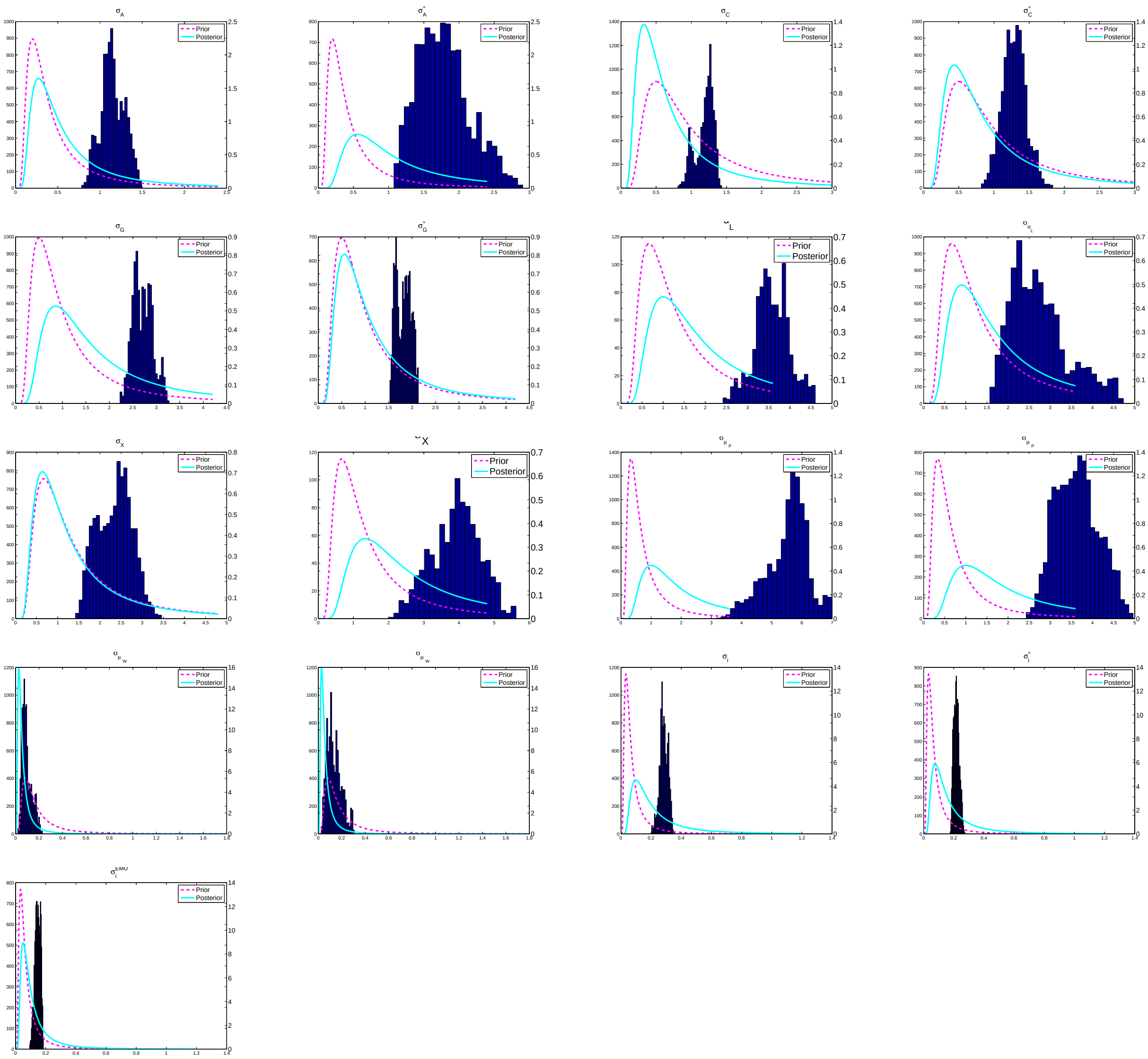


Figure 5: Impulse Response to a Productivity Shock in Austria

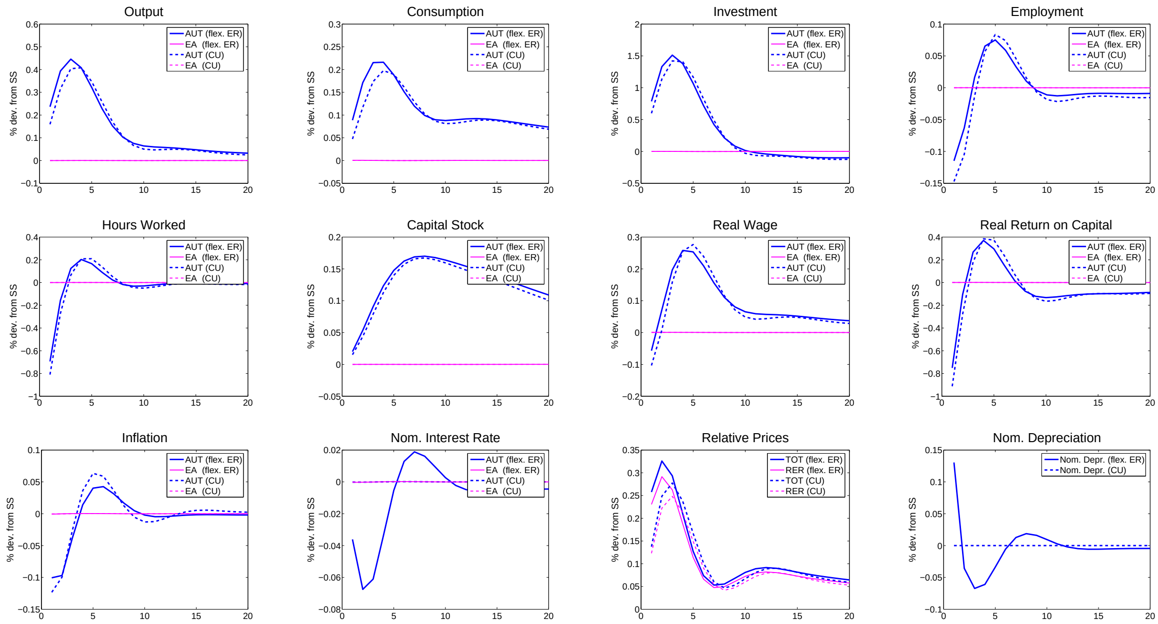


Figure 6: Impulse Response to a Productivity Shock in the rest of the Euro Area

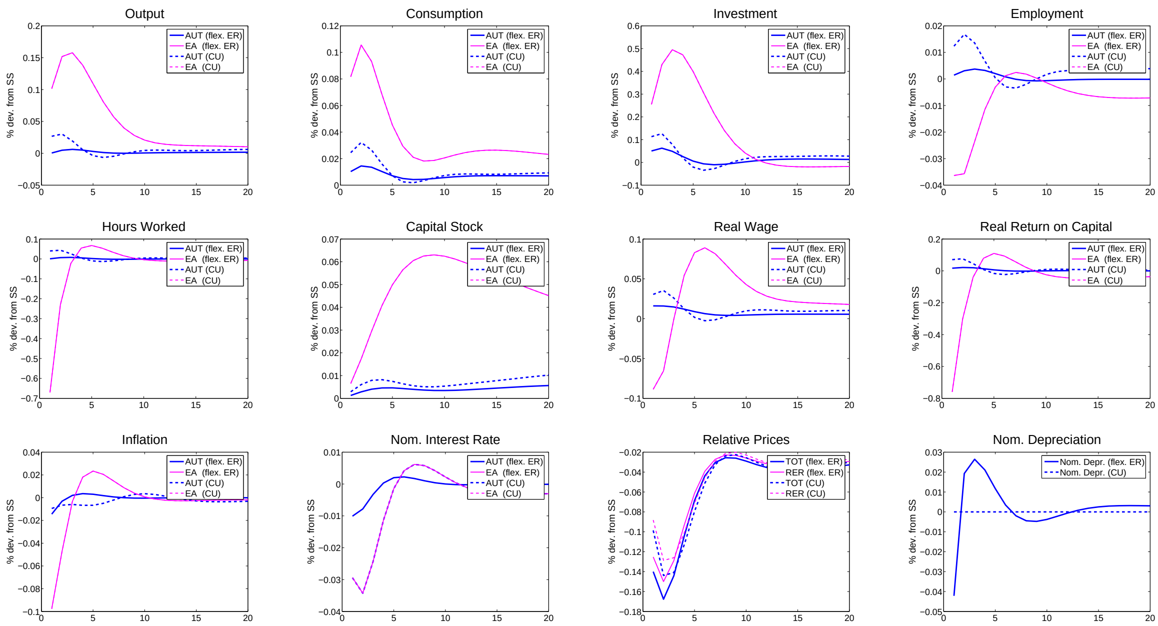


Figure 7: Impulse Response to a Labor Supply Shock in Austria

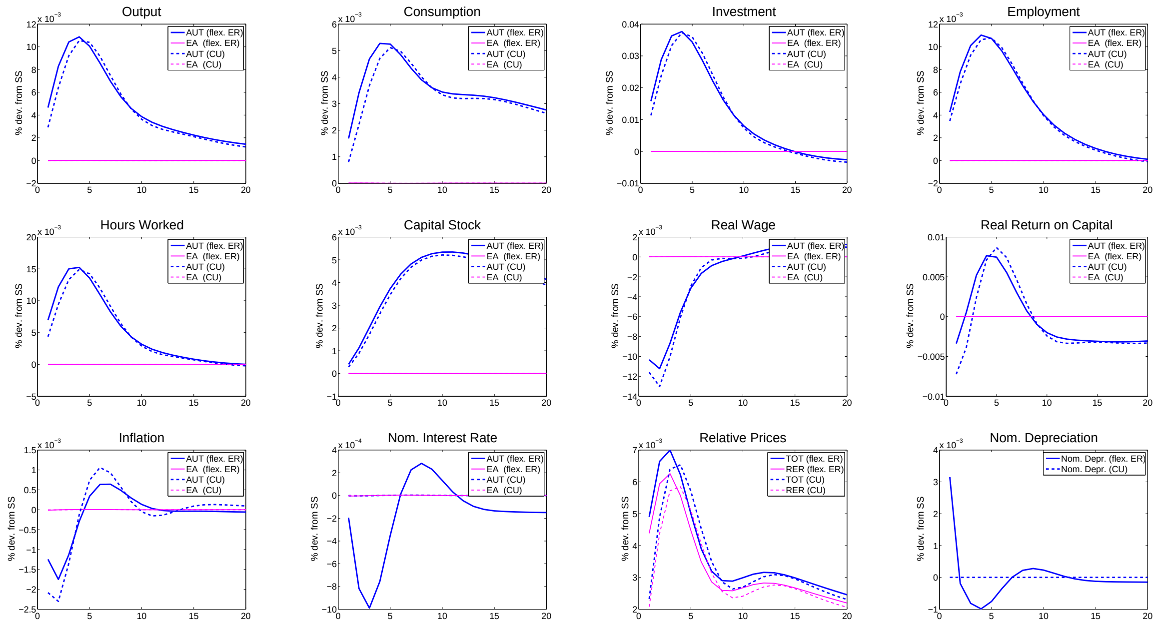


Figure 8: Impulse Response to a Labor Supply Shock in the rest of the Euro Area

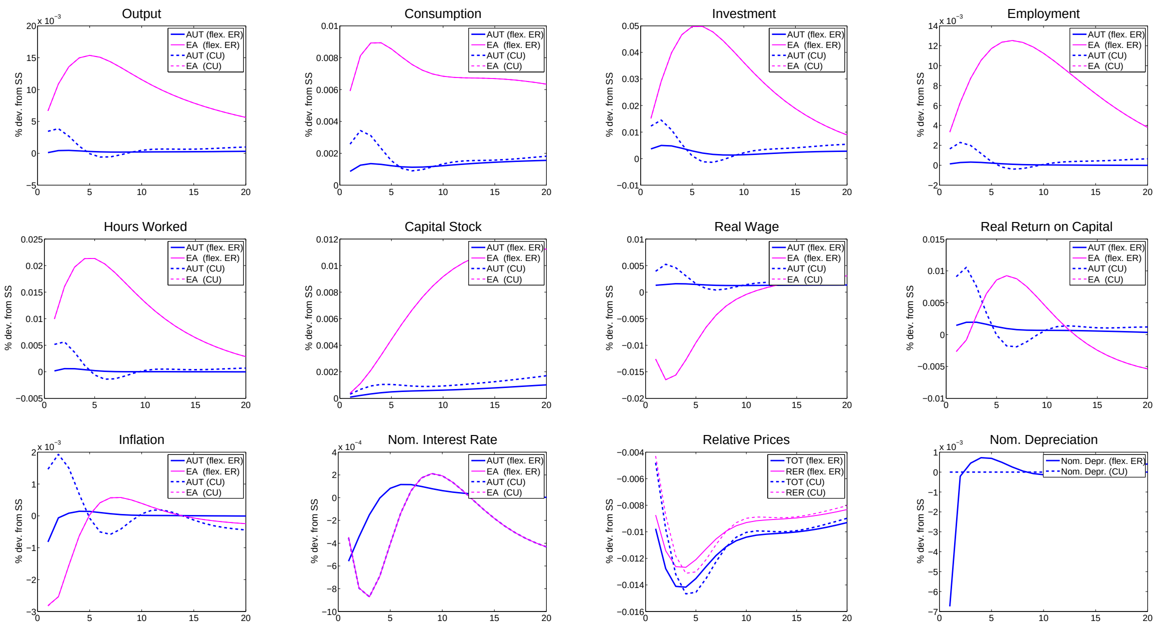


Figure 9: Impulse Response to a Wage Markup Shock in Austria

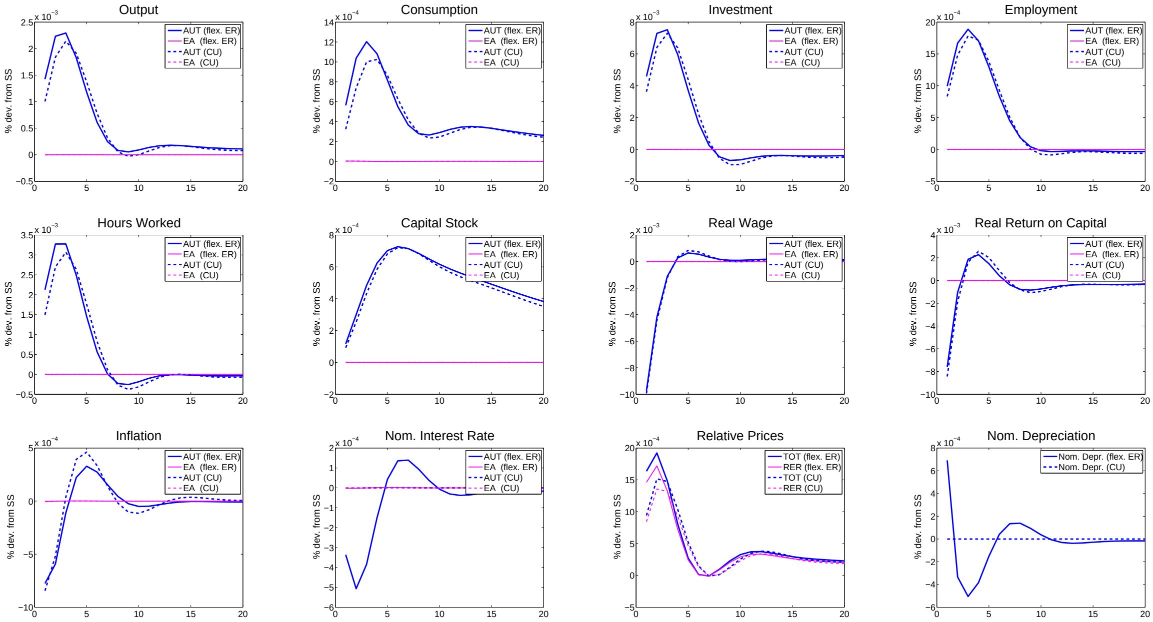


Figure 10: Impulse Response to a Wage Markup Shock in the rest of the Euro Area

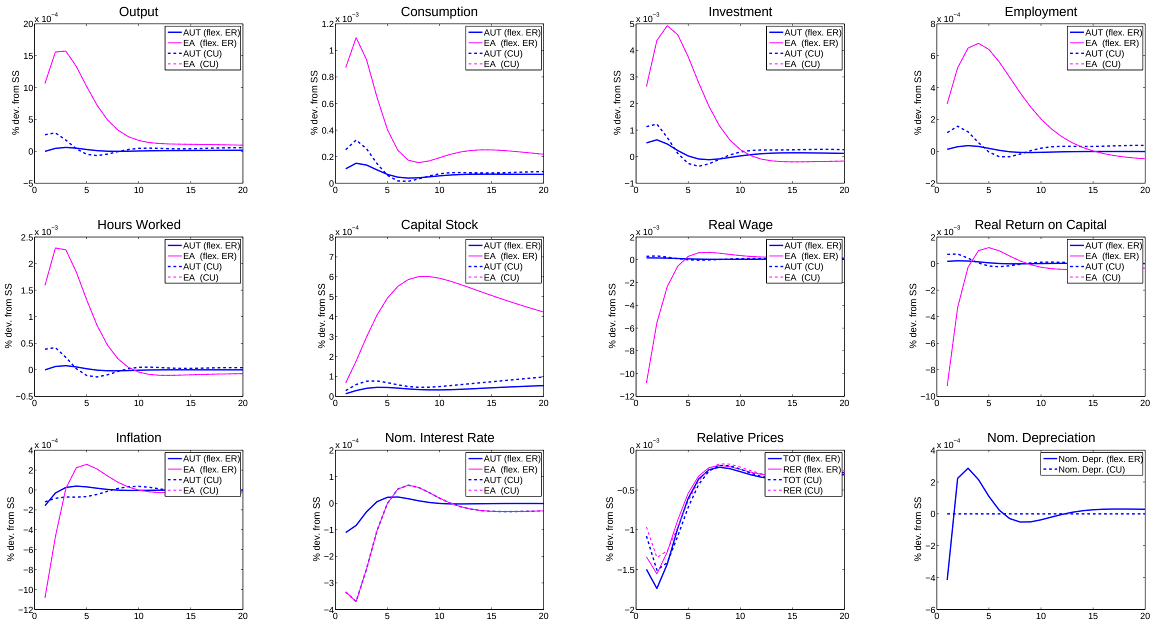


Figure 11: Impulse Response to a Price Markup Shock in Austria

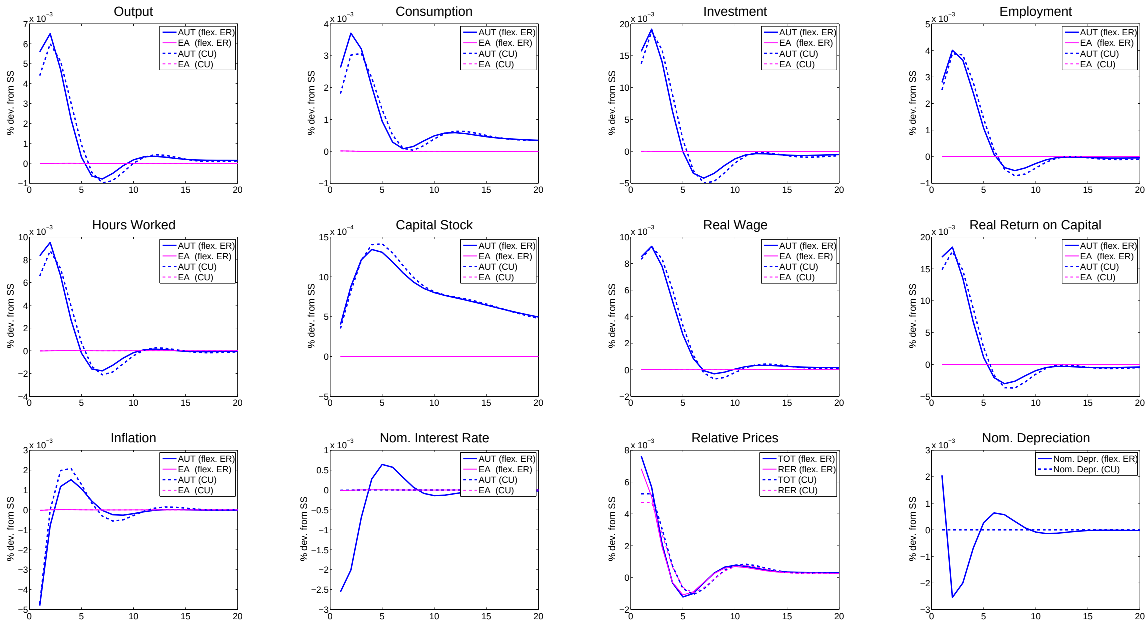


Figure 12: Impulse Response to a Price Markup Shock in the rest of the Euro Area

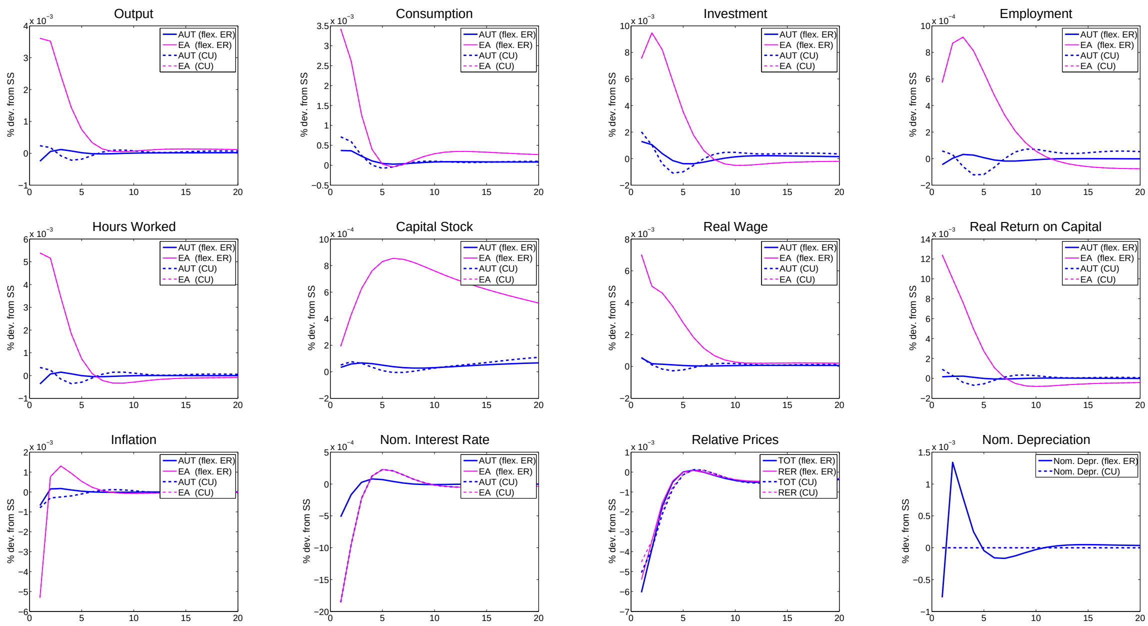


Figure 13: Impulse Response to a Consumption Preference Shock in Austria

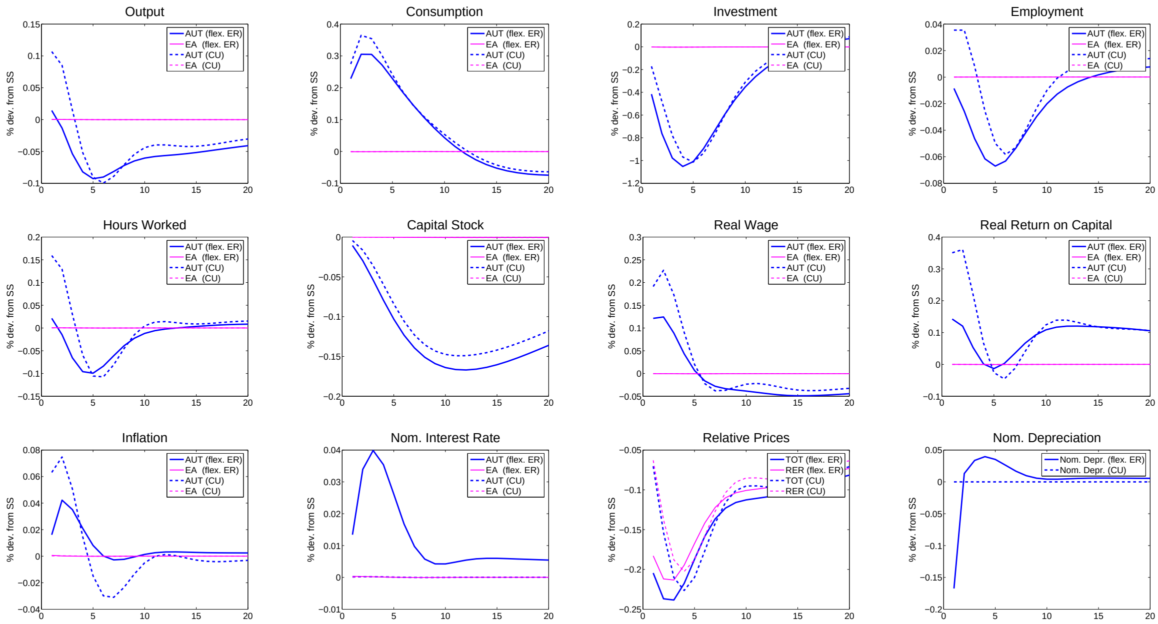


Figure 14: Impulse Response to a Consumption Preference Shock in the rest of the Euro Area

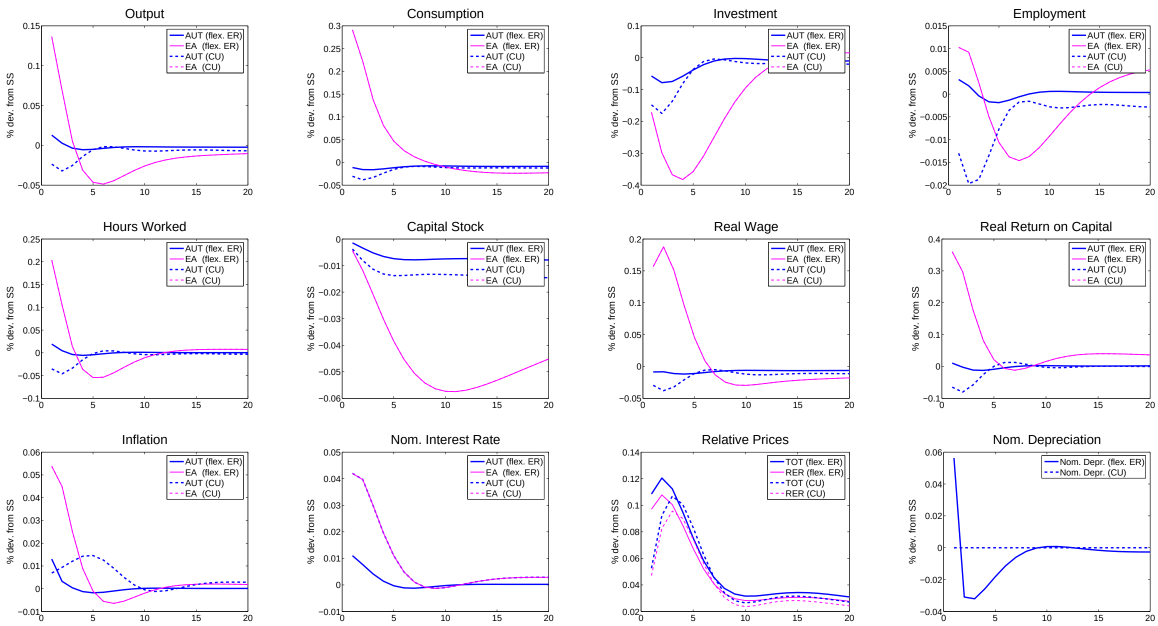


Figure 15: Impulse Response to an Investment Shock in Austria

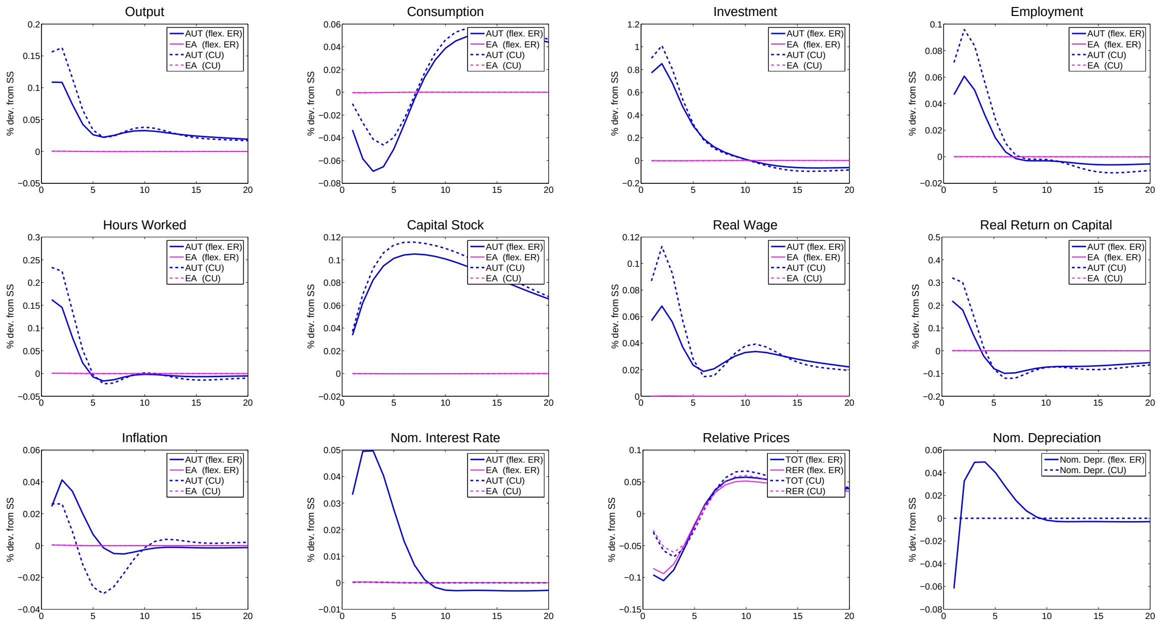


Figure 16: Impulse Response to an Investment Shock in the rest of the Euro Area

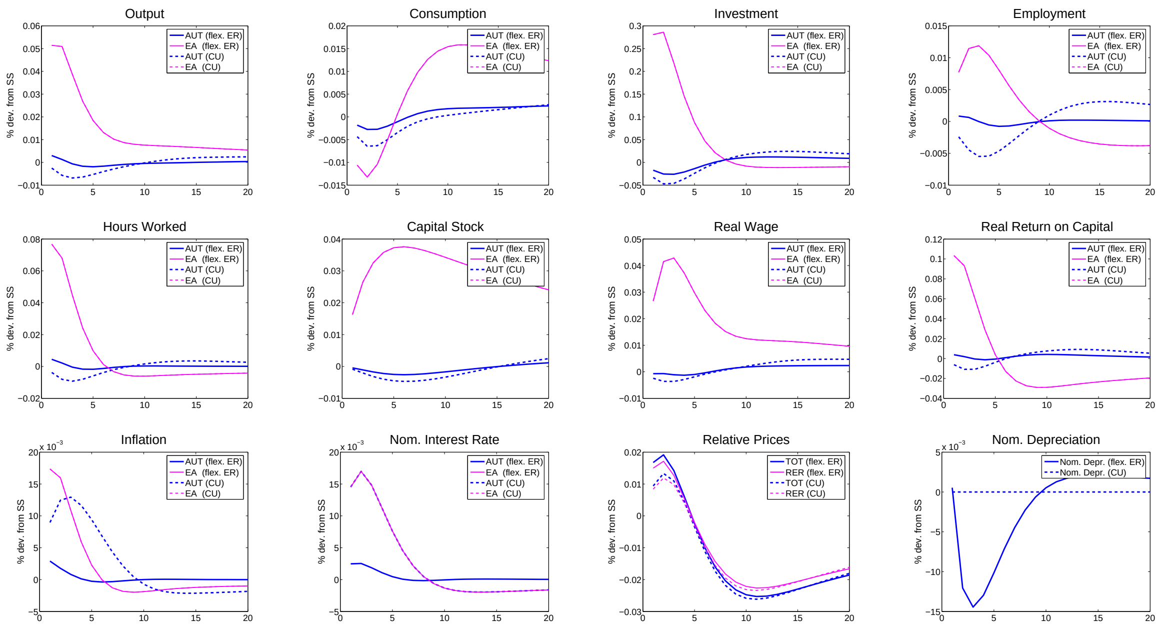


Figure 17: Impulse Response to a Government Expenditure Shock in Austria

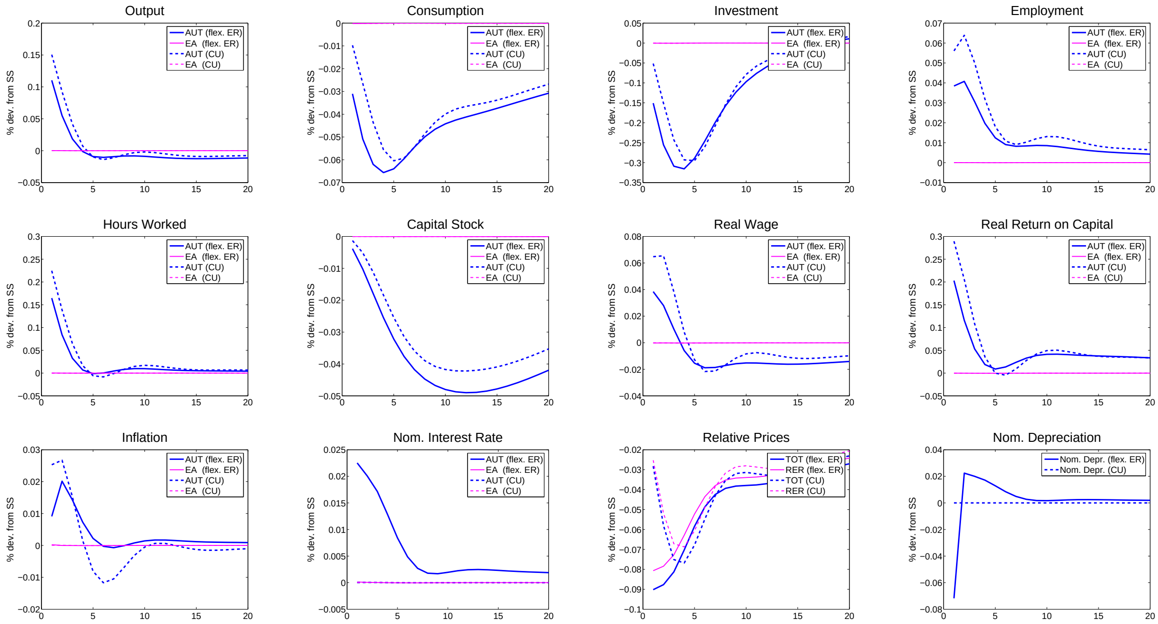


Figure 18: Impulse Response to a Government Expenditure Shock in the rest of the Euro Area

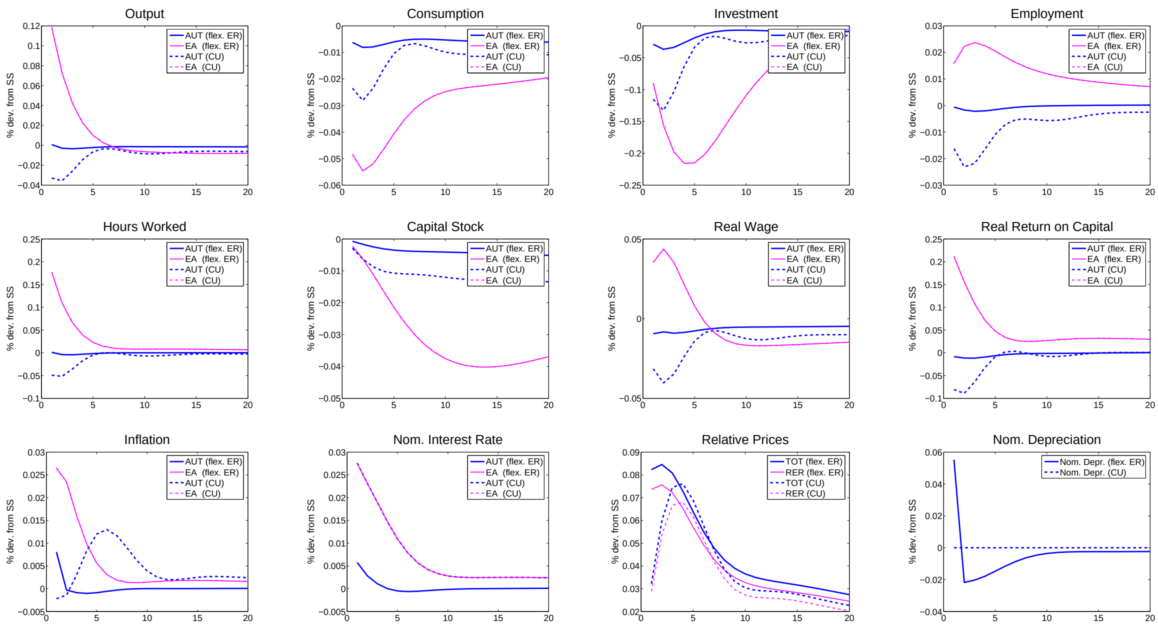


Figure 19: Impulse Response to a Monetary Shock in Austria

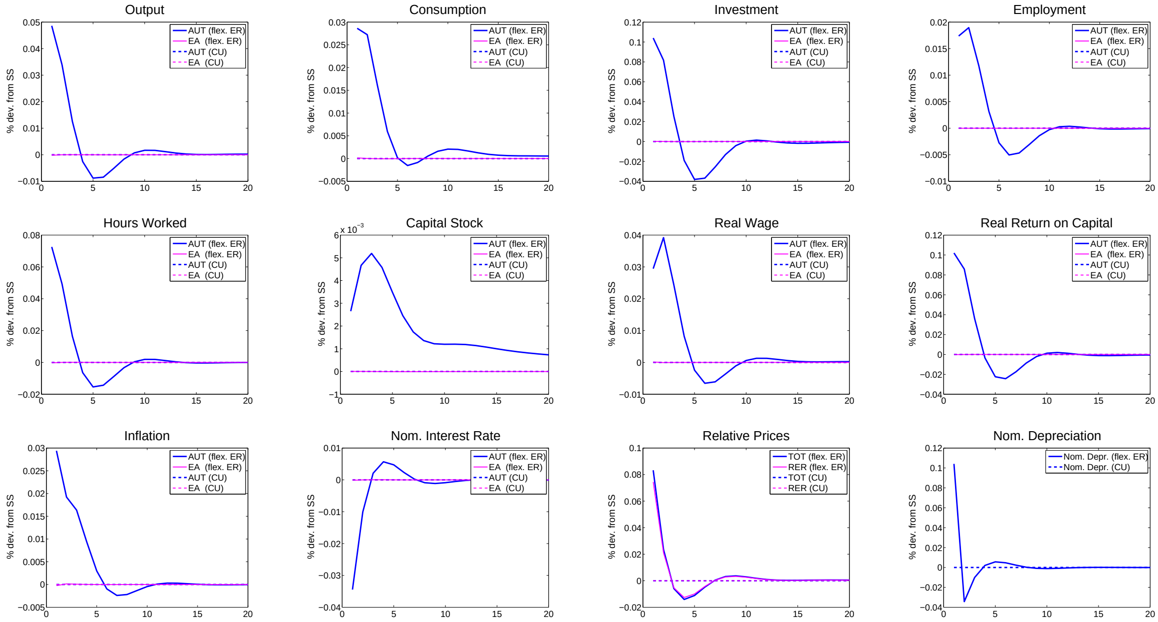
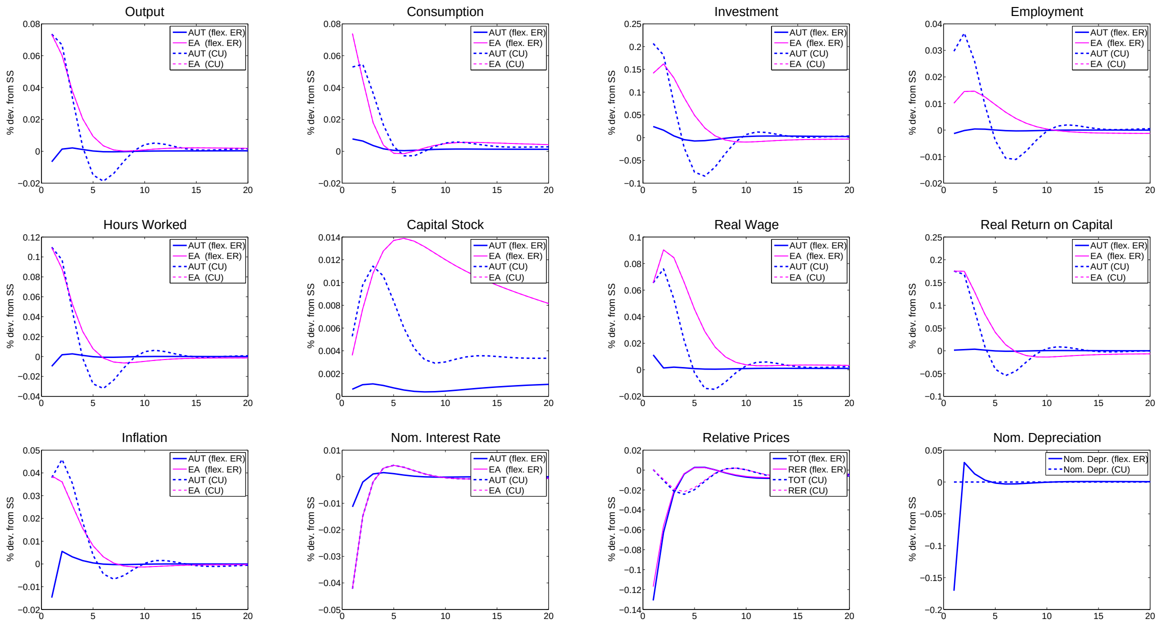


Figure 20: Impulse Response to a Monetary Shock in the rest of the Euro Area



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