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A structural interpretation of the impact of the great recession on the Austrian economy using an estimated DSGE model

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Editorial

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Gerhard Fenz, Lukas Reiss and Martin Schneider

January 30, 2012

Abstract

In this paper we present an analysis of the impact of the great recession of the years 2008 and 2009 on the Austrian economy. For this purpose, we utilize the new estimated DSGE model of the OeNB for the Austrian economy within the Euro area. This model is a small open-economy version of Smets & Wouters (2003), where the domestic economy is linked to a highly stylized representation of the rest of the Euro area via trade and financial flows. The model identifies foreign demand and confidence shocks as the main transmission channels. Moreover the risk premium shock contributed significantly to the downturn of the Austrian economy. In contrast price shocks (price markup and raw material shocks) were supportive throughout the crisis. The strong resilience of the Austrian labour market during the crisis and the subsequent upswing is reflected in a series of negative technology shocks.

1 Introduction

The great financial crisis of the years 2008 and 2009 has surprised policymakers as well as economists all over the world. Most of the factors that are now seen as important drivers of the crisis were well known among economists at the time of the outbreak. Huge macroeconomic imbalances (especially the US twin deficits in combination with huge savings in Asia) built up in the years preceding the crisis. In combination with ample world-wide liquidity, an extraordinary misperception of risks by financial markets and the spread of extremely complex financial instruments, the seedbed for the crisis was provided. Highly interconnected financial markets transmitted the triggering event problems on the US subprime mortgage markets around the globe.

The years before the great recession have seen fast progress in estimating DSGE models. Following the seminal paper by Smets & Wouters (2003) Bayesian inference methods have become increasingly popular in estimating large scale DSGE models (see Adolfson *et al.* (2007), Christiano *et al.* (2007), de Walque *et al.* (2005) and Christoffel *et al.* (2008) among others). As a consequence, DSGE models have become the workhorse model for macroeconomic analysis in many policy-oriented institutions all over the world. The IMF, the FED or the Bank of England - just to mention a few of them - use DSGE-models for policy analysis. In the Euro area, the ECB as well as many national central banks have developed DSGE models. DSGE models have been heavily criticized being unable to forecast the crisis. Whilst this is of course true, this critique applies to all model classes as well as to the whole economic profession. The fact that a model cannot predict an event does not imply that it cannot provide useful insights. What DSGE models can offer is a structural interpretation of the history. With a historical variance decomposition, the impact of structural shocks on the macroeconomic variables can be assessed for the past.

In this paper, we use an estimated DSGE model for the Austrian economy to offer a structural interpretation of the impact of the financial crisis on the Austria economy. Therefore we present a historical variance decomposition with the model estimated with current data. In addition, we compute the historical variance decomposition for the macroeconomic forecast of the OeNB from Autumn 2008. By comparing these two historical variance decomposition, we are able to identify the sources of the forecast errors.

The remainder of the paper is organized as follows: Section 2 presents the theoretical derivation of the model. The log-linearized model is outlined in section A. Section 3 discusses the data, assumptions about calibrated parameters and the final estimation results. In section 4 we analyse the empirical performance of the model. To that end, we discuss the forecast variance decomposition and the impulse responses to selected shocks. In a first application of the model we look at the Great Recession through the lense of the model in section 5. Finally, we summarize our main findings and draw some conclusions in section 6.

2 The Model

2.1 Overview

The model for the Austrian economy is a small open-economy version of Smets & Wouters (2003). As in Adolfson *et al.* (2007), Christiano *et al.* (2007) and de Walque *et al.* (2005) the domestic economy is linked to the (infinitely large) rest of the world via trade and financial flows. The main features of the model are as follows:

- **Households:** The domestic economy is populated by a continuum of infinitely living identical households that maximize expected lifetime utility, which depends on consumption and leisure. Preferences are characterized by constant relative risk aversion and external habit formation. Households accumulate capital, hold domestic and foreign bonds and own the firms. They receive capital income, interest payments and dividends in return. They pay lump-sum-taxes to finance unemployment benefits and government expenditures.
- **Labor market:** To keep things simple we use a labor market setting like in Erceg *et al.* (2000) with endogenous working hours. This will be extended in later papers to account for involuntary unemployment.
- **Production and foreign trade:** There is one homogeneous final good in the economy, which is used for consumption, investment, government consumption and exports. To produce that final good, the final goods assembling firms use domestically produced intermediate goods and imports. Their production technology is subject to adjustment costs, leading to a sluggish reaction of relative import demand in response to economic shocks. Intermediate goods producing firms use capital and labour as inputs into the production process and are subject to a permanent and a stationary technology shock. They operate under monopolistic competition. Exports are driven by export demand, which is exogenous to the domestic economy, and by the evolution of relative prices.
- **Rest of the world:** We assume that Austria only trades with the rest of the Euro area. So in the following we will use the terms 'rest of the Euro area', 'rest of the world' and 'foreign' synonymously. This rest of the Euro area is modelled in a parsimonious way using a simple standard three equation New Keynesian model as in Walsh (2003). The tree equations refer to output, inflation and interest rates. Although the rest of the Euro area is exogenous for the Austrian economy, we have modelled it as a three-equation system to ensure that foreign shocks have a strict economic meaning (e.g. that a monetary policy shock triggers a positive co-movement of Euro area output and prices). To ensure stationarity of net foreign assets and other macroeconomic aggregates in spite of the exogenous policy rate, a risk premium on interest payments based on the net foreign asset position is used (as suggested in Schmitt-Grohe & Uribe, 2003).
- **Rigidities and shocks:** The model includes a number of real and nominal rigidities that ensure smooth and realistic responses to shocks. Calvo pricing is introduced at the level of intermediate good production. Real adjustment costs occur for investment and for imports. Capital utilization is variable. Partial backward indexation leads to a deviation from rational expectations. Consumption is subject to habit formation. Moreover, shifts in the trade structure happen only gradually due to the assumption of adjustment costs. The model includes 14 shocks. Three of them (IS curve shock, Phillips curve shock and interest rate shock) are shocks to the foreign economy (rest of the Euro area), 11 shocks are purely domestic shocks.

All shocks are stationary with the exception of a unit-root technology shock, which is included to account for the high degree of persistence of the Austrian quarterly national account series.

- **Solution and estimation:** The model is highly non-linear, hence it is not possible to solve it analytically. We log-linearize the model around its steady state. The log-linear version is solved using DYNARE. The model is estimated using Bayesian techniques on the basis of twelve observable variables: GDP, private consumption, investment, export, imports, employment, real wages, domestic and foreign inflation, import inflation, Euro area interest rates and Euro area output. The estimation period ranges from 1995Q1 to 2011Q1.

2.2 Households and Wage Setting

The economy is populated by a continuum of households, indexed by $h \in [0,1]$. They maximize their intertemporal utility function which is given by

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s e^b_{t+s} \left(ln(C_{h,t+s} - \kappa C_{t+s-1}) - \frac{e^l_{t+s}}{1+\sigma_l} H^{1+\sigma_l}_{h,t+s} \right),$$

where $C_{h,t}$ is the consumption of household h, $H_{h,t}$ are working hours supplied by household h and C_{t-1} denotes the average consumption of the economy in the previous period. β is the subjective discount factor and κ the degree of (external) habit formation. $e^l_t = (1-\rho_l) + \rho_l e^l_{t-1} + \epsilon_{l,t}$ is a negative labor supply (in terms of hours) shock and $e^b_t = (1-\rho_b) + \rho_b e^b_{t-1} + \epsilon_{b,t}$ is a positive consumption shock. The budget constraint for the representative household is given by

$$C_{h,t} + I_{h,t} + T_t + \frac{B^f_{h,t}}{R^f_t \tilde{\phi}\left(nfa_t, e^{rp}_t\right) P_t} =$$
$$= \frac{B^f_{h,t-1}}{P_t} + W_{h,t}H_{h,t} + (R^k_t Z_{h,t} - \Psi(Z_{h,t}))K_{h,t-1} + D_t + \Gamma_t + \int_0^1 \Psi(Z_{h,t})K_{h,t-1} di, \quad (1)$$

where I_t is investment, T_t is lump-sum-tax, $B^f_{h,t}$ are foreign bonds held in period t,[1] P_t is the price level, R^f_t is the (gross) foreign interest rate paid on bonds, $\tilde{\phi}\left(nfa_t, e^{rp}_t\right)$ denotes a risk premium on foreign bond holdings,[2] R^k_t is the rate of return on physical capital, $W_{h,t}$ is the real wage rate, Z_t is utilization of capital, $\Psi(Z_t)$ is the cost of utilization of capital,[3] K_t is the stock of physical capital, D_t denote dividend payments and Γ_t is the net inflow from state-contingent securities (as we assume a complete market structure).

Households own the capital stock. The law of motion of capital is given by

$$K_{h,t} = (1-\tau)K_{h,t-1} + \left(1 - S\left(e^i_t \frac{I_{h,t}}{\mu^a I_{h,t-1}}\right)\right) I_{h,t}, \quad (2)$$

where τ is the rate of depreciation, $S(.)$ are investment adjustment costs ($S(1) = S^{'}(1) = 0$ and $S^{''}(1) > 0$), μ_a denotes the trend growth rate of the economy and e^i is a negative investment shock ($\mathbb{E}(e^i) = 1$; law of motion: $e^i_t = (1-\rho_i) + \rho_i e^i_{t-1} + \epsilon^i_t$).

The households maximize their utility by choosing the level of consumption, bond holdings, investment and the capital utilization rate subject to (1) and (2). In addition, they optimize wages when receiving a signal that they are allowed to (more on that below in the same section). $D_{h,t}$ and

[1] Bonds are zero-coupon bonds, i.e. a bond that pays 1 in period $t+1$ is bought in period t for $\frac{1}{R^f_t \tilde{\phi}(nfa_t, e^{rp})}$.

[2] For the definition of net foreign assets, see section 2.5.

[3] Z_t is normalized as such that in equilibrium $Z = 1$. So $\Psi(1) = 0$ and $\Psi'(1) = \frac{1}{\beta} - 1 + \tau$.

$\Gamma_{h,t}$ are taken as given. The complete household problem thus has the following form:

$$\Omega_{h,t} = \sum_{s=0}^{\infty} \beta^s \left[\begin{array}{l} e^b_{t+s} \left(\ln(C_{h,t+s} - \kappa C_{t+s-1}) - \frac{e^l_{t+s}}{1+\sigma_l} H^{1+\sigma_l}_{h,t+s} \right) \\ -\Lambda_{h,t+s} \left(\begin{array}{l} C_{h,t+s} + I_{h,t+s} + T_{t+s} + \frac{B^f_{h,t+s}}{R^f_{t+s}\tilde{\phi}(nfa_{t+s}, e^{rp}_{t+s})P_{t+s}} \\ -\frac{B^f_{h,t+s-1}}{P_{t+s}} - W_{h,t+s}H_{h,t+s} - \left(R^k_{t+s} Z_{h,t+s} - \Psi(Z_{h,t+s}) \right) K_{h,t+s-1} \\ -D_{h,t+s} - \Gamma_{h,t+s} - \int_0^1 \Psi(Z_{h,t+s}) K_{h,t+s-1} di \end{array} \right) \\ -\Lambda_{h,t+s} Q_{h,t+s} \left(K_{h,t+s} - K_{h,t+s-1}(1-\tau) - \left(1 - S\left(e^I_{t+s} \frac{I_{h,t+s}}{\mu^a I_{h,t+s-1}} \right) \right) I_{h,t+s} \right) \end{array} \right], \tag{3}$$

where Q_t is the real price of one unit of capital.

Differentiating with respect to $C_{h,t}$, $B^f_{h,t}$, $I_{h,t}$, $Z_{h,t}$ and $K_{h,t}$ (the derivative with regard to capital is taken to get the law of motion for the value of capital), gives us the following set of first order conditions:

$$\frac{\partial \Omega_{h,t}}{\partial B^f_{h,t}} = 0 \quad \rightarrow \quad \mathbb{E}_t \left[\beta \frac{\Lambda_{h,t+1}}{\Lambda_{h,t}} \frac{R^f_t \tilde{\phi}(nfa_t, e^{rp}_t) P_t}{P_{t+1}} \right] = 1, \tag{4}$$

$$\frac{\partial \Omega_{h,t}}{\partial C_{h,t}} = 0 \quad \rightarrow \quad \Lambda_t = e^b_t (C_{h,t} - \kappa C_{t-1})^{-1}, \tag{5}$$

$$\frac{\partial \Omega_{h,t}}{\partial K_{h,t}} = 0 \quad \rightarrow \quad Q_t = \mathbb{E}_t \beta \frac{\Lambda_{h,t+1}}{\Lambda_{h,t}} \left[Q_{h,t+1}(1-\tau) + Z_{h,t+1} R^k_{t+1} - \Psi(Z_{h,t+1}) \right], \tag{6}$$

$$\frac{\partial \Omega_{h,t}}{\partial I_{h,t}} = 0 \quad \rightarrow \quad 1 + Q_t \left(S' \left(e^i_t \frac{I_{h,t}}{\mu^a I_{h,t-1}} \right) e^i_t \frac{I_{h,t}}{\mu^a I_{h,t-1}} - 1 + S\left(e^i_t \frac{I_{h,t}}{\mu^a I_{h,t-1}} \right) \right) =$$

$$= \beta \mathbb{E}_t Q_{h,t+1} \frac{\Lambda_{h,t+1}}{\Lambda_{h,t}} S' \left(e^i_{t+1} \frac{I_{h,t+1}}{\mu^a I_{h,t}} \right) e^i_{t+1} \frac{I^2_{h,t+1}}{\mu^a I^2_{h,t}}, \tag{7}$$

$$\frac{\partial \Omega_{h,t}}{\partial Z_{h,t}} = 0 \quad \rightarrow \quad R^k_t = \Psi'(Z_{h,t}). \tag{8}$$

The optimality condition relating working hours and wages is derived as in Erceg *et al.* (2000). It is assumed that intermediate good firms buy homogeneous labour services (H_t) from perfectly competitive labor service firms, which aggregate differentiated labour provided by households $h \in [0,1]$. These labor service firms are modelled as simple CES-aggregators which minimize costs. The aggregator of hours is given by

$$H_t = \left(\int_0^1 (H_{h,t})^{\frac{1}{1+\lambda_w}} di \right)^{1+\lambda_w}. \tag{9}$$

The demand for labour from household h is given by the solution of the labor service firms' cost-minimization problem:

$$H_{h,t} = \left(\frac{W_{h,t}}{W_t} \right)^{\frac{-(1+\lambda_w)}{\lambda_w}} H_t. \tag{10}$$

These assumptions induce a monopolistic competitive market in which each household has some wage setting power and where λ_w can be interpreted as a wage mark-up (over the marginal rate of substitution between consumption and leisure). We adopt a Calvo wage setting mechanism, i.e. in each period a fraction $1 - \xi_w$ of the households receive a signal that permits them to (re)optimize their nominal wage. Households that are not allowed to optimize their wages index them partially (degree γ_w) to last period's CPI inflation and fully to the growth of the permanent technology process A_t (which will be further discussed below in section 2.3.2). So the expected value of the real wage of household h in period $t+s$ can be expressed as follows:

$$\begin{aligned} \mathbb{E}_t W_{h,t+s} &= \mathbb{E}_t \left(\xi_w \frac{A_{t+s}}{A_t} \Pi^{\gamma_w}_{t+s-1} W_{h,t+s-1} + (1-\xi_w) \tilde{W}_{h,t+s} \right) \\ &= \mathbb{E}_t \left(\xi^s_w \frac{A_{t+s}}{A_t} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\gamma_w} \frac{P_t}{P_{t+s}} W_{h,t} + \sum_{r=1}^{s} (1-\xi_w) \xi^{s-r}_w \frac{A_{t+s}}{A_{t+r}} \left(\frac{P_{t+s-1}}{P_{t+r-1}} \right)^{\gamma_w} \frac{P_{t+r}}{P_{t+s}} \tilde{W}_{h,t+s-r} \right) \end{aligned} \tag{11}$$

where $\tilde{W}_{h,t}$ stands for the solution to the optimization problem. While households can (sometimes) optimize wages they are assumed to just provide the hours demanded from equation (10).

The optimization problem of the households as wage-setters results in the following first-order condition for the real wage rate:

$$\sum_{s=0}^{\infty} \beta^s \Lambda_{t+s} \xi_w^s \frac{\Pi_{t-1,t+s-1}^{\gamma_w}}{\Pi_{t,t+s}} \frac{A_{t+s}}{A_t} \tilde{W}_{h,t} H_{h,t+s} = \sum_{s=0}^{\infty} \beta^s \Lambda_{t+s} \xi_w^s (1+\lambda_w) \frac{e_{t+s}^b e_{t+s}^l H_{h,t+s}^{1+\sigma_l}}{\Lambda_{t+s}}. \tag{12}$$

This equation is derived by combining the derivatives of (3) with respect to $W_{h,t}$ and thereby plugging in for $H_{h,t}$ from (10) and taking account from (11) of how $W_{h,t}$ influences future wages.

Using the assumptions on nominal wage rigidity made above, the law of motion of real wages can be formulated as a CES aggregate over the prices of adjusters and non-adjusters:

$$W_t = \left(\int_0^1 (W_{h,t})^{-\frac{1}{\lambda_w}} di \right)^{-\lambda_w} = \left[\xi_w \left(\mu_t^a W_{t-1} \Pi_{t-1}^{\gamma_w} \Pi_t^{-1} \right)^{-\frac{1}{\lambda_w}} + (1-\xi_w) \left(\tilde{W}_t \right)^{-\frac{1}{\lambda_w}} \right]^{-\lambda_w}. \tag{13}$$

2.3 Domestic Firms

Our domestic economy consists of three types of firms: intermediate goods producing firms, domestic goods assembling firms and final goods firms.

Intermediate goods firms produce differentiated intermediate goods by using capital and labour as inputs. Production is subject to both a transitory and a permanent technology shock. The domestic good assembling firms buy these differentiated intermediate goods and transform them into a homogeneous domestic good. Finally, the final good firm combines domestic goods and imported goods to produce a final good. For the sake of simplicity, we have assumed that there is only one final good in the economy.

There are several nominal and real rigidities in this economy. Intermediate goods producing firms are subject to price stickiness a la Calvo (1983). The final goods firm faces real adjustment costs in the spirit of de Walque *et al.* (2005) and Christoffel *et al.* (2008).

2.3.1 Domestic good assembling firms

The domestic good is assembled by competitive assembling firms which buy differentiated intermediate goods from a continuum of domestic intermediate goods producers and transforms them into a homogeneous domestic good:

$$Y_t = \left[\int_0^1 Y_{j,t}^{\frac{1}{1+\lambda_{p,t}}} dj \right]^{1+\lambda_{p,t}}, \tag{14}$$

where Y_t denotes the domestic good, $Y_{j,t}$ the differentiated intermediate goods and $\lambda_{p,t}$ is a time-varying mark-up subject to an iid cost-push shock ($\lambda_{p,t} = \lambda_p + \epsilon_t^p$). Cost minimization of the domestic goods assembling firm yields demand for output of firm j ($Y_{j,t}$),

$$Y_{j,t} = \left(\frac{P_{j,t}^d}{P_t^d} \right)^{\frac{-(1+\lambda_{p,t})}{\lambda_{p,t}}} Y_t, \tag{15}$$

where $P_{j,t}^d$ denotes the price of the differentiated good j. The aggregate price P_t^d of the domestic good is given by:

$$P_t^d = \left[\int_0^1 (P_{j,t}^d)^{\frac{-1}{\lambda_{p,t}}} dj \right]^{-\lambda_{p,t}}. \tag{16}$$

2.3.2 Firms producing domestic intermediate goods

There is a continuum $j \in [0,1]$ of intermediate goods producers that – using rented capital – transform the homogeneous labor services into a differentiated output. The production function is given by

$$Y_{j,t} = A_t^{1-\alpha} e_t^a \check{K}_{j,t}^{\alpha} H_{j,t}^{1-\alpha} - A_t \Phi, \tag{17}$$

where A_t is a non-stationary global technology process, e_t^a is a stationary domestic technology process, $H_{j,t}$ and $\check{K}_{j,t}$ denote labor and effective capital employed by firm j. $A_t\Phi$ are fixed real costs of production. The levels of the technology shocks evolve according to

$$\begin{aligned} \frac{A_t}{A_{t-1}} =: \mu_t^a &= (1-\rho_{\mu^a})\,\mu^a + \rho_{\mu^a}\mu_{t-1}^a + \mu^a \epsilon_t^{\mu^a} \qquad \text{and} \qquad (18) \\ e_t^a &= (1-\rho_a) + \rho_a e_{t-1}^a + \epsilon_t^a. \qquad (19) \end{aligned}$$

The effective capital stock $\check{K}_{j,t}$ employed by firms is related to the households' capital stock as follows:

$$\int_0^1 \check{K}_{j,t}dj = \int_0^1 Z_{h,t}K_{h,t-1}dh. \qquad (20)$$

The intermediate goods producers maximize their profits from selling their products to the domestic goods assembling firm. The cost-minimizing condition for all firms is given by

$$\frac{\check{K}_{j,t}}{H_{j,t}} = \frac{\alpha}{1-\alpha}\frac{W_t}{R_t^k}, \qquad (21)$$

leading to following equation for real marginal costs (which are identical over firms):

$$MC_{j,t} = MC_t = \frac{(R_t^k)^\alpha \left(\frac{W_t}{A_t}\right)^{1-\alpha}}{e_t^a \alpha^\alpha (1-\alpha)^{1-\alpha}}. \qquad (22)$$

Nominal profits of firm j are given by $Profit_{j,t} = (P_{j,t}^d - P_tMC_t)Y_{j,t} - P_tMC_tA_t\Phi$. Firm j sells its differentiated products to the domestic good assembling firm on a market with monopolistic competition. Plugging the demand function of the domestic good assembling firm (15) into this equation yields

$$Profit_{j,t} = \left(P_{j,t}^d - P_tMC_t\right)\left(\frac{P_{j,t}^d}{P_t^d}\right)^{\frac{-(1+\lambda_{p,t})}{\lambda_{p,t}}} Y_t - P_tMC_tA_t\Phi. \qquad (23)$$

We assume that firms face nominal frictions a la Calvo (1983) when maximizing their profits. In each period, only a fraction $1-\xi_p$ of firms is allowed to adjust their prices. These firms set the price $\tilde{P}_t^j$, which maximizes profits. The remaining ξ_p firms are assumed to follow a simple partial indexation rule based on past CPI inflation $P_{j,t}^d = \left(\Pi_{t-1}^d\right)^{\gamma_p} P_{j,t-1}^d$. So their optimization problem is given by $\max_{\tilde{P}_{j,t}^d} \sum_{s=0}^{\infty} \xi_p^s \beta^s \frac{\Lambda_{t+s}}{\Lambda_t} \frac{Profit_{j,t+s}}{P_{t+s}}$, which can be expressed as follows (using the indexation rule and (23)):

$$\sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{t+s} Y_{j,t+s}\left[\left(\frac{P_{t+s-1}^d}{P_{t-1}^d}\right)^{\gamma_p} \frac{\tilde{P}_{j,t}^d}{P_{t+s}} - (1+\lambda_{p,t})\,MC_{t+s}\right] = 0. \qquad (24)$$

Using (16), we can obtain the price of the domestic good P_t^d as a CES aggregate over the prices of adjusters and non-adjusters:

$$P_t^d = \left[\xi_p \left(P_{t-1}^d(\Pi_{t-1}^d)^{\gamma_p}\right)^{-\frac{1}{\lambda_{p,t}}} + (1-\xi_p)\left(\tilde{P}_{j,t}^d\right)^{-\frac{1}{\lambda_{p,t}}}\right]^{-\lambda_{p,t}}. \qquad (25)$$

2.3.3 Firms assembling final goods

For the sake of simplicity we assume that there is only one final good in the domestic economy (F_t), that is used for private consumption, investment, exports and for government consumption.[4]

[4]According to the Austrian input-output table for the year 2000, the dispersion of the import content of the GDP demand components (exports: 38%, private consumption: 27%, investment: 41%) is not so overwhelming that the assumption of a single final good is at odds with the data. The only exception is government consumption with an import share of 11% only.

This final good is assembled by a continuum of final good assembling firm, which work under perfect competition and use domestically produced and imported commodities as inputs. $F_t = \int_0^1 f(D_{i,t}, M_{i,t})di$, where $\int_0^1 D_{i,t}di = Y_t$ and $\int_0^1 M_{i,t}di = M_t$. The production function of final good assembling firm i has the following CES form:

$$F(D_{i,t}, M_{i,t}) = \left[\mu^{\frac{\sigma_m}{1+\sigma_m}} D_{i,t}^{\frac{1}{1+\sigma_m}} + (1-\mu)^{\frac{\sigma_m}{1+\sigma_m}} (\phi_{i,t} M_{i,t})^{\frac{1}{1+\sigma_m}}\right]^{1+\sigma_m}, \tag{26}$$

where μ is a parameter for a home bias for domestically produced goods, and $\frac{1+\sigma_m}{\sigma_m}$ is the elasticity of substitution between domestically produced and imported intermediate goods. There is an adjustment cost (represented by the function $\phi_{i,t}$) when firm i's ratio of imported over domestic inputs deviates from the previous period's average:

$$\phi_{i,t} = \left[1 - \phi_m \left(e_t^m - \frac{M_{i,t}/D_{i,t}}{M_{t-1}/D_{t-1}}\right)^2\right], \tag{27}$$

with $e_t^m = (1-\rho_m) + \rho_m e_{t-1}^m + \epsilon_t^m$ and $\mathbb{E}(e_t^m) = 1$. A final good assembling firm maximizes its profits by choosing the cost-minimizing amount of domestic and imported goods:

$$\max_{D_{i,t}, M_{i,t}} \left[P_t f(D_{i,t}, M_{i,t}) - P_t^d D_{i,t} - P_t^m M_{i,t}\right], \tag{28}$$

where P_t is the price of the final good.

2.4 The Foreign Economy

Austria is linked with the rest of the world via trade and financial flows. The foreign economy is modelled in a parsimonious way. It is infinitely large compared to Austria which implies that the share of imports from and exports to Austria tend to zero (and it is not affected by shocks occurring just in Austria). We denote foreign variables with superscript f (e.g. Y_t^f). As the rest of the world only consists of other Euro area countries, we neglect the potential impact of changes in demand in countries outside the Euro area and of exchange rate movements.

2.4.1 Three-equation model for output, inflation and the interest rate

The core model for the rest of the world consists of three equations for foreign output (Y_t^f), foreign inflation (Π_t^f) and the foreign interest rate (R_t^f).

The economy is populated by a continuum of households, indexed by $h \in [0, 1]$. They maximize their intertemporal utility function given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t e_t^{yf} \left(ln(C_{h,t}^f - \kappa^f C_{t-1}^f) - \frac{(H_{h,t}^f)^{1+\sigma_l^f}}{1+\sigma_l} \right),$$

where $e_t^{yf} = (1-\rho_{yf}) + \rho_{yf} e_{t-1}^{yf} + \epsilon_t^{yf}$ is a positive demand shock. The budget constraint for the representative household is given by

$$C_{h,t}^f + \frac{B_{h,t}^f}{R_t^f P_t^f} = \frac{B_{h,t-1}^f}{P_t^f} + W_t^f H_{h,t}^f + D_t^f,$$

where wages are now assumed to flexible and taken as given by households.

The FOCs for bonds and consumption are both similar to the domestic economy and can be combined with $Y_t^f = C_t^f$ to get to an Euler equation for output:

$$\mathbb{E}_t \left[\beta \frac{\Lambda_{t+1}^f}{\Lambda_t^f} \frac{R_t^f P_t^f}{P_{t+1}^f}\right] = 1, \tag{29}$$

$$\Lambda_t^f = e_t^{yf} (C_t^f - \kappa^f C_{t-1}^f)^{-1}. \tag{30}$$

Wages are flexible and hours are set optimally such that the marginal rate of substitution between leisure and consumption equals the real wage:

$$e_t^{yf}(H_{h,t}^f)^{\sigma_l^f} = \Lambda_t^f W_t^f. \tag{31}$$

Aggregate production is a simple function of aggregate working hours and the global technology process: $Y_t^f = A_t H_t^f$. So real marginal costs can be expressed as follows:

$$MC_t^f = \frac{W_t^f}{A_t} = \frac{\frac{(H_t^f)^{\sigma_l^f}}{(C_t^f - \kappa^f C_{t-1}^f)^{-1}}}{A_t} = \frac{\left(\frac{Y_t^f}{A_t}\right)^{\sigma_l^f}(C_t^f - \kappa^f C_{t-1}^f)}{A_t} = \left(\frac{Y_t^f}{A_t}\right)^{\sigma_l^f+1}\left(1 - \kappa^f \frac{Y_{t-1}^f}{Y_t^f}\right). \tag{32}$$

Optimal price setting and the law of motion of foreign price level are given by:

$$\sum_{s=0}^{\infty}(\xi_p^f)^s \beta^s \Lambda_{t+s}^f Y_{j,t+s}^f \left[\frac{\tilde{P}_{j,t}^f}{P_t^f}\left(\frac{P_{t+s-1}^f}{P_{t-1}^f}\right)^{\gamma_p^f}\frac{P_t^f}{P_{t+s}^f} - \left(1+\lambda_{p,t}^f\right)MC_t^f\right] = 0, \tag{33}$$

$$P_t^f = \left[\xi_p^f\left(P_{t-1}^f(\Pi_{t-1}^f)^{\gamma_p^f}\right)^{-\frac{1}{\lambda_{p,t}^f}} + \left(1-\xi_p^f\right)\left(\tilde{P}_t^f\right)^{-\frac{1}{\lambda_{p,t}^f}}\right]^{-\lambda_{p,t}^f}. \tag{34}$$

The last 3 equations can be combined to get to a simple New Keynesian Phillips curve.

Finally, monetary policy follows a simple log-linear rule:

$$\widehat{R}_t^f = \rho_r R_{t-1}^f + (1-\rho_r)(\psi_\pi^f \widehat{\Pi}_t^f + \psi_y^f \widehat{y}_t^f) + \epsilon_t^r. \tag{35}$$

2.4.2 Trade with Austria

Exports to Austria are assembled out of the foreign good (which has price P_t^f), differentiated and sold at price P_t^m to Austrian final good firms.

$$P_t^m = e_t^{\pi m} P_t^f. \tag{36}$$

The wedge $e_t^{\pi m}$ between P_t^f and P_t^m can be interpreted as a mark-up process ($e_t^{\pi m} = \rho_{\pi m} e_{t-1}^{\pi m} + (1-\rho_{\pi m})e^{\pi m} + e^{\pi m}\epsilon_t^{\pi m}$).

Imports from Austria (which are bought at price P_t) and domestic production are assembled to foreign final goods with the following production function:

$$F_{i,t}^f = \int_0^1 \left[\mu_f^{\frac{\sigma_{mf}}{1+\sigma_{mf}}}\left(D_{i,t}^f\right)^{\frac{1}{1+\sigma_{mf}}} + (1-\mu_f)^{\frac{\sigma_{mf}}{1+\sigma_{mf}}}\left(\phi_{i,t}^f M_{i,t}^f\right)^{\frac{1}{1+\sigma_{mf}}}\right]^{1+\sigma_{mf}} di, \tag{37}$$

where $\mu_f \to 1$. Therefore $F_t^f \to Y_t^f = D_t^f$ and – as assemblers are perfectly competitive – the price of the foreign final good P_t^f equals the price of the foreign intermediate good. $\phi_{i,t}^f$ represents import adjustment costs as in (27) with the shock process $e_t^{mf} = (1-\rho_{\phi_{mf}}) + \rho_{\phi_{mf}} e_{t-1}^{mf} + \epsilon_t^{mf}$.

2.5 Aggregate output and net foreign assets

In addition to the equations presented above, a set of market clearing conditions and a closure rule are needed to complete the model. The market clearing condition for the final goods market relates supply (F_t) to total demand, given by the sum of private consumption, investment, exogenous government consumption and exports:[5]

$$F_t = C_t + I_t + X_t + A_t e_t^g, \tag{38}$$

where e_t^g is the productivity-adjusted government consumption process with expected value g and law of motion $e_t^g = (1-\rho_g)g + \rho_g e_{t-1}^g + g\epsilon_{g,t}$.

[5]Since there is only one final good, the price index cancels out of the equation.

As final goods firms are competitive, we have that $P_tF_t = P_t^dY_t + P_t^mM_t$, which – using (38) – can be reformulated into the following familiar formulation:

$$P_t^dY_t = P_tF_t - P_t^mM_t = P_t(C_t + I_t + X_t + A_te_t^g) - P_t^mM_t. \tag{39}$$

The aggregate production function can be derived by putting (17) into (14):

$$Y_t = A_t^{1-\alpha}e_t^a\left(\int_0^1 \check{K}_{j,t}^{\frac{\alpha}{1+\lambda_{p,t}}} H_{j,t}^{\frac{1-\alpha}{1+\lambda_{p,t}}}dj\right)^{1+\lambda_{p,t}} - A_t\Phi. \tag{40}$$

For Austria as a small member country of the European Monetary Union, the Euro area interest rate can be treated as exogenous. Therefore we use a risk premium on net foreign debt (in the spirit of Schmitt-Grohe & Uribe, 2003) to ensure stationarity of net foreign assets and other macroeconomic aggregates. The risk-adjusted interest rate is given by $R_t^f\tilde{\phi}\left(nfa_t, e_t^{rp}\right)$, where $\tilde{\phi}$ denotes a risk premium on foreign bond holdings $B_{i,t}^f$ (similar to Adolfson *et al.*, 2007) with the following functional form:

$$\tilde{\phi}\left(nfa_t, e_t^{rp}\right) = \exp\left(-\phi_a nfa_t + e_t^{rp}\right), \tag{41}$$

where $nfa_t := \frac{B_t^f}{P_tY_t}$). When a country is a net borrower, the risk-adjusted interest rate increases. This dampens consumption and investment and increases net exports which brings the net foreign asset position back to zero. When a country is a net lender, it receives a lower interest rate on its savings, which boosts domestic demand. In the steady state, net foreign assets are assumed to equal zero.

The budget constraint of the government is given by

$$A_te_t^g + \frac{B_{g,t}^f}{R_t^f\tilde{\phi}\left(nfa_t, e_t^{rp}\right)P_t} = T_t + \frac{B_{g,t-1}^f}{P_t},$$

where $B_{g,t}^f$ are bonds held by the government in t (so in reality $B_{g,t}$ would be negative in most industrialized countries). Aggregating the budget constraints of the domestic households and the domestic government ($B_t^f = \int_0^1 B_{h,t}^f dh + B_{g,t}^f$), one gets to the law of motion of foreign bond holdings:

$$\frac{B_t^f}{R_t^f\tilde{\phi}\left(nfa_t, e_t^{rp}\right)} = B_{t-1}^f + P_tX_t - P_t^MM_t. \tag{42}$$

Dividing (42) by P_tY_t and using the definition of nfa_t:

$$\frac{nfa_t}{R_t^f\tilde{\phi}\left(nfa_t, e_t^{rp}\right)} = \frac{nfa_{t-1}}{\Pi_t\frac{Y_t}{Y_{t-1}}} + \frac{X_t}{Y_t} - \frac{P_t^M}{P_t}\frac{M_t}{Y_t}. \tag{43}$$

3 Estimation

3.1 Linearization, data and measurement equations

To be able to estimate the model, we have to linearize the equations from section 2 (the linearized equations are shown in appendix A).

Before linearizing, we have to transform the model into a stationary form. There are two sources of non-stationarity in our model. First, the permanent technology shock A_t introduces non-stationarity in all quantities (with the exception of hours worked, which are stationary due to the assumption that the intertemporal elasticity of substitution is 1) as well as in the real wage. So we have to transform the respective variables by dividing them by the level of technology. We use the convention that capital Roman letters refer to the original variables and small Roman letters refer to stationarized variables, i.e $c_t \equiv \frac{C_t}{A_t}$, $i_t \equiv \frac{I_t}{A_t}$, $k_t \equiv \frac{K_t}{A_t}$, $m_t \equiv \frac{M_t}{A_t}$, $w_t \equiv \frac{W_t}{A_t}$, $x_t \equiv \frac{X_t}{A_t}$ and $y_t \equiv \frac{Y_t}{A_t}$. In addition to these variables, we have to multiply marginal utility of consumption with A_t to stationarize it ($\lambda_t \equiv \Lambda_tA_t$).

So the measurement equations for non-stationary variables in this model are $\Delta \ln Y_t = \widehat{y}_t - \widehat{y}_{t-1} + \widehat{\mu}_t^a$ and so on ($\Delta \ln Y_t$ being the growth rate of Y).

The second source of non-stationarity comes from the nominal variables in the model: Inflation rates are stationary but price levels are not. So we have to express all price variables in inflation rates and relative prices. We choose the price of the final good as numeraire $\left(p_t^d \equiv \frac{P_t^d}{P_t};\ p_t^m \equiv \frac{P_t^m}{P_t};\ p_t^f \equiv \frac{P_t^f}{P_t}\right)$. The laws of motion of the relative price levels are therefore:

$$\widehat{p}_t^d = \widehat{p}_{t-1}^d + \widehat{\Pi}_t^d - \widehat{\Pi}_t, \tag{44}$$

$$\widehat{p}_t^m = \widehat{p}_{t-1}^m + \widehat{\Pi}_t^m - \widehat{\Pi}_t, \tag{45}$$

$$\widehat{p}_t^f = \widehat{p}_{t-1}^f + \widehat{\Pi}_t^f - \widehat{\Pi}_t. \tag{46}$$

The model is estimated using 12 quarterly data series from 1995Q1 to 2011Q1. The data set includes domestic and foreign GDP, private consumption, investment, export, imports, employment, real wages, domestic and foreign price levels, import deflator and the foreign short-term interest rate. All foreign series refer to the Euro area. All series with exception of the interest rate are seasonally adjusted. The variables are stationarized by taking growth rates to the previous quarter (with the exception of the interest rate, which is in levels, but divided by four to obtain a quarterly interest rate). In addition, a quadratic trend is removed from the real and nominal series in levels (meaning that growth rates are linearly detrended). Due to the expression of most quantities in efficiency units, we also have to include the following measurement equations:

$$y_t^{obs} = \widehat{y}_t - \widehat{y}_{t-1} + \widehat{\mu}_t^a, \tag{47}$$

$$c_t^{obs} = \widehat{c}_t - \widehat{c}_{t-1} + \widehat{\mu}_t^a, \tag{48}$$

$$i_t^{obs} = \widehat{i}_t - \widehat{i}_{t-1} + \widehat{\mu}_t^a, \tag{49}$$

$$x_t^{obs} = \widehat{x}_t - \widehat{x}_{t-1} + \widehat{\mu}_t^a, \tag{50}$$

$$m_t^{obs} = \widehat{m}_t - \widehat{m}_{t-1} + \widehat{\mu}_t^a, \tag{51}$$

$$w_t^{obs} = \widehat{w}_t - \widehat{w}_{t-1} + \widehat{\mu}_t^a, \tag{52}$$

$$y_t^{f,obs} = \widehat{y}_t^f - \widehat{y}_{t-1}^f + \widehat{\mu}_t^a. \tag{53}$$

Furthermore time data on employment in persons is perceived by us as being of relatively higher quality than data on working hours in Austria. Therefore we proceed similar to Smets & Wouters (2003) and Christoffel *et al.* (2008) and link the data on employment in persons N_t to working hours per person H_t in our model via the following measurement equation:

$$\widehat{N}_t = \frac{1-\beta\xi_e}{1-\xi_e}(\widehat{H}_t - \widehat{N}_t) + \beta \mathbb{E}_t \widehat{N}_{t+1}. \tag{54}$$

3.2 Calibration and priors

Due to the well-known identification problems of DSGE models (see Iskrev (2008) among others), we have to restrain the number of estimated parameters. In our model we estimated 43 parameters. Hence, 12 parameters remain to be calibrated. The steady state growth rate of the permanent technology shock ($\bar{\mu}_a$) is set to 0.5% per quarter. The discount factor β equals 0.995 (=0.99 times the steady state growth rate of the permanent technology shock ($\bar{\mu}_a = 1.005$)), which implies a steady state interest rate of 4%. The depreciation rate τ is set to 0.025. The steady state ratios also have to be calibrated, since the detrended data used for estimation does no longer include the relevant information. Steady state GDP is set to one. The steady state values of private consumption, investment and exports are computed from national accounts data and are set to 0.57, 0.23 and 0.58, respectively (the share of government consumption is implied by the assumption that the trade balance is zero in the steady state). The share of capital in the production function α amounts to 0.31. In addition to these parameters, we calibrate some parameters which were not identifiable. Following the results of Breuss & Rabitsch (2009) we set the degree of habit formation in Austria to 0.79. Since consumption is more volatile in the euro area than in Austria the foreign habit parameter is significantly lower (0.57 see Christoffel *et al.* (2008)). The inflation coefficient in the Taylor rule is taken from Christoffel *et al.* (2008) and amounts to 1.9. The complete list of all calibrated parameters can be found in table 1.

The model is estimated using Bayesian methods. Hence we have to choose appropriate priors for all parameters. The variances of the shocks are assumed to follow an inverted Gamma distribution, whereas for the shock autocorrelations we assume a Beta distribution. For the structural parameters, the choice of the prior depends on the parameter at hand. The priors for the shock variances of the two technology shocks are based on the estimation results of Adolfson *et al.* (2007), Pytlarczyk (2005), Christoffel *et al.* (2008) and Breuss & Rabitsch (2009). These authors have found that the variance of the permanent technology shock (0.1-0.4) to be much lower than for the transitory technology shock (0.7-1.2). There is a great variation for the variance of the preference shock in the literature, ranging from 0.15 to 2.3. The priors for the import adjustment costs parameters are based on the results of de Walque *et al.* (2005). For the substitution elasticity between imports and domestic production we follow Christoffel *et al.* (2008) and use a gamma distribution.

3.3 Estimation results

We have estimated the model by taking 1,000,000 draws of the Metropolis-Hastings algorithm (where the first 10% of the draws has been discarded as burn-in draws). The estimates of the parameter values can be found in table 2. We just want to highlight some selected results: We find a share of 89% of firms that do not change their prices in a given quarter (ξ_p). This can be translated into an average duration of price contracts ($= \frac{1}{1-\xi_p}$) of nine quarters. On the wage side, the average contract lasts for three quarters. These findings are in line with the empirical literature.

The degree of indexation for prices (γ_p) is estimated to amount to 0.85, which is slightly higher than the findings of Breuss & Rabitsch (2009) for Austria and significantly higher than our estimate for the euro area (0.24). On the other hand, the degree of indexation for wages (0.12) is found to be significantly lower than what is commonly found in the literature (0.5-0.7). This can be explained by the effects of the permanent technology shock: As the real wage has to be divided by the level of labour productivity to achieve a stationary series, a large share of the persistence of the real wage series is explained by the permanent technology shock.

The absolute magnitude of the shock standard deviations cannot easily be compared with the literature. When looking at the relative standard deviation of the two technology shocks, we find that the standard deviation of the transitory TFP process is five times as high as the standard deviation of the non-stationary labour productivity process. This finding is in line with the literature, although the magnitude of this ratio varies from 3.5 (Adolfson *et al.*, 2007) to 6 (Christoffel *et al.*, 2008). Regarding the autocorrelation of the shocks, we find that majority of shocks is relatively persistent with estimates of 0.6 to 0.9.

4 Application I: Forecast error variance decomposition

Having estimated the model, we now (in the following two sections) want to see how the model decomposes the fluctuations of observable variables into the contributions of different shocks.

As a first step we conduct a forecast error variance decomposition which is used to analyse the relative importance of the shocks in driving the model variables *over different time horizons.*[6] Tables 3 and 4 present the forecast error variance decomposition for the most important model variables. As one might expect for a small open economy variations in Austrian *GDP* are strongly determined by shocks related to foreign trade. In the very short run, i.e. at the one to four quarter horizon, shocks related to Austrian exports (shocks to foreign import adjustment costs, which can be interpreted as export demand shocks, and shocks to foreign demand) explain around 1/2 of the variation.[7] Another

[6]This decomposition builds on the impulse responses of the model. A description of impulse responses to selected shocks can be found in appendix B.

[7]The model relates the main bulk of exports shocks to foreign import adjustment costs while the influence of shocks to foreign output remains more limited. As both shocks have a very similar impact on Austrian exports (but a different impact on Euro area output), this indicates that the relationship between Austrian exports and Euro area output is more complex than in our model.

1/4 to 1/3 of fluctuations are driven by shocks by domestic import adjustment costs.[8] Overall in the short run almost 80% of output variations are related to foreign trade disturbances. Regarding domestic shocks government consumption add almost 10% to short run output fluctuations while interest rate shocks account for less than 5% (which is well in line with the results of other empirical studies). Since the import preference shocks can be treated as demand shocks, GDP is in the short run to a very large extent demand-driven. This result is more or less in line with Breuss & Rabitsch (2009) and Breuss & Fornero (2009), who also find an important role of both foreign and domestic demand shocks for Austria. At medium business cycle frequencies, i.e. at 8 to 16 quarters horizon, supply shocks (i.e. transitory and permanent technology shocks and price mark-up shocks) are gaining quickly importance. As expected, the permanent technology shock becomes the dominant force in the long run while demand shocks are loosing importance. The share of interest rate shocks (monetary policy and risk premium shocks) in the variance decomposition remains relatively stable at around 5% over the whole horizon.

Regarding the demand components of GDP, the picture is similar with the respective specific shocks (i.e. investment adjustment costs, consumption preference shock ...) being more important especially in the short run. For the variance of *exports* only three shocks have a non-negligible influence. In the short run exports are almost completely demand driven. Shocks to foreign import adjustment costs and foreign demand explain more than 80% of export variations. In the medium to long run the permanent technology shock is gaining some importance. Due to the high import content of exports, shocks to foreign import adjustment costs are also important in explaining *import* fluctuations in the short run. Moreover shocks to domestic import adjustment costs, which can be interpreted as import demand shocks, contribute significantly to the import-variance in the short to medium run. The import price shock accounts for only 10% of import fluctuations in the short run but is gaining importance in the long run due to its high persistence. *Investment* variations are mainly driven by the investment shock in the short run while in the case of *consumption* the interest rate and risk premium shock as well as the consumption preference shock are important.

In contrast to output and its demand components, *employment* is – almost by definition – not dominated by the permanent technology shock in the long run. Supply shocks (transitory technology shock, mark-up shock) account for 20% and demand shocks for 60% of the variance in the short run. Surprisingly the impact of the labour supply shock on employment remains rather limited at all horizons. The price mark-up shock has a non-negligible influence on *real wages* at all horizons. Moreover import price shocks are an important determinant of real wages in the short run, while the permanent technology shock dominates at longer horizons.

Finally, *inflation* fluctuations are mainly determined by import price shocks and to a lesser extent by domestic and foreign mark-up shocks in the very short run. At medium and long run horizons demand shocks (import and export demand shocks) are gaining some importance but supply shocks remain the driving force.

5 Application II: A structural interpretation of the effects of the great recession on Austria

In this section we look at the recent financial crisis through the lens of our model. We do this by analysing the historical variance decomposition of the latest quarterly National Accounts data from the fourth quarter of 2008 to the fourth quarter of 2010. We compare these results with the variance decomposition of the macroeconomic forecast of the OeNB of Autumn 2008 in order to identify the main sources of forecast errors.

Our model includes 14 shocks. To keep the analysis simple and traceable, we aggregate those shocks to six groups. We have two technology shocks (stationary and permanent), three domestic demand shocks (government spending, investment adjustment costs, consumption preference shock),

[8] The historical variance decomposition in section 5 reveals that domestic and foreign import demand shocks typically work in opposite directions in explaining historical output fluctuations. This can be explained by the assumption that the import content of exports, consumption and investment is the same, while in reality the one of exports is highest. Therefore the sum of both shocks in the variance decomposition should be interpreted as an upper limit of their true contributions to total output fluctuations.

four price shocks (price mark-up, labour supply, foreign inflation, shock to relative prices), one risk premium shock, one foreign monetary shock and three foreign trade shocks (shock to the foreign IS curve, domestic import preference shock, foreign import preference shock).

The crisis is a global phenomenon and Austria being a small open economy was mainly hit via the external trade channel. In the second half of 2008 strong negative foreign demand shocks turned Austrian GDP growth negative. Import and export demand shocks account for more than half of the downturn of the Austrian economy in the first quarters of the crisis. Confidence effects represent the second main transmission channel. In the model they are captured by negative domestic demand shocks. Large investment adjustment cost shocks triggered a fall in investment activity. Consumption was dampened by negative preference shocks.

A striking feature of the Austrian economy during the crises and the subsequent upswing was the resilience of the labour market. Similar to Germany employment dropped less than past crises episodes would have suggested and grew stronger in the subsequent upswing. Overall the unemployment rate increased by just 1.5 percentage points during the crises and returned to pre-crises average levels thereafter rather quickly. Three reasons are frequently cited as explanation. First, the experience of labour shortage in the years before the outbreak of the crises led to massive labour hoarding during the crisis. Second, in order to cushion the impact of the crisis on the labour market, the Austrian government introduced short-time employment schemes ('Kurzarbeit'). Third, the crisis hit the manufacturing sector, which exhibits high labour productivity, much harder than the service sector. In the model negative technology shocks - characterized by a negative co-movement of output and employment - capture the unusual resilience of the labour market.

Inflation fell by more than the drop in economic activity would have suggested. The years before the crisis were characterized by wage moderation, strong growth of profit margins and high productivity gains. Thus, firms had ample scope to reduce prices in order to retain their market shares. Moreover, the boom bust cycle was accompanied by strong procyclical swings in oil and raw material prices. Both phenomena contributed positively to GDP growth during the crisis. In the model they show up as mark-up and raw material shocks, respectively.

Since our model does not include a financial market, we are not able to capture several important features of the current crisis like the sharp increase in yield spreads or the huge losses on stock markets. As a short-cut we introduced a risk premium shock which directly affects real interest rates. As one might expect the risk premium shock contributes negatively to GDP growth during the crises explaining about 10% of the economic downturn. In contrast monetary policy shocks were only restrictive around the beginning of the crisis but supportive thereafter.

The recovery that began in the second half of 2009 was also mainly driven by foreign demand shocks. In the course of 2010, positive demand shocks also contributed to output growth. The surprisingly strong growth of employment relative to GDP in the course of 2010 is again reflected in a series of negative technology shocks.

The forecast of the OeNB that was published in December 2008 drew a too favourable picture of expected future developments. Although there were already signs of a downturn available at that time, the strength of the contraction was heavily underestimated. At the beginning of the forecast horizon in the fourth quarter of 2008 the main driver of the forecast error were negative domestic demand shocks which can to a large extent be explained by huge revisions of the Austrian National Account data. In the first quarter of 2009 the forecast error resulted from a massive negative foreign demand shock. The upswing starting in the second half of 2009 turned out to be more pronounced than expected at this time. Initially the main driver of the forecast error was once again the foreign demand shock while in 2010 additionally domestic demand and monetary policy shocks played an important role.

6 Summary

Our model for the Austrian economy is a small open-economy version of a typical DSGE model where the domestic economy is linked to the highly stylized (and relative to Austria infinitely large) rest of the Euro area via trade and financial flows. The empirical performance of the model is encouraging. It captures the main time series properties as measured by the moments of the key macroeconomic variables. Finally the historical variance decomposition gives a reasonable picture of past economic developments. The main transmission channels during the crises identified by the model have been widely recognized as having been crucial for explaining the economic downturn of the Austrian economy during the Great Recession. In future work the model at hand will be extended along several lines. Among the next steps are the introduction of financial frictions and a detailed representation of the labour market allowing for involuntary unemployment.

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A The Log-Linearized Model

In this section we present the log-linearization of the model around the steady state.[9] We use the convention that log-deviations from the steady state are indicated by a hat ($\widehat{y}_t \equiv \ln\left(\frac{y_t}{y}\right)$). Variables without a time subscript denote steady state values. In the steady state, the behaviour of all households and firms is identical to the average. Therefore we can drop the indices i, j and h.

A.1 Households and labor markets

Log-linearizing the first order conditions (4) to (8) yields the following set of equations for the households:

(55) is derived from (4) and states the intertemporal Euler equation. It relates the marginal utility in period t and $t+1$ to the real interest rate including the risk premium on foreign bond holdings. Note that we have included the stationarized marginal utility of consumption ($\lambda_t \equiv \Lambda_t A_t$) to account for the permanent technology shock:

$$\widehat{\lambda}_t - \mathbb{E}_t\widehat{\lambda}_{t+1} = \widehat{R}^f_t - \mathbb{E}_t\widehat{\Pi}_{t+1} - \phi_a dnfa_t - \widehat{\mu}^a_{t+1} + e^{rp}_t. \tag{55}$$

The log-linear version of (5) describes marginal utility of consumption, which decreases as consumption increases:

$$\widehat{\lambda}_t = \widehat{e}^b_t - \frac{1}{1-\kappa\mu_a^{-1}}\left(\widehat{c}_t - \frac{\kappa}{\mu_a}\left(\widehat{c}_{t-1} - \widehat{\mu}^a_t\right)\right). \tag{56}$$

The law of motion for the real value of capital Q_t is derived from (6):

$$\widehat{Q}_t = \mathbb{E}_t\left(\widehat{\lambda}_{t+1} - \widehat{\lambda}_t - \widehat{\mu}^a_{t+1} + \frac{\beta}{\mu_a}\left((1-\tau)\widehat{Q}_{t+1} + R^k\widehat{R}_{k,t+1}\right)\right). \tag{57}$$

The investment equation is derived from (7):

$$\widehat{i}_t = \frac{1}{1+\beta}\left(\widehat{i}_{t-1} - \widehat{e}^I_t - \widehat{\mu}_{a,t}\right) + \frac{\beta}{1+\beta}\left(\widehat{i}_{t+1} + \widehat{e}^I_{t+1} + \widehat{\mu}_{a,t+1}\right) + \frac{\varphi}{1+\beta}\widehat{Q}_t. \tag{58}$$

Linearization of (8) yields

$$\widehat{Z}_t = \Psi\widehat{R}^k_t, \tag{59}$$

where $\Psi = \frac{\Psi'(1)}{\Psi''(1)}$. In addition to the first order conditions, the log-linear capital accumulation equation can be obtained by log-linearizing (2):

$$\widehat{k}_t = \frac{(1-\tau)}{\mu_a}\left(\widehat{k}_{t-1} - \widehat{\mu}^a_t\right) + \left(1 - \frac{1-\tau}{\mu_a}\right)\widehat{i}_t. \tag{60}$$

The wage Phillips curve can be derived from (12) and (25):

$$\begin{aligned}(1+\zeta_w)\widehat{w}_t \quad &= \quad \frac{\beta}{1+\beta}\mathbb{E}_t\widehat{w}_{t+1} + \frac{1}{1+\beta}\widehat{w}_{t-1}\zeta_w\left(\sigma_l\widehat{H}_t - \widehat{\lambda}_t + \widehat{e}_{l,t} + \widehat{e}_{b,t}\right) \\ &\quad + \frac{\beta}{1+\beta}\widehat{\Pi}_{t+1} - \frac{1+\beta\gamma_w}{1+\beta}\widehat{\Pi}_t + \frac{\gamma_w}{1+\beta}\widehat{\Pi}_{t-1},\end{aligned} \tag{61}$$

with $\zeta_w = \frac{(1-\beta\xi_w)(1-\xi_w)}{(1+\beta)(1+\frac{(1+\lambda_w)}{\lambda_w})\xi_w}$.

[9] A technical appendix, in which these linearized equations are derived, is available on demand from the authors.

A.2 Domestic Firms

Combining (24) with (25) and log-linearizing gives us the Phillips curve for the price of the domestically produced good:

$$\widehat{\Pi}_t^d = \frac{\gamma_p}{1+\beta\gamma_p}\widehat{\Pi}_{t-1}^d + \frac{\beta}{1+\beta\gamma_p}\mathbb{E}_t\widehat{\Pi}_{t+1}^d + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p(1+\beta\gamma_p)}\left(\widehat{mc}_t - \widehat{p}_t^d\right) + \epsilon_t^{\lambda_p}, \tag{62}$$

with real marginal costs $\widehat{mc}_t = \alpha\widehat{R}_t^k + (1-\alpha)\widehat{w}_t - \widehat{e}_t^a$ (=log-linearization of (22)) and where $\epsilon_t^{\lambda_p}$ is a rescaled version of ϵ_t^p. The Phillips curve is identical to the one in Smets & Wouters (2003) with two exceptions: Due to the permanent technology shock, the stationarized real wage ($\widehat{w}_t$) instead of the real wage itself ($\widehat{W}_t$) drives marginal costs, and since intermediate goods producers discount expected future profits with the consumer price level P_t, the relative price $\widehat{p}_t^d$ also enters the Phillips curve.

Linearizing equation (21) and then averaging over firms i gives us an equation for labour demand (in hours):

$$\widehat{w}_t + \widehat{H}_t + \widehat{\mu}_t^a = \widehat{R}_t^k + \widehat{Z}_t + \widehat{k}_{t-1}. \tag{63}$$

Computing the optimization problem of the final goods assembling firms (and using equations (26) and (27)) gives us demand equations for domestic goods and imports:

$$\widehat{p}_t^m = \frac{\sigma_m\mu}{1+\sigma_m}\left(\widehat{y}_t - \widehat{m}_t\right) + 2\phi_m\left(-\widehat{y}_{t-1} + \widehat{m}_{t-1} + \widehat{y}_t - \widehat{m}_t + \widehat{e}_t^m\right), \tag{64}$$

$$\widehat{p}_t^d = \frac{\sigma_m(1-\mu)}{1+\sigma_m}\left(\widehat{m}_t - \widehat{y}_t\right) - 2\phi_m\frac{(1-\mu)}{\mu}\left(-\widehat{y}_{t-1} + \widehat{m}_{t-1} + \widehat{y}_t - \widehat{m}_t + \widehat{e}_t^m\right). \tag{65}$$

A.3 Foreign economy

The Euler equation for foreign consumption (which is equal to output) is:

$$\widehat{y}_t^f = \frac{\frac{\kappa_f}{\mu_a}}{1+\frac{\kappa_f}{\mu_a}}\left(\widehat{y}_{t-1}^f - \widehat{\mu}_t^a\right) + \frac{1}{1+\frac{\kappa_f}{\mu_a}}\mathbb{E}_t\left(\widehat{y}_{t+1}^f + \widehat{\mu}_{t+1}^a\right) - \frac{1-\frac{\kappa_f}{\mu_a}}{1+\frac{\kappa_f}{\mu_a}}\mathbb{E}_t\left(\widehat{R}_t^f - \widehat{\Pi}_{t+1}^f + \widehat{e}_t^{yf} - \widehat{e}_{t+1}^{yf}\right). \tag{66}$$

The Phillips curve is given by:

$$\begin{aligned}\widehat{\Pi}_t^f = \; & \frac{\gamma_{p,f}}{1+\beta\gamma_{p,f}}\widehat{\Pi}_{t-1}^f + \frac{\beta}{1+\beta\gamma_{p,f}}\mathbb{E}_t\widehat{\Pi}_{t+1}^f \\ & + \frac{(1-\beta\xi_{p,f})(1-\xi_{p,f})}{\xi_{p,f}(1+\beta\gamma_{p,f})}\left((1+\sigma_l^f)\widehat{y}_t^f + \frac{\frac{\kappa_f}{\mu_a}}{1-\frac{\kappa_f}{\mu_a}}(\widehat{y}_t^f - \widehat{y}_{t-1}^f + \widehat{\mu}_t^a)\right) + \epsilon_t^{\Pi f}.\end{aligned} \tag{67}$$

As stated before, the monetary policy rule is:

$$\widehat{R}_t^f = \rho_r R_{t-1}^f + (1-\rho_r)(\psi_\pi^f\widehat{\Pi}_t^f + \psi_y^f\widehat{y}_t^f) + \epsilon_t^r. \tag{68}$$

Demand for imports from Austria is:

$$\widehat{p}_t^f = \frac{\sigma_f}{1+\sigma_f}(\widehat{y}_t^f - \widehat{x}_t) + 2\phi_f\left(-\widehat{y}_{t-1}^f + \widehat{x}_{t-1} + \widehat{y}_t^f - \widehat{x}_t + \widehat{e}_t^{mf}\right). \tag{69}$$

A.4 GDP and Net Foreign Assets

The log-linearized version evolution of net foreign assets is given by:

$$\beta\, dnfa_t = \frac{1}{\mu^a}dnfa_{t-1} + x_y\left(\widehat{x}_t - \widehat{m}_t - \widehat{p}_t^m\right). \tag{70}$$

The nominal GDP identity is:

$$\widehat{p}_t^d + \widehat{y}_t = c_y\widehat{c}_t + \tau k_y\widehat{i}_t + (1-\tau k_y - c_y)\widehat{e}_t^G + x_y\left(\widehat{x}_t - \widehat{m}_t - \widehat{p}_t^m\right). \tag{71}$$

Supply of real GDP is given by

$$\widehat{y}_t = (1+\phi)\left(\widehat{e}_t^a + \alpha\left(\widehat{Z}_t + \widehat{k}_{t-1}\right) + (1-\alpha)\widehat{H}_t\right), \tag{72}$$

where $\phi = \frac{\Phi}{y}$ (the ratio of fixed costs over GDP).

A.5 Exogenous Processes

It is assumed that the interest rate shock ϵ_t^r and the mark-up shocks $\epsilon_t^{\lambda_p}$ and $\epsilon_t^{\pi f}$ are iid. All the other shock processes are assumed to be AR(1):

$$\begin{aligned}
\widehat{e}_t^l &= \rho_l \widehat{e}_{t-1}^l + \epsilon_t^l && \text{[Labour supply shock]}, && (73)\\
\widehat{e}_t^a &= \rho_a \widehat{e}_{t-1}^a + \epsilon_t^a && \text{[Stationary technology shock]}, && (74)\\
\widehat{\mu}_t^a &= \rho_{\mu_a} \widehat{\mu}_{t-1}^a + \epsilon_t^{\mu^a} && \text{[Permanent technology shock]}, && (75)\\
\widehat{e}_t^b &= \rho_b \widehat{e}_{t-1}^b + \epsilon_t^b && \text{[Preference shock]}, && (76)\\
\widehat{e}_t^g &= \rho_g \widehat{e}_{t-1}^g + \epsilon_t^g && \text{[Government spending shock]}, && (77)\\
\widehat{e}_t^i &= \rho_I \widehat{e}_{t-1}^i + \epsilon_t^i && \text{[Investment shock]}, && (78)\\
\widehat{e}_t^m &= \rho_{\phi_m} \widehat{e}_{t-1}^m + \epsilon_t^m && \text{[Own import shock]}, && (79)\\
\widehat{e}_t^{mf} &= \rho_{\phi_{mf}} \widehat{e}_{t-1}^{mf} + \epsilon_t^{mf} && \text{[Foreign import shock]}, && (80)\\
\widehat{e}_t^{yf} &= \rho_{yf} \widehat{e}_{t-1}^{yf} + \epsilon_t^{yf} && \text{[World demand shock]}, && (81)\\
\widehat{e}_t^{rp} &= \rho_{rp} \widehat{e}_{t-1}^{rp} + \epsilon_t^{rp} && \text{[Risk premium shock]}, && (82)\\
\widehat{e}_t^{\pi m} &= \rho_{\pi m} \widehat{e}_{t-1}^{\pi m} + \epsilon_t^{\pi m} && \text{[Import price shock]}. && (83)
\end{aligned}$$

B Description of important impulse responses

Figure 6 shows that the reaction of the model to a *temporary technology shock* is relatively standard. A temporary technology shock increases the production capacity of the economy and decreases marginal production costs. The output of the economy rises. Output reaches its maximum after 10 quarters and thereafter converges back to the steady state. In terms of domestic demand components, it is investment that reacts significantly stronger than consumption. Exports go up as the domestic economy gains price competitiveness. Due to nominal rigidities in the model (consumption habits, investment and import adjustment costs, and price and wage rigidities) and the (known) temporary nature of the shock, demand increases by less than the production capacity. Consequently less factor inputs are needed in the production to meet demand and both capital utilization and hours worked drop initially. The drop in marginal costs triggers a fall in inflation. The real rental rate of capital drops as the capital stock can adjust only slowly despite variable capital utilization. Real wages move only little due to the sharp decline in hours worked.

Next we turn to the *permanent technology shock* (figure 7). Due to the permanent nature of this shock, all quantities (with the exception of hours worked) do not return to the old steady state, but converge to a new one. Since households and firms anticipate the increase in activity, all quantities show a strong and steady increase. While consumption and exports approach their new equilibrium levels steadily, investment activity "overshoots" initially before slowly returning to its new steady state. This enables the capital stock to adjust rather quickly. Due to the high import content of investment, imports show a similar albeit less pronounced pattern. The net foreign asset position turns negative. In contrast to the stationary technology shock both capital utilization and hours worked increase from the beginning. Moreover the high demand for factor inputs causes – again in contrast to the stationary technology shock – real wages and the real rental rate of capital to rise significantly. The rise in factor costs is almost completely offset by the productivity-shock-driven drop in marginal costs, so inflation moves only little. Overall inflation rises slightly initially leading to a positive co-movement of output and inflation as in Christoffel *et al.* (2008). This stands in sharp contrast to the results for a traditional temporary supply shock which is typically characterized by a negative co-movement of prices and output.

A negative *monetary policy shock* in the Euro area, that is, a temporary increase in Euro area interest rate, leads in both the Euro area and Austria to the standard hump shaped responses of output and inflation (see figure 8). The decline of output in Austria is somewhat stronger than in the Euro area (see Breuss & Rabitsch (2009) for a similar result), while the reverse holds for inflation. Moreover the response of the Austrian economy is more sluggish. This can be explained by the fact that the model for the Austrian economy is much more detailed and richer of nominal and real rigidities than the simple three-equations-model for the Euro area. The stronger decline in Euro area inflation affects the price competitiveness of Austrian exports negatively leading to a worsening of the net foreign asset position. Regarding domestic demand components higher interest rates dampen investment more than consumption. The impact of the shock is relatively short-lived. Domestic output reaches its minimum already after 4 quarters, producer price inflation after 5 quarters.

For Austria as a small open economy foreign developments are of utmost importance. Figure 9 shows the reaction of the model to a *world demand shock*. To be more precise, this shock constitutes a shock to the Euro area IS curve, causing Euro area output as well as the price level to increase. Consequently, the monetary authority reacts by increasing interest rates. The higher level of Euro area activity translates into higher exports by Austrian firms. Capital utilization, firms demand for labour and output go up. But the higher export demand is only partly met by an increase in output. Initially it is also optimal to reduce investment and consumption as supply side restrictions prevent output from increasing stronger. This stands in sharp contrast to results from Keynesian models or models in the tradition of the neoclassical synthesis which typically feature a positive co-movement of all demand components in response to a foreign demand shock from the very beginning of the simulation horizon. In the model at hand the initial drop in consumption and investment adds to an increase in the net foreign asset position which is reinforced by gains in price competitiveness. After a few quarters the picture is reversed and the net foreign asset holdings are used to finance additional consumption and investment expenditures. The transmission is slightly higher than in the other models of the OeNB for the Austrian economy (Fenz & Spitzer (2005), Schneider & Leibrecht (2006), Fenz & Schneider (2007)). In the first year of the shock an increase of Euro area output by 1% leads to an increase of output in Austria by about 0.5%.

Finally figure 10 shows the reaction of the model to a *price mark-up shock*. Firms set prices as a mark-up over marginal costs. An increase in the domestic mark-up leads to an immediate surge in domestic inflation and a drop in international price competitiveness. The shock induces a fall in output and all demand components which is most pronounced for investment. Real wages and the real rate of return fall immediately. Hours worked and the rate of capital utilization decline. The shock is iid and relatively short lived. The effects on the real side peak already after six quarters, those on the nominal side after two years.

C Tables

Table 1: Calibrated parameters

Parameter		Value
Domestic structural parameters		
Discount factor	β	0.995
Share of capital	α	0.31
Depreciation rate	τ	0.025
Wage markup	$\overline{\lambda_w}$	0.5
Degree of habit formation	κ	0.79
Calvo parameter for determination of hours	ξ_e	0.6
Foreign structural parameters		
Degree of habit formation	κ_f	0.57
Inflation coefficient in Taylor rule	ψ_f	1.9
Steady State values		
Growth of permanent technology shock	$\overline{\mu^a}$	1.005
Consumption	$\bar{c}_y$	0.57
Investment	$\bar{i}_y$	0.23
Exports	$\bar{x}_y$	0.58

Table 2: Estimation results for structural parameters

Parameter		Prior			Posterior		
		Type	Mean	Std Err	Mean	5%	95%
Structural parameters							
Foreign trade adjustment costs	χ_f	beta	0.100	0.050	0.180	0.089	0.271
Domestic trade adjustment costs	χ_m	beta	0.100	0.050	0.355	0.265	0.439
Inverse of second derivative of investment adjustment cost function	χ	norm	0.100	0.050	0.097	0.038	0.155
Indexation for goods prices	γ_p	beta	0.700	0.150	0.855	0.741	0.972
Indexation for foreign goods prices	γ_{p_f}	beta	0.500	0.150	0.235	0.098	0.363
Indexation for wages	γ_w	beta	0.300	0.150	0.118	0.018	0.209
Risk premium on foreign bond holdings	$\tilde{\phi}_a$	invg	0.010	Inf	0.004	0.002	0.005
Output coefficient in foreign Phillips curve	η_f	norm	6.000	1.000	5.420	3.647	7.151
Output coefficient in foreign Taylor rule	ψ_{y_f}	norm	0.150	0.050	0.172	0.096	0.248
Elasticity of substitution of foreign importers	σ_f	norm	1.500	1.000	2.281	1.070	3.398
Inverse elasticity of labour supply	σ_L	norm	7.000	1.500	6.102	3.510	8.974
Elasticity of substitution of domestic importers	σ_m	norm	1.500	1.000	0.718	0.166	1.306
Calvo parameter firms	ξ_p	beta	0.800	0.100	0.887	0.857	0.917
Calvo parameter wages	ξ_w	beta	0.700	0.100	0.693	0.625	0.765
Calvo parameter foreign firms	ξ_{p_f}	beta	0.650	0.100	0.881	0.845	0.918
Share of fixed cost	ϕ	norm	0.200	0.100	0.495	0.351	0.639
Capital adjustment costs	ψ	norm	0.200	0.050	0.224	0.144	0.306
Shock autocorrelations							
Labour supply	ρ_L	beta	0.800	0.100	0.872	0.767	0.983
Transitory technology	ρ_a	beta	0.800	0.100	0.795	0.707	0.883
Preference	ρ_b	beta	0.800	0.100	0.885	0.796	0.990
Government spending	ρ_G	beta	0.800	0.100	0.850	0.788	0.917
Investment	ρ_i	beta	0.800	0.100	0.600	0.491	0.716
Euro area interest rate	ρ_R	beta	0.700	0.200	0.855	0.829	0.879
Import prices	ρ_{π_o}	beta	0.800	0.100	0.936	0.885	0.990
Import adjustment costs	ρ_{ϕ_m}	beta	0.800	0.100	0.737	0.662	0.811
Permanent technology	ρ_{μ_a}	beta	0.800	0.100	0.837	0.755	0.924
Foreign imports	$\rho_{\phi_{mf}}$	beta	0.800	0.100	0.802	0.728	0.879
Risk premium	ρ_{RP}	beta	0.800	0.100	0.773	0.603	0.932
World output	ρ_{y_f}	beta	0.750	0.100	0.635	0.550	0.715
Variances of shock innovations							
Transitory technology	ϵ_a	invg	0.500	Inf	0.519	0.398	0.643
Permanent technology	ϵ_{μ_a}	invg	0.100	Inf	0.095	0.062	0.129
Preference	ϵ_b	invg	2.000	Inf	0.649	0.419	0.875
Government spending	ϵ_G	invg	3.000	Inf	2.039	1.733	2.326
Investment	ϵ_i	invg	0.500	Inf	1.280	1.053	1.506
Labour supply	ϵ_L	invg	2.000	Inf	7.138	2.562	11.63
Price markup domestic	ϵ_{λ_p}	invg	0.500	Inf	0.096	0.079	0.112
Domestic import preferences	ϵ_{ϕ_m}	invg	1.000	Inf	1.403	1.083	1.714
Foregin import preferences	$\epsilon_{\phi_{mf}}$	invg	1.000	Inf	1.555	1.307	1.801
World inflation	ϵ_{π_f}	invg	0.500	Inf	0.264	0.219	0.309
Import prices	ϵ_{π_o}	invg	0.500	Inf	0.570	0.487	0.650
Euro area interest rate	ϵ_R	invg	0.100	Inf	0.102	0.083	0.119
Risk premium	ϵ_{RP}	invg	0.100	Inf	0.056	0.026	0.088
World demand	ϵ_{y_f}	invg	1.000	Inf	1.409	1.138	1.681

Table 3: Variance decomposition 1

	1	**4**	**8**	**16**	**40**	**100**
Y						
ϵ_a	0.001	0.006	0.025	0.057	0.051	0.035
ϵ_b	0.002	0.004	0.004	0.004	0.006	0.005
ϵ_G	0.087	0.034	0.023	0.020	0.018	0.013
ϵ_i	0.026	0.037	0.043	0.049	0.055	0.038
ϵ_L	0.000	0.000	0.000	0.002	0.003	0.002
ϵ_{λ_p}	0.011	0.049	0.092	0.098	0.081	0.055
ϵ_{μ_a}	0.012	0.024	0.041	0.079	0.212	0.457
ϵ_{ϕ_m}	0.245	0.334	0.322	0.284	0.234	0.161
$\epsilon_{\phi_{mf}}$	0.515	0.387	0.310	0.268	0.220	0.151
ϵ_{π_f}	0.006	0.014	0.021	0.022	0.018	0.013
ϵ_{π_m}	0.001	0.007	0.009	0.008	0.011	0.008
ϵ_R	0.022	0.036	0.044	0.044	0.037	0.025
ϵ_{RP}	0.008	0.019	0.027	0.030	0.027	0.019
ϵ_{yf}	0.064	0.049	0.038	0.033	0.027	0.019
Sum	1.000	1.000	1.000	1.000	1.000	1.000
π						
ϵ_a	0.002	0.013	0.015	0.021	0.022	0.022
ϵ_b	0.000	0.000	0.001	0.001	0.001	0.001
ϵ_G	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_i	0.000	0.000	0.000	0.002	0.003	0.004
ϵ_L	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_{λ_p}	0.109	0.136	0.148	0.167	0.165	0.164
ϵ_{μ_a}	0.000	0.001	0.001	0.002	0.002	0.002
ϵ_{ϕ_m}	0.001	0.013	0.023	0.025	0.031	0.031
$\epsilon_{\phi_{mf}}$	0.001	0.010	0.017	0.019	0.023	0.023
ϵ_{π_f}	0.162	0.141	0.135	0.130	0.128	0.127
ϵ_{π_m}	0.684	0.588	0.550	0.525	0.517	0.517
ϵ_R	0.009	0.035	0.047	0.048	0.047	0.047
ϵ_{RP}	0.000	0.001	0.001	0.003	0.004	0.005
ϵ_{yf}	0.031	0.062	0.060	0.058	0.057	0.057
Sum	1.000	1.000	1.000	1.000	1.000	1.000
n						
ϵ_a	0.169	0.096	0.080	0.086	0.084	0.084
ϵ_b	0.003	0.004	0.004	0.005	0.005	0.005
ϵ_G	0.026	0.018	0.015	0.015	0.015	0.015
ϵ_i	0.023	0.024	0.022	0.022	0.022	0.022
ϵ_L	0.000	0.001	0.002	0.006	0.007	0.007
ϵ_{λ_p}	0.049	0.086	0.114	0.116	0.120	0.119
ϵ_{μ_a}	0.000	0.001	0.001	0.001	0.001	0.001
ϵ_{ϕ_m}	0.286	0.327	0.321	0.315	0.315	0.315
$\epsilon_{\phi_{mf}}$	0.316	0.287	0.263	0.256	0.255	0.256
ϵ_{π_f}	0.018	0.026	0.033	0.034	0.033	0.033
ϵ_{π_m}	0.010	0.015	0.018	0.017	0.017	0.017
ϵ_R	0.037	0.049	0.057	0.057	0.056	0.056
ϵ_{RP}	0.017	0.024	0.027	0.027	0.028	0.028
ϵ_{yf}	0.045	0.043	0.042	0.042	0.041	0.041
Sum	1.000	1.000	1.000	1.000	1.000	1.000

Table 4: Variance decomposition 2

	1	**4**	**8**	**16**	**40**	**100**
X						
ϵ_a	0.000	0.001	0.004	0.008	0.007	0.006
ϵ_b	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_G	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_i	0.000	0.000	0.000	0.001	0.006	0.005
ϵ_L	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_{λ_p}	0.002	0.011	0.018	0.018	0.017	0.013
ϵ_{μ_a}	0.005	0.013	0.025	0.049	0.129	0.299
ϵ_{ϕ_m}	0.000	0.001	0.006	0.020	0.022	0.018
$\epsilon_{\phi_{mf}}$	0.839	0.822	0.799	0.747	0.663	0.533
ϵ_{π_f}	0.000	0.000	0.001	0.001	0.001	0.001
ϵ_{π_m}	0.015	0.022	0.034	0.053	0.060	0.049
ϵ_R	0.012	0.017	0.017	0.016	0.014	0.011
ϵ_{RP}	0.000	0.000	0.000	0.001	0.003	0.003
ϵ_{yf}	0.126	0.112	0.094	0.087	0.078	0.063
Sum	1.000	1.000	1.000	1.000	1.000	1.000
M						
ϵ_a	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_b	0.002	0.003	0.004	0.004	0.004	0.004
ϵ_G	0.063	0.024	0.016	0.013	0.011	0.009
ϵ_i	0.019	0.025	0.026	0.022	0.022	0.018
ϵ_L	0.000	0.000	0.000	0.000	0.000	0.000
ϵ_{λ_p}	0.000	0.000	0.002	0.002	0.002	0.002
ϵ_{μ_a}	0.009	0.019	0.036	0.078	0.175	0.339
ϵ_{ϕ_m}	0.379	0.433	0.368	0.291	0.254	0.203
$\epsilon_{\phi_{mf}}$	0.380	0.290	0.268	0.272	0.246	0.196
ϵ_{π_f}	0.009	0.016	0.014	0.011	0.009	0.007
ϵ_{π_m}	0.101	0.162	0.221	0.257	0.225	0.178
ϵ_R	0.009	0.006	0.004	0.003	0.003	0.002
ϵ_{RP}	0.006	0.015	0.026	0.033	0.031	0.027
ϵ_{yf}	0.023	0.007	0.014	0.013	0.016	0.013
Sum	1.000	1.000	1.000	1.000	1.000	1.000
I						
ϵ_a	0.002	0.006	0.016	0.033	0.031	0.027
ϵ_b	0.000	0.001	0.003	0.011	0.018	0.015
ϵ_G	0.000	0.001	0.004	0.010	0.012	0.011
ϵ_i	0.900	0.820	0.722	0.607	0.522	0.455
ϵ_L	0.000	0.000	0.000	0.001	0.002	0.002
ϵ_{λ_p}	0.011	0.024	0.037	0.039	0.033	0.029
ϵ_{μ_a}	0.005	0.011	0.023	0.053	0.127	0.233
ϵ_{ϕ_m}	0.012	0.020	0.028	0.036	0.043	0.038
$\epsilon_{\phi_{mf}}$	0.010	0.017	0.024	0.033	0.039	0.034
ϵ_{π_f}	0.000	0.001	0.003	0.006	0.005	0.004
ϵ_{π_m}	0.002	0.006	0.012	0.024	0.026	0.023
ϵ_R	0.011	0.014	0.017	0.018	0.015	0.013
ϵ_{RP}	0.041	0.071	0.104	0.124	0.114	0.103
ϵ_{yf}	0.006	0.007	0.006	0.006	0.013	0.012
Sum	1.000	1.000	1.000	1.000	1.000	1.000

D Figures

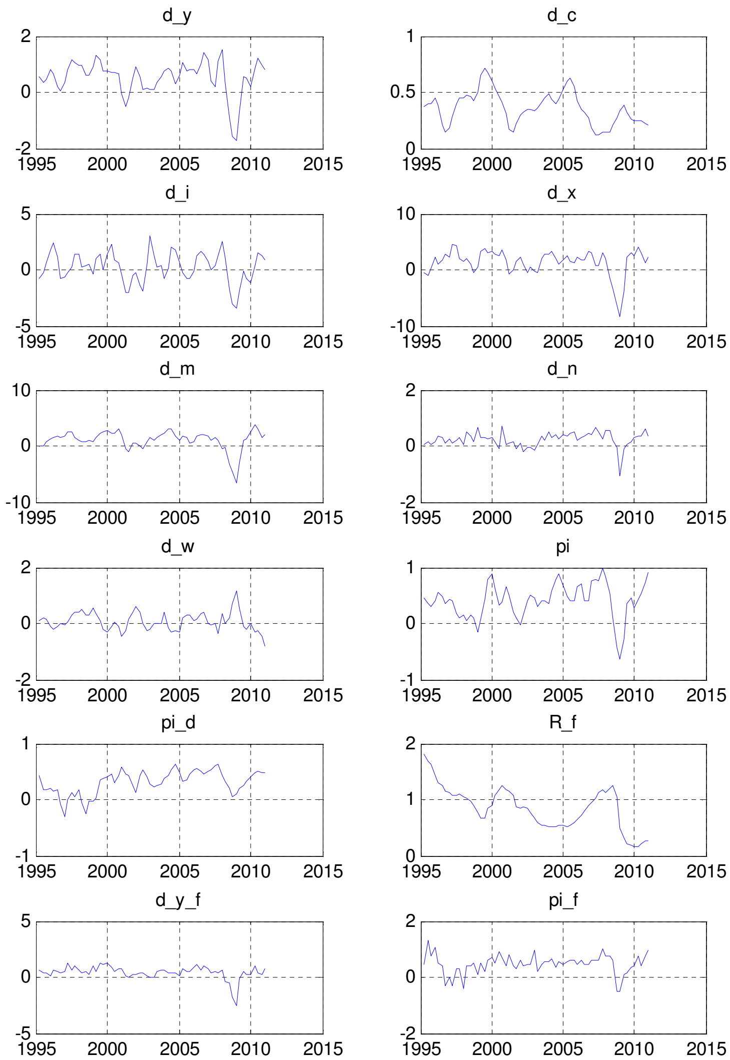

Figure 1: Historical data series

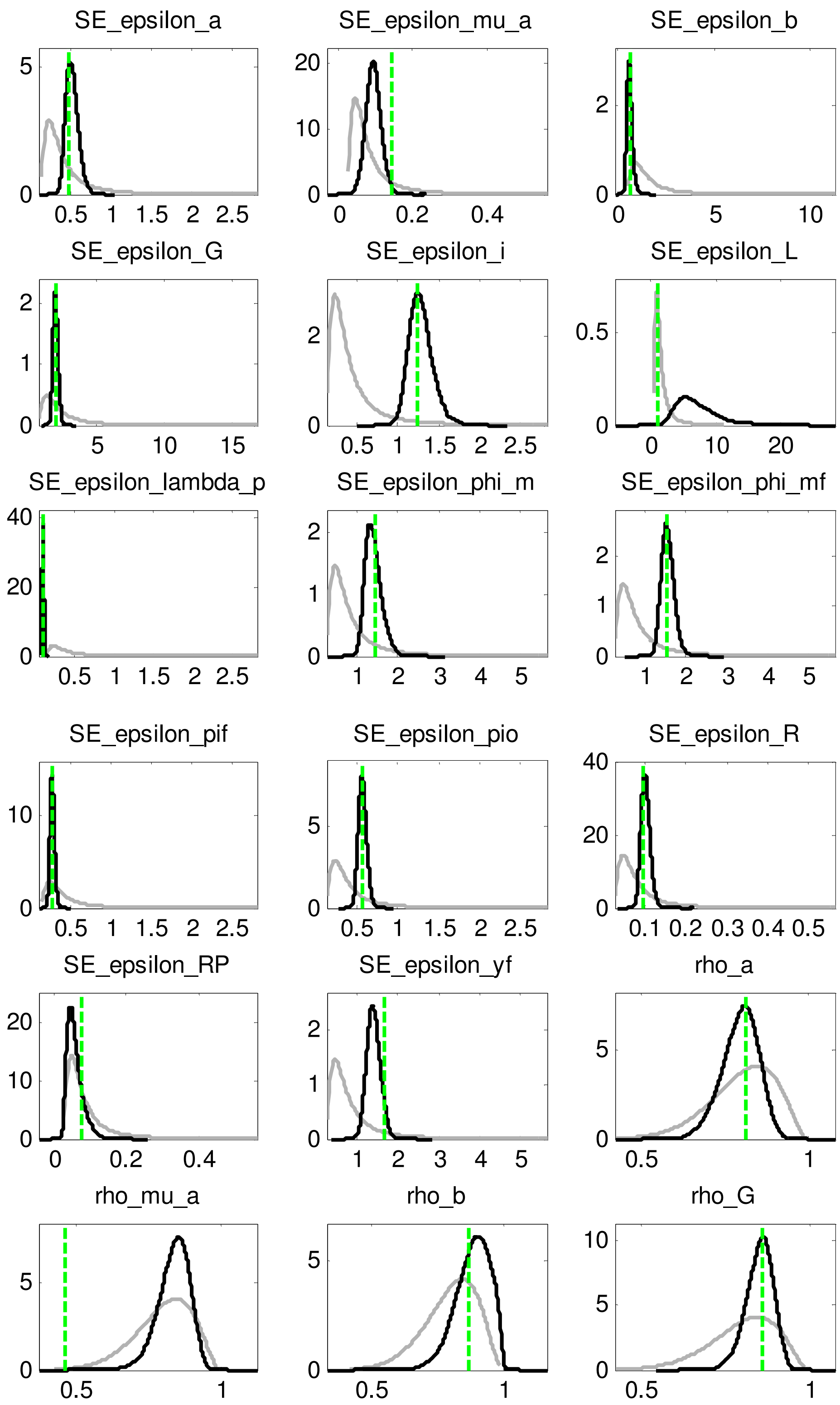

Figure 2: Priors and posteriors

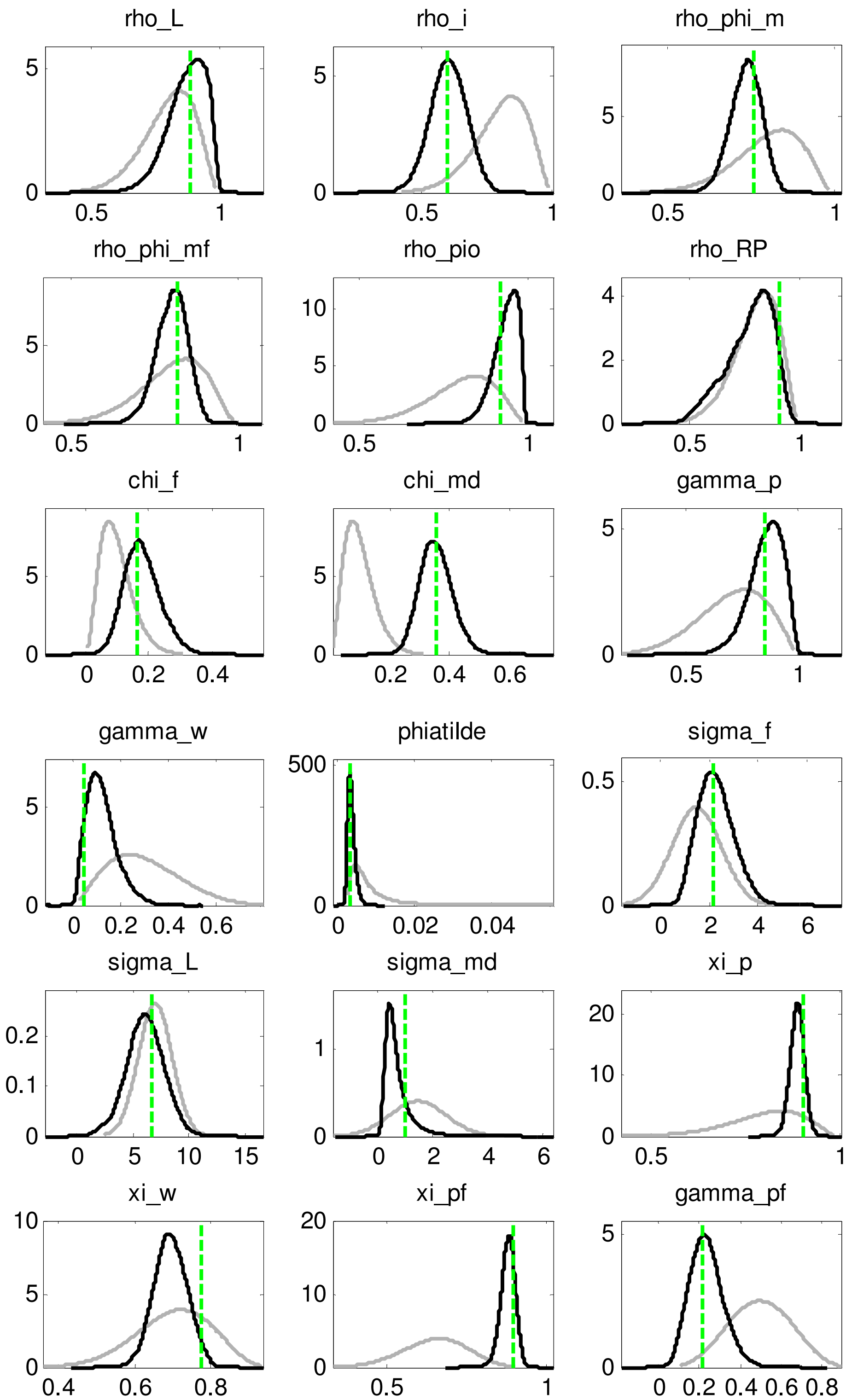

Figure 3: Priors and posteriors

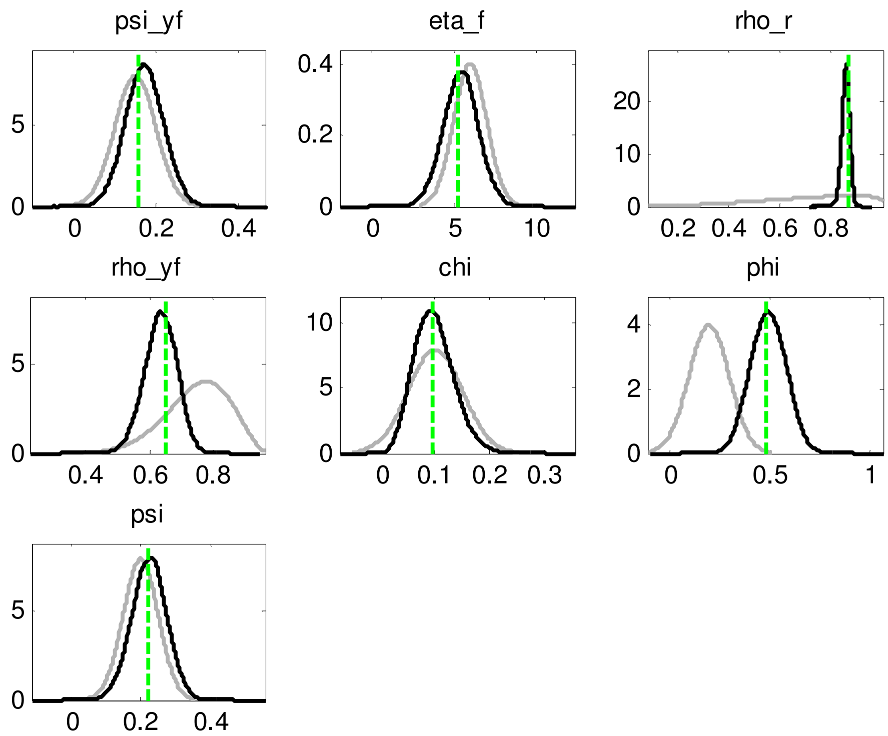

Figure 4: Priors and posteriors

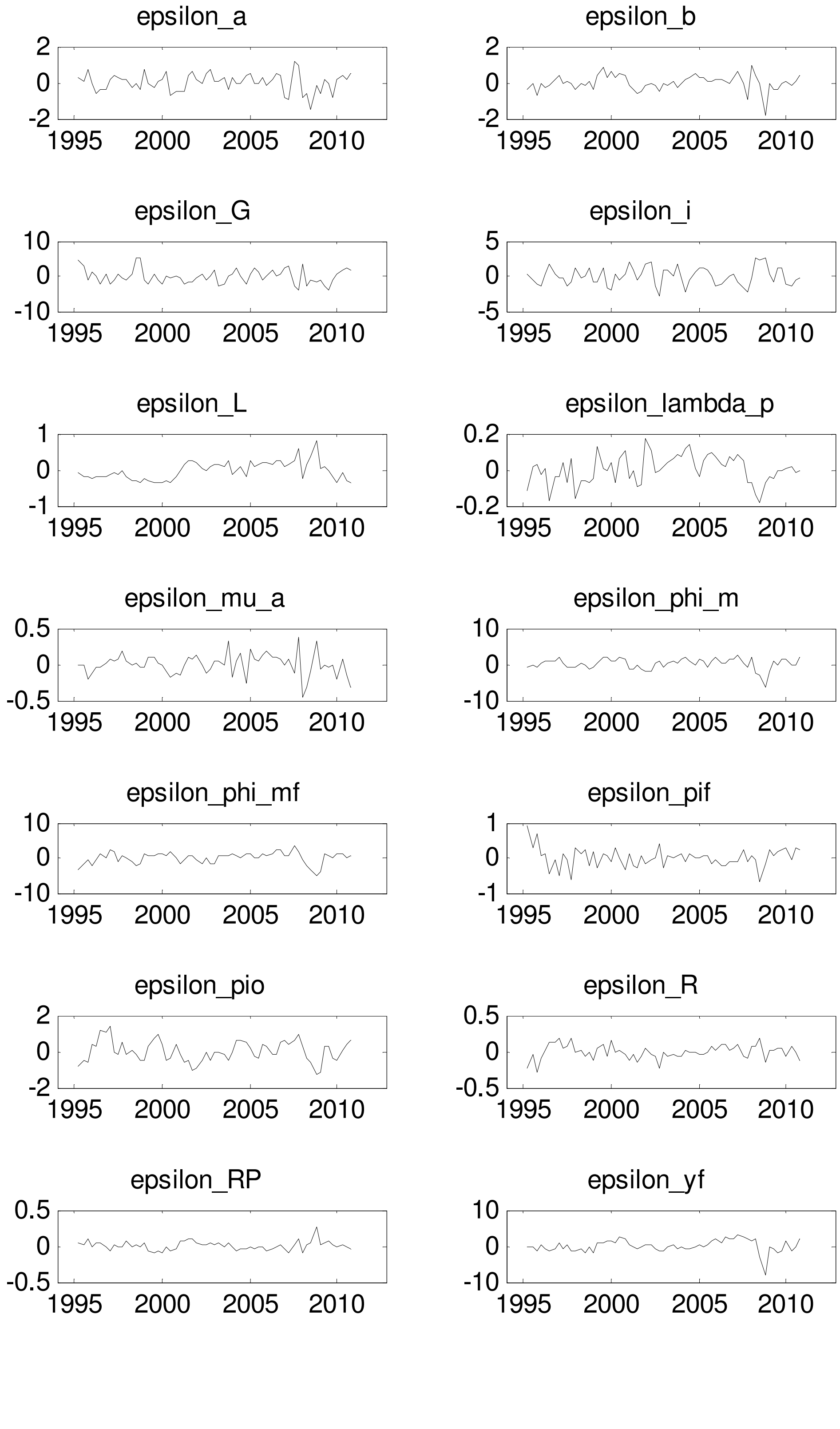

Figure 5: Smoothed Shocks

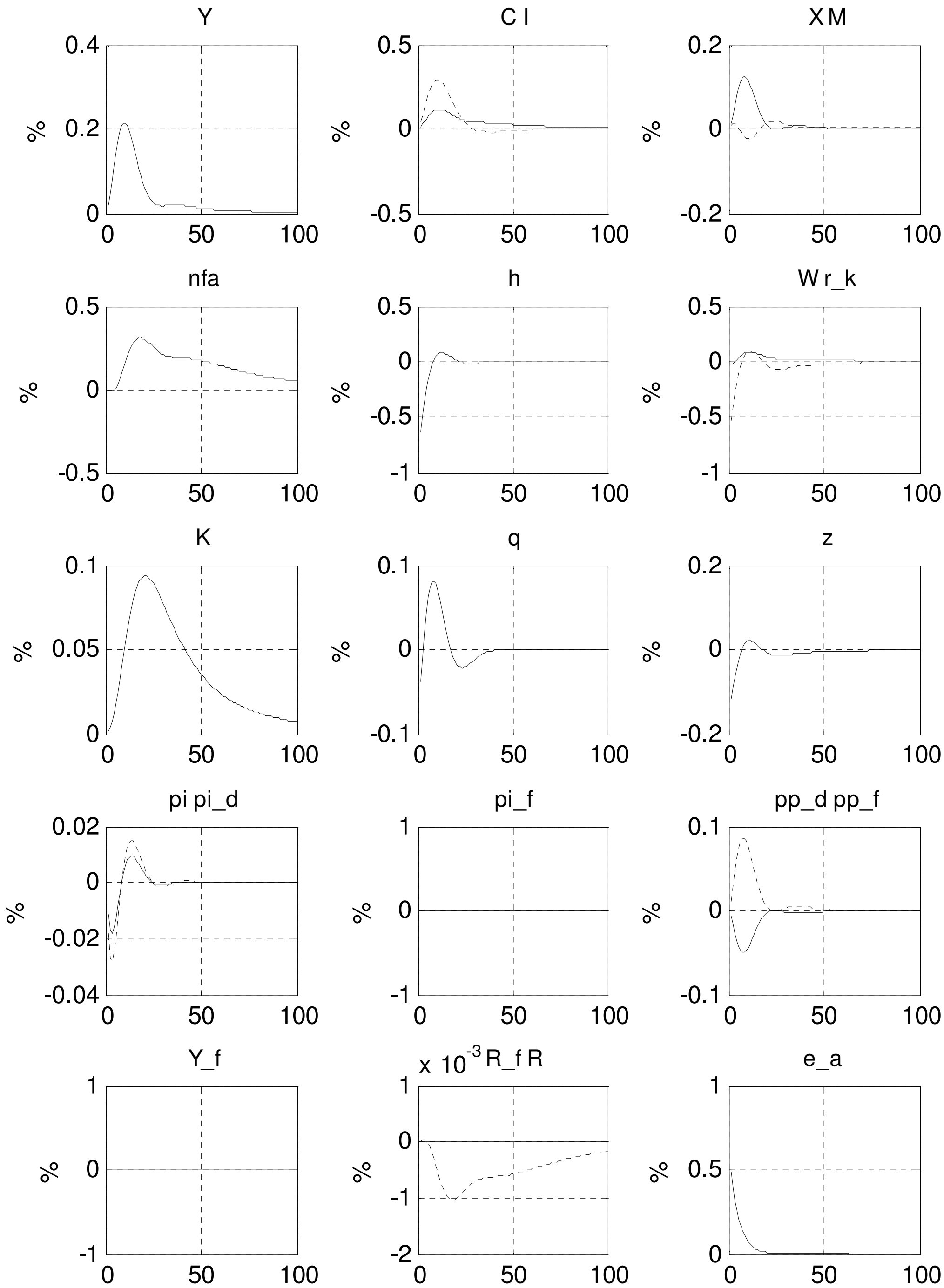

Figure 6: Impulse responses for a stationary technology shock (ϵ_a)

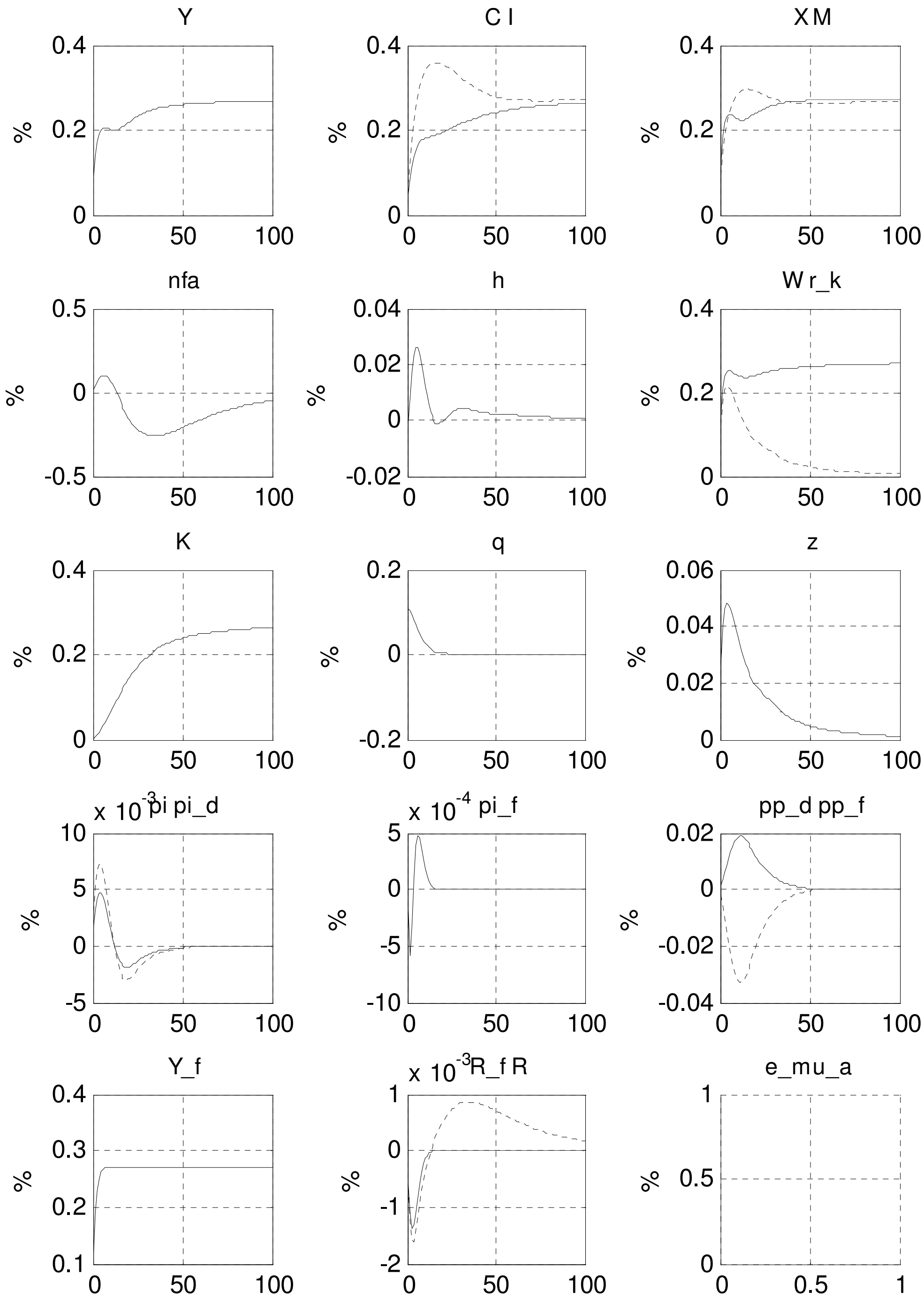

Figure 7: Impulse responses for a permanent technology shock (ϵ_{μ_a})

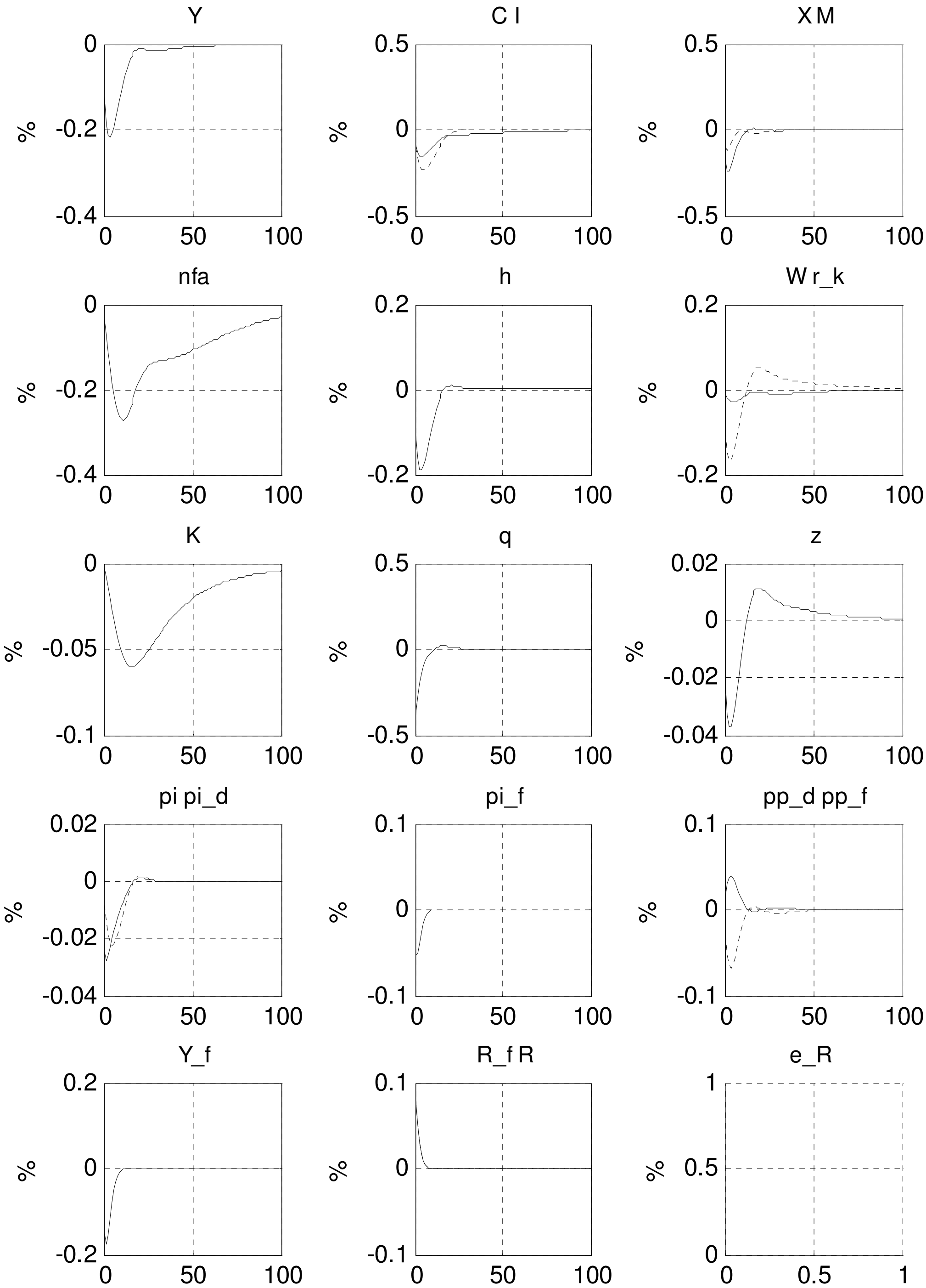

Figure 8: Impulse responses for an interest rate shock (ϵ_R)

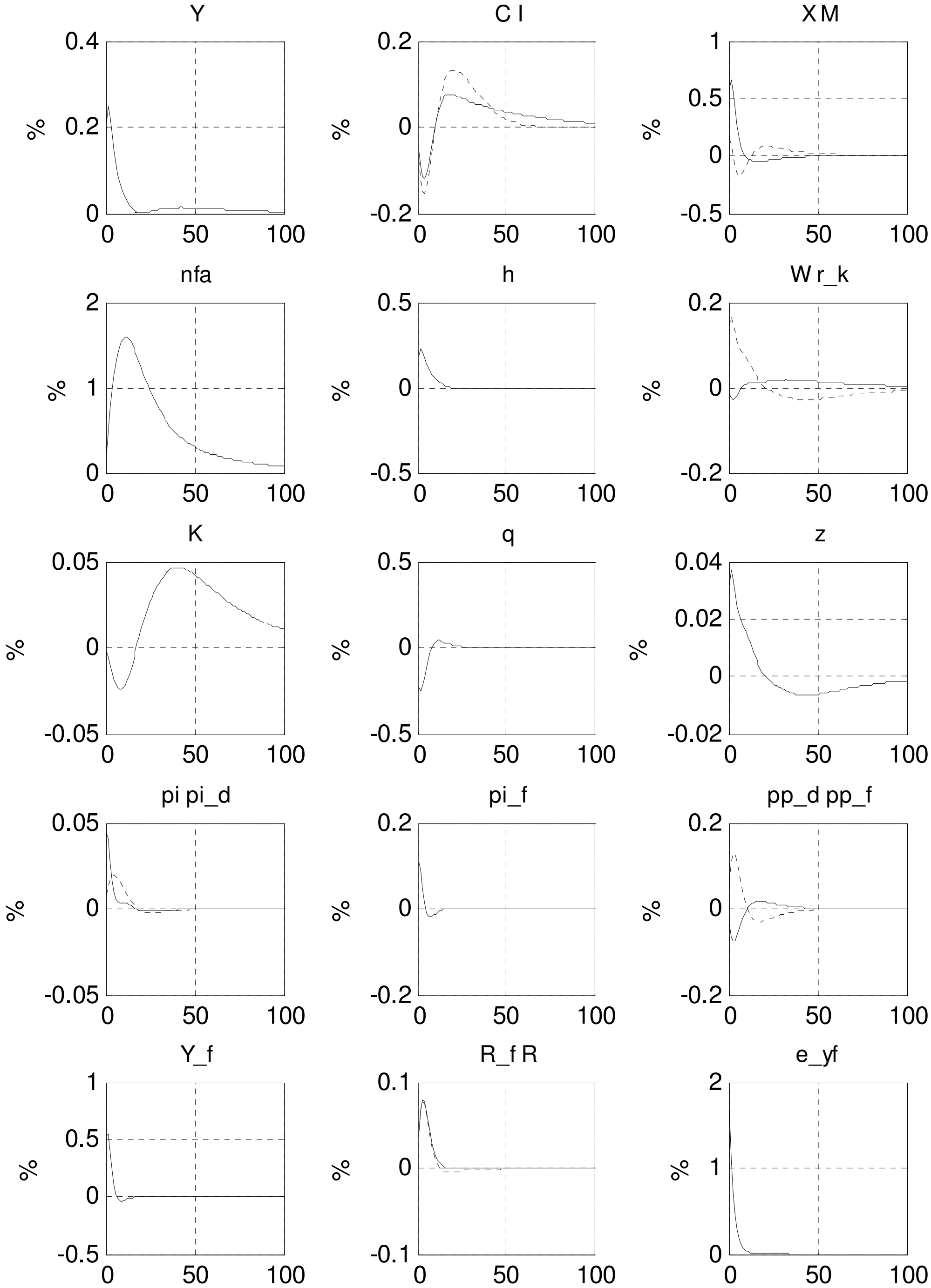

Figure 9: Impulse responses for a world demand shock (ϵ_{y_f})

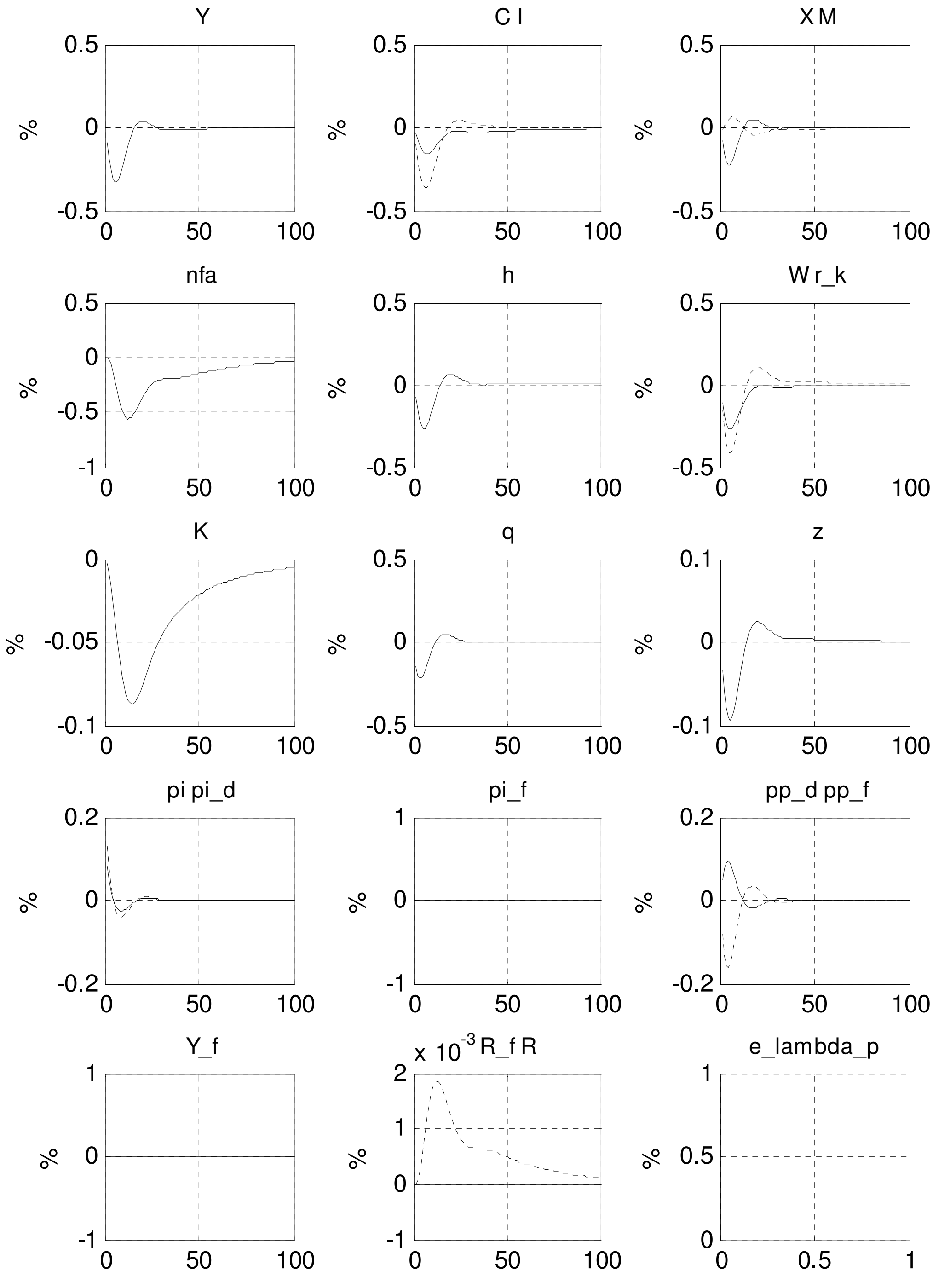

Figure 10: Impulse responses for a price mark up shock (ϵ_{lambda_p})

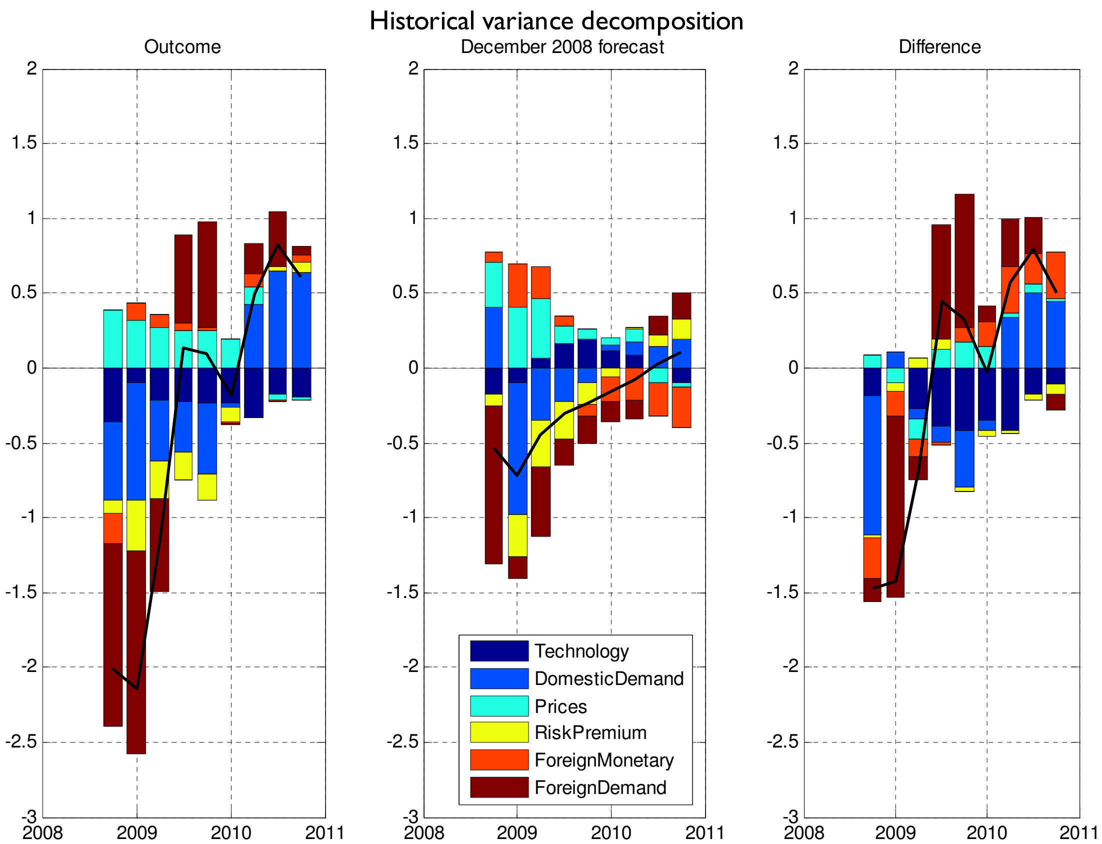

Figure 11: Shock decomposition of real GDP growth during the Great Recession ex post and ex ante (December 2008 forecast)

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Call for Applications: Visiting Research Program

The Oesterreichische Nationalbank (OeNB) invites applications from external researchers for participation in a Visiting Research Program established by the OeNB's Economic Analysis and Research Department. The purpose of this program is to enhance cooperation with members of academic and research institutions (preferably post-doc) who work in the fields of macroeconomics, international economics or financial economics and/or with a regional focus on Central, Eastern and Southeastern Europe.

The OeNB offers a stimulating and professional research environment in close proximity to the policymaking process. Visiting researchers are expected to collaborate with the OeNB's research staff on a prespecified topic and to participate actively in the department's internal seminars and other research activities. They are provided with accommodation on demand and have, as a rule, access to the department's data and computer resources and to research assistance. Their research output will be published in one of the department's publication outlets or as an OeNB Working Paper. Research visits should ideally last between 3 and 6 months, but timing is flexible.

Applications (in English) should include

- a curriculum vitae,
- a research proposal that motivates and clearly describes the envisaged research project,
- an indication of the period envisaged for the research stay, and
- information on previous scientific work.

Applications for 2012/13 should be e-mailed to *eva.gehringer-wasserbauer@oenb.at* by May 1, 2012.

Applicants will be notified of the jury's decision by mid-June. The next round of applications will close on November 1, 2012.