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Contents

Abstract

This study describes a compact dynamic stochastic general equilibrium (DSGE) model fitted for the Swiss economy with Bayesian techniques. The model features two economies (small home economy, large foreign economy), five types of agents (households, producers of tradables, producers of non-tradables, retailers, monetary authority), nominal and real frictions, and a number of shocks. The study gives details on the specification and the estimation of the model. The evaluation is based on impulse responses and variance decompositions, a DSGE-VAR to assess misspecifications, and results of forecasting experiments. The model is one of the tools used for policy analysis and forecasting at the Swiss National Bank.

JEL Classification: E30, E40, E50
Keywords: DSGE model, open economy, Bayesian estimation, forecasting, monetary policy.

1. Introduction

Dynamic stochastic general equilibrium (DSGE) models with New Keynesian frictions such as price rigidities have become a standard tool in quantitative macroeconomics. This paper describes an open-economy DSGE model fitted for the Swiss economy with Bayesian techniques. The model is part of a suite of models employed by Swiss National Bank (SNB) staff for policy analysis and forecasting. Versions of this model have been used at the SNB since 2009.

The model belongs to the category of small-scale New Keynesian open-economy DSGE models. The core of these models can be traced to Galí and Monacelli (2005), who extended the benchmark New Keynesian DSGE model to a small open economy setting. Monacelli (2005) then incorporated price-setting retailers and incomplete exchange-rate pass-through. Justiniano and Preston (2010b) added habit persistence in consumption and partial indexation to inflation. Models of this sort have been estimated for several countries, e.g. by Bäuerle and Menz (2008) and Beltran and Draper (2008) for Switzerland. They are all smaller in size than the typical medium-scale open-economy DSGE models exemplified by Adolfson et al. (2007). While the latter models include sticky wages and capital accumulation, the small-scale models do not. The scope for storytelling and policy analysis increases with the size of the model. On the downside, however, large models are often less transparent and identification problems tend to be worse.

Our model assumes two economies linked by trade and portfolio flows: the home economy and the foreign economy. Households in the home economy receive utility from consumption and leisure. They spend on goods produced at home and abroad, supply labour to domestic producers, own the domestic firms, and hold domestic and foreign bonds. Consumption responds slowly due to habit persistence. The firms are of three types: retailers, producers of tradables, and producers of non-tradables. The retailers sell imported goods in the domestic market. The other firms employ labour to produce either non-tradables in demand at home or tradables in demand at home and abroad. All firms are monopolistically competitive and set prices in a staggered fashion, as in Calvo (1983). In addition, there is partial indexation to inflation observed in the previous period. The pass-through of the nominal exchange rate to import prices is incomplete, reflecting the assumption of price stickiness in the retail sector. The foreign economy is modelled along the same lines as the home economy. However, international trade and portfolio flows are ignored in modelling the foreign economy because the home economy is assumed to be small, relative to the foreign economy.

The model's structure is similar to that in Justiniano and Preston (2010b), with three notable differences. First, a non-traded sector is incorporated in the home economy following Matheson (2010). This allows us not only to obtain a more complete picture of CPI inflation and its components, but also to account for the cross-section differences in price stickiness and exchange rate pass-through that we observe in the data. Secondly, the uncovered interest parity (UIP) is modified as in Adolfson et al. (2008) to address the forward premium puzzle. Under the modified UIP, the exchange rate exhibits a hump-shaped pattern after a monetary policy shock. The effects on real output and other variables are therefore more persistent than under the standard UIP. Thirdly, we assume that preference (demand) shocks in the foreign economy spill over to those in the home economy. This provides a short cut to capture the cross-border effects of a foreign demand shock on the home economy documented in the empirical literature. Without this modification, the cross-border effects of a demand shock in the foreign economy would be implausibly small, similar to the results discussed in Justiniano and Preston (2010a).

The present study provides a comprehensive documentation of the model and its evaluation. Sections 2 and 3 present the model in its original and its log-linearised forms. Section 4 describes the methodology and the results of the estimation, including some results for alternative model specifications. Section 5 evaluates the model's empirical properties. We report results of impulse responses and forecast-error variance decompositions to gauge the credibility of the model. Fluctuations in the rate of inflation and the output gap are decomposed to assess the importance of various shocks over the last few years. Following Del Negro et al. (2007), a DSGE-VAR version is estimated in order to study misspecification of the DSGE model. Finally, results of a forecasting experiment are reported in order to shed light on the forecasting ability of the model. Section 6 concludes. The appendix contains more complete results for the alternative model specifications.

2. Model specification

This section describes the decision problem of households and firms, and the monetary policy function of the central bank. The various nominal and real rigidities are introduced and the shock processes are defined. More detailed accounts of some aspects of the model can be found in Galí and Monacelli (2005), Monacelli (2005), and Justiniano and Preston (2010b).

2.1 Domestic households

The domestic economy is populated by infinitely lived households whose preferences are given by the intertemporal utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t Z_{G,t} \left[\frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right], \tag{2.1}$$

where C_t is a composite consumption index, and N_t is labour input. Labour is supplied to the traded and the non-traded sector, $N_t = N_{N,t} + N_{H,t}$, where the subscripts N and H refer to non-tradables and tradables produced in the home country. Consumption patterns are assumed to change sluggishly (habit persistence) which is reflected in $H_t \equiv hC_{t-1}$. The parameter β denotes the discount factor, $\sigma > 0$ is the coefficient of relative risk aversion (or the inverse elasticity of intertemporal substitution in consumption), and $\varphi > 0$ is the inverse elasticity of the labour supply. $Z_{G,t}$ is a preference shifter common to all households. The composite consumption index C_t is given by

$$C_t = \left[\gamma^{\frac{1}{\nu}} C_{N,t}^{\frac{\nu-1}{\nu}} + (1-\gamma)^{\frac{1}{\nu}} C_{T,t}^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}},$$

where $C_{N,t}$ and $C_{T,t}$ are the indices of consumption of non-traded and traded goods, respectively, γ is the share of non-traded goods in the consumption bundle, and $\nu > 0$ is the elasticity of substitution between tradable and non-tradable goods. The index of consumption of traded goods $C_{T,t}$ is given by

$$C_{T,t} = \left[\alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} + (1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}},$$

where α is the share of foreign goods in the consumption bundle of traded goods and $\eta > 0$ is the elasticity of substitution between domestic and foreign traded goods. The indices of consumption of non-traded goods ($C_{N,t}$), traded goods imported from the foreign economy ($C_{F,t}$) and traded goods produced in the home economy ($C_{H,t}$) are given by the CES aggregates

$$C_{N,t} \equiv \left[\int_0^1 C_{N,t}(i)^{\frac{\epsilon-1}{\epsilon}} di\right]^{\frac{\epsilon}{1-\epsilon}}, \quad C_{F,t} \equiv \left[\int_0^1 C_{F,t}(i)^{\frac{\epsilon-1}{\epsilon}} di\right]^{\frac{\epsilon}{1-\epsilon}}, \quad C_{H,t} \equiv \left[\int_0^1 C_{H,t}(i)^{\frac{\epsilon-1}{\epsilon}} di\right]^{\frac{\epsilon}{1-\epsilon}}$$

with $\epsilon > 1$ denoting the elasticity of substitution between varieties $i \in [0,1]$ within a given sector and country. The demand functions of these products are given by

$$C_{N,t}(i) = \left[\frac{P_{N,t}(i)}{P_{N,t}}\right]^{-\epsilon} C_{N,t}, \quad C_{F,t}(i) = \left[\frac{P_{F,t}(i)}{P_{F,t}}\right]^{-\epsilon} C_{F,t}, \quad C_{H,t}(i) = \left[\frac{P_{H,t}(i)}{P_{H,t}}\right]^{-\epsilon} C_{H,t}, \tag{2.2}$$

where

$$P_{N,t} \equiv \left[\int_0^1 P_{N,t}(i)^{1-\epsilon} di\right]^{\frac{1}{1-\epsilon}}, \quad P_{F,t} \equiv \left[\int_0^1 P_{F,t}(i)^{1-\epsilon} di\right]^{\frac{1}{1-\epsilon}}, \quad P_{H,t} \equiv \left[\int_0^1 P_{H,t}(i)^{1-\epsilon} di\right]^{\frac{1}{1-\epsilon}}$$

are the price indexes of non-traded goods ($P_{N,t}$), foreign traded goods ($P_{F,t}$), and domestic traded goods ($P_{H,t}$). These demand functions are the result of the individual household's intraperiod optimisation problem which determines the optimal allocation of expenditure on all types of goods.

The households' allocation of expenditure on domestic and foreign tradable goods is based on the demand functions

$$C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_{T,t}}\right)^{-\eta} C_{T,t}, \quad C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\eta} C_{T,t}, \tag{2.3}$$

and their allocation of total expenditure on tradable and non-tradable goods is based on

$$C_{N,t} = \gamma\left(\frac{P_{N,t}}{P_t}\right)^{-\nu} C_t, \quad C_{T,t} = (1-\gamma)\left(\frac{P_{T,t}}{P_t}\right)^{-\nu} C_t, \tag{2.4}$$

where $P_{T,t}$ is the price index of tradables defined as

$$P_{T,t} \equiv \left[\alpha P_{F,t}^{1-\eta} + (1-\alpha) P_{H,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{2.5}$$

and P_t is the consumer price index defined as

$$P_t \equiv \left[\gamma P_{N,t}^{1-\nu} + (1-\gamma) P_{T,t}^{1-\nu}\right]^{\frac{1}{1-\nu}}. \tag{2.6}$$

Assuming that all households face identical decision problems and that markets are complete, the aggregate flow budget constraint takes the form

$$P_t C_t + D_t + S_t B_t \leq W_t N_t + \Pi_{N,t} + \Pi_{H,t} + \Pi_{F,t} + R_{t-1} D_{t-1} + S_t R_{t-1}^{*} \Phi_t(\cdot) B_{t-1} + T_t, \tag{2.7}$$

where W_t is the nominal wage rate, $\Pi_{N,t}$, $\Pi_{H,t}$ and $\Pi_{F,t}$ are distributed profits from domestic producers and retail firms, T_t are transfers net of taxes, S_t is the nominal exchange rate defined as the home currency per unit of foreign currency, D_t and B_t are domestic and foreign one-period, nominally riskless bonds held by the home economy's households between time t and t+1, R_t and R_t^* are the corresponding gross interest rates, and $\Phi_t(\cdot)$ is a risk premium (to be discussed below in detail).

Households maximise the intertemporal utility function Eq. (2.1) subject to a sequence of budget constraints Eq. (2.7) and the borrowing constraints $D_{t+1} \leq \Im$ and $B_{t+1} \leq \Im^*$ which prevent agents from borrowing an unlimited amount. This yields the first-order conditions:

$$U_{C,t} = \lambda_t P_t, \tag{2.8}$$

$$-U_{N,t} = -\lambda_t W_t, \tag{2.9}$$

$$\lambda_t = \beta E_t \lambda_{t+1} R_t, \tag{2.10}$$

$$S_t \lambda_t = \beta E_t [\lambda_{t+1} S_{t+1} R_t^* \Phi_t], \tag{2.11}$$

where λ_t denotes the Lagrange multiplier, $U_{C,t} = Z_{G,t}(C_t - H_t)^{-\sigma}$ is the marginal utility of consumption, and $U_{N,t} = -Z_{G,t} N_t^{\varphi}$ is the marginal disutility of labour. We complete the set of optimality conditions by adding a transversality condition and specifying that the flow budget constraint must hold with equality in every period. Combining Eq. (2.8) with Eq. (2.9) yields the intratemporal consumption/leisure choice:

$$\frac{N_t^{\varphi}}{(C_t - H_t)^{-\sigma}} = \frac{W_t}{P_t}, \tag{2.12}$$

stating that the marginal rate of substitution between leisure and consumption is equal to the real wage. Combining Eq. (2.8) with Eq. (2.10) gives the intertemporal consumption choice (consumption Euler equation):

$$\frac{1}{R_t} = \beta E_t \left[\frac{Z_{G,t+1}(C_{t+1} - H_{t+1})^{-\sigma}}{Z_{G,t}(C_t - H_t)^{-\sigma}} \frac{P_t}{P_{t+1}} \right]. \tag{2.13}$$

2.2 Domestic producers of tradable and non-tradable goods

Domestic producers produce either tradables or non-tradables. In each group there is a continuum of monopolistically competitive firms indexed $i \in [0,1]$. In what follows, we use the subscript $j = N,H$ to describe the decision problem of firms producing non-tradables (N) and tradables (H) respectively. Each firm i produces differentiated goods using the production function

$$Y_{j,t}(i) = Z_{T,t} Z_{A_j,t} N_{j,t}(i), \tag{2.14}$$

where $Z_{T,t}$ is a non-stationary technology process that is common to all domestic producers, $Z_{A_j,t}$ is a stationary technology shock common to domestic producers of non-tradables and tradables respectively, and $N_{j,t}(i)$ is the labour input of firm i where the labour market is assumed to be perfectly competitive. We can write $\ln Z_{T,t} = \ln Z_{T,t-1} + \overline{\gamma}_Z + z_{T,t}$ where $\overline{\gamma}_Z > 0$ is the steady-state growth rate of output and $z_{T,t}$ is a stationary AR(1) process.

Prices are subject to Calvo-type price setting. In every period, each firm has a probability $(1 - \xi_H)$ of being able to reoptimise its price. Firms that cannot reoptimise are assumed to partially index their prices to recent home goods inflation according to

$$P_{j,t}(i) = P_{j,t-1}(i)\left(\frac{P_{j,t-1}}{P_{j,t-2}}\right)^{\kappa_j},$$

where $0 \le \kappa_j \le 1$ is the indexation parameter. Since all the firms that can reoptimise in a given period face the same decision problem, they will choose a common new price $P'_{j,t}$. The CES aggregate for the price level $P_{j,t}$ can then be rewritten as

$$P_{j,t} = \left[(1-\xi_j)P'^{(1-\epsilon)}_{j,t} + \xi_j\left[P_{j,t-1}\left(\frac{P_{j,t-1}}{P_{j,t-2}}\right)^{\kappa_H}\right]^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}. \quad (2.15)$$

When firms are able to reoptimise their prices, they choose the new price in a way that maximises a weighted sum of discounted current and expected future profits:

$$E_t\sum_{T=t}^{\infty}\xi_j^{T-t}Q_{t,T}Y_{j,T}(i)\left[P'_{j,t}(i)\left(\frac{P_{j,T-1}}{P_{j,t-1}}\right)^{\kappa_j} - P_{j,T}MC_{j,T}\right],$$

subject to the demand equation

$$Y_{H,T}(i) = \left[\frac{P'_{H,t}(i)}{P_{H,T}}\left(\frac{P_{H,T-1}}{P_{H,t-1}}\right)^{\kappa_H}\right]^{-\epsilon}(C_{H,T} + C^*_{H,T})$$

and

$$Y_{N,T}(i) = \left[\frac{P'_{N,t}(i)}{P_{N,T}}\left(\frac{P_{N,T-1}}{P_{N,t-1}}\right)^{\kappa_N}\right]^{-\epsilon}C_{N,T},$$

respectively, depending on the type of firm considered.

With a common production technology Eq. (2.14) and a fully competitive labour market, all firms of a given type face the same real marginal cost $MC_{j,T} = W_T/(Z_{A_j,T}\,Z_{T,T}\,P_{j,T})$. The parameter ξ_j^{T-t} denotes the probability that the currently set price will still be in place periods from now; $Q_{t,T}$ is the stochastic discount factor, where $Q_{t,T} = (\Pi_{j=0}^{T-t-1}R_{t+j})^{-1}$, and $C^*_{H,T}$ is the foreign consumption of goods produced in the home economy. The resulting first-order condition for the producer's optimisation problem is

$$E_t\sum_{T=t}^{\infty}\xi_j^{T-t}Q_{t,T}Y_{j,T}(i)\left[P'_{j,t}(i)\left(\frac{P_{j,T-1}}{P_{j,t-1}}\right)^{\kappa_H} - \frac{\epsilon}{\epsilon-1}P_{j,T}MC_{j,T}\right] = 0. \quad (2.16)$$

2.3 Domestic importers

There is a continuum of monopolistically competitive retail firms indexed $i \in [0,1]$. These firms sell imported goods in the domestic market. Due to their price-setting power, the price these firms charge in the domestic market differs from the world market price. Again, we assume that in each period a fraction $(1 - \xi_F)$ of all firms optimally sets prices, while a fraction ξ_F follow the backward-looking rule of thumb that partially indexes prices to the last period's inflation. The price index of imported goods is

$$P_{F,t} = \left[(1-\xi_F) P_{F,t}^{\prime(1-\epsilon)} + \xi_F \left[P_{F,t-1} \left(\frac{P_{F,t-1}}{P_{F,t-2}} \right)^{\kappa_F} \right]^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}. \tag{2.17}$$

Reoptimising firms choose the price for good i by maximising the expected present discounted value of profits

$$E_t \sum_{T=t}^{\infty} \xi_F^{T-t} Q_{t,T} C_{F,T}(i) \left[P'_{F,t}(i) \left(\frac{P_{F,T-1}}{P_{F,t-1}} \right)^{\kappa_F} - S_T P^*_{F,T} \right],$$

subject to the demand curve

$$C_{F,T}(i) = \left[\frac{P'_{F,t}(i)}{P_{F,T}} \left(\frac{P_{F,T-1}}{P_{F,t-1}} \right)^{\kappa_F} \right]^{-\epsilon} C_{F,T},$$

for all t. The resulting first-order condition for the retailer's optimisation problem is

$$E_t \sum_{T=t}^{\infty} \xi_F^{T-t} Q_{t,T} C_{F,T}(i) \left[P'_{F,t}(i) \left(\frac{P_{F,T-1}}{P_{F,t-1}} \right)^{\kappa_F} - \frac{\epsilon}{\epsilon - 1} S_T P^*_{F,T} \right] = 0. \tag{2.18}$$

The wedge between the world market price of foreign goods paid by importing firms ($S_t P^*_{F,t}$) and the domestic currency price ($P_{F,t}$) of these goods paid by domestic consumers is called the law-of-one-price gap, defined as

$$\Psi_t \equiv \frac{S_t P^*_{F,t}}{P_{F,t}}. \tag{2.19}$$

There is a law-of-one-price gap if $\Psi_t \neq 1$.

2.4 Uncovered interest rate parity and international prices

From the asset pricing conditions Eq. (2.10) and Eq. (2.11), we obtain a UIP condition of the form

$$E_t\left(\frac{\lambda_{t+1}S_{t+1}}{\lambda_t S_t}\right)\Phi_t(\cdot)=\frac{R_t}{R_t^*}, \tag{2.20}$$

where $\Phi_t(\cdot)$ denotes a risk premium. A positive (negative) risk premium implies that the expected returns on the foreign economy bond are smaller (larger) than the expected returns on the home economy bond.

As pointed out by Schmitt-Grohe and Uribe (2003), the introduction of a risk premium which depends on the scaled foreign asset position ensures a well-defined steady state. Various authors propose modifications to account for the observation that, in the data, the risk premia are strongly negatively correlated with the expected change in the exchange rate (forward premium puzzle). Adolfson et al. (2008) let the risk premium depend on the expected change in the exchange rate between $t+1$ and $t-1$. The risk premium $\Phi_t(\cdot)$ then takes the form

$$\Phi\left(A_t,\frac{S_{t+1}}{S_{t-1}},R_t^*-R_t,Z_{\phi,t}\right)=\exp\left[-\phi_A\left(A_t-\overline{A}_t\right)-\phi_S E_t\left(\frac{S_{t+1}}{S_{t-1}}-1\right)+Z_{\phi,t}\right], \tag{2.21}$$

where $A_t \equiv (S_t B_t)/(Z_{T,t}P_t)$ is the real quantity of outstanding debt expressed in terms of domestic currency as a fraction of steady state output, and $Z_{\phi,t}$ is the exogenous component of the risk premium. The modification proposed by Adolfson et al. is reverted if we set $\phi_S=0$.

It is convenient at this stage to introduce the real exchange rate, $S_{r,t}$, and the terms of trade, X_t. Both definitions will be used later when considering the log-linearised version of the model. The real exchange rate is defined as

$$S_{r,t}\equiv\frac{S_t P_t^*}{P_t}, \tag{2.22}$$

while the terms of trade are defined as

$$X_t\equiv\frac{P_{F,t}}{P_{H,t}}. \tag{2.23}$$

The definition of the terms of trade corresponds to the relative price of foreign goods in terms of domestic goods sold in the home economy. We assume producer currency pricing for the home economy's export sector. The price charged to customers abroad is the same as the price charged in the home economy (complete exchange rate pass-through).

2.5 Monetary policy

The central bank follows a Taylor-type interest rate rule of the form

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left[\left(\frac{P_t}{P_{t-1}}\right)^{\psi_\pi} \left(\frac{Y_t}{\bar{Y}_t}\right)^{\psi_y}\right]^{1-\rho_R} \left(\frac{Y_t / \bar{Y}_t}{Y_{t-1} / \bar{Y}_{t-1}}\right)^{\psi_{\Delta y}} Z_{R,t}, \tag{2.24}$$

where $\bar{R}$ and $\bar{Y}_t$ are steady-state values of gross nominal interest rates and output, and $Z_{R,t}$ is an exogenous monetary policy shock. The rule is fairly general in that monetary policy responds to contemporaneous inflation, the output gap, and changes in the output gap. In addition, the specification allows for policy inertia or interest-rate smoothing behaviour of the central bank.

The interest rule does not feature feedback from the nominal exchange rate. Exchange rate considerations are accounted for to the extent that they are reflected in the output gap and the rate of inflation.[1]

2.6 Foreign economy and general equilibrium

The small open economy assumption implies that the home economy is negligible in size, relative to the foreign economy. Exports to and imports from the home economy are assumed to be too small to matter for the foreign economy. The same holds for portfolio flows from and to the foreign economy. Thus the shares of home economy goods and bonds in the consumption bundle and portfolio of the foreign economy households are set to zero. Furthermore, we make the simplifying assumptions that the foreign economy produces only traded goods and that, as described in Section 2.4, the price of home economy goods paid by consumers in the foreign economy corresponds to the price of these goods set in the home economy divided by the exchange rate (complete exchange rate pass-through). Apart from that, the foreign economy is specified as the closed economy variant of the model described above for the home economy. With starred variables denoting the foreign economy variables, we can write $P_t^* = P_{F,t}^*$, $Y_t^* = Y_{F,t}^*$ and $C_t^* = C_{F,t}^*$.

The foreign demand for the traded good produced in the home economy is assumed to be determined as

$$C_{H,t}^* = \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\eta^*} Y_t^*,$$

where $\eta^* > 0$.

1 In September 2011 the SNB set a minimum exchange rate at 1.20 Swiss francs per euro against the background of a massive appreciation of the Swiss franc and the perceived risk of deflationary developments. The minimum exchange rate was announced as an additional operational target, as the target for the short-term interest rate could not be lowered further due to the zero bound. Eq. (2.24) does not model this modification of the SNB's monetary policy framework.

In equilibrium, all markets must clear. Market clearing in the home economy requires that the markets for all individual traded and non-traded goods are cleared:

$$\begin{aligned} Y_{H,t}(i) &= C_{H,t}(i) + C^*_{H,t}(i) \\ &= (1-\gamma)\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon}\left[(1-\alpha)\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\eta}\left(\frac{P_{T,t}}{P_t}\right)^{-\nu}C_t + \alpha\left(\frac{P_{H,t}}{S_t P^*_t}\right)^{-\eta^*}C^*_t\right], \end{aligned} \tag{2.25}$$

$$Y_{N,t}(i) = C_{N,t}(i) = \gamma\left(\frac{P_{N,t}(i)}{P_{N,t}}\right)^{-\epsilon}\left(\frac{P_{N,t}}{P_t}\right)^{-\nu}C_t. \tag{2.26}$$

The second equalities in Eq. (2.25) and Eq. (2.26) make use of Eq. (2.2) and the assumptions that preferences are symmetric in the home and the foreign economy, and that in equilibrium domestic bonds are in zero net supply. Plugging Eq. (2.26) and Eq. (2.25) into the definition of the aggregate domestic output

$$Y_t \equiv \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}}di\right)^{\frac{\epsilon}{1-\epsilon}}$$

yields

$$Y_t = \left[\gamma\left(\frac{P_{N,t}}{P_t}\right)^{-\nu} + (1-\gamma)(1-\alpha)\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\eta}\left(\frac{P_{T,t}}{P_t}\right)^{-\nu}\right]C_t + (1-\gamma)\alpha\left(\frac{P_{H,t}}{S_t P^*_t}\right)^{-\eta^*}C^*_t. \tag{2.27}$$

Market clearing in the foreign economy requires

$$Y^*_t = C^*_t. \tag{2.28}$$

3. Linearised model

In this section, we describe the log-linearised version of the model presented in Section 2. The model is log-linearised around the stationary steady state of the detrended variables. The resulting equations are linear in the log-deviations of the variables from the steady state. The log-deviations are denoted by lower case letters.[2]

Log-linearising the domestic households' Euler equation Eq. (2.13) yields

$$c_t - hc_{t-1} = E_t c_{t+1} - hc_t - \frac{1}{\sigma}(1-h)(i_t - E_t \pi_{t+1}) + \frac{1}{\sigma}(1-h)(z_{G,t} - E_t z_{G,t+1}). \tag{3.1}$$

Consumption depends both on past consumption, reflecting habit persistence, and on future consumption, implying consumption smoothing. We can also see that monetary policy will have real effects if it affects the real interest rate.

CPI inflation defined by Eq. (2.6) becomes

$$\begin{aligned} \pi_t &= \gamma \pi_{N,t} + (1-\gamma)\pi_{T,t} \\ &= \gamma \pi_{N,t} + (1-\gamma)\left[(1-\alpha)\pi_{H,t} + \alpha \pi_{F,t}\right] \\ &= \gamma \pi_{N,t} + (1-\gamma)\left(\pi_{H,t} + \alpha \Delta x_t\right), \end{aligned} \tag{3.2}$$

where the change in the terms of trade defined by Eq. (2.23) is

$$\Delta x_t = \pi_{F,t} - \pi_{H,t}. \tag{3.3}$$

The log-linearised versions of the aggregate import price index Eq. (2.17) and the retail firms' first-order condition Eq. (2.18) imply the Phillips curve for imported goods:

$$\pi_{F,t} - \kappa_F \pi_{F,t-1} = \beta(E_t \pi_{F,t+1} - \kappa_F \pi_{F,t}) + \theta_F \psi_t + z_{m_F,t}, \tag{3.4}$$

where $\psi_t = s_t + p_t^* - p_{F,t}$ is the law-of-one-price gap, $\theta_F = (1-\xi_F)(1-\beta\xi_F)(\xi_F)^{-1}$, and $z_{m_F,t}$ is a shock to the desired mark-up.

Similarly, taking log-linearisation of the aggregate price index Eq. (2.15) and the producers' first-order condition Eq. (2.16) gives the New Keynesian Phillips curves for non-tradables and tradables produced in the home economy:

$$\pi_{N,t} - \kappa_N \pi_{N,t-1} = \beta(E_t \pi_{N,t+1} - \kappa_N \pi_{N,t}) + \theta_N mc_{N,t} + z_{m_N,t}, \tag{3.5}$$

2 A technical appendix containing more details on the log-linearisation is available from the authors.

$$\pi_{H,t} - \kappa_H \pi_{H,t-1} = \beta(E_t \pi_{H,t+1} - \kappa_H \pi_{H,t}) + \theta_H mc_{H,t} + z_{m_H,t}, \tag{3.6}$$

where $\theta_N = (1-\xi_N)(1-\beta\xi_N)(\xi_N)^{-1}$ and $\theta_H = (1-\xi_H)(1-\beta\xi_H)(\xi_H)^{-1}$, while $z_{m_N,t}$ and $z_{m_H,t}$ are shocks to the respective mark-up desired.

The real marginal costs $mc_{N,t}$ and $mc_{H,t}$ are derived from the log-linearised versions of the production function Eq. (2.14) and the intratemporal consumption-leisure choice Eq. (2.12), yielding

$$\begin{aligned} mc_{N,t} &= \varphi y_t - (1+\varphi) z_{T,t} - (1+\varphi) z_{A_N,t} + \sigma(1-h)^{-1}(c_t - hc_{t-1}) \\ &\quad + \frac{1-\gamma}{\gamma}(s_{r,t} - \psi_t) - \frac{(1-\gamma)(1-\alpha)}{\gamma} x_t \end{aligned} \tag{3.7}$$

and

$$\begin{aligned} mc_{H,t} &= \varphi y_t - (1+\varphi) z_{T,t} - (1+\varphi) z_{A_H,t} + \sigma(1-h)^{-1}(c_t - hc_{t-1}) \\ &\quad - s_{r,t} + \psi_t + x_t, \end{aligned} \tag{3.8}$$

respectively.

The log-linearised UIP derived from Eq. (2.20) and Eq. (2.21) can be written as

$$i_t - i_t^* = (1-\phi_S) E_t \Delta s_{t+1} - \phi_S \Delta s_t - \phi_A a_t + z_{\phi,t} \tag{3.9}$$

while the real exchange rate becomes

$$\begin{aligned} s_{r,t} &= s_t + p_t^* - p_t \\ &= \psi_t + x_t - p_t + p_{H,t}, \end{aligned} \tag{3.10}$$

where $x_t = p_{F,t} - p_{H,t}$.

The flow budget constraint Eq. (2.7) implies

$$\begin{aligned} a_t &= \frac{i^*}{\bar{\gamma}_Z} a_{t-1} - (1-\eta^* + \nu)\psi_t + \left[\nu\alpha + \eta(1-\alpha) - (1-\eta^* + \nu)\right] x_t \\ &\quad + \nu s_{r,t} - c_t + \ln\left(\frac{Z_{T^*,t}}{Z_{T,t}}\right) + y_t^*, \end{aligned} \tag{3.11}$$

where

$$a_t = \frac{1}{(1-\gamma)\alpha}\left(\frac{S_t B_t}{Z_{T,t} P_t}\right),$$

i^* is the steady-state interest rate in the foreign economy, $\bar{\gamma}_Z$ is the steady-state output growth, and $\ln(Z_{T^*,t} / Z_{T,t})$ is the relative productivity trend. In deriving Eq. (3.11), we use that domestic debt is in zero net supply in equilibrium, and

$$W_t N_t + \Pi_{N,t} + \Pi_{H,t} + \Pi_{F,t} - T_t - P_t C_t = P_{H,t} C_{H,t}^* - S_t P_t^* C_{F,t}.$$ [3]

3 See Justiniano and Preston (2008).

Market clearing of the goods market implies

$$\begin{aligned} y_t = & [\gamma + (1-\gamma)(1-\alpha)]c_t \\ & -(1-\gamma)\alpha(\nu - \eta^*)\psi_t \\ & +(1-\gamma)\alpha[\eta - \alpha(\eta - \nu) - (\nu - \eta^*)]x_t \\ & +(1-\gamma)\alpha\nu s_{r,t} \\ & +(1-\gamma)\alpha\left[\ln\left(\frac{Z_{T^*,t}}{Z_{T,t}}\right) + y_t^*\right], \end{aligned} \quad (3.12)$$

where we make use of the log-linearised demand functions from the optimal allocation of expenditures between traded and non-traded goods and between domestic and foreign tradables.

Finally, the monetary policy rule described by Eq. (2.24) becomes

$$i_t = \rho_R i_{t-1} + (1-\rho_R)(\psi_\pi \pi_t + \psi_y y_t) + \psi_{\Delta y}\Delta y_t + z_{R,t}, \quad (3.13)$$

which is a Taylor-type rule with interest-rate smoothing.

Turning to the foreign economy, the log-linearised equations are

$$y_t^* - h^* y_{t-1}^* = E_t y_{t+1}^* - h^* y_t^* - \frac{1}{\sigma^*}(1-h^*)(i_t^* - E_t \pi_{t+1}^*) + \frac{1}{\sigma^*}(1-h^*)(z_{G^*,t} - E_t z_{G^*,t+1}), \quad (3.14)$$

$$\pi_t^* - \kappa^* \pi_{t-1}^* = \beta(E_t \pi_{t+1}^* - \kappa^* \pi_t^*) + \theta^* mc_t^* + z_{m^*,t}, \quad (3.15)$$

$$mc_t^* = \varphi^* y_t^* - (1+\varphi^*) z_{T^*,t} + \sigma^*(1-h^*)^{-1}(y_t^* - h^* y_{t-1}^*), \quad (3.16)$$

$$i_t^* = \rho_R^* i_{t-1}^* + (1-\rho_R^*)(\psi_{\pi^*}\pi_t^* + \psi_{y^*} y_t^*) + \psi_{\Delta y^*}\Delta y_t^* + z_{R^*,t}. \quad (3.17)$$

These are closed-economy counterparts of the log-linearised equations derived for the home economy.

The system of log-linear equations described above is driven by 13 exogenous shocks. There are three technology shocks in the domestic economy – a unit-root technology shock ($z_{T,t}$) and two stationary technology shocks, one in the tradable goods sector ($z_{A_H,t}$) and one in the non-tradable goods sector ($z_{A_N,t}$). Furthermore, we have a preference shock ($z_{G,t}$), a country risk premium shock that affects the relative riskiness of foreign to domestic assets ($z_{\phi,t}$), three mark-up shocks, one for each type of good ($z_{m_H,t}, z_{m_N,t}, z_{m_F,t}$) and a monetary policy shock ($z_{R,t}$). In the foreign economy block, there are a unit-root technology shock ($z_{T^*,t}$), a preference shock ($z_{G^*,t}$), a mark-up shock in the pricing of foreign goods ($z_{m^*,t}$) and a monetary policy shock ($z_{R^*,t}$). These shocks are defined as AR(1)processes with *i.i.d.* innovations. Exceptions are the two monetary policy shocks which are assumed as *i.i.d.* In addition, it should be emphasised that we specify the home economy's preference shock, $z_{G,t}$, as a weighted average of a domestic preference shock, $z_{G,t}{}^d$, and the foreign economy's preference shock, $z_{G^*,t}$. This specification allows the preference shock in the home economy to co-move with the corresponding shock in the foreign economy. The empirical evidence strongly suggests a common factor in international business cycles (see Kose et al. (2008) among others). The case with no spillover ($\alpha_G = 0$ in Eq. (3.18)) is considered in Section 4.5.

The shock processes can be written as

$$
\begin{aligned}
z_{T,t} &= \rho_T z_{T,t-1} + \epsilon_{T,t} \\
z_{A_H,t} &= \rho_{A_H} z_{A_H,t-1} + \epsilon_{A_H,t} \\
z_{A_N,t} &= \rho_{A_N} z_{A_N,t-1} + \epsilon_{A_N,t} \\
z_{G,t} &= (1-\alpha_G) z^d_{G,t} + \alpha_G z_{G^*,t} \\
z^d_{G,t} &= \rho^d_G z^d_{G,t-1} + \epsilon^d_{G,t} \\
z_{\phi,t} &= \rho_\phi z_{\phi,t-1} + \epsilon_{\phi,t} \\
z_{m_H,t} &= \rho_{m_H} z_{m_H,t-1} + \epsilon_{m_H,t} \\
z_{m_F,t} &= \rho_{m_F} z_{m_F,t-1} + \epsilon_{m_F,t} \\
z_{m_N,t} &= \rho_{m_N} z_{m_N,t-1} + \epsilon_{m_N,t} \\
z_{R,t} &= \epsilon_{R,t} \\
z_{T^*,t} &= \rho_{T^*} z_{T^*,t-1} + \epsilon_{T^*,t} \\
z_{G^*,t} &= \rho_{G^*} z_{G^*,t-1} + \epsilon_{G^*,t} \\
z_{m^*,t} &= \rho_{m^*} z_{m^*,t-1} + \epsilon_{m^*,t} \\
z_{R^*,t} &= \epsilon_{R^*,t},
\end{aligned}
\tag{3.18}
$$

where the AR(1) parameters are $0 < \rho_i < 1$, for all i.

We adopt three additional assumptions to estimate the model. First, the stationary technology shock in the traded goods sector is identical with the one in the non-traded goods sector ($z_{A_H,t} = z_{A_N,t} = z_{A,t}$). This assumption is introduced because the parameters are hard to identify separately from the data. Secondly, the substitution elasticity between domestic and foreign traded goods is the same in both economies ($\eta = \eta^*$). Thirdly, an equation for inflation of oil products $\pi_{oil,t}$ is added to the model and CPI inflation is calculated as a linear combination of CPI inflation ex oil products and oil product inflation. Alternatively, we could specify the presence of an imported input of production whose demand would be optimally chosen by the traded goods firm. We take a short cut for reasons of simplicity and convenience. The prices of oil products are notoriously hard to predict. They have a substantial effect on the volatility of the CPI inflation rate while their effect through the production function is hard to pin down. In addition, the model simulations underlying the inflation forecast published by the SNB are typically based on the assumption that the oil price stays constant at its current level. Thus oil product inflation in the model is assumed to follow an AR(1) process of the form

$$\pi_{oil,t} = \rho_{oil} \pi_{oil,t-1} + z_{oil,t}, \tag{3.19}$$

where $z_{oil,t} = \epsilon_{oil,t}$ is a white noise innovation.

4. Estimation

The rational expectation solution of the log-linearised model is estimated with Bayesian Maximum Likelihood on data for Switzerland.[4] Following Smets and Wouters (2003), Bayesian Maximum Likelihood has become the standard method for estimating DSGE models. The Bayesian approach requires choosing prior distributions of the parameters to be estimated. These priors represent our previous knowledge. The priors are updated with observed data using Bayes' rule. The resulting posterior distributions are then used to compute the parameter estimates.

4.1 Methodology

The estimation of DSGE models with Bayesian methods is described in a series of papers by Frank Schorfheide and various co-authors. This section gives a brief outline based on An and Schorfheide (2007) and Schorfheide et al. (2010).

Eq. (3.1) to Eq. (3.19) form a linear rational expectations system. The solution of this system can be written as

$$\mathbf{s}_t = \Phi_1(\theta)\mathbf{s}_{t-1} + \Phi_\epsilon(\theta)\boldsymbol{\epsilon}_t, \tag{4.1}$$

where the vector $\mathbf{s}_t$ contains the state variables, the vector $\boldsymbol{\epsilon}_t$ contains the innovations to the exogenous processes, and the coefficients of the matrices Φ_1 and Φ_ϵ are functions of the model parameters collected in vector θ.

The state variables are linked to observed data via a set of measurement equations (to be discussed in Section 4.2). As some variables in the observed data set are in growth rates, we augment the set of states $\mathbf{s}_t$ with lagged values of state variables to allow for lagged state variables in the measurement equations. The augmented vector of state variables takes the form

$$\varsigma_t = [\mathbf{s}_t', \mathbf{s}_{t-1}' M_s'(\theta)]', \tag{4.2}$$

where $M_s(\theta)$ is a suitably chosen matrix. Eq. (4.1) can be rewritten as

$$\varsigma_t = \Phi_1'(\theta)\varsigma_{t-1} + \Phi_\epsilon'(\theta)\boldsymbol{\epsilon}_t, \tag{4.3}$$

and the measurement equations can be written in compact form as

4 We use the *gensys* procedure described in Sims (2002) to compute the rational expectations solution of the DSGE model and one of the Gauss routines provided on Frank Schorfheide's homepage to perform the Bayesian estimation.

$$\mathbf{y}_t = A_0(\theta) + A_1\varsigma_t + \boldsymbol{\varepsilon}_t^{\mathbf{y}}, \tag{4.4}$$

where the vector $\mathbf{y}_t$ contains the observables and the vector $\boldsymbol{\varepsilon}_t^{\mathbf{y}}$ collects the measurement errors.

Eq. (4.3) and Eq. (4.4) form the state space representation of the DSGE model. Assuming that the innovations ϵ_t are *i.i.d.* realisations of a normal distribution, the likelihood function $p(\mathbf{Y}^T|\theta)$, where $\mathbf{Y}^T=[\mathbf{y}_t,\ldots,\mathbf{y}_T]$, can be evaluated using the Kalman filter. The Kalman filter also generates a sequence of estimates of the state vector ς_t:

$$\varsigma_{t|t}(\theta) = E_t[\varsigma_t \,|\, \theta, \mathbf{Y}^t]. \tag{4.5}$$

The Bayesian estimation of the DSGE model combines a prior density $p(\theta)$ with the likelihood function $p(\mathbf{Y}^T|\theta)$ to obtain a joint probability density function for data and parameters. The posterior distribution is given by

$$p(\theta \,|\, \mathbf{Y}^T) = \frac{p(\mathbf{Y}^T \,|\, \theta)\, p(\theta)}{p(\mathbf{Y})}, \tag{4.6}$$

where $p(\mathbf{Y}^T) = \int p(\mathbf{Y}^T \,|\, \theta) p(\theta) d\theta \; p(\mathbf{Y}^T)$ is the marginal data density.

We employ Markov-Chain-Monte-Carlo (MCMC) methods described in An and Schorfheide (2007) to implement the Bayesian inference. More specifically, a random-walk Metropolis-Hastings algorithm is used to generate draws from the posterior distribution $p(\theta|\mathbf{Y}^T)$. The posterior moments are computed from the posterior draws.

4.2 Data and measurement equations

Data for Switzerland are taken from two sources: the Swiss Federal Statistical Office (SFSO) and the Swiss National Bank (SNB). Output is measured by real GDP (SFSO), the price level by the CPI (SFSO), the interest rate by the three-month CHF Libor (SNB), the terms of trade by the ratio of CPI foreign goods to CPI home goods (SFSO) and prices of oil products by the CPI component of gasoline, diesel and fuel oil (SFSO). The real exchange rate is defined as a weighted average of the EUR/CHF and USD/CHF real exchange rates, where the weights are 0.7 and 0.3 respectively. The bilateral real exchange rates are computed using the corresponding nominal exchange rates and CPI data for Switzerland, the euro area and the US. All foreign variables are weighted averages of the euro area and US data (i.e. euro area and US real GDP for foreign output, euro area and US CPI for the foreign price level, and EUR and USD three-month Libor for the foreign interest rate). The weights correspond to those on the bilateral exchange rates in the calculation of the effective exchange rate.

Prior to estimation, we transform real GDP and the terms of trade into quarter-on-quarter growth rates and the price levels into annualised quarter-on-quarter growth rates (computed as first differences in the natural logarithm of the seasonally adjusted variable and multiplied by 100 and 400, respectively). Furthermore, potential labour hours (in logs) are subtracted from the Swiss real GDP (in logs) to remove the time varying trend in the growth rate of labour input in Switzerland. A smooth HP trend (smoothing parameter 10,000) is removed from the log of foreign real GDP, the log of the real exchange rate and the log of the terms of trade. To account for disinflation in the early 1990s, the mean inflation rate and the mean interest rate in the 1983–1994 period are matched with those in the post-1994 period (by subtracting from the rates in the 1983–1994 period the difference between the mean of the 1983–1994 period and the mean of the post-1994 period). This is done for all domestic and foreign inflation rates and interest rates, except oil product inflation.

The resulting set of stationary observables (measurement variables) includes

$$\Delta y_t^{Data},\ \pi_t^{Data},\ \pi_{F,t}^{Data},\ i_t^{Data},\ s_{r,t}^{Data},\ \Delta x_t^{Data},\ \Delta y_t^{*,Data},\ \pi_t^{*,Data},\ i_t^{*,Data},\ \pi_{oil,t}^{Data}. \tag{4.7}$$

These ten variables constitute vector $\mathbf{y}_t$. Chart 1 shows the time series of the variables for the period 1983Q2 to 2013Q2.

The ten measurement equations are

$$\begin{aligned}
\Delta y_t^{Data} &= 100(\overline{\gamma}_Z + y_t - y_{t-1} + z_{T,t} + \varepsilon_{y^{Data},t})\\
\pi_t^{Data} &= 400(\pi + (1-\alpha_{oil})\pi_t + \alpha_{oil}\pi_{oil,t}^{Data} + \varepsilon_{\pi^{Data},t})\\
\pi_{F,t}^{Data} &= 400(\pi_F + \pi_{F,t} + \varepsilon_{\pi_F^{Data},t})\\
i_t^{Data} &= 400(i + i_t)\\
s_{r,t}^{Data} &= 100(s_r + s_{r,t} + \varepsilon_{s_r^{Data},t})\\
\Delta x_t^{Data} &= 100(\Delta x + x_t - x_{t-1} + \varepsilon_{x^{Data},t})\\
\Delta y_t^{*,Data} &= 100(\overline{\gamma}_Z^* + y_t^* - y_{t-1}^* + z_{T^*,t} + \varepsilon_{y^{*Data},t})\\
\pi_t^{*,Data} &= 400(\pi^* + \pi_t^* + \varepsilon_{\pi^{*Data},t})\\
i_t^{*,Data} &= 400(i^* + i_t^*)\\
\pi_{oil,t}^{Data} &= 400(\pi_{oil} + \pi_{oil,t} + \varepsilon_{\pi_{oil}^{Data},t}).
\end{aligned} \tag{4.8}$$

4.3 Calibration and prior distributions

Most parameters of the model are estimated, but some parameters are calibrated. The calibrated parameters are displayed in Table 1. The steady-state discount factor is set to $\beta = 0.995$, and the risk premium parameter is set to $\phi_A = 0.005$. The weight of non-traded goods and services in the CPI (ex oil products) is set to $\gamma = 0.6$, the weight of foreign goods in the traded goods component of the CPI (ex oil products) is set to $\alpha = 0.23$ and the share of oil products in the CPI is set to $\alpha_{oil} = 0.04$. These values for γ, α and α_{oil} are calculated as multi-year averages based on CPI weights provided by SFSO. The spillover from foreign to home preference shocks is set to $\alpha_G = 0.4$, based on a grid search to find the appropriate parameter for capturing the co-movement of domestic and foreign output fluctuations. The steady-state values $\overline{\gamma}_Z$, π, π_F, i, s_r, Δx, $\overline{\gamma}_Z^*$, π^*, i^* and π_{oil} are set to their sample means. The measurement errors have zero mean and the variance is set to 0.05 in $\varepsilon_{\pi^{Data},t}$, $\varepsilon_{\pi_F^{Data},t}$, $\varepsilon_{s_r^{Data},t}$, $\varepsilon_{x^{Data},t}$, $\varepsilon_{\pi^{*Data},t}$, and 0.1 in $\varepsilon_{y^{Data},t}$, $\varepsilon_{y^{*Data},t}$, $\varepsilon_{\pi_{oil}^{Data},t}$.

The assumptions about the prior distributions of the estimated parameters are summarised in Table 2. Our choice is guided by the evidence gathered from micro-studies and by the specifications found in similar studies for other countries. In what follows, we focus on the prior distributions of the home economy parameters. The corresponding foreign economy assumptions are the same, except that prior parameters governing the monetary policy rule are less concentrated in the foreign economy block than in the home economy block of the model.

Chart 1

DATA

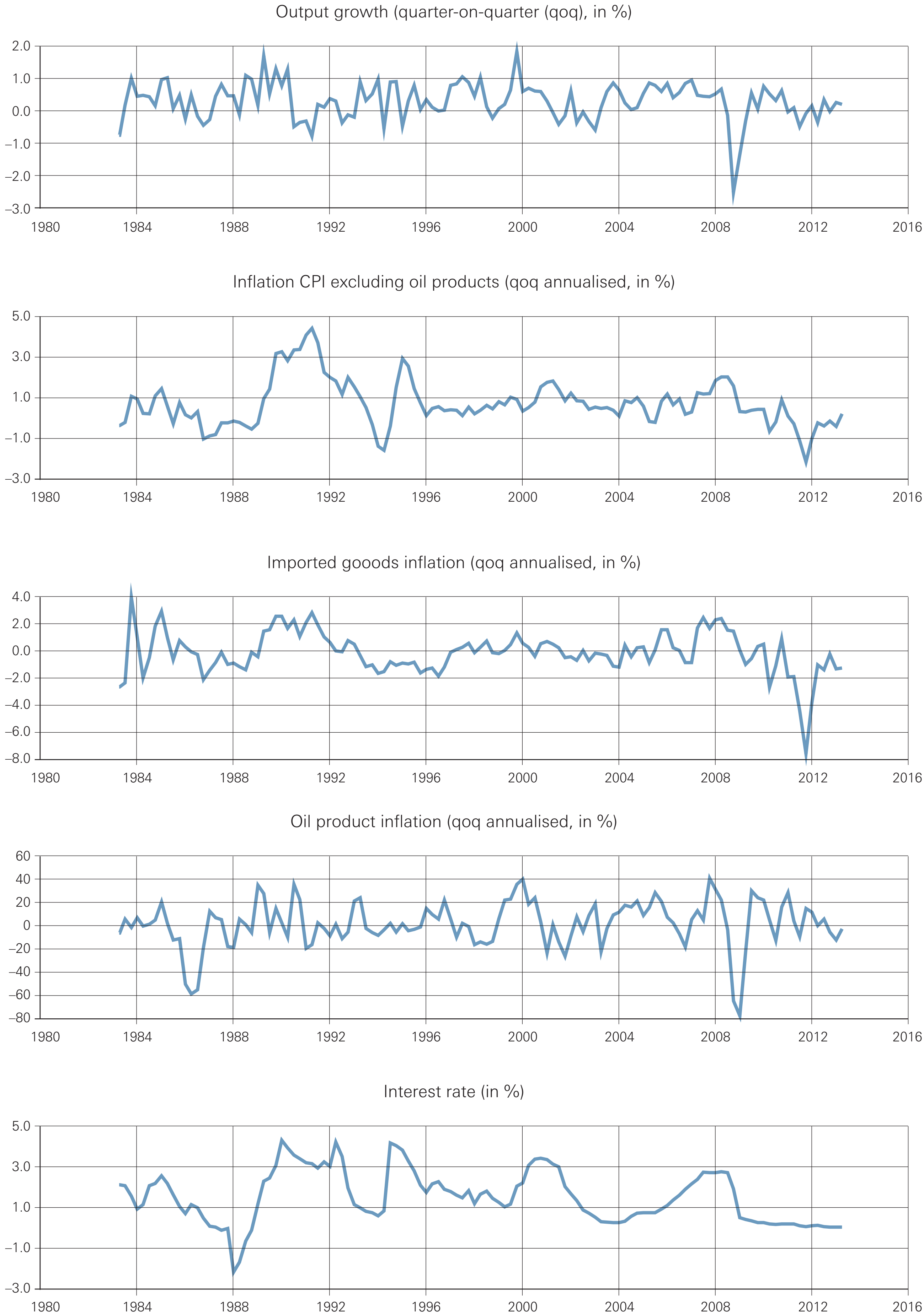
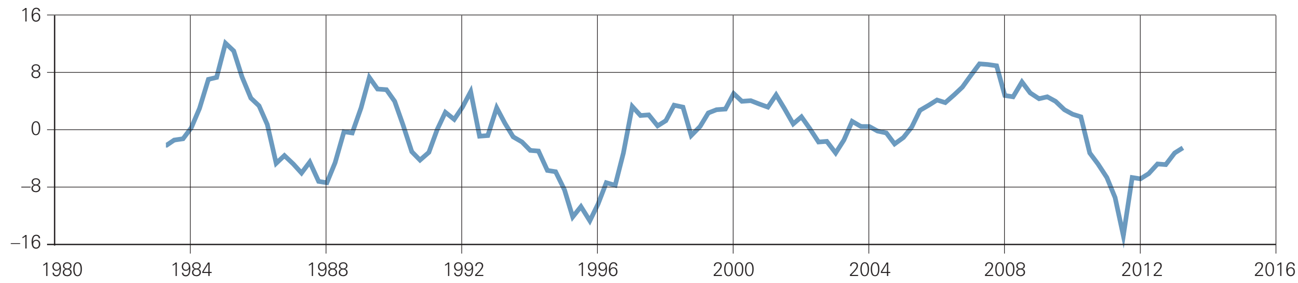
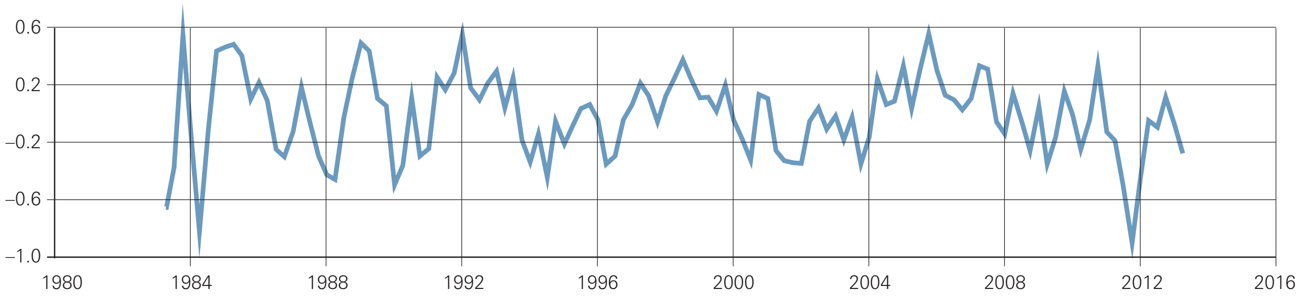

Output growth (quarter-on-quarter (qoq), in %)
2.0
1.0
0.0
–1.0
–2.0
–3.0
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
Inflation CPI excluding oil products (qoq annualised, in %)
5.0
3.0
1.0
–1.0
–3.0
Imported gooods inflation (qoq annualised, in %)
4.0
2.0
0.0
–2.0
–4.0
–6.0
–8.0
Oil product inflation (qoq annualised, in %)
60
40
20
0
–20
–40
–60
–80
Interest rate (in %)
5.0
3.0
1.0
–1.0
–3.0

Chart 1 continued

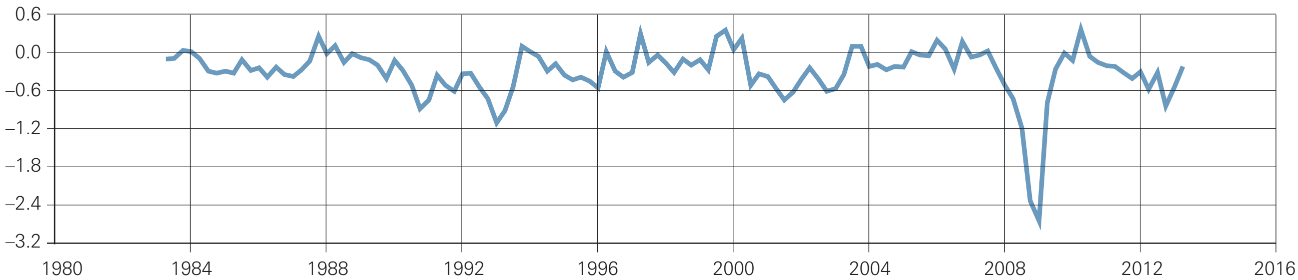
Real exchange rate (% dev.)



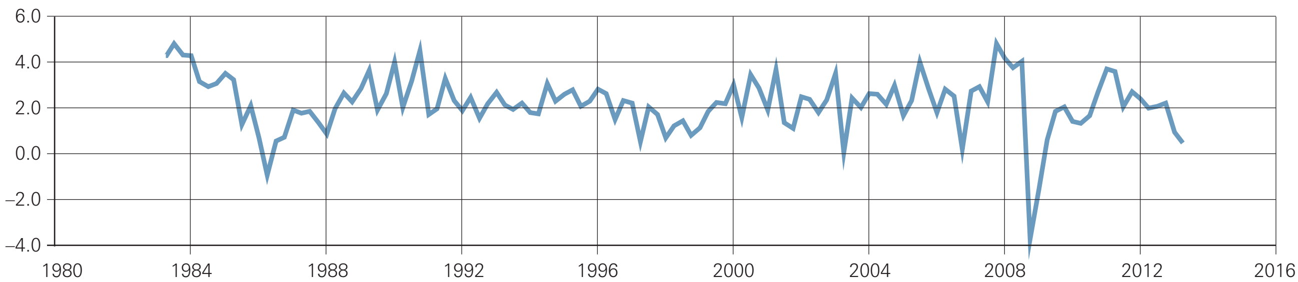
Terms of trade change (qoq, in %)



Foreign output growth (qoq, in %)



Foreign inflation (qoq annualised, in %)



Foreign interest rate (in %)

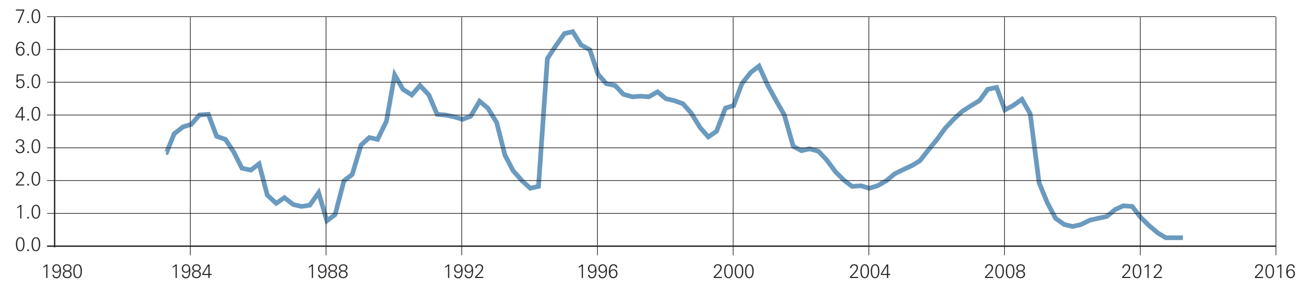


Table 1

CALIBRATED PARAMETERS

Structural parameters		
Discount factor	β	0.995
Share of non-traded goods and services in CPI (ex oil products)	γ	0.6
Share of foreign goods in traded goods component of CPI (ex oil products)	α	0.23
Share of oil products in CPI	α_{oil}	0.04
Risk premium	ϕ_A	0.005
Spillover from foreign to home preference shock	α_G	0.4
Steady state calibrations		
Steady state output growth	$\bar{\gamma}_Z$	0.0029
Steady state inflation rate	π	0.0017
Steady state inflation rate, imported goods	π_F	–0.0003
Steady state nominal interest rate	i	0.0038
Steady state real exchange rate	s_r	–0.0004
Steady state change in terms of trade	Δx	–0.0002
Steady state output growth in foreign economy	$\bar{\gamma}^*_Z$	–0.0001
Steady state inflation rate in foreign economy	π^*	0.0055
Steady state nominal interest rate in foreign economy	i^*	0.0078
Steady state oil product price inflation	π_{oil}	0.0037
Distribution of measurement errors		
$\varepsilon_{y^{Data},t}$	N(0,0.1)	
$\varepsilon_{\pi^{Data},t}$	N(0,0.05)	
$\varepsilon_{\pi_F^{Data},t}$	N(0,0.05)	
$\varepsilon_{s_r^{Data},t}$	N(0,0.05)	
$\varepsilon_{x^{Data},t}$	N(0,0.05)	
$\varepsilon_{y^{*Data},t}$	N(0,0.1)	
$\varepsilon_{\pi^{*Data},t}$	N(0,0.05)	
$\varepsilon_{\pi_{oil}^{Data},t}$	N(0,0.1)	

Table 2

PRIOR DISTRIBUTIONS

Parameter		*type*	*mean*	*stdv.*
Domestic behavioural parameters				
Calvo: Home	ξ_H	Beta	0.75	0.05
Calvo: Foreign	ξ_F	Beta	0.75	0.05
Calvo: Non-traded	ξ_N	Beta	0.75	0.05
Indexation: Home	κ_H	Beta	0.50	0.10
Indexation: Foreign	κ_F	Beta	0.50	0.10
Indexation: Non-traded	κ_N	Beta	0.50	0.10
Habit formation	h	Beta	0.70	0.05
Inverse elasticity: Cons/Labour	σ	Gamma	1.50	0.10
Inverse elasticity: Labour	φ	Gamma	1.00	0.10
Elasticity: Home/Foreign	η	Gamma	1.00	0.10
Elasticity: Traded/Non-traded	ν	Gamma	1.00	0.10

Table 2 continued

Parameter		*type*	*mean*	*stdv.*
UIP risk premium: Modification Adolfson et al.	ϕ_S	Beta	0.40	0.10
UIP risk premium: Modification Christiano et al.	ϕ_i	Gamma	1.10	0.10
Policy: Interest rate smoothing	ρ_R	Beta	0.80	0.05
Policy: Inflation	ψ_π	Gamma	1.50	0.05
Policy: Output	ψ_Y	Gamma	0.50	0.05
Policy: Output growth	$\psi_{\Delta Y}$	Gamma	0.20	0.05
Foreign behavioural parameters				
Foreign Calvo	ξ^*	Beta	0.75	0.05
Foreign indexation	κ^*	Beta	0.50	0.10
Foreign habit formation	h^*	Beta	0.70	0.05
Foreign inverse elasticity: Cons/Labour	σ^*	Gamma	1.50	0.10
Foreign inverse elasticity: Labour	φ^*	Gamma	1.00	0.10
Foreign policy: Interest rate smoothing	ρ_{R^*}	Beta	0.80	0.10
Foreign policy: Inflation	ψ_{π^*}	Gamma	1.50	0.10
Foreign policy: Output	ψ_{Y^*}	Gamma	0.25	0.10
Foreign policy: Output growth	$\psi_{\Delta Y^*}$	Gamma	0.20	0.10
AR(1) coefficients and standard deviations				
Non-stationary technology shock	ρ_T	Beta	0.80	0.10
Stationary technology shock	ρ_A	Beta	0.50	0.10
Preference shock	ρ_G^d	Beta	0.80	0.10
Risk premium shock	ρ_ϕ	Beta	0.50	0.10
Mark-up shock: Home	ρ_{m_H}	Beta	0.50	0.10
Mark-up shock: Foreign	ρ_{m_F}	Beta	0.50	0.10
Mark-up shock: Non-traded	ρ_{m_N}	Beta	0.50	0.10
Foreign technology shock	ρ_{T^*}	Beta	0.80	0.10
Foreign preference shock	ρ_{G^*}	Beta	0.80	0.10
Foreign mark-up shock	ρ_{m^*}	Beta	0.50	0.10
Oil price shock	ρ_{oil}	Beta	0.50	0.10
Std dev: Non-stationary technology shock	σ_T	InvGamma	0.20	4
Std dev: Stationary technology shock	σ_A	InvGamma	0.50	4
Std dev: Preference shock	σ_G^d	InvGamma	0.50	4
Std dev: Risk premium shock	σ_ϕ	InvGamma	0.50	4
Std dev: Mark-up shock: Home	σ_{m_H}	InvGamma	0.50	4
Std dev: Mark-up shock: Foreign	σ_{m_F}	InvGamma	0.50	4
Std dev: Mark-up shock: Non-traded	σ_{m_N}	InvGamma	0.50	4
Std dev: Monetary policy shock	σ_R	InvGamma	0.50	4
Std dev: Foreign technology shock	σ_{T^*}	InvGamma	0.20	4
Std dev: Foreign preference shock	σ_{G^*}	InvGamma	0.50	4
Std dev: Foreign mark-up shock	σ_{m^*}	InvGamma	0.50	4
Std dev: Foreign monetary policy shock	σ_{R^*}	InvGamma	0.50	4
Std dev: Oil price shock	σ_{oil}	InvGamma	0.50	4

Parameters bounded by theory between 0 and 1 are given standardised beta distributions. This pertains to the Calvo and indexation parameters constraining the price-setting decisions of producers and retailers, the habit formation parameter, the Adolfson et al. modification of the UIP risk premium, the degree of interest-rate smoothing in the monetary policy rule, and the AR(1) coefficients of the shock processes. The prior means for the Calvo parameters are set to 0.75, implying an average price spell duration of four quarters. This corresponds with the average duration of price rigidity for Switzerland reported in Kaufmann (2009). The standard deviation is set to 0.05, implying a relatively small uncertainty about the degree of price rigidity. The prior means for the indexation parameters are set to 0.5 with a standard deviation of 0.1, reflecting a lack of knowledge on this parameter. For the UIP modification, we set a prior mean of 0.4 with a standard deviation of 0.1. For the degree of habit persistence in consumption, the prior mean is set to 0.7 and the standard deviation to 0.05, broadly in line with assumptions made in other DSGE models. The interest-rate smoothing parameter is centred around 0.8 with a standard deviation of 0.05, consistent with estimated values obtained in standard Taylor rule equations with the three-month Libor, CPI inflation and various measures for the output gap. Priors for the AR(1) coefficients of the exogenous shock processes are assumed to have a mean of 0.5 (0.8 in the case of unit-root technology shocks and preference shocks).

Parameters restricted to be positive are given either gamma or inverse gamma distributions. The priors of the inverted elasticity of intertemporal substitution in consumption (prior mean: 1.5), the inverted labour supply elasticity (1.0), the elasticity of substitution between tradables and non-tradables (1.0) and the elasticity of substitution between traded home goods and imported goods (1.0) are all specified as gamma distributions. With standard deviations of 0.1, they are set to be relatively non-informative, allowing the posteriors to be primarily influenced by the data. For the parameters on the central bank's response to inflation and output movements, the prior mean is set to 1.5 and 0.5 respectively, in line with the values proposed by Taylor (1993). The prior mean of the central banks' responses to output growth is set to 0.2.

The prior distributions for the standard deviations of the structural shocks are modelled as inverse gamma distributions with 2 degrees of freedom and a common mode of 0.10, reflecting the fact that there is little prior information on these parameters.

4.4 Estimation results

The model is estimated for the sample period 1983Q2 to 2013Q2. The posterior moments are computed from 250,000 posterior parameter draws after the first 50,000 have been discarded. Table 3 shows the results in terms of posterior means and 90 percent credible intervals.

In the home economy, the posterior mean of the Calvo parameter is in the neighbourhood of 0.9 for all three goods categories, significantly above the prior mean of 0.75. The indexation parameter is highest for non-traded goods ($\kappa_N = 0.58$), followed by imported goods ($\kappa_F = 0.46$) and domestic traded goods ($\kappa_H = 0.40$), with fairly large standard deviations.

The habit persistence is estimated at $h = 0.48$, which is smaller than the prior and the estimates in Smets and Wouters (2003) or Adolfson et al. (2007). The intertemporal elasticity of substitution ($1/\sigma$) is below 1 and in line with the literature. The inverse of the labour supply elasticity is estimated at $\varphi = 0.98$, while the substitution elasticities between traded and non-traded goods and between home and foreign traded goods are $\nu = 1.02$ and $\eta = 0.88$ respectively. The parameter governing the UIP modification, $\phi_S = 0.38$, is somewhat lower than what Adolfson et al. (2007) found for Sweden.

In the monetary policy reaction function, we find evidence for strong interest rate smoothing ($\rho_R = 0.90$). The posterior means and standard deviations for the responses to inflation ($\psi_\pi = 1.49$), the output gap ($\psi_y = 0.49$) and the change in the output gap ($\psi_{\Delta y} = 0.24$) are all near their priors.

With few exceptions, the estimates for the foreign economy are reasonably close to the estimates obtained for the home economy. The largest differences emerge in the indexation parameter (estimated at $\kappa^* = 0.25$) and habit persistence ($h^* = 0.71$).

The posterior means for the shock parameters show a similar pattern in both the home and the foreign economy. Preference shocks are more persistent than technology shocks which, in turn, are more persistent than mark-up shocks.

Table 4 compares the observed and model-implied moments (means, standard deviations and autocorrelations) of selected variables. The model-implied moments are calculated from 2,500 Metropolis-Hastings draws from the posterior parameter distribution. The variables considered are output growth, CPI inflation (ex oil products), imported goods inflation (ex oil products), the short-term interest rate, the real effective exchange rate, the changes in the terms of trade, and oil product inflation, all in the home economy.

The model appears to reflect the moments of the observed data quite well. Posterior means are reasonably close to those in the observed data. For all variables, the sample mean falls inside the uncertainty band computed for the model-implied data. Posterior standard deviations tend to be larger than those observed in the data. The differences are significant for the changes in the terms of trade. With respect to autocorrelations, we find significant differences for CPI inflation and the changes in the terms of trade.

Chart 2 displays the smoothed shock processes over the period 1988Q1 to 2013Q2. Overall, the shocks are stationary and their variances do not increase over time. However, several large shocks are identified by the model in the last few years of the sample period. In 2008–2009 there are large negative unit-root technology shocks both in the home economy and in the foreign economy, indicating a sudden decrease of steady-state output after the collapse of Lehman Brothers. At about the same time, large positive monetary policy shocks occur, indicating that central banks were not expansionary enough from the model's point of view.[5] This is followed by negative risk premium shocks in 2010 and 2011, when the Swiss franc strengthened substantially until the SNB set a minimum exchange rate of 1.20 francs per euro in September 2011. Furthermore, negative mark-up shocks for imported goods in 2011 suggest a temporarily higher pass-through following the strong appreciation of the Swiss franc.

5 We should remember that the interest rate was approaching the zero lower bound after 2008. The interest rate is the only monetary policy instrument in this model. The model does not account for unconventional monetary policy actions such as those undertaken by central banks after the Lehman collapse. See the discussion of the historical decomposition of the output gap and the inflation gap in Section 5.3.

Table 3

POSTERIOR ESTIMATES

	Prior		Posterior	
Domestic behavioural parameters				
ξ_H	0.75	[0.67, 0.83]	0.89	[0.86, 0.92]
ξ_F	0.75	[0.67, 0.83]	0.91	[0.89, 0.93]
ξ_N	0.75	[0.67, 0.83]	0.89	[0.87, 0.92]
κ_H	0.50	[0.34, 0.67]	0.40	[0.24, 0.53]
κ_F	0.50	[0.34, 0.67]	0.46	[0.30, 0.61]
κ_N	0.50	[0.33, 0.66]	0.58	[0.43, 0.72]
h	0.70	[0.62, 0.78]	0.48	[0.39, 0.56]
σ	1.50	[1.34, 1.67]	1.32	[1.16, 1.46]
φ	1.00	[0.83, 1.16]	0.98	[0.82, 1.14]
η	1.00	[0.83, 1.16]	0.88	[0.79, 0.97]
ν	1.00	[0.84, 1.16]	1.02	[0.86, 1.18]
ϕ_S	0.40	[0.23, 0.56]	0.38	[0.31, 0.45]
ρ_R	0.80	[0.72, 0.88]	0.90	[0.87, 0.93]
ψ_π	1.50	[1.42, 1.58]	1.49	[1.41, 1.58]
ψ_Y	0.50	[0.42, 0.58]	0.49	[0.41, 0.57]
$\psi_{\Delta Y}$	0.20	[0.12, 0.28]	0.24	[0.17, 0.29]
Foreign behavioural parameters				
ξ^*	0.75	[0.67, 0.83]	0.86	[0.82, 0.91]
κ^*	0.50	[0.34, 0.67]	0.25	[0.14, 0.35]
h^*	0.70	[0.62, 0.78]	0.71	[0.65, 0.77]
σ^*	1.50	[1.33, 1.66]	1.47	[1.31, 1.62]
φ^*	1.00	[0.83, 1.16]	0.97	[0.82, 1.13]
ρ_{R^*}	0.80	[0.65, 0.96]	0.89	[0.85, 0.92]
ψ_{π^*}	1.50	[1.34, 1.67]	1.53	[1.36, 1.70]
ψ_{Y^*}	0.25	[0.09, 0.40]	0.36	[0.18, 0.54]
$\psi_{\Delta Y^*}$	0.20	[0.05, 0.35]	0.25	[0.13, 0.36]
AR(1) coefficients and standard deviations				
ρ_T	0.80	[0.65, 0.96]	0.63	[0.47, 0.80]
ρ_A	0.50	[0.33, 0.66]	0.49	[0.33, 0.66]
ρ_G^d	0.80	[0.65, 0.96]	0.72	[0.60, 0.84]
ρ_ϕ	0.50	[0.33, 0.66]	0.72	[0.60, 0.86]
ρ_{m_H}	0.50	[0.34, 0.67]	0.29	[0.19, 0.39]
ρ_{m_F}	0.50	[0.33, 0.66]	0.34	[0.23, 0.45]
ρ_{m_N}	0.50	[0.34, 0.67]	0.26	[0.17, 0.35]
ρ_{T^*}	0.80	[0.65, 0.96]	0.71	[0.60, 0.83]
ρ_{G^*}	0.80	[0.65, 0.96]	0.81	[0.75, 0.87]
ρ_{m^*}	0.50	[0.33, 0.66]	0.23	[0.14, 0.32]
ρ_{oil}	0.50	[0.33, 0.66]	0.53	[0.43, 0.62]
σ_T	0.25	[0.10, 0.39]	0.18	[0.10, 0.25]
σ_A	0.63	[0.26, 0.99]	0.53	[0.27, 0.78]
σ_G^d	0.63	[0.26, 0.99]	3.39	[2.46, 4.28]
σ_ϕ	0.63	[0.26, 0.99]	0.55	[0.38, 0.71]
σ_{m_H}	0.63	[0.27, 1.00]	0.16	[0.14, 0.19]
σ_{m_F}	0.63	[0.26, 0.99]	0.17	[0.15, 0.20]

Table 3 continued

	Prior		*Posterior*	
σ_{m_N}	0.63	[0.26, 0.99]	0.14	[0.12, 0.16]
σ_R	0.63	[0.27, 0.99]	0.18	[0.16, 0.21]
σ_{T^*}	0.25	[0.11, 0.40]	0.18	[0.12, 0.23]
σ_{G^*}	0.63	[0.26, 0.99]	2.00	[1.46, 2.53]
σ_{m^*}	0.63	[0.27, 0.98]	0.20	[0.17, 0.22]
σ_{R^*}	0.63	[0.27, 0.99]	0.16	[0.14, 0.18]
σ_{oil}	0.63	[0.26, 0.99]	4.11	[3.68, 4.55]

Notes: Posterior means and 90% intervals in parentheses, from 250,000 draws with the first 50,000 draws discarded. 90% intervals for priors are taken from 100,000 draws.

Table 4

UNCONDITIONAL MOMENTS

	Data	*Model*	
Mean			
Δy_t^{Data}	0.29	0.29	[0.21, 0.36]
π_t^{Data}	0.69	0.70	[0.07, 1.30]
$\pi_{F,t}^{Data}$	–0.12	–0.11	[–0.59, 0.42]
i_t^{Data}	1.51	1.52	[0.79, 2.26]
$s_{r,t}^{Data}$	–0.04	–0.31	[–6.94, 6.87]
Δx_t^{Data}	–0.02	–0.02	[–0.11, 0.09]
$\pi_{oil,t}^{Data}$	1.72	1.54	[–4.07, 6.55]
Standard deviations			
Δy_t^{Data}	0.58	0.62	[0.53, 0.72]
π_t^{Data}	1.13	1.21	[0.94, 1.48]
$\pi_{F,t}^{Data}$	1.54	2.05	[1.54, 2.50]
i_t^{Data}	1.29	1.42	[1.00, 1.80]
$s_{r,t}^{Data}$	5.15	6.88	[4.45, 8.95]
Δx_t^{Data}	0.28	0.64	[0.50, 0.76]
$\pi_{oil,t}^{Data}$	19.82	19.06	[15.72, 22.73]
Autocorrelations			
Δy_t^{Data}	0.38	0.29	[0.14, 0.44]
π_t^{Data}	0.85	0.72	[0.62, 0.83]
$\pi_{F,t}^{Data}$	0.65	0.71	[0.60, 0.83]
i_t^{Data}	0.90	0.85	[0.78, 0.93]
$s_{r,t}^{Data}$	0.90	0.92	[0.87, 0.96]
Δx_t^{Data}	0.50	0.68	[0.57, 0.80]
$\pi_{oil,t}^{Data}$	0.57	0.50	[0.36, 0.66]

Notes: For the model the mean and the 90% uncertainty intervals (in parentheses) are calculated from simulating the model 2,000 times (using individual draws from the posterior distribution of model parameters) with 122 periods.

Chart 2

HISTORICAL SHOCKS

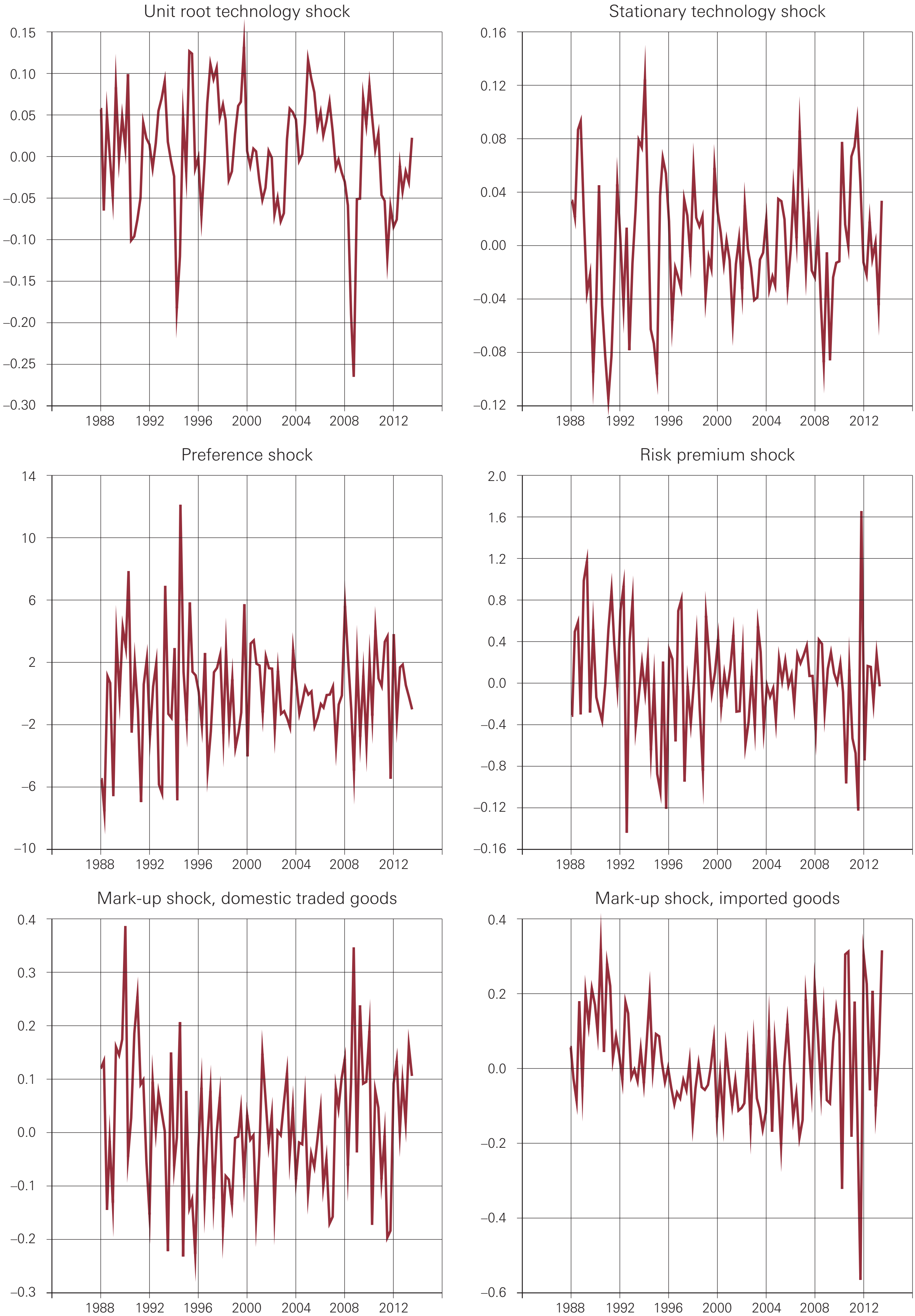
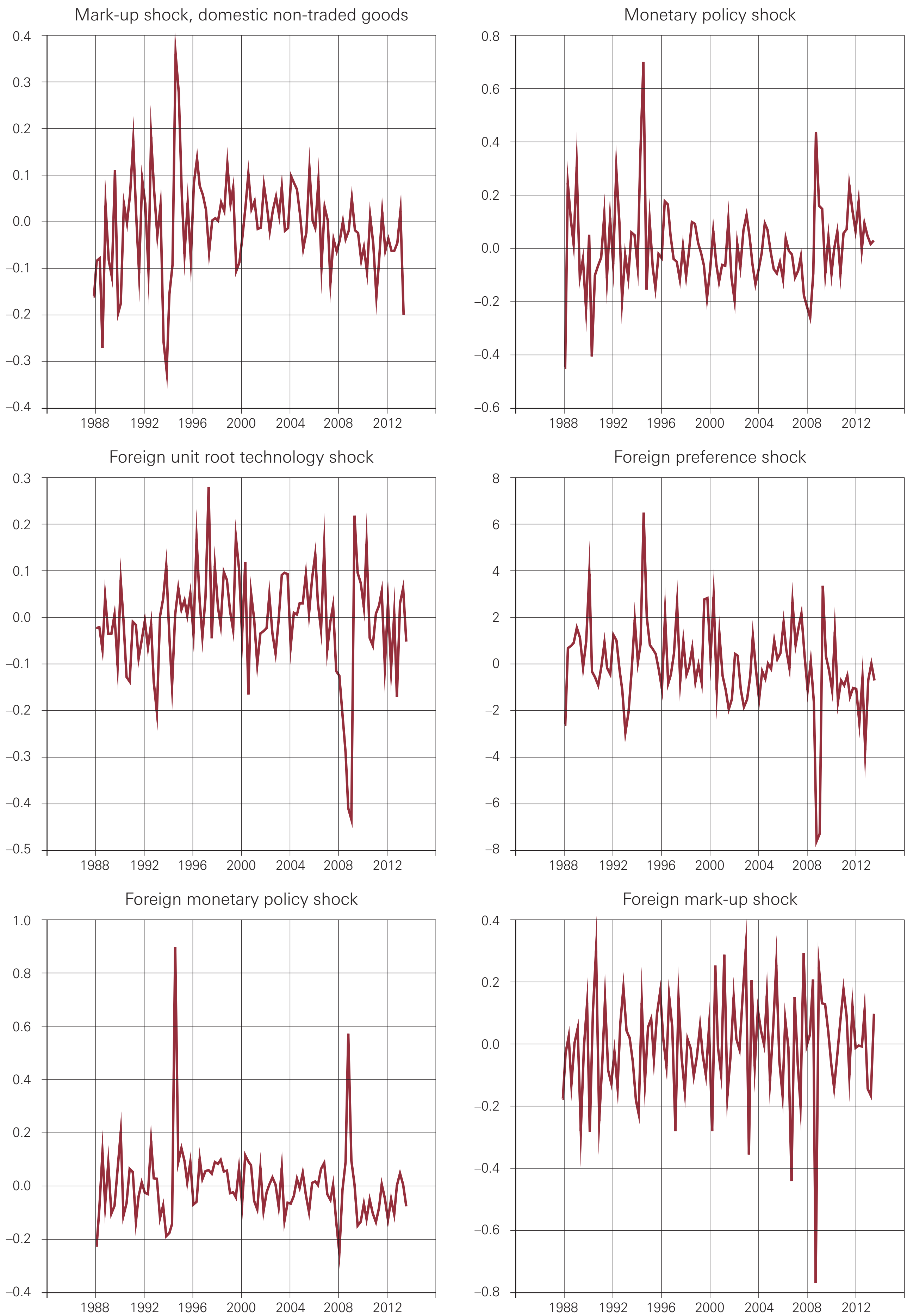


Chart 2 continued



4.5 Estimation of alternative specifications

To illustrate the effect of selected modelling decisions, the model is reestimated for alternative specifications. The assumptions about the prior distributions are identical to those underlying the results reported in Section 4.4. In all comparisons with alternative specifications, the model described above is referred to as the baseline model.

Specification without non-traded goods. In the baseline model, consumers in the home economy spend on three different goods (one non-traded good produced in the home economy and two traded goods produced in the home and foreign economy, respectively). Alternatively, we can set the share of non-traded goods in the consumption bundle to zero ($\gamma = 0$) so that the goods considered in the model are two traded goods produced in the home and foreign economy, respectively.

Parameter estimates for the alternative model specification are presented in Table A.1 in the appendix. The results for the baseline model are given for comparison. Most parameters differ little in the two specifications. Among the few exceptions is the indexation parameter of the traded goods produced in the home economy, $\kappa_H = 0.51$ (up from 0.4 in the baseline) which is pushed towards the level of the indexation parameter for non-traded goods, κ_N, when the non-traded goods are dropped from the model. Similarly, the AR(1) coefficient governing the mark-up shock process for traded home economy goods goes down in value (and towards the level of the corresponding coefficient for non-traded goods) when we move from the model with three goods to the one with two goods.

Specification of preference shock. In the baseline model, preference shocks are assumed to comove across the two economies. That is, we have $\alpha_G = 0.4$ in Eq. 3.18. Alternatively, we can set $\alpha_G = 0$ to prevent spillovers from foreign to home preference shocks. The preference shock then takes the standard form

$$z_{G,t} = \rho_G z_{G,t-1} + \epsilon_{G,t}$$

as in, for example, Justiniano and Preston (2010b).

The marginal likelihoods reported in Table 5 indicate that the baseline model performs better than the alternative. Parameter estimates for the two models are given in Table A.2 in the appendix. Most parameters differ little in the two specifications. Exceptions are habit persistence estimated at $h = 0.53$ (up from 0.48 in the baseline), the inverse elasticity of intertemporal substitution estimated at $\sigma = 1.39$ (up from 1.32 in the baseline), and the elasticity of substitution between traded and non-traded goods estimated at $\eta = 1.11$ (up from 0.88 in the baseline). The autoregressive coefficient of the preference shock in the home economy, ρ_G, is nearly unchanged, whereas the variance of this shock is lower than in the baseline model.

Higher values of η generate stronger co-movements between domestic and foreign output. To some extent this compensates for the shutdown of the spillovers from foreign to domestic preference shocks. However, the value for η still is relatively low when compared with models for other countries. Models for the US often use values for η between 1 and 2. The value estimated by Adolfson et al. (2008) for Sweden is even higher. The relatively low value for Switzerland may be due to the large share of pharmaceuticals and other highly technical products in Swiss exports. Therefore export and import goods tend to be relatively poor substitutes in Switzerland.

Table 5

MARGINAL DATA DENSITIES

Baseline specification	
Baseline model: 3 goods (2 traded produced in H and F, respectively; 1 non-traded produced in H; $\gamma=0.6$), $\alpha_G=0.4$, UIP as in Adolfson et al. (2008).	–1669.4
Alternative specifications	
Model with 2 traded goods produced in H and F, respectively: $\gamma=0$.	–1529.4
Model w/o spillovers from foreign to domestic preference shocks: $\alpha_G=0$.	–1674.2
Model with modified UIP as in Christiano et al. (2011): $\phi_i>1$, $\phi_S=0$.	–1697.6
Model with standard UIP: $\phi_i, \phi_S=0$.	–1685.8
DSGE-VAR with 4 Lags, priors derived from baseline model	
$\lambda=1.00$	–1668.6
$\lambda=2.00$	–1652.7
$\lambda=3.00$	–1653.8
$\lambda=4.00$	–1656.4
$\lambda=5.00$	–1659.0
$\lambda=100$	–1675.8

Notes: The fit of the model is given in terms of the log marginal likelihood. The baseline model is described in Sections 3 and 4.4, the alternative specifications in Section 4.5, and the DSGE-VAR in Section 5.4. The log marginal densities for the DSGE and the DSGE-VAR are based on 250,000 draws from the posterior density where the first 50,000 draws have been discarded.

Specification of uncovered interest parity. The baseline model uses the UIP modification proposed by Adolfson et al. (2008). The log-linearised version of this modified UIP is repeated here for convenience:

$$i_t - i_t^* = (1-\phi_S)E_t\Delta s_{t+1} - \phi_S\Delta s_t - \phi_A a_t + z_{\phi,t}.$$

Alternatively, we can either adopt the UIP modification proposed by Christiano et al. (2011),

$$(1-\phi_i)(i_t - i_t^*) = E_t\Delta s_{t+1} - \phi_A a_t + z_{\phi,t}, \tag{4.9}$$

or we can go back to the standard form of the UIP by setting $\phi_S=\phi_i=0$:

$$i_t - i_t^* = E_t\Delta s_{t+1} - \phi_A a_t + z_{\phi,t}. \tag{4.10}$$

The modifications proposed by Adolfson et al. (2008) and Christiano et al. (2011) address the forward premium puzzle by generating a hump-shaped response of the exchange rate to a monetary policy shock. According to Christiano et al. (2011), this requires $\phi_i>1$ in Eq. (4.9). We therefore assume that ϕ_i is gamma-distributed with a prior mean of 1.1 and a standard deviation of 0.05.

The marginal likelihood reported in Table 5 shows that the baseline model (with the modified UIP by Adolfson et al.) provides a better fit than the two alternatives with the standard UIP and the modified UIP by Christiano et al. respectively. The estimation results for the parameters are displayed in Table A.3 in the appendix. We note that the extra parameter in the UIP version by Christiano et al. is estimated at $\phi_i=1.05$. Furthermore, the autoregressive coefficient on the risk premium shock, ρ_{ϕ}, is smaller in the baseline model than in the two alternative models. With the risk premium depending on the change in the exchange rate over two periods (UIP modification by Adolfson et al.), less persistence has to be generated by the corresponding shock process.

5. Evaluation

This section reports results on the evaluation of the model and presents some applications. First, impulse-response analysis is used to examine the dynamic effects of domestic and external shocks on inflation, output growth and other variables of interest. Secondly, variance decompositions are employed to quantify the relative importance of the various shocks in explaining the fluctuations of these variables. Thirdly, we show how the model can contribute to our knowledge of the factors that influenced the cyclical variations in output and inflation between 2000 to 2013. Fourthly, the DSGE-VAR approach is used to assess model misspecification; and fifthly, some results on forecast accuracy are presented.

5.1 Impulse responses to various shocks

The impulse responses trace out the response of each variable to one of the shocks. Each shock amounts to one standard deviation of the innovation to the shock process. The shock processes refer to technology, mark-up on imported goods, risk premium, monetary policy (all in the home economy) and preferences (in the home economy and in the foreign economies). Charts 3 to 8 show the results in terms of deviations from steady state for the rate of inflation (in annualised percentage points), the level of output (percentages), the interest rate (annualised percentage points) and the nominal exchange rate (percentages). In each case, the mean and the 90% confidence interval are computed based on 2,000 MCMC draws from the posterior distribution.

The effects of a shock to the unit-root technology process ($z_{T,t}$) are shown in Chart 3. Potential output increases relative to the actual output in the short run, causing the output gap to turn negative. Since all variables are defined as deviations from steady state this is pictured as a fall in output. Output then gradually recovers through time, turning positive four quarters after the shock. Domestic inflation declines, because real marginal costs respond negatively to the technology shock and prices are set as a mark-up over marginal costs. Although the exchange rate depreciates (s_t increases) and drives import prices higher, CPI inflation declines as well. With downward pressure on CPI inflation and the output gap turning negative, interest rates are lowered by the central bank.

The effect of a shock to preferences ($z_{G,t}$) is shown in Chart 4. A shock to preferences is a demand shock. The increase in hours worked pushes output up. Higher output leads to an increase in inflation. Monetary policy responds to the increase in inflation and output by raising the interest rate. The currency of the home country appreciates on impact, but the appreciation is reversed over time into a depreciation.

Before proceeding with the responses to shocks originating in the home economy, we shall look at the effect of a shock to preferences in the foreign economy ($z_{G^*,t}$) which is a foreign demand shock. The spillover effects summarised in Chart 5 show that output and inflation increase on impact. As a result, monetary policy is tightened by raising the interest rate. These effects are qualitatively similar to those reported for a demand shock in the home economy. The main difference is in the exchange rate: the home currency depreciates on impact when the demand shock comes from abroad. The depreciation is reversed over time into an appreciation.

Chart 6 displays the response to a shock to the mark-up on imported goods in the home economy ($z_{m_F,t}$). Because prices are set as mark-up over marginal costs, imported inflation increases strongly, and so does CPI inflation. The impact effect on output is small. The nominal exchange rate appreciates and the terms of trade improve. Monetary policy responds to the increase in CPI inflation by raising interest rates.

Chart 7 shows the effects of a shock to the risk premium process ($z_{\phi,t}$). The risk premium affects deviations from uncovered interest rate parity. With nominal interest rates at home and abroad determined by the respective monetary policy rules, the risk premium has a major effect on the exchange rate. The nominal exchange rate increases. This means that import prices increase, and so do CPI inflation and output. Monetary policy responds by raising interest rates.

The effects of a monetary policy shock ($z_{R,t}$) are shown in Chart 8. The interest rate rises by about 0.4 percentage points on impact. The exchange rate strengthens in response, with the appreciation of the home currency building up over three quarters. Tighter monetary conditions, in turn, put downward pressure on inflation and output.

Selected impulse responses for the alternative model specifications reported in Section 4.5 are displayed in the appendix in Charts A.1 to A.3. Chart A.1 shows the effect of a monetary policy shock in the model without non-traded goods. The effects closely follow those in the baseline model. The appreciation of the home currency is a little weaker, causing the rate of inflation to fall a tick less temporarily. Chart A.2 shows the effect of a foreign preference (demand) shock under the assumption of no co-movement of foreign and home preference shocks. The impact effects on output, inflation and the interest rate are smaller than those reported for the baseline specification. The only exception is the exchange rate. Chart A.3 shows the effect of a monetary policy shock under alternative specifications of the UIP. If the standard UIP is adopted in the model, we obtain a jump appreciation of the home currency, followed by a gradual depreciation. As described above, this contradicts the empirical evidence from a large number of studies (forward premium puzzle). By contrast, the two modified UIP specifications generate a period of currency appreciation, which is consistent with the empirical evidence. The results suggest that the modification proposed by Adolfson et al. is more convenient for generating this result in our model than the modification proposed by Christiano et al.

Chart 3

RESPONSES TO UNIT-ROOT TECHNOLOGY SHOCK

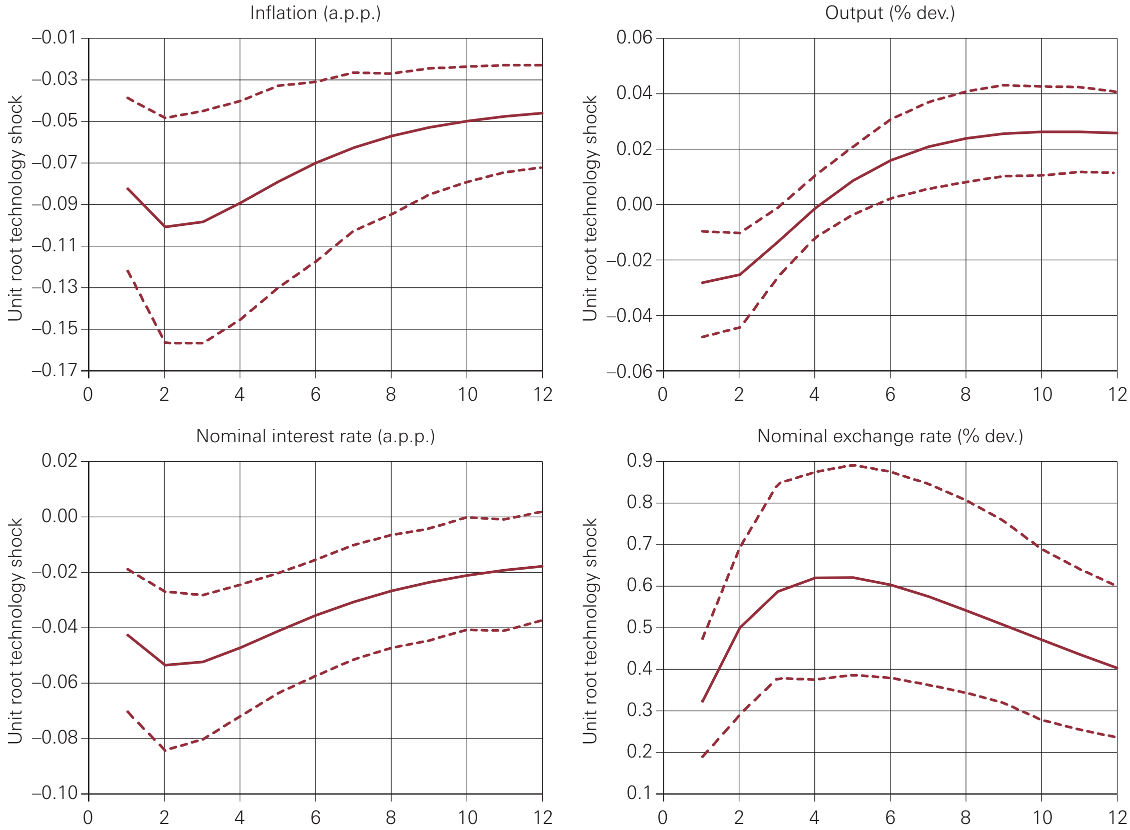
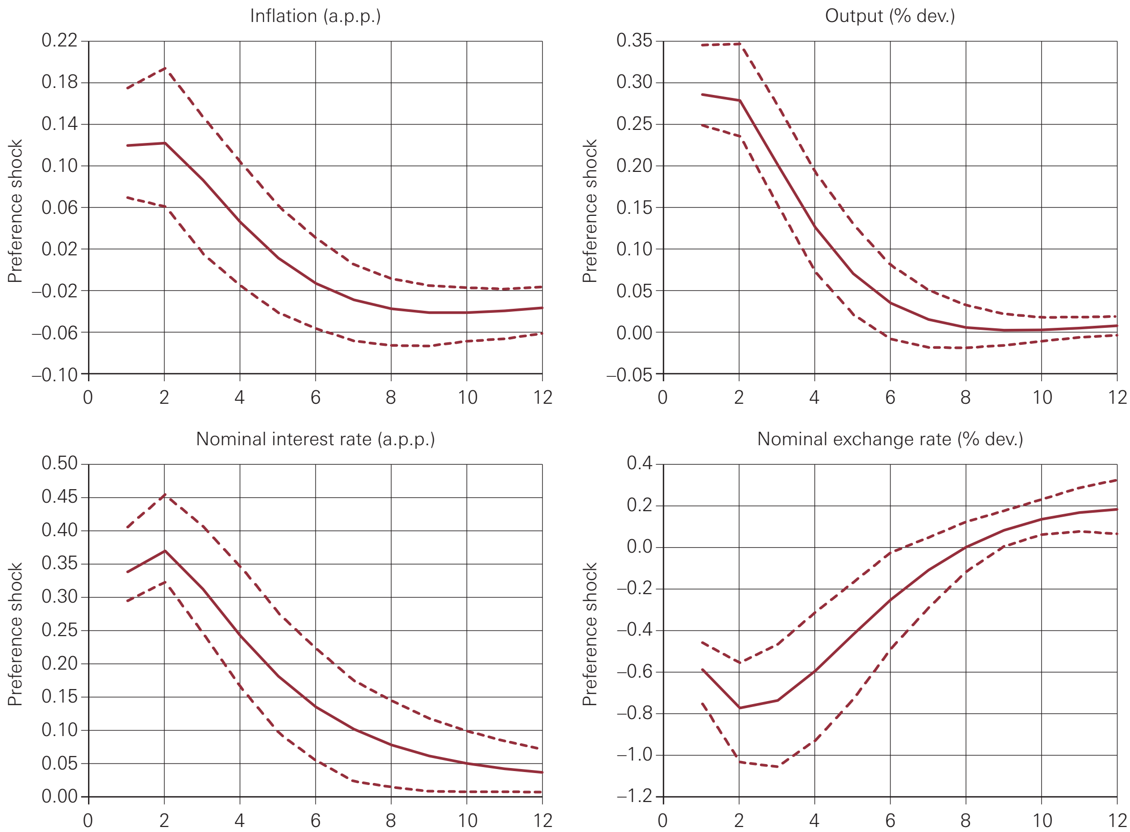


Chart 4

RESPONSES TO PREFERENCE (DEMAND) SHOCK



Notes: One-standard-deviation shock to innovation in shock process in period 1.
Impulse responses with 90% confidence intervals.

Chart 5

RESPONSES TO FOREIGN PREFERENCE (DEMAND) SHOCK

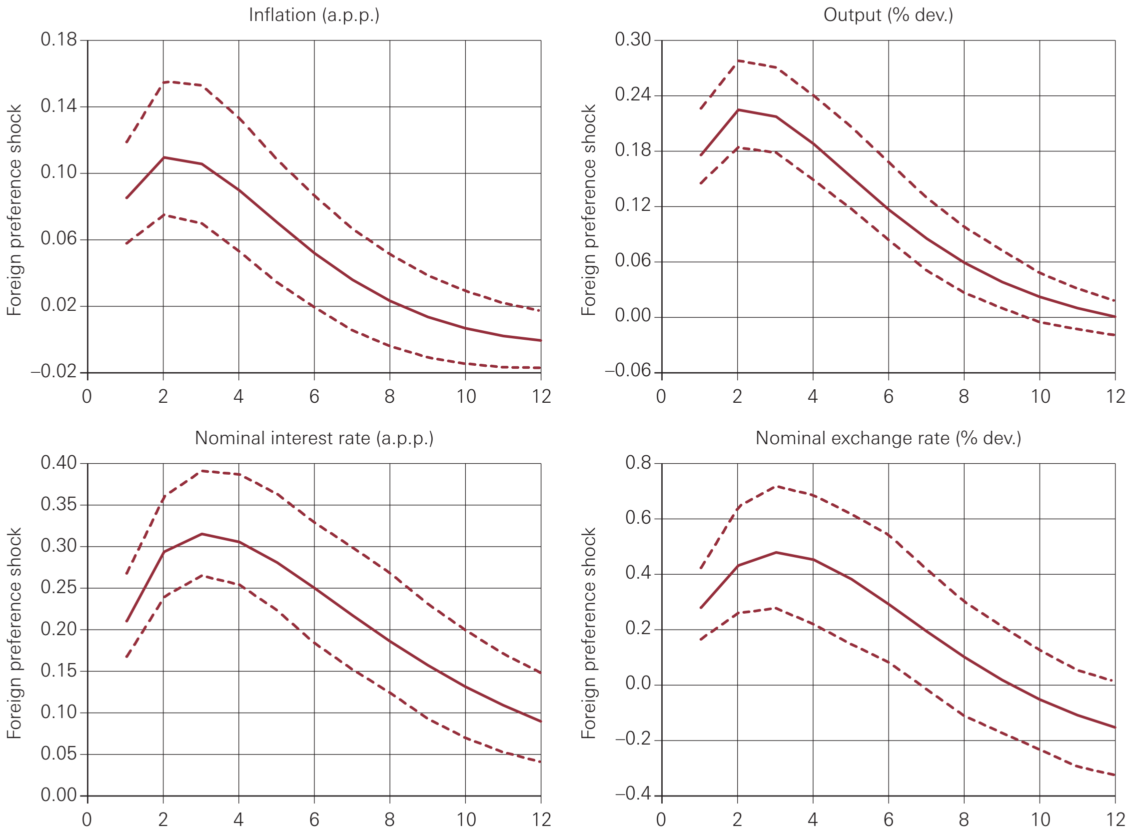
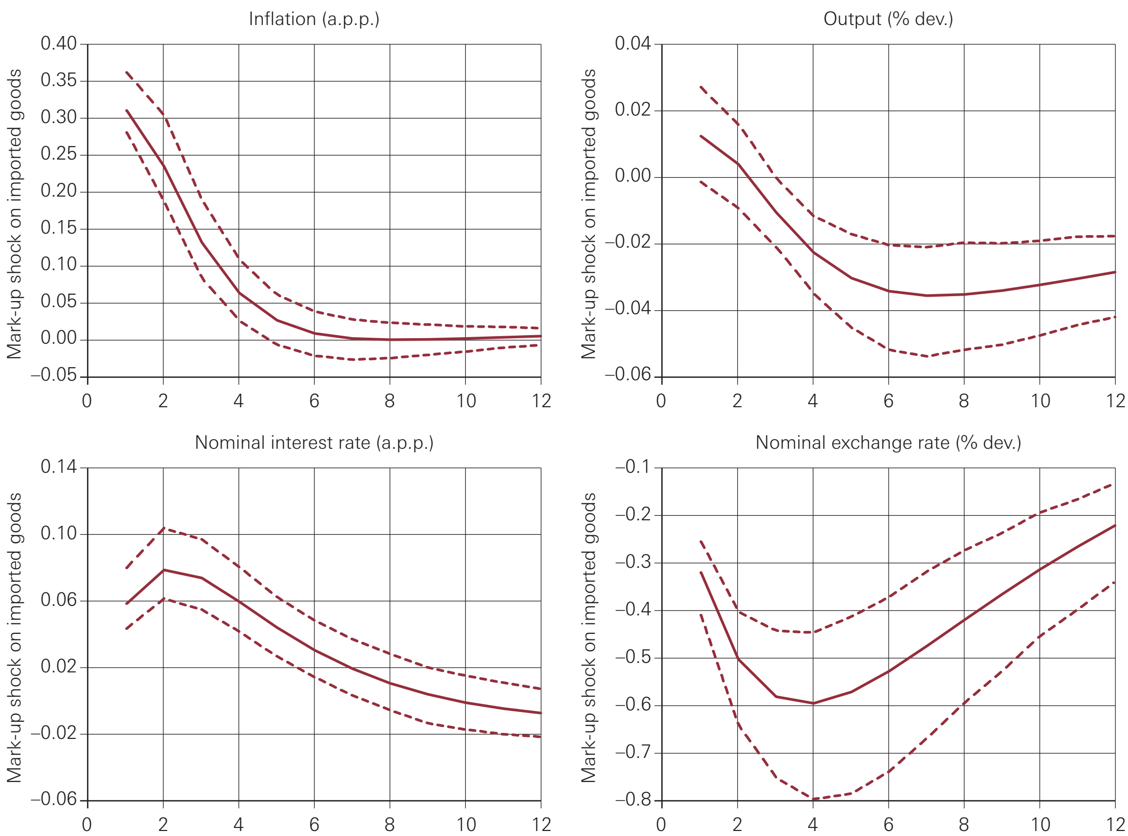


Chart 6

RESPONSES TO MARK-UP SHOCK ON IMPORTED GOODS



Notes: One-standard-deviation shock to innovation in shock process in period 1.
Impulse responses with 90% confidence intervals.

Chart 7

RESPONSES TO RISK PREMIUM SHOCK

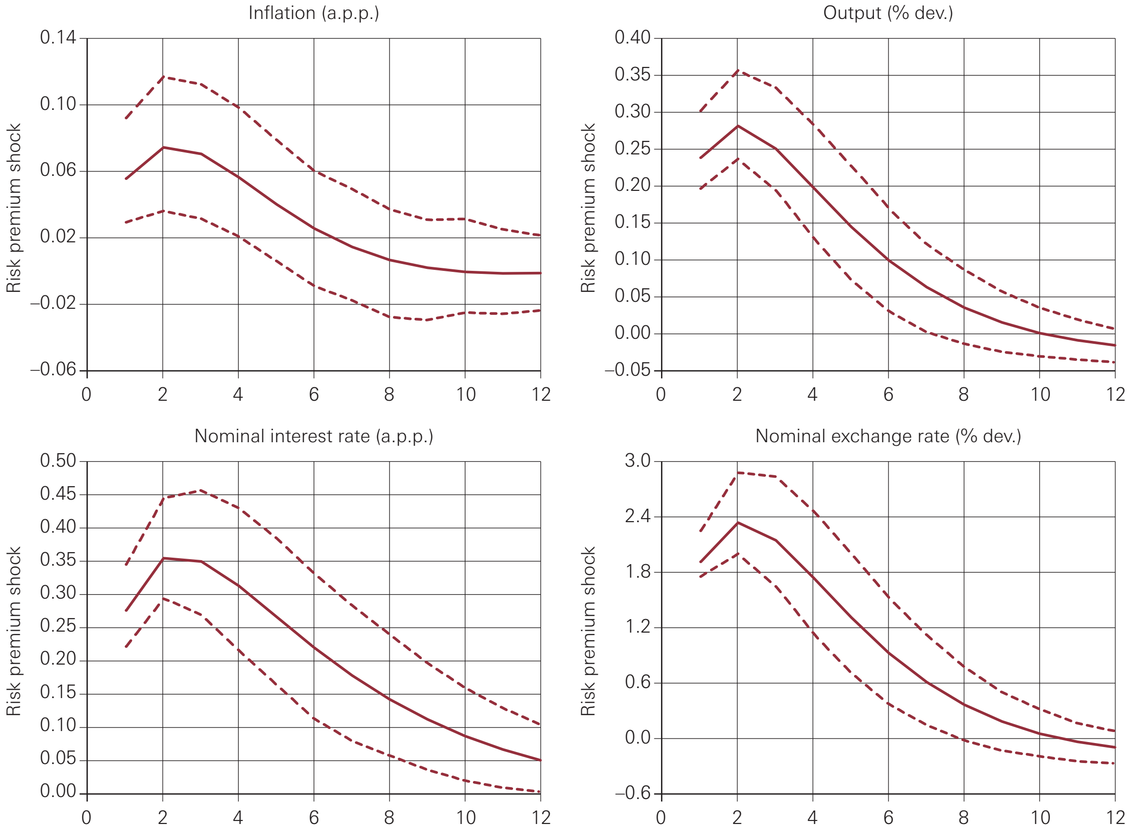
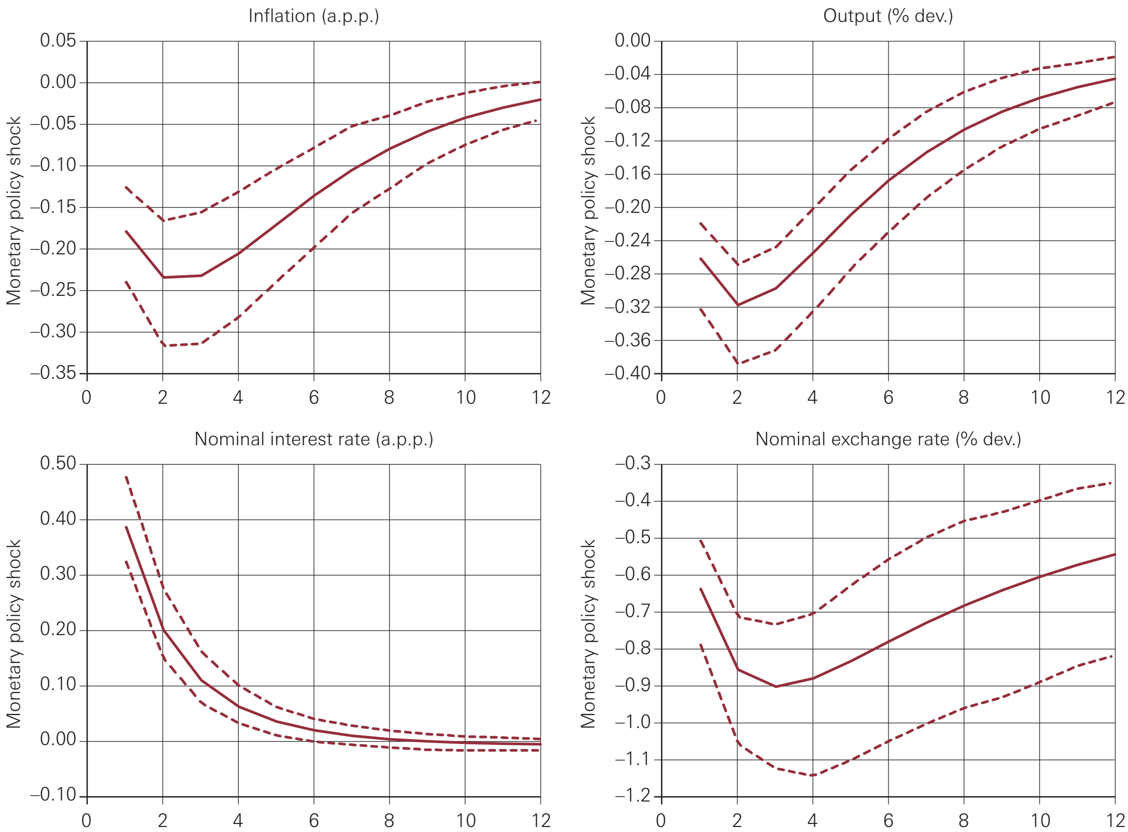


Chart 8

RESPONSES TO MONETARY POLICY SHOCK



Notes: One-standard-deviation shock to innovation in shock process in period 1.
Impulse responses with 90% confidence intervals.

5.2 Variance decomposition

The forecast-error variance decomposition computes the contributions of the various shocks to the variance of the error made in forecasting a specific variable at a given horizon. Table 6 considers 13 shocks and three variables at four different time horizons. The three variables are output growth, the rate of inflation and the short-term interest rate. The time horizons are 1, 4, 12 and 40 quarters. The results are given in terms of the mean and the 5th and 95th percentiles of the posterior distribution.

The variance decomposition of output growth shows that, in the very short run, 63% of the variability of output growth is accounted for by domestic shocks (technology shocks, mark-up shocks, preference shock and monetary policy shock in the home economy) and 35% by external shocks (foreign economy shocks, risk premium shock, oil product price shock). Preference shocks (23%) are the most important shocks among domestic shocks, followed by monetary policy shocks (19%) and permanent technology shocks (12%). Mark-up shocks do not seem to matter much. Among external shocks, risk premium shocks (17%) and preference shocks in the foreign economy (10%) are the main factors. With the lengthening of the time horizon, risk premium shocks become more important, whereas the contribution of technology shocks diminishes. We should emphasise that the unit-root technology shock is the only permanent shock and therefore accounts for 100% of output variability in the very long run. However, the effect on the variability of growth in output diminishes gradually.

For inflation, the variance decomposition suggests that the mark-up shocks in the home economy account for half of the variability in the very short run. Monetary policy shocks (17%) and technology shocks (8%) also play a role, but preference shocks account for little. Among the external shocks, the technology shocks are the only shocks that matter. For longer time horizons, the contribution from the mark-up shocks increases, whereas the technology shocks both at home and abroad become less important. Of the three mark-up shocks in the home economy, the shocks on non-traded goods and, to a lesser degree, the shocks on imported goods are far more important than the shocks on tradables produced in the home economy. This might reflect forecast errors due to the important share of goods with administered prices in non-traded goods, and variations in the exchange rate pass-through.

For the interest rate, the variance decomposition suggests that risk premium shocks account for 29% of the fluctuations in the very short run. The preference shocks at home (23%) and abroad (29%) and the monetary policy shocks in the home economy (10%) also have a significant effect. The contributions from the other shocks are minor.

Turning to the alternative model specifications described in Section 4.5, we observe that the contribution of foreign preference (demand) shocks to fluctuations in output falls significantly, once the spillovers from foreign to domestic preference shocks are shut down. The results displayed in Table A.4 in the appendix indicate that the foreign preference shocks account for 5% of output fluctuations in the short run and 9% in the long run, compared to 10% and 23% in the baseline model. This suggests that our assumption of such spillovers in the baseline model is crucial for generating sizable co-movements between home and foreign output growth.

In a similar model, Justiniano and Preston (2010a) find very little transmission of disturbances from the US to Canada. The variance decompositions in Tables 6 and A.4 point to a more substantial but still moderate role of foreign shocks (technology, preference, mark-up, monetary policy) in driving the domestic variables.[6]

6 Results for output cannot be compared properly with those in Justiniano and Preston (2010a) because their results refer to fluctuations in output, while our results refer to fluctuations in output growth.

Table 6

VARIANCE DECOMPOSITION

	1 quarter		4 quarters		12 quarters		40 quarters	
Shock	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval
Output growth								
ϵ_{Z_T}	0.12	[0.05, 0.18]	0.02	[0.01, 0.03]	0.01	[0.00, 0.03]	0.02	[0.00, 0.03]
ϵ_{Z_A}	0.02	[0.02, 0.02]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_G^d	0.23	[0.17, 0.28]	0.27	[0.17, 0.36]	0.27	[0.18, 0.37]	0.25	[0.16, 0.34]
ϵ_ϕ	0.17	[0.12, 0.22]	0.29	[0.19, 0.39]	0.28	[0.17, 0.39]	0.26	[0.15, 0.37]
ϵ_{m_H}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_{m_F}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.02]
ϵ_{m_N}	0.03	[0.02, 0.03]	0.01	[0.00, 0.02]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_R	0.19	[0.13, 0.25]	0.11	[0.07, 0.14]	0.14	[0.09, 0.19]	0.18	[0.10, 0.26]
ϵ_{A^*}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.02	[0.00, 0.03]	0.02	[0.00, 0.04]
ϵ_{G^*}	0.10	[0.07, 0.14]	0.25	[0.17, 0.34]	0.24	[0.16, 0.34]	0.23	[0.14, 0.32]
ϵ_{m^*}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.00	[0.00, 0.01]
ϵ_{R^*}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.00	[0.00, 0.01]
ϵ_{oil}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]
Inflation								
ϵ_{Z_T}	0.07	[0.01, 0.13]	0.03	[0.01, 0.05]	0.03	[0.01, 0.05]	0.03	[0.01, 0.05]
ϵ_{Z_A}	0.01	[0.00, 0.02]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]
ϵ_G^d	0.04	[0.01, 0.07]	0.05	[0.01, 0.08]	0.05	[0.01, 0.08]	0.05	[0.01, 0.08]
ϵ_ϕ	0.02	[0.00, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]
ϵ_{m_H}	0.05	[0.03, 0.08]	0.06	[0.02, 0.09]	0.06	[0.02, 0.09]	0.06	[0.02, 0.09]
ϵ_{m_F}	0.11	[0.07, 0.16]	0.13	[0.07, 0.20]	0.14	[0.08, 0.20]	0.14	[0.08, 0.20]
ϵ_{m_N}	0.38	[0.28, 0.50]	0.48	[0.34, 0.62]	0.48	[0.34, 0.61]	0.48	[0.34, 0.61]
ϵ_R	0.17	[0.07, 0.26]	0.13	[0.07, 0.20]	0.13	[0.07, 0.20]	0.13	[0.07, 0.20]
ϵ_{A^*}	0.09	[0.01, 0.16]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]
ϵ_{G^*}	0.03	[0.01, 0.06]	0.03	[0.02, 0.05]	0.03	[0.02, 0.05]	0.03	[0.02, 0.05]
ϵ_{m^*}	0.00	[0.00, 0.00]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{R^*}	0.00	[0.00, 0.00]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{oil}	0.02	[0.01, 0.03]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]
Interest rate								
ϵ_{Z_T}	0.02	[0.00, 0.04]	0.01	[0.00, 0.02]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{Z_A}	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_G^d	0.23	[0.13, 0.35]	0.32	[0.24, 0.41]	0.33	[0.25, 0.41]	0.33	[0.25, 0.41]
ϵ_ϕ	0.29	[0.15, 0.43]	0.30	[0.21, 0.40]	0.30	[0.21, 0.40]	0.30	[0.21, 0.40]
ϵ_{m_H}	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_{m_F}	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]
ϵ_{m_N}	0.01	[0.00, 0.01]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]
ϵ_R	0.10	[0.05, 0.14]	0.11	[0.04, 0.17]	0.11	[0.04, 0.18]	0.11	[0.04, 0.18]
ϵ_{A^*}	0.03	[0.00, 0.06]	0.01	[0.00, 0.02]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{G^*}	0.29	[0.18, 0.40]	0.21	[0.14, 0.28]	0.20	[0.13, 0.27]	0.20	[0.13, 0.27]
ϵ_{m^*}	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{R^*}	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{oil}	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]

5.3 Historical decompositions

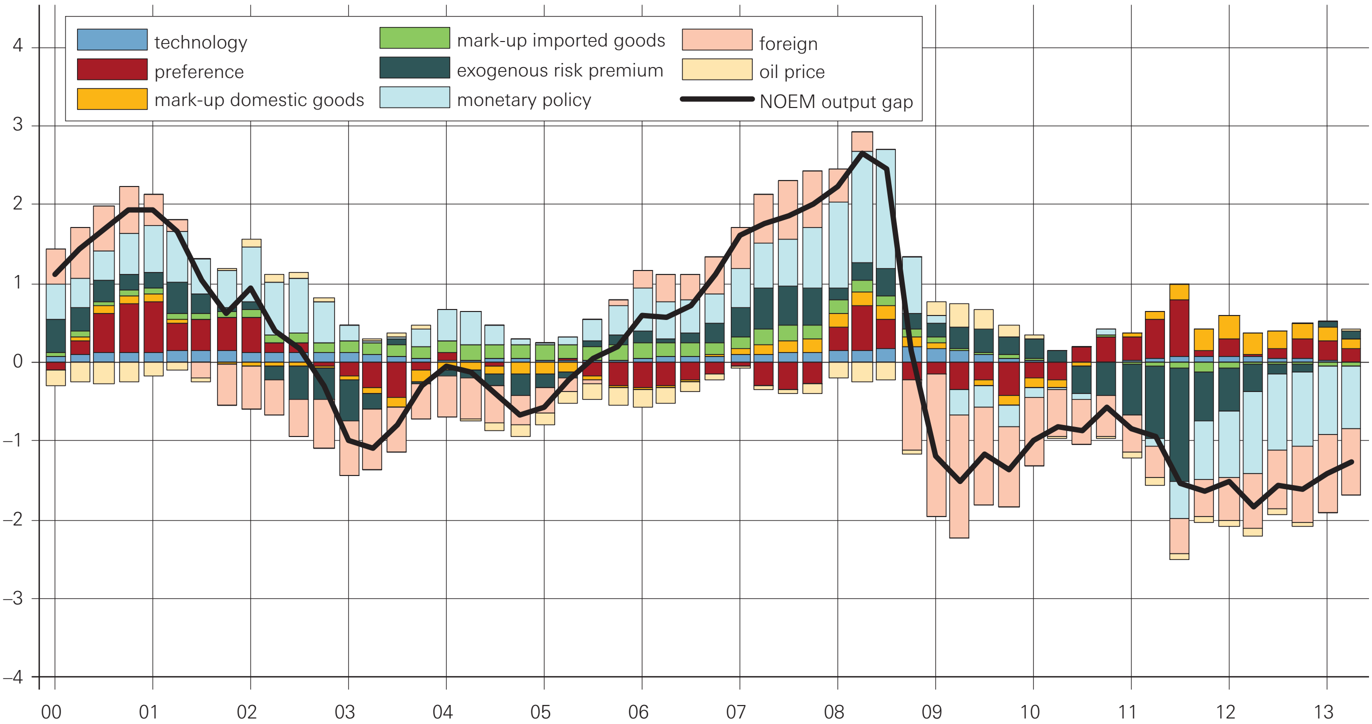
To assess the importance of the various shocks at particular points in time, we can decompose each variable into the contributions from the shocks. Charts 9 and 10 show the results for the output gap and the inflation gap over the period 2000Q1 to 2013Q2. Output gap and inflation gap are measured as deviations of output and inflation from their steady-state levels. There are various definitions of potential output in the literature (see Vetlov et al. (2011)). In this section, potential output is defined as the stochastic non-stationary steady-state trend. The resulting output gap corresponds to y_t, i.e., the output gap variable used in the model's monetary policy rule. An alternative definition of potential output is the natural rate level of output which measures the output that would prevail if nominal prices were fully flexible. This flexible price output corresponds to the output path obtained by simulating the estimated model with all nominal rigidities switched off. The shocks are grouped in eight sets: technology ($z_{T,t}$, $z_{A,t}$), preference ($z_{G,t}$), mark-up domestic goods ($z_{m_H,t}$, $z_{m_N,t}$), mark-up imported goods ($z_{m_F,t}$), risk premium ($z_{\phi t}$), monetary policy ($z_{R,t}$), foreign variables ($z_{T^*,t}$, $z_{G^*,t}$, $z_{m^*,t}$, $z_{R^*,t}$), and prices of oil products ($z_{oil,t}$).

We can see that in the years leading up to the 2008–2009 recession, the positive output gap was fuelled by foreign shocks, monetary policy shocks, and risk premium shocks. In other words, the world economy, low interest rates and a weak Swiss franc were the driving factors behind the increasingly positive output gap. Preference (demand) shocks acted as a drag on output, in stark contrast to the period 2000–2002 when preference shocks considerably contributed to the positive output gap. Then, in 2008, the output gap rapidly shifted from positive to negative. Shocks emanating from the foreign economy explain much of the negative output gap in 2008–2009. Shocks to preferences also had a negative impact, suggesting that the decline rattled consumers and dampened their spending. Later, risk premium shocks and monetary policy shocks were the dominant negative factors. The negative contributions from these shocks reflect the strong appreciation of the Swiss franc in 2010–2011 and the fact that monetary policy could not lower short-term interest rates further, once the zero lower bound had been reached. The contribution from monetary policy shocks depicted in Chart 9 does not account for the unconventional measures adopted by the SNB in 2010–2013 (i.e. the expansion of the SNB's balance sheet after short-term interest rates hit zero) because monetary policy is equated with setting the interest rate in this model.

Chart 10 documents that inflation was low and stable in the period 2000–2013. Shocks to oil product prices accounted for a relatively large share of the inflation deviations from their steady-state level. During the first half of the period, the dampening effect from mark-up shocks for imported goods is clearly visible, suggesting that globalisation may have played some role. The rise in inflation in 2006–2007 can be attributed to oil price shocks, foreign shocks, and monetary policy shocks. Oil price shocks and foreign shocks were again the key driving forces behind the swift fall in inflation in 2008. Subsequently, mark-up shocks and monetary policy shocks were among the main factors that kept inflation very low. The negative contribution from monetary policy shocks again may be interpreted as a consequence of the zero lower bound on nominal interest rates.

Chart 9

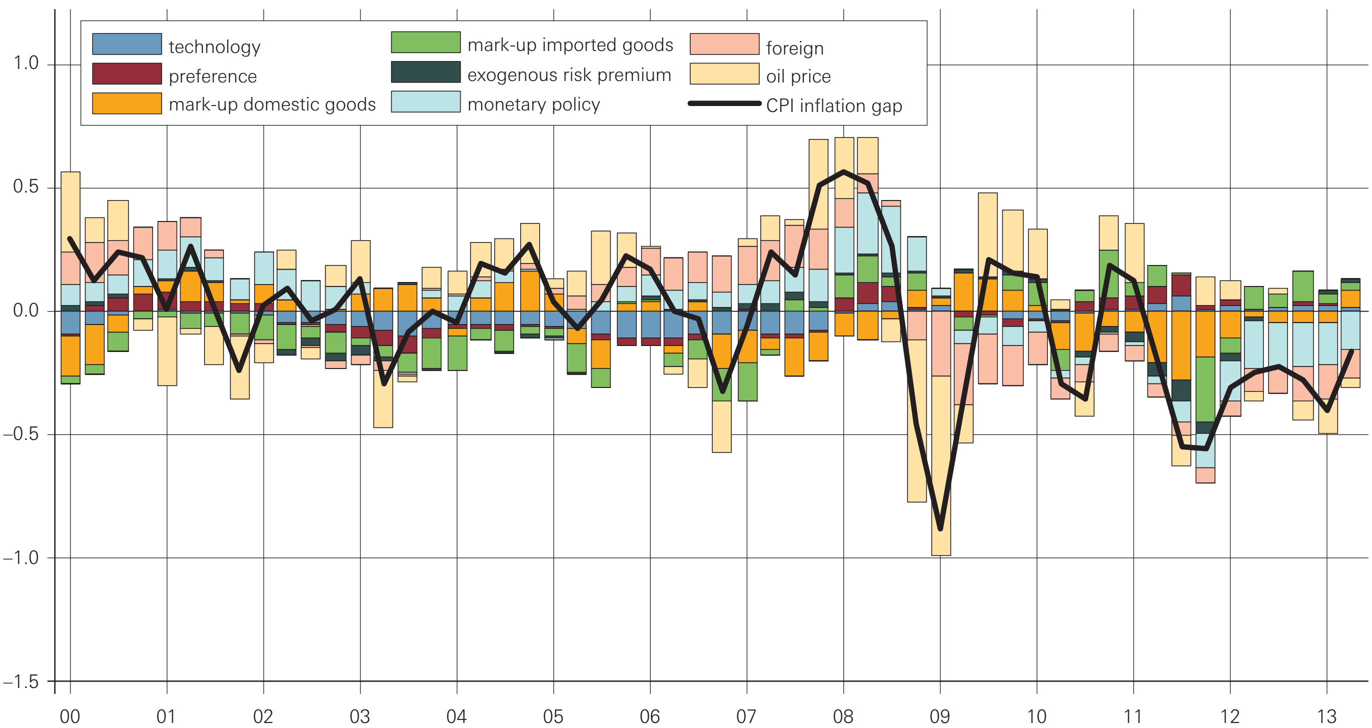
HISTORICAL DECOMPOSITION OF OUTPUT GAP



Notes: Contributions of shocks to output gap, 2000Q1 to 2013Q2, in percentage points. The output gap is the percentage deviation of the output from potential output, where the potential output is represented by the model's stochastic non-stationary steady-state trend.

Chart 10

HISTORICAL DECOMPOSITION OF CPI INFLATION GAP



Notes: Contributions of shocks to inflation gap, 2000Q1 to 2013Q2, in percentage points. The inflation gap is the deviation of the inflation rate from its steady-state level.

5.4 DSGE-VAR model

Del Negro and Schorfheide (2006) and Del Negro et al. (2007) propose a procedure for assessing the time series fit and the degree of misspecification of a DSGE model. The state-space representation of a log-linearised DSGE model is approximated by a vector autoregression (VAR). Then the implied cross-equation restrictions are systematically relaxed. The goal is to obtain a VAR specification that fits better than the DSGE model and yet stays as close as possible to the DSGE restrictions. The resulting DSGE-VAR model is a hybrid model where the weight of the DSGE restrictions is governed by a parameter λ. The optimal λ is selected based on the log marginal likelihood. The DSGE-VAR reduces to the unrestricted VAR as λ approaches zero. As λ approaches infinity, the DSGE-VAR collapses to the VAR approximation of the DSGE model. The resulting DSGE-VAR could be used for forecasting. However, in the context of this study we only use it as a tool for evaluating the DSGE model.

We estimate the DSGE-VAR for the ten observed variables described in Section 4.2. The seven home economy variables include GDP growth, CPI inflation, imported-goods inflation, changes in the terms of trade, the short-term interest rate, the real effective exchange rate, and oil product price inflation. The three foreign economy variables are GDP growth, CPI inflation, and the short-term interest rate. The lag length of the DSGE-VAR is 4. The data cover the period 1983Q2 to 2013Q2. The first four observations are used to initialise the lags.[7]

Table 5 shows the results. The log marginal likelihood from the estimation of the state-space representation DSGE model is given at the top of the table. The log marginal densities for the DSGE-VAR are based on 250,000 draws from the posterior density where the first 50,000 draws have been discarded. The corresponding results for the DSGE-VAR models are given at the bottom of the table for five different values of the parameter λ (1.0, 2.0, 3.0, 4.0, 5.0, 100). The restrictions imposed by the DSGE on the VAR representation are relaxed as we approach 0. We find that $\lambda = 2.0$ gives the model with the highest log marginal likelihood. The value of λ suggests that the information from the DSGE model is useful, but leaves room for improvement. The DSGE-VAR fits the data better than an unrestricted VAR.

5.5 Forecasting

Forecasting is an evaluation tool as well as an important area of model application. In this section, we show how our model can be used to provide forecasts. This is followed by a discussion of some forecasting results. A more detailed analysis of the forecasting performance of the model is beyond the scope of this paper.

Unconditional and conditional forecasts

Economic projections or forecasts are either conditional on assumptions about a subset of variables, or they are unconditional, implying that variables are determined purely by the model. The conditioning typically refers to assumptions about the future path of the international economy, oil prices, the exchange rate or the short-term interest rate. Applying restrictions on short-term interest rates (e.g. the zero lower bound) or the exchange rate

7 For a detailed description of the DSGE-VAR approach, see Del Negro and Schorfheide (2006), Del Negro et al. (2007) and the bibliographies in these two studies.

(e.g. the minimum exchange rate announced by the SNB in September 2011) also gives rise to conditional forecasting.

We recall that the solution to the log-linearised model Eq. (4.2), combined with the system of measurement equations Eq. (4.4), can be cast in state space form:

$$\begin{aligned} \varsigma_t &= \Phi_1'(\theta)\varsigma_{t-1} + \Phi_\epsilon'(\theta)\epsilon_t, \\ \mathbf{y}_t &= A_0(\theta) + A_1\varsigma_t + \boldsymbol{\varepsilon}_t^{\mathbf{y}}, \end{aligned} \tag{5.1}$$

where ς_t is the (extended) vector of state variables, ϵ_t collects the innovations to the exogenous shock processes, the vector $\mathbf{y}_t$ contains the observable variables, and $\boldsymbol{\varepsilon}^{\mathbf{y}}{}_t$ collects the measurement errors. The matrices $\Phi_1'(\theta)$ and A_1 capture the dynamics of the model, the matrix $\Phi_\epsilon'(\theta)$ indicates the link between the shocks and the state variables, and the vector elements in A_0 are the sample means of the observable variables.
For a given estimate of the parameter vector θ, we apply the Kalman filter to the state space system Eq. (5.1) to compute the posterior mean estimates of the state vector in the last period in the sample:

$$\varsigma_{T|T}(\theta) = E_t[\varsigma_T \,|\, \theta, \mathbf{Y}^T], \tag{5.2}$$

where $\mathbf{Y}^T = [\mathbf{y}_t, \ldots, \mathbf{y}_T]$ and $\varsigma_{T|T}$ is the starting point for the forecast.

Unconditional point forecasts for $T+1$, $T+2$, …, $T+h$ are obtained for the vector of state variables, $\varsigma_{T+h|T}$, by simply running Eq. (5.1) forward h quarters:

$$\varsigma_{T+h|T} = \Phi_1'(\theta)\varsigma_{T|T} + \Phi_\epsilon'(\theta)\epsilon_T \tag{5.3}$$
$$\mathbf{y}_{T+h|T} = A_0(\theta) + A_1(\theta)\varsigma_{T+h|T}. \tag{5.4}$$

In a conditional forecast, the forecasts are conditioned on a specific path for a subset of endogenous measurement variables. We proceed as described by Christoffel et al. (2007). The exogenous assumptions for a subset of measurement variables are incorporated by using the updating rule of the Kalman filter. The forecast error $\mathbf{u}_{T+1|T}$ is

$$\mathbf{u}_{T+1,T} = \mathbf{y}_{T+1}^{exo} - \mathbf{y}_{T+1|T},$$

where $\mathbf{u}_{T+1,T}$ is assumed to be normally distributed with mean zero and variance matrix $\boldsymbol{\Gamma}_{T+1,T}^u = A(1)\boldsymbol{\Sigma}_{T+1|T}^{\varsigma}A(1)' + \boldsymbol{\Sigma}_{\varepsilon^y}$, and $\boldsymbol{\Sigma}_{T+1|T}^{\varsigma} = E[(\varsigma_{T+1|T+1} - \varsigma_{T+1|T})(\varsigma_{T+1|T+1} - \varsigma_{T+1|T})]$ being the estimated prediction error covariance matrix of the state variables.

Updating the unconditional forecast of the state variables in $T+1$ yields:

$$\begin{aligned} \varsigma_{T+1|T}^{cond} &= \varsigma_{T+1|T} + G_{T+1,T}\mathbf{u}_{T+1,T}, \\ G_{T+1,T} &= \boldsymbol{\Sigma}_{T|T-1}^{\varsigma}A_1(\theta)'(A_1(\theta)\boldsymbol{\Sigma}_{T|T-1}^{\varsigma}A_1(\theta)' + \boldsymbol{\Sigma}_{\varepsilon^y})^{-1}, \\ \boldsymbol{\Sigma}_{T+1|T}^{\varsigma,cond} &= \boldsymbol{\Sigma}_{T+1|T}^{\varsigma} - G_{T+1,T}\Omega(\theta)\boldsymbol{\Sigma}_{T+1|T}^{\varsigma}, \end{aligned}$$

where G denotes the Kalman Gain matrix and $\boldsymbol{\Sigma}_{T+1|T}^{\varsigma,cond}$ denotes the update of the estimated prediction error covariance matrix of the state variables. Finally, the conditional one-step-ahead forecast is obtained by updating the measurement equation

$$\mathbf{y}^{cond}_{T+1|T} = A_0(\theta) + A_1(\theta)\varsigma^{cond}_{T+1|T}. \quad (5.5)$$

The procedure is repeated *h* times in order to obtain conditional *h*-quarter-ahead forecasts.

Results of a forecasting experiment

We illustrate the forecasting ability of the model by a set of conditional forecasts. The forecasts are conditioned on the actual values of the model's three foreign variables and the prices of oil products. This is not realistic in the sense that the actual values of the four variables are not known at the time the forecasts are made. However, it can be defended on the grounds that in practical macroeconomic forecasting the path of foreign variables and oil product prices is often determined by satellite models.[8] By setting the three foreign variables as well as the prices of oil products to their actual values, we avoid mixing up the forecast error assignable to our model with the errors in the exogenous scenarios.

Chart 11 shows the results of rolling twelve-quarter forecasts of CPI inflation, GDP growth, the three-month Swiss franc Libor, and the weighted exchange rate (CHF per USD and CHF per EUR). The model parameters are reestimated every quarter. The first forecast goes from 2002Q3 to 2005Q2 and the last from 2010Q3 to 2013Q2, giving a total of 33 forecasts for horizons $h=1, 2, \dots, 12$. The forecasts indicate that the model tends to underestimate changes. Underestimating changes is a result well known from most studies examining the forecast accuracy of macroeconomic models. In particular, we find that forecasts of the interest rate were mostly above actual values between 2002 and 2008. This is in line with criticism that monetary policy was unduly lax in the years before the financial crisis of 2008–2009. Furthermore, with the interest rate forecasted too high, it is not surprising that the Swiss franc was weaker than predicted by the model during that period.

The inflation forecasts appear to be very accurate until 2011, helped by the fact that prices of oil products are set to their actual values in these simulations. The large fluctuations of the oil price explain a substantial proportion of the volatility of CPI inflation observed during this period. Rapidly rising oil prices caused CPI inflation rates to rise in 2008. This trend was reversed in 2009, when the global financial crisis hit the economy. Since 2011 the errors of the inflation forecasts conducted up to 2010Q3 have increased. The model failed to foresee the huge appreciation of the Swiss franc that was caused by investors' fears regarding the sovereign debt crisis in the euro area. With the Swiss franc substantially stronger than predicted by the model, the rate of inflation fell below the forecast.

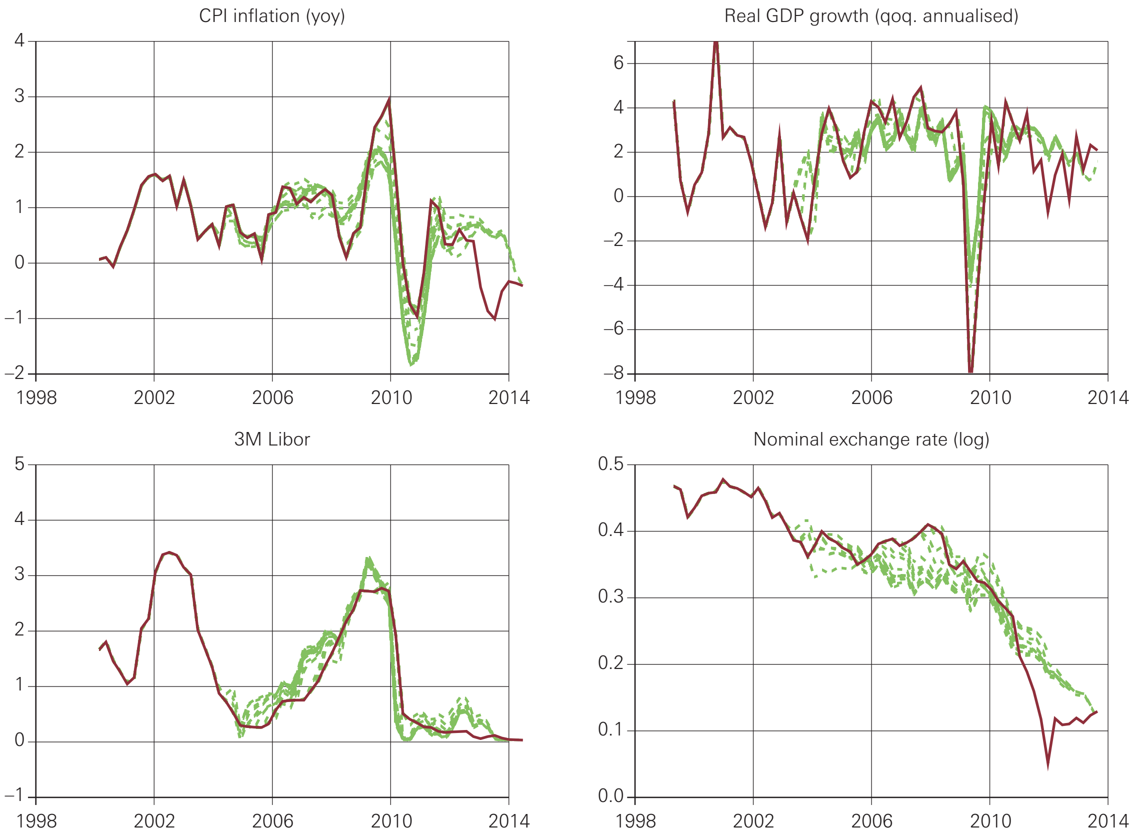
We next look at root-mean-squared errors (RMSE) for the twelve forecasting horizons. Chart 12 shows RMSEs for the whole period and for the two subsamples that include the forecasts starting between 2002Q3 and 2006Q4 and between 2007Q1 and 2010Q3, respectively. Most forecasts in the first subsample cover the period before the global financial crisis intensified in September 2008 with the fall of Lehman Brothers, while most forecasts in the second subsample cover the period after this event.[9] The results suggest that the model forecasts are more accurate in the earlier period. Exceptions are the long end of the GDP forecast (nine quarters and longer) and the long end of the interest rate forecast

8 At the SNB, for example, a number of models of the Swiss economy are employed to forecast inflation and other economic variables. The forecasts performed by these models are usually based on a common scenario for the world economy and the oil price. This common scenario, in turn, is derived from satellite models and judgement.

9 There are exceptions because the long end of some forecasts in the first subsample falls into the period after September 2008, and the short end of some forecasts in the second subsample falls into the period before September 2008.

Chart 11

ROLLING FORECASTS



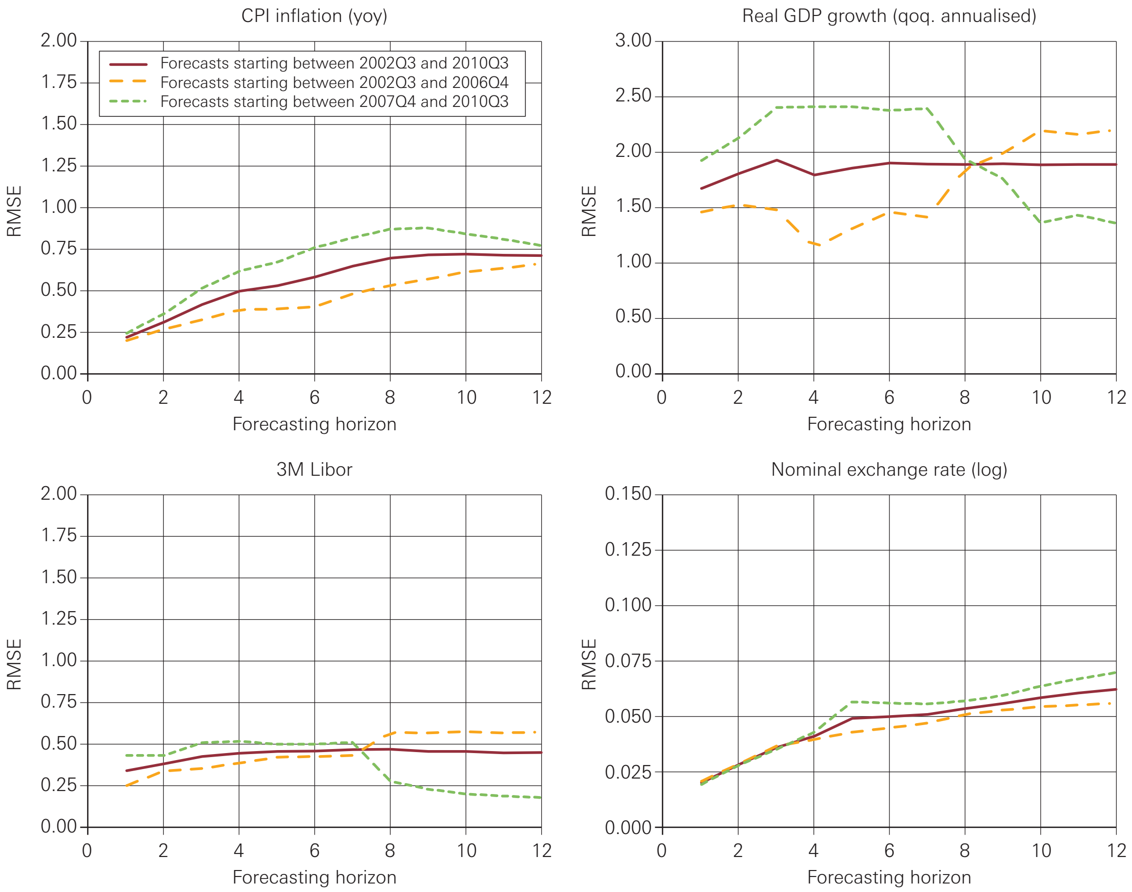
Notes: 32 rolling twelve-quarter forecasts, starting between 2002Q3 and 2010Q3.

(eight quarters and longer). The latter reflects the fact that the short-term interest rate has been stuck at the ZLB for most of the second subsample. For CPI inflation the errors were modest in the first subsample. They increased substantially across all forecast horizons in the second subsample.

Comparing the forecasting performance of the baseline model to that of the alternative model specification without non-traded goods described in Section 4.5, we observe very similar results (Charts A.4 and A.5). Looking at the RMSEs for inflation displayed in Charts 12 and A.5, we find that the baseline model performs better than the alternative model at short horizons in the first subsample. By contrast, the alternative model is slightly ahead for most forecast horizons in the second subsample. The small differences suggest that the model without non-tradables provides a reasonably good approximation to the baseline model.

Chart 12

ROOT MEAN SQUARED ERRORS



Notes: Root mean squared errors are computed for 32 rolling twelve-quarter forecasts, starting between 2002Q3 and 2010Q3.

6. Concluding remark

In this paper, we have described a compact open-economy model of Switzerland. We find the model to have plausible properties and to fit the data reasonably well. The model supports a variety of applications and provides a useful tool for monetary policy purposes. The focus of the model is on the effects of international factors and the trade-off between inflation and the output gap. By differentiating between traded and non-traded goods, the model provides greater detail about the composition of the CPI than many other small-scale models. There is little or no focus, however, on the financial sector, the labour market and capital formation. Going forward, the model can be enriched in various directions, depending on the changing needs of policy makers and the evolution of the economic environment.

A. Appendix

This appendix contains results for the alternative specifications described in Section 4.5.

Table A.1

POSTERIOR ESTIMATES FOR ALTERNATIVE MODEL SPECIFICATION WITHOUT NON-TRADABLES

	Prior		*Baseline, $\gamma = 0.6$*		*Traded goods only, $\gamma = 0$*	
Domestic behavioural parameters						
ξ_H	0.75	[0.67, 0.83]	0.89	[0.86, 0.92]	0.90	[0.88, 0.92]
ξ_F	0.75	[0.67, 0.83]	0.91	[0.89, 0.93]	0.90	[0.88, 0.92]
ξ_N	0.75	[0.67, 0.83]	0.89	[0.87, 0.92]		
κ_H	0.50	[0.34, 0.67]	0.40	[0.24, 0.53]	0.51	[0.36, 0.67]
κ_F	0.50	[0.34, 0.67]	0.46	[0.30, 0.61]	0.45	[0.29, 0.59]
κ_N	0.50	[0.33, 0.66]	0.58	[0.43, 0.72]		
h	0.70	[0.62, 0.78]	0.48	[0.39, 0.56]	0.48	[0.40, 0.55]
σ	1.50	[1.34, 1.67]	1.32	[1.16, 1.46]	1.32	[1.16, 1.48]
φ	1.00	[0.83, 1.16]	0.98	[0.82, 1.14]	0.99	[0.83, 1.15]
η	1.00	[0.83, 1.16]	0.88	[0.79, 0.97]	0.88	[0.78, 0.96]
ν	1.00	[0.84, 1.16]	1.02	[0.86, 1.18]		
ϕ_S	0.40	[0.23, 0.56]	0.38	[0.31, 0.45]	0.37	[0.30, 0.44]
ρ_R	0.80	[0.72, 0.88]	0.90	[0.87, 0.93]	0.90	[0.87, 0.93]
ψ_π	1.50	[1.42, 1.58]	1.49	[1.41, 1.58]	1.50	[1.41, 1.58]
ψ_y	0.50	[0.42, 0.58]	0.49	[0.41, 0.57]	0.48	[0.41, 0.56]
$\psi_{\Delta y}$	0.20	[0.12, 0.28]	0.24	[0.17, 0.29]	0.23	[0.17, 0.29]
Foreign behavioural parameters						
ξ^*	0.75	[0.67, 0.83]	0.86	[0.82, 0.91]	0.86	[0.82, 0.90]
κ^*	0.50	[0.34, 0.67]	0.25	[0.14, 0.35]	0.24	[0.14, 0.34]
h^*	0.70	[0.62, 0.78]	0.71	[0.65, 0.77]	0.70	[0.64, 0.76]
σ^*	1.50	[1.33, 1.66]	1.47	[1.31, 1.62]	1.46	[1.32, 1.62]
φ^*	1.00	[0.83, 1.16]	0.97	[0.82, 1.13]	0.97	[0.81, 1.14]
ρ_{R^*}	0.80	[0.65, 0.96]	0.89	[0.85, 0.92]	0.90	[0.86, 0.93]
ψ_{π^*}	1.50	[1.34, 1.67]	1.53	[1.36, 1.70]	1.52	[1.36, 1.68]
ψ_{y^*}	0.25	[0.09, 0.40]	0.36	[0.18, 0.54]	0.52	[0.37, 0.67]
$\psi_{\Delta y^*}$	0.20	[0.05, 0.35]	0.25	[0.13, 0.36]	0.26	[0.14, 0.38]
AR(1) coefficients and standard deviations						
ρ_T	0.80	[0.65, 0.96]	0.63	[0.47, 0.80]	0.65	[0.49, 0.81]
ρ_A	0.50	[0.33, 0.66]	0.49	[0.33, 0.66]	0.50	[0.33, 0.67]
ρ_G^d	0.80	[0.65, 0.96]	0.72	[0.60, 0.84]	0.78	[0.69, 0.88]
ρ_ϕ	0.50	[0.33, 0.66]	0.72	[0.60, 0.86]	0.74	[0.63, 0.86]
ρ_{m_H}	0.50	[0.34, 0.67]	0.29	[0.19, 0.39]	0.21	[0.13, 0.30]

Table A.1 continued

	Prior		Baseline, $\gamma=0.6$		Traded goods only, $\gamma=0$	
ρ_{m_F}	0.50	[0.33, 0.66]	0.34	[0.23, 0.45]	0.31	[0.21, 0.42]
ρ_{m_D}	0.50	[0.34, 0.67]	0.26	[0.17, 0.35]		
ρ_{T^*}	0.80	[0.65, 0.96]	0.71	[0.60, 0.83]	0.71	[0.61, 0.83]
ρ_{G^*}	0.80	[0.65, 0.96]	0.81	[0.75, 0.87]	0.82	[0.76, 0.88]
ρ_{m^*}	0.50	[0.33, 0.66]	0.23	[0.14, 0.32]	0.22	[0.14, 0.31]
ρ_{oil}	0.50	[0.33, 0.66]	0.53	[0.43, 0.62]	0.53	[0.43, 0.62]
σ_T	0.25	[0.10, 0.39]	0.18	[0.10, 0.25]	0.18	[0.10, 0.24]
σ_A	0.63	[0.26, 0.99]	0.53	[0.27, 0.78]	0.54	[0.27, 0.82]
σ_G^d	0.63	[0.26, 0.99]	3.39	[2.46, 4.28]	3.82	[2.94, 4.78]
σ_ϕ	0.63	[0.26, 0.99]	0.55	[0.38, 0.71]	0.53	[0.37, 0.69]
σ_{m_H}	0.63	[0.27, 1.00]	0.16	[0.14, 0.19]	0.13	[0.11, 0.14]
σ_{m_F}	0.63	[0.26, 0.99]	0.17	[0.15, 0.20]	0.18	[0.15, 0.20]
σ_{m_N}	0.63	[0.26, 0.99]	0.14	[0.12, 0.16]		
σ_R	0.63	[0.27, 0.99]	0.18	[0.16, 0.21]	0.18	[0.16, 0.21]
σ_{T^*}	0.25	[0.11, 0.40]	0.18	[0.12, 0.23]	0.18	[0.12, 0.24]
σ_{G^*}	0.63	[0.26, 0.99]	2.00	[1.46, 2.53]	2.10	[1.52, 2.66]
σ_{m^*}	0.63	[0.27, 0.98]	0.20	[0.17, 0.22]	0.20	[0.17, 0.22]
σ_{R^*}	0.63	[0.27, 0.99]	0.16	[0.14, 0.18]	0.16	[0.14, 0.18]
σ_{oil}	0.63	[0.26, 0.99]	4.11	[3.68, 4.55]	4.12	[3.65, 4.57]

Notes: Posterior means and 90% intervals in parentheses, from 250,000 draws with the first 50,000 draws discarded. Results for baseline model are given for comparison. The alternative specification assumes $\gamma=0$, instead of the baseline assumption $\gamma=0.6$.

Table A.2

POSTERIOR ESTIMATES FOR ALTERNATIVE PREFERENCE SHOCK SPECIFICATION: WITHOUT SPILLOVERS FROM FOREIGN TO DOMESTIC PREFERENCE SHOCKS

	Prior		Baseline, $\alpha_G=0.4$		No spillovers, $\alpha_G=0$	
Domestic behavioural parameters						
ξ_H	0.75	[0.67, 0.83]	0.89	[0.86, 0.92]	0.89	[0.86, 0.92]
ξ_F	0.75	[0.67, 0.83]	0.91	[0.89, 0.93]	0.90	[0.88, 0.93]
ξ_N	0.75	[0.67, 0.83]	0.89	[0.87, 0.92]	0.90	[0.87, 0.92]
κ_H	0.50	[0.34, 0.67]	0.40	[0.24, 0.53]	0.41	[0.26, 0.55]
κ_F	0.50	[0.34, 0.67]	0.46	[0.30, 0.61]	0.46	[0.31, 0.61]
κ_N	0.50	[0.33, 0.66]	0.58	[0.43, 0.72]	0.58	[0.44, 0.73]
h	0.70	[0.62, 0.78]	0.48	[0.39, 0.56]	0.53	[0.44, 0.62]
σ	1.50	[1.34, 1.67]	1.32	[1.16, 1.46]	1.39	[1.23, 1.54]
φ	1.00	[0.83, 1.16]	0.98	[0.82, 1.14]	0.97	[0.81, 1.13]
η	1.00	[0.83, 1.16]	0.88	[0.79, 0.97]	1.11	[0.94, 1.28]
ν	1.00	[0.84, 1.16]	1.02	[0.86, 1.18]	1.03	[0.86, 1.19]
ϕ_S	0.40	[0.23, 0.56]	0.38	[0.31, 0.45]	0.36	[0.29, 0.43]
ρ_R	0.80	[0.72, 0.88]	0.90	[0.87, 0.93]	0.90	[0.87, 0.93]
ψ_π	1.50	[1.42, 1.58]	1.49	[1.41, 1.58]	1.49	[1.41, 1.58]
ψ_y	0.50	[0.42, 0.58]	0.49	[0.41, 0.57]	0.48	[0.40, 0.56]
$\psi_{\Delta y}$	0.20	[0.12, 0.28]	0.24	[0.17, 0.29]	0.24	[0.18, 0.31]

Table A.2 continued

	Prior		*Baseline,* α_G=0.4		*No spillovers,* α_G=0	
Foreign behavioural parameters						
ξ^*	0.75	[0.67, 0.83]	0.86	[0.82, 0.91]	0.86	[0.81, 0.90]
κ^*	0.50	[0.34, 0.67]	0.25	[0.14, 0.35]	0.25	[0.14, 0.36]
h^*	0.70	[0.62, 0.78]	0.71	[0.65, 0.77]	0.72	[0.65, 0.79]
σ^*	1.50	[1.33, 1.66]	1.47	[1.31, 1.62]	1.47	[1.32, 1.62]
φ^*	1.00	[0.83, 1.16]	0.97	[0.82, 1.13]	0.97	[0.82, 1.13]
ρ_{R^*}	0.80	[0.65, 0.96]	0.89	[0.85, 0.92]	0.87	[0.83, 0.91]
ψ_{π^*}	1.50	[1.34, 1.67]	1.53	[1.36, 1.70]	1.53	[1.36, 1.69]
ψ_{Y^*}	0.25	[0.09, 0.40]	0.36	[0.18, 0.54]	0.36	[0.19, 0.52]
$\psi_{\Delta Y^*}$	0.20	[0.05, 0.35]	0.25	[0.13, 0.36]	0.26	[0.11, 0.40]
AR(1) coefficients and standard deviations						
ρ_T	0.80	[0.65, 0.96]	0.63	[0.47, 0.80]	0.61	[0.45, 0.77]
ρ_A	0.50	[0.33, 0.66]	0.49	[0.33, 0.66]	0.50	[0.33, 0.66]
ρ^d_G	0.80	[0.65, 0.96]	0.72	[0.60, 0.84]	0.73	[0.62, 0.85]
ρ_ϕ	0.50	[0.33, 0.66]	0.72	[0.60, 0.86]	0.69	[0.56, 0.81]
ρ_{m_H}	0.50	[0.34, 0.67]	0.29	[0.19, 0.39]	0.28	[0.18, 0.39]
ρ_{m_F}	0.50	[0.33, 0.66]	0.34	[0.23, 0.45]	0.35	[0.24, 0.47]
ρ_{m_D}	0.50	[0.34, 0.67]	0.26	[0.17, 0.35]	0.25	[0.16, 0.35]
ρ_{T^*}	0.80	[0.65, 0.96]	0.71	[0.60, 0.83]	0.71	[0.60, 0.82]
ρ_{G^*}	0.80	[0.65, 0.96]	0.81	[0.75, 0.87]	0.80	[0.73, 0.87]
ρ_{m^*}	0.50	[0.33, 0.66]	0.23	[0.14, 0.32]	0.24	[0.15, 0.33]
ρ_{oil}	0.50	[0.33, 0.66]	0.53	[0.43, 0.62]	0.54	[0.44, 0.64]
σ_T	0.25	[0.10, 0.39]	0.18	[0.10, 0.25]	0.19	[0.11, 0.27]
σ_A	0.63	[0.26, 0.99]	0.53	[0.27, 0.78]	0.56	[0.27, 0.86]
σ^d_G	0.63	[0.26, 0.99]	3.39	[2.46, 4.28]	2.46	[1.81, 3.07]
σ_ϕ	0.63	[0.26, 0.99]	0.55	[0.38, 0.71]	0.55	[0.39, 0.70]
σ_{m_H}	0.63	[0.27, 1.00]	0.16	[0.14, 0.19]	0.16	[0.14, 0.19]
σ_{m_F}	0.63	[0.26, 0.99]	0.17	[0.15, 0.20]	0.17	[0.15, 0.20]
σ_{m_N}	0.63	[0.26, 0.99]	0.14	[0.12, 0.16]	0.14	[0.12, 0.16]
σ_R	0.63	[0.27, 0.99]	0.18	[0.16, 0.21]	0.18	[0.16, 0.21]
σ_{T^*}	0.25	[0.11, 0.40]	0.18	[0.12, 0.23]	0.20	[0.14, 0.26]
σ_{G^*}	0.63	[0.26, 0.99]	2.00	[1.46, 2.53]	1.84	[1.28, 2.37]
σ_{m^*}	0.63	[0.27, 0.98]	0.20	[0.17, 0.22]	0.20	[0.17, 0.23]
σ_{R^*}	0.63	[0.27, 0.99]	0.16	[0.14, 0.18]	0.17	[0.14, 0.19]
σ_{oil}	0.63	[0.26, 0.99]	4.11	[3.68, 4.55]	4.13	[3.65, 4.60]

Notes: Posterior means and 90% intervals in parentheses, from 250,000 draws with the first 50,000 draws discarded. Results for baseline model are given for comparison. The alternative specification assumes α_G=0, instead of the baseline assumption α_G=0.4.

Table A.3

POSTERIOR ESTIMATES FOR ALTERNATIVE UIP SPECIFICATIONS

	Prior		*Baseline*		$\phi_i > 1, \phi_s = 0,$		$\phi_i = \phi_s = 0$	
Domestic behavioural parameters								
ξ_H	0.75	[0.67, 0.83]	0.89	[0.86, 0.92]	0.88	[0.85, 0.91]	0.89	[0.86, 0.92]
ξ_F	0.75	[0.67, 0.83]	0.91	[0.89, 0.93]	0.90	[0.88, 0.92]	0.90	[0.88, 0.92]
ξ_N	0.75	[0.67, 0.83]	0.89	[0.87, 0.92]	0.88	[0.86, 0.91]	0.89	[0.86, 0.91]
κ_H	0.50	[0.34, 0.67]	0.40	[0.24, 0.53]	0.41	[0.26, 0.56]	0.40	[0.25, 0.54]
κ_F	0.50	[0.34, 0.67]	0.46	[0.30, 0.61]	0.40	[0.26, 0.54]	0.40	[0.26, 0.54]
κ_N	0.50	[0.33, 0.66]	0.58	[0.43, 0.72]	0.62	[0.48, 0.77]	0.59	[0.43, 0.73]
h	0.70	[0.62, 0.78]	0.48	[0.39, 0.56]	0.50	[0.42, 0.58]	0.51	[0.42, 0.59]
σ	1.50	[1.34, 1.67]	1.32	[1.16, 1.46]	1.47	[1.31, 1.63]	1.38	[1.22, 1.53]
φ	1.00	[0.83, 1.16]	0.98	[0.82, 1.14]	0.94	[0.79, 1.10]	0.97	[0.81, 1.12]
η	1.00	[0.83, 1.16]	0.88	[0.79, 0.97]	0.76	[0.66, 0.85]	0.84	[0.75, 0.93]
ν	1.00	[0.84, 1.16]	1.02	[0.86, 1.18]	1.03	[0.86, 1.19]	1.07	[0.90, 1.24]
ϕ_S	0.40	[0.23, 0.56]	0.38	[0.31, 0.45]	–	[–, –]	–	[–, –]
ϕ_i	1.10	[0.93, 1.26]	–	[–, –]	1.05	[0.89, 1.21]	–	[–, –]
ρ_R	0.80	[0.72, 0.88]	0.90	[0.87, 0.93]	0.90	[0.87, 0.92]	0.90	[0.87, 0.92]
ψ_π	1.50	[1.42, 1.58]	1.49	[1.41, 1.58]	1.46	[1.38, 1.54]	1.49	[1.40, 1.57]
ψ_Y	0.50	[0.42, 0.58]	0.49	[0.41, 0.57]	0.51	[0.43, 0.59]	0.49	[0.42, 0.57]
$\psi_{\Delta Y}$	0.20	[0.12, 0.28]	0.24	[0.17, 0.29]	0.19	[0.14, 0.24]	0.21	[0.16, 0.26]
Foreign behavioural parameters								
ξ^*	0.75	[0.67, 0.83]	0.86	[0.82, 0.91]	0.87	[0.83, 0.90]	0.87	[0.83, 0.91]
κ^*	0.50	[0.34, 0.67]	0.25	[0.14, 0.35]	0.23	[0.13, 0.32]	0.23	[0.14, 0.33]
h^*	0.70	[0.62, 0.78]	0.71	[0.65, 0.77]	0.72	[0.66, 0.78]	0.72	[0.66, 0.78]
σ^*	1.50	[1.33, 1.66]	1.47	[1.31, 1.62]	1.48	[1.32, 1.65]	1.47	[1.31, 1.63]
φ^*	1.00	[0.83, 1.16]	0.97	[0.82, 1.13]	0.97	[0.82, 1.14]	0.97	[0.81, 1.12]
ρ_{R^*}	0.80	[0.65, 0.96]	0.89	[0.85, 0.92]	0.90	[0.87, 0.93]	0.89	[0.86, 0.92]
ψ_{π^*}	1.50	[1.34, 1.67]	1.53	[1.36, 1.70]	1.53	[1.36, 1.70]	1.53	[1.37, 1.69]
ψ_{Y^*}	0.25	[0.09, 0.40]	0.36	[0.18, 0.54]	0.42	[0.24, 0.60]	0.39	[0.22, 0.55]
$\psi_{\Delta Y^*}$	0.20	[0.05, 0.35]	0.25	[0.13, 0.36]	0.22	[0.12, 0.31]	0.21	[0.12, 0.30]
AR(1) coefficients and standard deviations								
ρ_T	0.80	[0.65, 0.96]	0.63	[0.47, 0.80]	0.63	[0.46, 0.80]	0.66	[0.50, 0.81]
ρ_A	0.50	[0.33, 0.66]	0.49	[0.33, 0.66]	0.49	[0.32, 0.66]	0.49	[0.33, 0.65]
ρ_G^d	0.80	[0.65, 0.96]	0.72	[0.60, 0.84]	0.58	[0.46, 0.70]	0.62	[0.50, 0.75]
ρ_ϕ	0.50	[0.33, 0.66]	0.72	[0.60, 0.86]	0.82	[0.76, 0.87]	0.84	[0.78, 0.89]
ρ_{m_H}	0.50	[0.34, 0.67]	0.29	[0.19, 0.39]	0.29	[0.19, 0.40]	0.29	[0.19, 0.40]
ρ_{m_F}	0.50	[0.33, 0.66]	0.34	[0.23, 0.45]	0.31	[0.21, 0.41]	0.34	[0.23, 0.45]
ρ_{m_D}	0.50	[0.34, 0.67]	0.26	[0.17, 0.35]	0.27	[0.17, 0.37]	0.27	[0.18, 0.36]
ρ_{T^*}	0.80	[0.65, 0.96]	0.71	[0.60, 0.83]	0.71	[0.60, 0.83]	0.72	[0.60, 0.84]
ρ_{G^*}	0.80	[0.65, 0.96]	0.81	[0.75, 0.87]	0.80	[0.74, 0.86]	0.81	[0.75, 0.87]
ρ_{m^*}	0.50	[0.33, 0.66]	0.23	[0.14, 0.32]	0.22	[0.13, 0.30]	0.22	[0.14, 0.31]
ρ_{oil}	0.50	[0.33, 0.66]	0.53	[0.43, 0.62]	0.55	[0.45, 0.65]	0.54	[0.44, 0.63]
σ_T	0.25	[0.10, 0.39]	0.18	[0.10, 0.25]	0.19	[0.11, 0.27]	0.16	[0.10, 0.22]
σ_A	0.63	[0.26, 0.99]	0.53	[0.27, 0.78]	0.52	[0.27, 0.78]	0.52	[0.27, 0.77]
σ_G^d	0.63	[0.26, 0.99]	3.39	[2.46, 4.28]	3.44	[2.60, 4.26]	3.68	[2.78, 4.58]
σ_ϕ	0.63	[0.26, 0.99]	0.55	[0.38, 0.71]	0.46	[0.34, 0.59]	0.48	[0.36, 0.60]

Table A.3 continued

	Prior		*Baseline*		$\phi_i > 1, \phi_s = 0,$		$\phi_i = \phi_s = 0$	
σ_{m_H}	0.63	[0.27, 1.00]	0.16	[0.14, 0.19]	0.16	[0.14, 0.19]	0.16	[0.14, 0.19]
σ_{m_F}	0.63	[0.26, 0.99]	0.17	[0.15, 0.20]	0.17	[0.15, 0.20]	0.17	[0.15, 0.20]
σ_{m_N}	0.63	[0.26, 0.99]	0.14	[0.12, 0.16]	0.14	[0.12, 0.16]	0.14	[0.12, 0.16]
σ_R	0.63	[0.27, 0.99]	0.18	[0.16, 0.21]	0.18	[0.15, 0.20]	0.18	[0.16, 0.21]
σ_{T^*}	0.25	[0.11, 0.40]	0.18	[0.12, 0.23]	0.17	[0.11, 0.22]	0.16	[0.10, 0.21]
σ_{G^*}	0.63	[0.26, 0.99]	2.00	[1.46, 2.53]	2.20	[1.62, 2.77]	2.19	[1.64, 2.72]
σ_{m^*}	0.63	[0.27, 0.98]	0.20	[0.17, 0.22]	0.20	[0.17, 0.23]	0.20	[0.17, 0.23]
σ_{R^*}	0.63	[0.27, 0.99]	0.16	[0.14, 0.18]	0.16	[0.14, 0.18]	0.16	[0.14, 0.18]
σ_{oil}	0.63	[0.26, 0.99]	4.11	[3.68, 4.55]	4.10	[3.65, 4.54]	4.11	[3.66, 4.56]

Notes: Posterior means and 90% intervals in parentheses, from 250,000 draws with the first 50,000 draws discarded. Results for baseline model are given for comparison. The baseline specification uses the modified UIP proposed by Adolfson et al. which is characterised by $\phi_i=0$, $\phi_s>0$; the modified UIP proposed by Christiano et al. is characterised by $\phi_i>1$, $\phi_s=0$; and the standard UIP is characterised by $\phi_i=\phi_s=0$.

Table A.4

VARIANCE DECOMPOSITION FOR ALTERNATIVE PREFERENCE SHOCK SPECIFICATION: WITHOUT SPILLOVERS FROM FOREIGN TO DOMESTIC PREFERENCE SHOCK

	1 quarter		4 quarters		12 quarters		40 quarters	
Shock	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval
Output growth								
ϵ_{Z_T}	0.14	[0.06, 0.22]	0.02	[0.01, 0.04]	0.02	[0.00, 0.03]	0.02	[0.00, 0.04]
ϵ_{Z_A}	0.02	[0.02, 0.02]	0.00	[0.00, 0.01]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_G^d	0.25	[0.20, 0.33]	0.37	[0.27, 0.49]	0.40	[0.30, 0.49]	0.36	[0.27, 0.47]
ϵ_ϕ	0.17	[0.12, 0.21]	0.26	[0.20, 0.34]	0.25	[0.18, 0.33]	0.22	[0.15, 0.29]
ϵ_{m_H}	0.02	[0.02, 0.03]	0.01	[0.00, 0.01]	0.00	[0.00, 0.01]	0.00	[0.00, 0.00]
ϵ_{m_F}	0.02	[0.02, 0.03]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]	0.01	[0.00, 0.02]
ϵ_{m_N}	0.03	[0.02, 0.04]	0.01	[0.01, 0.02]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_R	0.18	[0.12, 0.24]	0.14	[0.10, 0.18]	0.17	[0.11, 0.22]	0.23	[0.14, 0.32]
ϵ_{A^*}	0.02	[0.02, 0.03]	0.01	[0.00, 0.02]	0.02	[0.00, 0.05]	0.03	[0.00, 0.06]
ϵ_{G^*}	0.05	[0.04, 0.06]	0.11	[0.07, 0.16]	0.10	[0.05, 0.14]	0.09	[0.04, 0.13]
ϵ_{m^*}	0.03	[0.02, 0.03]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{R^*}	0.03	[0.02, 0.03]	0.01	[0.01, 0.02]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{oil}	0.03	[0.02, 0.03]	0.01	[0.00, 0.02]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
Inflation								
ϵ_{Z_T}	0.08	[0.01, 0.14]	0.03	[0.01, 0.05]	0.03	[0.01, 0.05]	0.03	[0.01, 0.05]
ϵ_{Z_A}	0.01	[0.00, 0.02]	0.02	[0.01, 0.04]	0.02	[0.01, 0.04]	0.02	[0.01, 0.04]
ϵ_G^d	0.05	[0.02, 0.10]	0.06	[0.02, 0.11]	0.06	[0.02, 0.11]	0.06	[0.02, 0.11]
ϵ_ϕ	0.01	[0.00, 0.02]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]
ϵ_{m_H}	0.05	[0.02, 0.07]	0.06	[0.02, 0.09]	0.06	[0.02, 0.10]	0.06	[0.02, 0.10]
ϵ_{m_F}	0.11	[0.06, 0.15]	0.14	[0.07, 0.20]	0.14	[0.08, 0.21]	0.14	[0.08, 0.21]
ϵ_{m_N}	0.36	[0.25, 0.47]	0.47	[0.31, 0.60]	0.47	[0.31, 0.60]	0.47	[0.31, 0.60]
ϵ_R	0.16	[0.06, 0.25]	0.13	[0.07, 0.20]	0.13	[0.07, 0.20]	0.13	[0.07, 0.20]
ϵ_{A^*}	0.13	[0.03, 0.22]	0.02	[0.01, 0.05]	0.02	[0.01, 0.05]	0.02	[0.01, 0.05]

Table A.4 continued

	1 quarter		4 quarters		12 quarters		40 quarters	
Shock	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval
ϵ_{G^*}	0.01	[0.00, 0.02]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]	0.01	[0.01, 0.02]
ϵ_{m^*}	0.00	[0.00, 0.00]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{R^*}	0.00	[0.00, 0.00]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{oil}	0.02	[0.01, 0.03]	0.01	[0.01, 0.02]	0.02	[0.01, 0.02]	0.02	[0.01, 0.02]
Interest rate								
ϵ_{Z_T}	0.03	[0.00, 0.06]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]
ϵ_{Z_A}	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_G^d	0.37	[0.23, 0.50]	0.44	[0.35, 0.54]	0.45	[0.36, 0.54]	0.45	[0.36, 0.54]
ϵ_ϕ	0.24	[0.15, 0.33]	0.28	[0.21, 0.35]	0.28	[0.21, 0.36]	0.28	[0.21, 0.36]
ϵ_{m_H}	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ϵ_{m_F}	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]	0.02	[0.01, 0.03]
ϵ_{m_N}	0.01	[0.00, 0.01]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]
ϵ_R	0.12	[0.07, 0.18]	0.13	[0.05, 0.22]	0.13	[0.05, 0.22]	0.13	[0.05, 0.22]
ϵ_{A^*}	0.05	[0.01, 0.10]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]
ϵ_{G^*}	0.13	[0.07, 0.20]	0.07	[0.04, 0.09]	0.06	[0.04, 0.08]	0.06	[0.04, 0.08]
ϵ_{m^*}	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{R^*}	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]
ϵ_{oil}	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]	0.01	[0.00, 0.01]

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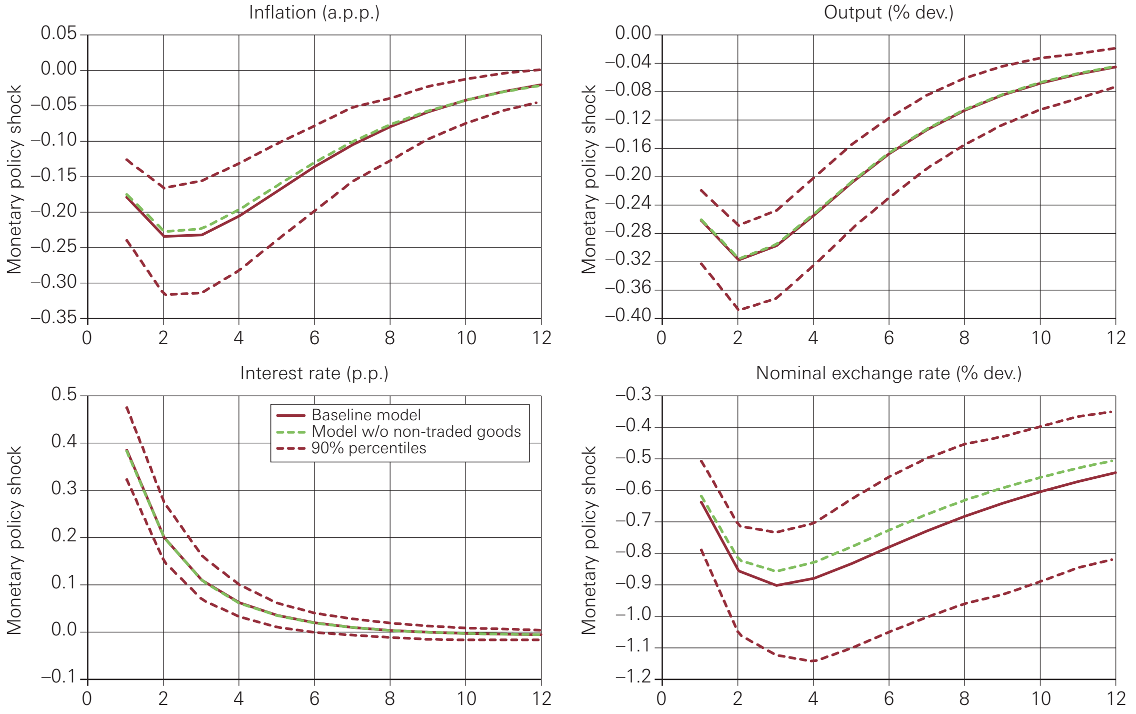
Chart A.1

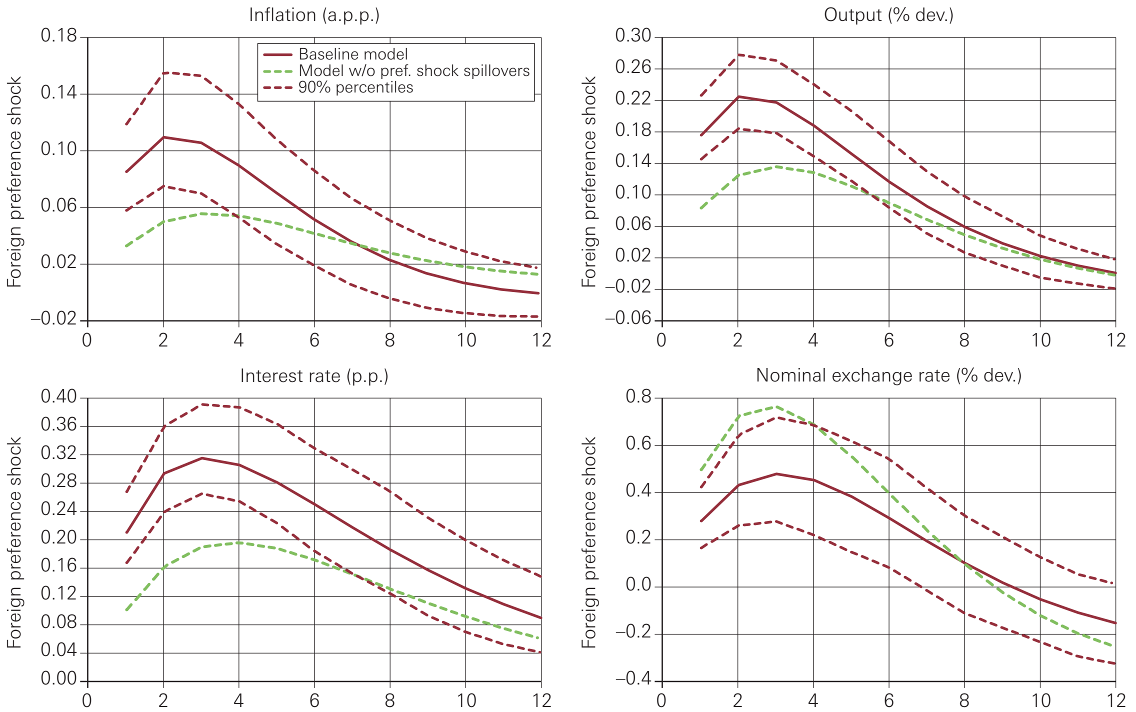
RESPONSES TO MONETARY POLICY SHOCK FOR ALTERNATIVE MODEL SPECIFICATION WITHOUT NON-TRADABLES



Notes: One-standard-deviation shock to innovation in shock process in period 1. The model specification without non-tradables assumes $\gamma = 0$, instead of the baseline assumption $\gamma = 0.6$; see Section 4.5. The results for the baseline model are given with the 90% confidence interval.

Chart A.2

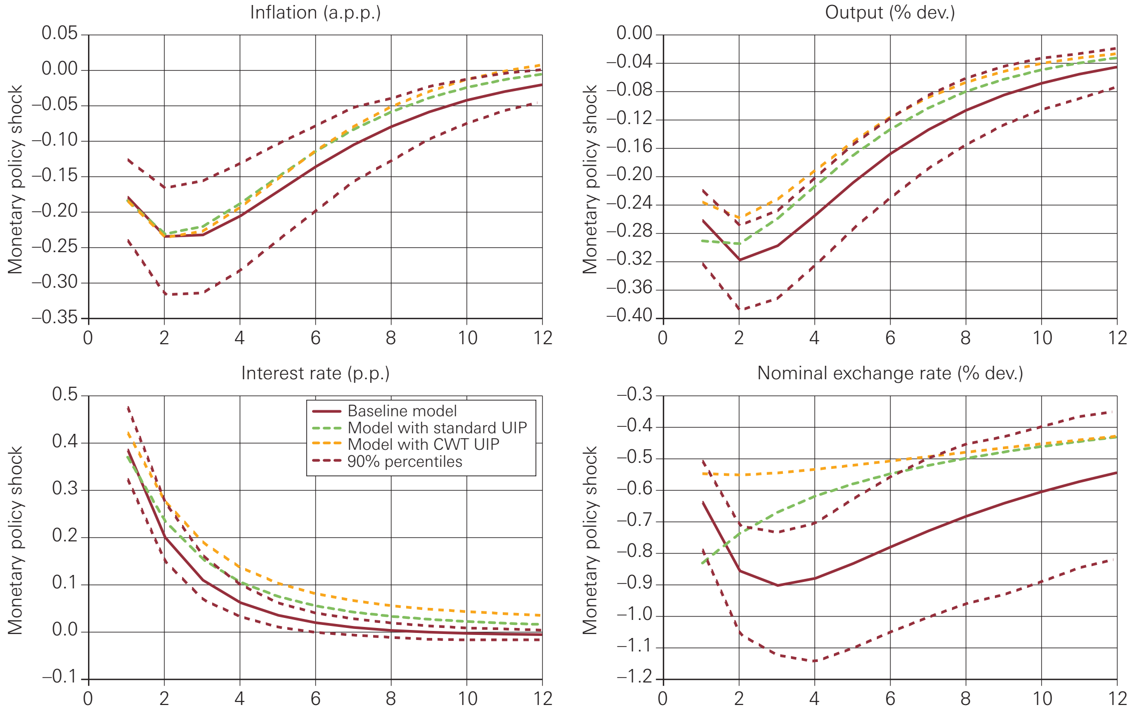
RESPONSES TO FOREIGN PREFERENCE (DEMAND) SHOCK FOR ALTERNATIVE HOME PREFERENCE SHOCK SPECIFICATION



Notes: One-standard-deviation shock to innovation in shock process in period 1. The alternative preference shock specification assumes no spillovers from foreign preference shocks to domestic preference shocks, i.e., $\alpha_G = 0$, instead of the baseline assumption $\alpha_G = 0.4$; see Section 4.5. The results for the baseline model are given with the 90% confidence interval.

Chart A.3

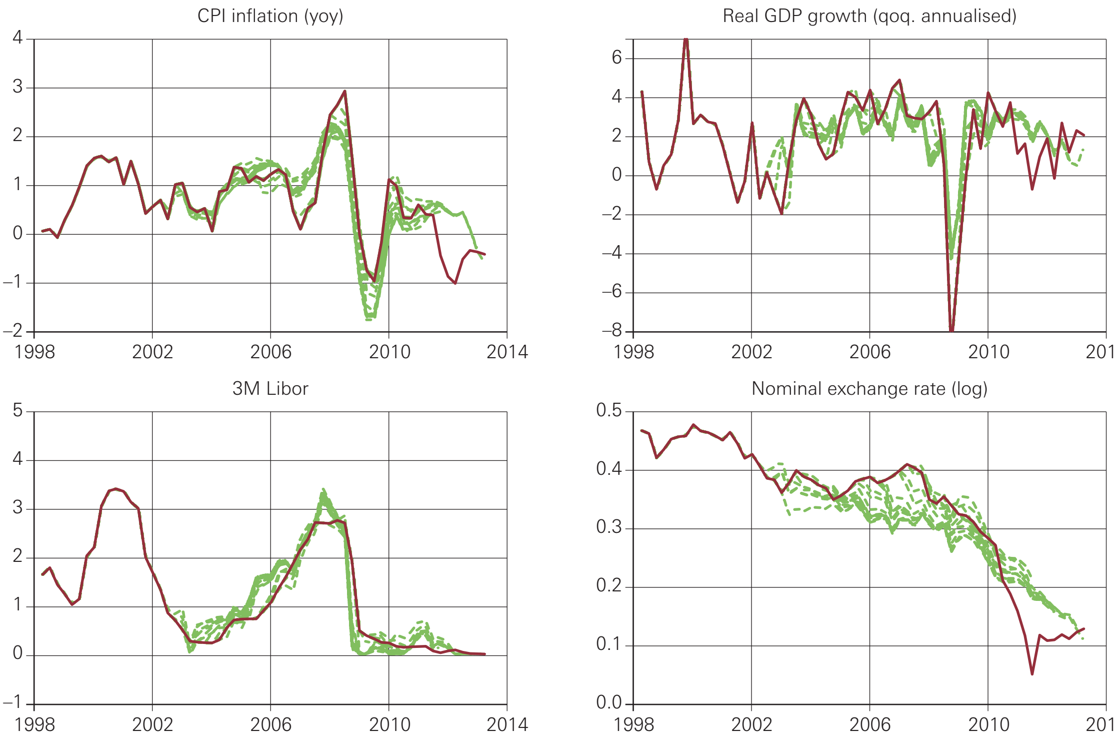
RESPONSES TO MONETARY POLICY SHOCK FOR ALTERNATIVE UIP SPECIFICATIONS



Notes: One-standard-deviation shock to innovation in shock process in period 1. The models considered use the modified UIP proposed by Adolfson et al. (Baseline), the modified UIP proposed by Christiano et al. (CWT UIP), and the UIP with neither of these two modifications (standard UIP); see Section 4.5. The results for the baseline model are given with the 90% confidence interval.

Chart A.4

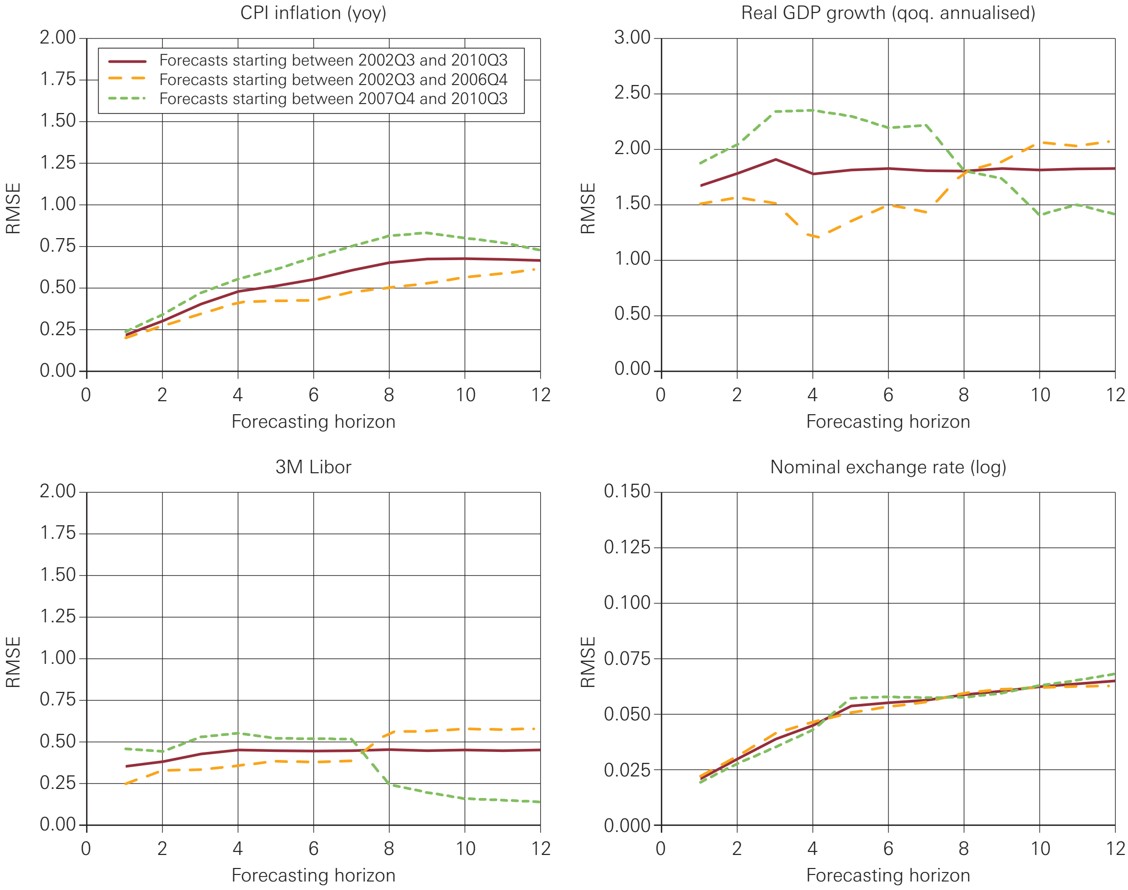
ROLLING FORECASTS, ALTERNATIVE MODEL SPECIFICATION WITHOUT NON-TRADABLES



Notes: 32 rolling twelve-quarter forecasts, starting between 2002Q3 and 2010Q3. The model specification without non-tradables assumes $\gamma = 0$ instead of the baseline assumption $\gamma = 0.6$; see Section 4.5.

Chart A.5

ROOT MEAN SQUARED ERRORS, ALTERNATIVE MODEL SPECIFICATION WITHOUT NON-TRADABLES



Notes: Root mean squared errors are computed for 32 rolling twelve-quarter forecasts, starting between 2002Q3 and 2010Q3. The model specification without non-tradables assumes $\gamma = 0$, instead of the baseline assumption $\gamma = 0.6$; see Section 4.5.

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