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

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Abstract

In this paper we develop a Dynamic Stochastic General Equilibrium (DSGE) model for an open economy, and estimate it on euro area data using Bayesian estimation techniques. The model incorporates several open economy features, as well as a number of nominal and real frictions that has proven to be relevant in the closed economy context The paper offers, *i*) a theoretical development of the benchmark DSGE model into the open economy setting, *ii*) Bayesian estimation of the model, determining the relative importance of various shocks and frictions for explaining the dynamic development of an open economy, and *iii*) an evaluation of the open economy DSGE model's forecasting abilities.

1. Introduction

In this paper we develop a Dynamic Stochastic General Equilibrium (DSGE) model for an open economy and estimate it on euro area data. We extend the benchmark (closed economy) DSGE model of Christiano, Eichenbaum and Evans (2001) and Altig et al. (2003) by incorporating open economy aspects into it. Our model combines elements of their closed economy setting with some of the features and findings of the New Open Economy Macroeconomics literature.

The model is derived from microfoundations and based on agents' optimizing behavior. The consumers attain utility from consumption of domestically produced goods as well as imported goods, which are supplied by domestic firms and importing firms, respectively. We adopt the assumption that the foreign prices, output and interest rate are exogenously given. We allow for incomplete exchange rate pass-through in both the import and export sectors by including nominal price rigidities (i.e., there is local currency price stickiness), as in for example Smets and Wouters (2002). Thus, there will be short-run deviations from the Law of One Price.

Following Christiano, Eichenbaum and Evans (2001), a number of nominal and real frictions such as sticky prices, sticky wages, variable capital utilization, capital adjustment costs and habit persistence are included in the theoretical model to capture the persistence in the data. The relevance of these frictions will be empirically determined in the estimation procedure. In addition, we introduce stochastic fiscal policy in the model since prior research has shown the potential importance of such shocks for explaining business cycles (see e.g. Jonsson and Klein, 1996, and Lindé, 2003).

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We estimate the model on euro area data using Bayesian estimation techniques. Smets and Wouters (2003a, 2003b) have shown that one can successfully estimate closed economy DSGE models using Bayesian methods, and that the forecasting performance of such models is quite good compared to standard, and Bayesian, vector autoregressive (VAR) models. We extend their work to the open economy setting, and by using data for the euro area we offer a direct comparison to their closed economy framework. Note though that our model differs to Smets and Wouters' in several respects. Apart from bringing in the exchange rate channel, we also include a working capital channel (i.e., firms lend money from a financial intermediary to finance part of their wage bill). The working capital channel implies that an interest rate change will directly affect the firms' marginal costs. Consequently, both these channels will have effects on the transmission of monetary policy. Examining the role of the working capital channel is of particular interest, since Christiano, Eichenbaum and Evans (2001) obtain a low estimated degree of price stickiness when allowing for working capital when matching the impulse responses after a monetary policy shock. In contrast, Smets and Wouters (2003a, 2003b) obtain a much higher degree of estimated price stickiness in a model without the working capital channel.

Compared to Smets and Wouters (2003a, 2003b) we also allow for a larger set of structural shocks, due to the open economy aspects but also because fiscal policy enters our model. The relative importance of the various identified shocks for explaining the business cycle fluctuations will be determined in the empirical estimation, and an interesting feature of the analysis in this paper is to examine to what extent the frictions and shocks differ between the open and closed economy setting. Lastly, as in Altig et al. (2003), we have a stochastic unit-root technology shock which grows over time in the model. This allows us to work with raw data when we estimate the DSGE model.

Consequently, this paper offers, *i*) a theoretical development of the benchmark DSGE model into the open economy setting, *ii*) Bayesian estimation of the model, determining the relevance of various shocks and frictions for explaining the dynamic development of an open economy, and *iii*) an evaluation of the open economy DSGE model's forecasting abilities.

[**Summary of the obtained results. Remains to be written**]

The paper is organized as follows. In Section 2 the theoretical model is derived and described. In particular, its open economy aspects are discussed. Section 3 presents how the model is solved, using a numerical solution procedure on the log-linearized model equations. Section 4 contains a short description of the data used, and discusses measurement issues that arise when taking the theoretical model to the data. In Section 5, we first discuss which parameters we have chosen to calibrate, and the prior distributions for the parameters we have chosen to estimate. We then report our estimation results and explore the role of varying the nominal and real frictions in the model. Section 6 shows the impulse responses from different shocks and discusses the role of various shocks in explaining business cycles. In Section 7, we compare the forecasting abilities of our estimated DSGE model with a Bayesian VAR model. Lastly, Section 8 provides some conclusions.

2. Model

In this Section we derive the open economy DSGE model from the optimizing behavior of the households and the firms. We build on the work of Christiano et al. (2001) and Altig et al. (2003) and augment their benchmark DSGE model with open economy aspects. As in the (closed economy) benchmark model the households maximize a utility function consisting of consumption, leisure and cash balances. However, in our open economy model the households attain utility from consuming a basket consisting of domestically produced goods *and* imported products. These products are supplied by domestic and importing firms, respectively. Note also that the consumption preferences are subject to habit formation.

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

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

2.1. Firms

There are three main categories of firms operating in this open economy; domestic, importing and exporting firms. The intermediate domestic firms produce a differentiated good, using capital and labour inputs, which it sells to a final good producer who uses a continuum of these intermediate goods in her production. The importing firms, in turn, transform a homogenous good, bought in the world market, into a differentiated import good, which it sells to the domestic households. The exporting firms pursue a similar scheme. The exporting firms buy the domestic final good and differentiates it by brand naming. Each exporting firm is thus a monopoly supplier of its specific product in the world market.

2.1.1. Domestic firms

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

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

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

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

$$\lambda_{f,t} = \left(1 - \rho_{\lambda_f}\right) \lambda_f + \rho_{\lambda_f} \lambda_{f,t-1} + \varepsilon_{\lambda_f,t}.$$

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

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

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

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

Output of the i^{th} *intermediate good firm* is:

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

where z_t is a permanent technology shock, ϵ_t is a covariance stationary technology shock, and $H_{i,t}$ denotes homogeneous labour hired by the i^{th} firm. Notice that $K_{i,t}$ is not the physical capital stock, but rather the capital services stock, since we allow for variable capital utilization in the model. Also, a fixed (to the firm) cost is included in the production function to make sure that profits are zero in steady state. The fixed cost is assumed to grow at the same rate as consumption, investment, the real wage, and output do in steady state. If the fixed cost did not grow at the rate of growth of z_t, eventually the fixed cost term would become irrelevant and profits would be systematically positive because of the presence of monopoly power.

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

$$\frac{z_t}{z_{t-1}} = \mu_{z,t}, \tag{2.5}$$

and

$$\mu_{z,t} = (1 - \rho_{\mu_z})\mu_z + \rho_{\mu_z}\mu_{z,t-1} + \varepsilon_{z,t}. \tag{2.6}$$

For the stationary shock in (2.4), we assume $\mathrm{E}(\epsilon_t) = 1$ and that $\hat{\epsilon}_t = (\epsilon_t - 1)/1$ has the following univariate representation:

$$\hat{\epsilon}_t = \rho_\epsilon \hat{\epsilon}_{t-1} + \varepsilon_{\epsilon,t}. \tag{2.7}$$

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

The cost minimization problem facing the intermediate firm i in period t is (assuming that $P_{i,t}$ is given this constrains the firm to produce $Y_{i,t}$):

$$\min_{K_{i,t},H_{i,t}} W_t R_t^f H_{i,t} + R_t^k K_{i,t} + \lambda_t P_{i,t}\left[Y_{i,t} - z_t^{1-\alpha}\epsilon_t K_{i,t}^{\alpha} H_{i,t}^{1-\alpha} + z_t\phi\right]. \tag{2.8}$$

Note again that $K_{i,t}$ is the capital services stock, and not the physical capital stock. R_t^k is the gross nominal rental rate per unit of capital services and W_t is the nominal wage rate per unit of aggregate, homogeneous, labour $H_{i,t}$. The inclusion of the gross nominal rate of interest paid by firms, R_t^f, reflects the assumption that a fraction, ν_t, of the intermediate firms' wage bill has to be financed in advance. Then the end of period labour costs of the firm are:

$$\nu_t W_t H_{i,t} R_{t-1} + (1 - \nu_t) W_t H_{i,t} = W_t H_{i,t} R_t^f,$$

where

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

and where R_{t-1} is the gross nominal interest rate. So, the effective net rate of nominal interest on one currency unit paid to the workers is $R_t^f - 1$. Also, $\mathrm{E}(\nu_t) = \nu$ and $\hat{\nu}_t$ has the following time series representation:

$$\hat{\nu}_t = \rho_\nu \hat{\nu}_{t-1} + \varepsilon_{\nu,t}. \tag{2.10}$$

In the following, we will refer to $\varepsilon_{\nu,t}$ as firm money demand shocks. By log-linearizing the (2.9) equation, we obtain

$$\hat{R}_t^f = \frac{\nu R}{\nu R + 1 - \nu} \hat{R}_{t-1} + \frac{\nu (R-1)}{\nu R + 1 - \nu} \hat{\nu}_t, \tag{2.11}$$

which describes the relationship between the effective interest rate paid by the firms and the economy-wide nominal interest rate. Note that $\frac{\nu R}{\nu R+1-\nu}$ and $\frac{\nu(R-1)}{\nu R+1-\nu}$ are bounded between 0 and 1.[1]

Because of the permanent technology shock the model evolves along a stochastic growth path, and from Altig et al. (2003) we know that we need to stationarize the real variables of this economy in the following way

$$Y_t/z_t, K_{t+1}/z_t \text{ and } \bar{K}_{t+1}/z_t, \tag{2.12}$$

where $\bar{K}_{t+1}$ denotes the physical capital stock. It is important to notice that the physical capital stock in period $t+1$ is scaled with z_t since it is determined in period t, whereas capital services in period $t+1$, K_{t+1}, are for convenience also scaled with z_t although K_{t+1} are determined in period $t+1$.

The first order conditions of (2.8) with respect to $H_{i,t}$ and $K_{i,t}$ are

$$\begin{aligned} W_t R_t^f &= (1-\alpha) \lambda_t P_{i,t} z_t^{1-\alpha} \epsilon_t K_{i,t}^{\alpha} H_{i,t}^{-\alpha} \\ R_t^k &= \alpha \lambda_t P_{i,t} z_t^{1-\alpha} \epsilon_t K_{i,t}^{\alpha-1} H_{i,t}^{1-\alpha}. \end{aligned} \tag{2.13}$$

Substituting out for $\lambda_t P_{i,t}$, and stationarizing the variables according to (2.12) we obtain the following equation for R_t^k

$$R_t^k = \frac{\alpha}{1-\alpha} w_t \mu_{z,t} R_t^f k_{i,t}^{-1} H_{i,t},$$

where lower case variables denote stationarized variables. Recalling that

$$r_t^k \equiv \frac{R_t^k}{P_t}, \bar{w}_t \equiv \frac{w_t}{P_t} \tag{2.14}$$

will be stationary along a balanced growth path, we obtain the following stationary solution for the scaled rental rate of capital

$$r_t^k = \frac{\alpha}{1-\alpha} \bar{w}_t \mu_{z,t} R_t^f k_{i,t}^{-1} H_{i,t} \tag{2.15}$$

We notice that the unit-root technology shock enter into the expression for r_t^k, but not the stationary technology shock ϵ_t.

The log-linearized version of real rental rate of capital equation is (letting hats denote log-linearized variables)

$$\hat{r}_t^k = \hat{\mu}_{z,t} + \widehat{\bar{w}}_t + \hat{R}_t^f + \hat{H}_t - \hat{k}_t. \tag{2.16}$$

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

Note that the subscripts i has been dropped in this equation since all intermediate firms will be identical in equilibrium.

Finally, note that the Lagrangian multiplier in equation (2.8) $\lambda_t P_{i,t}$ can be interpreted as the nominal cost of producing one additional unit of the domestic good (i.e., the nominal marginal cost). The *real* marginal cost for the intermediate firms is, consequently, given by λ_t. Using the first order conditions in (2.13), it is possible to show that in equilibrium the real marginal cost ($mc_t \equiv \lambda_t$) follows

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\left(r_t^k\right)^{\alpha}\left(\bar{w}_t R_t^f\right)^{1-\alpha}\frac{1}{\epsilon_t}, \tag{2.17}$$

which implies that the log-linearized real marginal costs in this economy is given by

$$\begin{aligned}\widehat{mc}_t &= \alpha \hat{r}_t^k + (1-\alpha)\left[\hat{\bar{w}}_t + \hat{R}_t^f\right] - \hat{\epsilon}_t \\ &= \alpha\left(\hat{\mu}_{z,t} + \hat{H}_t - \hat{k}_t\right) + \hat{\bar{w}}_t + \hat{R}_t^f - \hat{\epsilon}_t.\end{aligned} \tag{2.18}$$

Given the setup above, the price setting problem of the intermediate firms is similar to the one in Smets and Wouters (2003b), following Calvo (1983). Each intermediate firm faces a random probability $(1-\xi^d)$ that she can reoptimize her price in any period. The reoptimized price is denoted P_t^{new}. With probability ξ^d the firm does not reoptimize, and its price in period $t+1$ follows $P_{t+1} = (\pi_t)^{\kappa_d}\left(\bar{\pi}_{t+1}^c\right)^{1-\kappa_d} P_t^{new}$ (i.e., it is indexed to last period's inflation, $\pi_t = \frac{P_t}{P_{t-1}}$, and the current inflation target, $\bar{\pi}_{t+1}^c$).[2] The price in period $t+s$ is then $(\pi_t\pi_{t+1}...\pi_{t+j-1})^{\kappa_d}\left(\bar{\pi}_{t+1}^c\bar{\pi}_{t+2}^c...\bar{\pi}_{t+j}^c\right)^{1-\kappa_d} P_t^{new}$. The firm faces the following optimization problem when setting its price:

$$\begin{aligned}\max_{P_t^{new}}\ \mathrm{E}_t\sum_{s=0}^{\infty}\left(\beta\xi^d\right)^s \upsilon_{t+s}[&\left((\pi_t\pi_{t+1}...\pi_{t+j-1})^{\kappa_d}\left(\bar{\pi}_{t+1}^c\bar{\pi}_{t+2}^c...\bar{\pi}_{t+j}^c\right)^{1-\kappa_d} P_t^{new}\right) Y_{i,t+s} \\ &-MC_{i,t+s}Y_{i,t+s} - MC_{i,t+s}z_{t+s}\phi],\end{aligned} \tag{2.19}$$

where the firm is using the stochastic discount factor $\beta\upsilon_{t+s}$ to make profits conditional upon utility. β is the discount factor and υ_{t+s} the marginal utility of the households' nominal income in period $t+s$. ϕ is a fixed cost (growing at the same rate as z_t) that enters the firms' optimization problem because we want to ensure that profits are zero in steady state. Note that letting $\kappa_d = 1$ retrieves the optimization problem found in Altig et al. (2003). Inserting equation (2.2) above, the first order condition of the firms' optimization problem can be written (after some rearranging)

$$\begin{aligned}\mathrm{E}_t\sum_{s=0}^{\infty}\left(\beta\xi^d\right)^s \upsilon_{t+s}&\left(\frac{\left(\frac{P_{t+s-1}}{P_{t-1}}\right)^{\kappa_d}\left(\bar{\pi}_{t+1}^c\bar{\pi}_{t+2}^c...\bar{\pi}_{t+s}^c\right)^{1-\kappa_d}}{\left(\frac{P_{t+s}}{P_t}\right)}\right)^{-\frac{\lambda_{f,t+s}}{\lambda_{f,t+s}-1}} Y_{t+s}P_{t+s}\times \\ &\left[\frac{\left(\frac{P_{t+s-1}}{P_{t-1}}\right)^{\kappa_d}\left(\bar{\pi}_{t+1}^c\bar{\pi}_{t+2}^c...\bar{\pi}_{t+s}^c\right)^{1-\kappa_d}}{\left(\frac{P_{t+s}}{P_t}\right)}\frac{P_t^{new}}{P_t} - \frac{\lambda_{f,t}MC_{i,t+s}}{P_{t+s}}\right] = 0\end{aligned} \tag{2.20}$$

From the aggregate price index (2.3) follows that the average price in period t is:

$$\begin{aligned}P_t &= \left[\left(\int_0^{\xi^d}\left(P_{t-1}(\pi_{t-1})^{\kappa_d}(\bar{\pi}_t^c)^{1-\kappa_d}\right)^{\frac{1}{1-\lambda_{f,t}}} + \int_{\xi^d}^{1}(P_t^{new})^{\frac{1}{1-\lambda_{f,t}}}\right) di\right]^{1-\lambda_{f,t}} \\ &= \left[\xi^d\left(P_{t-1}(\pi_{t-1})^{\kappa_d}(\bar{\pi}_t^c)^{1-\kappa_d}\right)^{\frac{1}{1-\lambda_{f,t}}} + (1-\xi^d)(P_t^{new})^{\frac{1}{1-\lambda_{f,t}}}\right]^{1-\lambda_{f,t}}.\end{aligned} \tag{2.21}$$

[2]The inflation target process is described in the central bank subsection below.

Log-linearizing equations (2.20) and (2.21), and simplifying yields the following aggregate Phillips curve relation

$$\begin{aligned}\left(\widehat{\pi}_t-\widehat{\bar{\pi}}_t^c\right) &= \frac{\beta}{1+\kappa_d\beta}\left(\mathrm{E}_t\widehat{\pi}_{t+1}-\rho_\pi\widehat{\bar{\pi}}_t^c\right)+\frac{\kappa_d}{1+\kappa_d\beta}\left(\widehat{\pi}_{t-1}-\widehat{\bar{\pi}}_t^c\right) \\ &\quad -\frac{\kappa_d\beta\left(1-\rho_\pi\right)}{1+\kappa_d\beta}\widehat{\bar{\pi}}_t^c+\frac{(1-\xi^d)(1-\beta\xi^d)}{\xi^d\left(1+\kappa_d\beta\right)}\left(\widehat{mc}_t+\widehat{\lambda}_{f,t}\right),\end{aligned} \tag{2.22}$$

where we have used that all firms are alike in equilibrium. Note that letting $\kappa_d=1$, this relation can be simplified to

$$\widehat{\pi}_t=\frac{\beta}{1+\beta}\mathrm{E}_t\widehat{\pi}_{t+1}+\frac{1}{1+\beta}\widehat{\pi}_{t-1}+\frac{(1-\xi^d)(1-\beta\xi^d)}{\xi^d(1+\beta)}\left(\widehat{mc}_t+\widehat{\lambda}_{f,t}\right). \tag{2.23}$$

2.1.2. Importing firms

The import sector consists of firms that buy a homogenous good in the world market. There are two different types of these import goods firms; one that turns the imported product into a differentiated *consumption* good $C_{i,t}^m$ (through access to a "differentiating" technology, i.e. brand naming), and another that turns it into a differentiated *investment* good $I_{i,t}^m$ through a similar technology. In each of the two categories there is a continuum of importing firms that sell their differentiated (consumption or investment) goods to the households.

The different importing firms buy the homogenous good at price P_t^* in the world market. The importing firms follow Calvo price setting and are allowed to change their price only when they receive a random price change signal. Each importing *consumption* firm face a random probability $(1-\xi^{m,c})$ that she can reoptimize her price in any period. Each importing *investment* firms face a different probability $(1-\xi^{m,i})$ that she can reoptimize her price in any period. Let the reoptimized price for an imported consumption (investment good) be denoted $P_{new,t}^{m,c}$ $(P_{new,t}^{m,i})$. With probability $\xi^{m,c}$ $(\xi^{m,i})$ the firm does not reoptimize, and its price is then indexed to last period's inflation. The price in period $t+1$ thus follows $P_{t+1}^{m,j}=\pi_t^{m,j}P_{new,t}^{m,j}$ for $j=\{c,i\}$. The price in period $t+s$ is thus $\left(\pi_t^{m,j}\pi_{t+1}^{m,j}...\pi_{t+s-1}^{m,j}\right)P_{new,t}^{m,j}$ for $j=\{c,i\}$.[3] Note that the importing firms do not update to the domestic inflation target since domestic inflation does not affect their pricing decision directly. The profit maximization involves the firms' own price relative to the aggregate import price, as well as the firms' marginal cost which is $S_tP_t^*$. Hence, it is not obvious why the domestic inflation target should be included in the updating scheme. The consumption and investment importing firms then face the following optimization problem, respectively:

$$\begin{aligned}\max_{P_{new,t}^{m,c}}\ \mathrm{E}_t\sum_{s=0}^{\infty}\left(\beta\xi^{m,c}\right)^s\upsilon_{t+s}[&\left(\left(\pi_t^{m,c}\pi_{t+1}^{m,c}...\pi_{t+s-1}^{m,c}\right)P_{new,t}^{m,c}\right)C_{i,t+s}^m \\ &-S_{t+s}P_{t+s}^*C_{i,t+s}^m-S_{t+s}P_{t+s}^*z_{t+s}\phi^{m,c}],\end{aligned} \tag{2.24}$$

$$\begin{aligned}\max_{P_{new,t}^{m,i}}\ \mathrm{E}_t\sum_{s=0}^{\infty}\left(\beta\xi^{m,i}\right)^s\upsilon_{t+s}[&\left(\left(\pi_t^{m,c}\pi_{t+1}^{m,c}...\pi_{t+s-1}^{m,c}\right)P_{new,t}^{m,i}\right)I_{i,t+s}^m \\ &-S_{t+s}P_{t+s}^*I_{i,t+s}^m-S_{t+s}P_{t+s}^*z_{t+s}\phi^{m,i}],\end{aligned} \tag{2.25}$$

[3]Note that all importing firms are alike in equilibrium so the subscript i can be dropped.

where profits are discounted by $\left(\beta\xi^{m,j}\right)^{s}\upsilon_{t+s}$ for $j=\{c,i\}$. Again $\phi^{m,c}$ ($\phi^{m,i}$) are fixed costs (in real terms) ensuring that import profits are zero in steady state. The final import consumption good is a composite of a continuum of i differentiated imported goods, each supplied by a different firm, which follow the CES function:

$$C_{t}^{m}=\left[\int_{0}^{1}\left(C_{i,t}^{m}\right)^{\frac{\eta_{t}^{m,c}-1}{\eta_{t}^{m,c}}}di\right]^{\frac{\eta_{t}^{m,c}}{\eta_{t}^{m,c}-1}},\eta_{t}^{m,c}>1. \tag{2.26}$$

It can then be shown that each importing firm i, faces the demand for imported consumption goods given by

$$C_{i,t}^{m}=\left(\frac{P_{i,t}^{m,c}}{P_{t}^{m,c}}\right)^{-\eta_{t}^{m,c}}C_{t}^{m}. \tag{2.27}$$

Equivalently, the final imported investment good is a composite good of a continuum of differentiated investment goods as follows:

$$I_{t}^{m}=\left[\int_{0}^{1}\left(I_{i,t}^{m}\right)^{\frac{\eta_{t}^{m,i}-1}{\eta_{t}^{m,i}}}di\right]^{\frac{\eta_{t}^{m,i}}{\eta_{t}^{m,i}-1}},\eta_{t}^{m,i}>1. \tag{2.28}$$

where the demand for the differentiated imported investment goods is given by

$$I_{i,t}^{m}=\left(\frac{P_{i,t}^{m,i}}{P_{t}^{m,i}}\right)^{-\eta_{t}^{m,i}}I_{t}^{m}. \tag{2.29}$$

The substitution elasticities between the differentiated import goods $\eta_{t}^{m,c}$ and $\eta_{t}^{m,i}$ determine the time varying markups on the import consumption goods and the import investment goods, respectively. These processes are assumed to follow

$$\begin{aligned}\eta_{t}^{m,c} &= \left(1-\rho_{\eta^{m,c}}\right)\eta^{m,c}+\rho_{\eta^{m,c},t}\eta_{t-1}^{m,c}+\varepsilon_{\eta^{m,c},t},\\ \eta_{t}^{m,i} &= \left(1-\rho_{\eta^{m,i}}\right)\eta^{m,i}+\rho_{\eta^{m,i},t}\eta_{t-1}^{m,i}+\varepsilon_{\eta^{m,i},t}.\end{aligned} \tag{2.30}$$

Inserting the demand for the imported good i in the firm's optimization problem, the first order condition with respect to the consumption good and the investment good is, respectively

$$\begin{aligned}&\mathrm{E}_{t}\sum_{s=0}^{\infty}\left(\beta\xi^{m,c}\right)^{s}\upsilon_{t+s}\left(\pi_{t}^{m,c}\pi_{t+1}^{m,c}...\pi_{t+s-1}^{m,c}\right)^{-\eta_{t+s}^{m,c}}\left(P_{t+s}^{m,c}\right)^{\eta_{t+s}^{m,c}}C_{t+s}^{m}\left(P_{new,t}^{m,c}\right)^{-\eta_{t+s}^{m,c}-1}\times\\ &[\left(\pi_{t}^{m,c}\pi_{t+1}^{m,c}...\pi_{t+s-1}^{m,c}\right)P_{new,t}^{m,c}-\frac{\eta_{t+s}^{m,c}}{(\eta_{t+s}^{m,c}-1)}S_{t+s}P_{t+s}^{*}]=0.\end{aligned} \tag{2.31}$$

$$\begin{aligned}&\mathrm{E}_{t}\sum_{s=0}^{\infty}\left(\beta\xi^{m,i}\right)^{s}\upsilon_{t+s}\left(\pi_{t}^{m,i}\pi_{t+1}^{m,i}...\pi_{t+s-1}^{m,i}\right)^{-\eta_{t+s}^{m,i}}\left(P_{t+s}^{m,i}\right)^{\eta_{t+j}^{m,i}}I_{t+s}^{m}\times\\ &[\left(\pi_{t}^{m,i}\pi_{t+1}^{m,i}...\pi_{t+s-1}^{m,i}\right)P_{new,t}^{m,i}-\frac{\eta_{t+s}^{m,i}}{(\eta_{t+s}^{m,i}-1)}S_{t+s}P_{t+s}^{*}]=0.\end{aligned} \tag{2.32}$$

Stationarizing these equations and using the aggregate price indices

$$\begin{aligned} P_t^{m,c} &= \left[\int_0^1 (P_{it}^{m,c})^{1-\eta_t^{m,c}}\, di\right]^{\frac{1}{1-\eta_t^{m,c}}} \\ &= \left[\xi^{m,c}\left(P_{t-1}^{m,c}\pi_{t-1}^{m,c}\right)^{1-\eta_t^{m,c}} + (1-\xi^{m,c})\left(P_{new,t}^{m,c}\right)^{1-\eta_t^{m,c}}\right]^{\frac{1}{1-\eta_t^{m,c}}}, \end{aligned} \tag{2.33}$$

and

$$P_t^{m,i} = \left[\xi^{m,i}\left(P_{t-1}^{m,c}\pi_{t-1}^{m,i}\right)^{1-\eta_t^{m,i}} + (1-\xi^{m,i})\left(P_{new,t}^{m,i}\right)^{1-\eta_t^{m,i}}\right]^{\frac{1}{1-\eta_t^{m,i}}}. \tag{2.34}$$

implies that the log-linearized versions of the two pricing equations can be written as Phillips curve relations for the imported consumption and investment good, respectively:

$$\widehat{\pi}_t^{m,c} = \frac{\beta}{1+\beta}\mathrm{E}_t\widehat{\pi}_{t+1}^{m,c} + \frac{1}{1+\beta}\widehat{\pi}_{t-1}^{m,c} + \frac{(1-\xi^{m,c})(1-\beta\xi^{m,c})}{\xi^{m,c}(1+\beta)}\left(\widehat{mc}_t^{m,c} - \frac{1}{(\eta^{m,c}-1)}\widehat{\eta}_t^{m,c}\right), \tag{2.35}$$

$$\widehat{\pi}_t^{m,i} = \frac{\beta}{1+\beta}\mathrm{E}_t\widehat{\pi}_{t+1}^{m,i} + \frac{1}{1+\beta}\widehat{\pi}_{t-1}^{m,i} + \frac{(1-\xi^{m,i})(1-\beta\xi^{m,i})}{\xi^{m,i}(1+\beta)}\left(\widehat{mc}_t^{m,i} - \frac{1}{(\eta^{m,i}-1)}\widehat{\eta}_t^{m,i}\right), \tag{2.36}$$

where $\widehat{mc}_t^{m,c} = \widehat{p}_t^* + \widehat{s}_t - \widehat{p}_t^{m,c}$, and $\widehat{mc}_t^{m,i} = \widehat{p}_t^* + \widehat{s}_t - \widehat{p}_t^{m,i}$.[4]

2.1.3. Exporting firms

The exporting firms buy the *final* domestic good and differentiates it by brand naming. Subsequently they sell the (continuum of) differentiated goods to the households in the foreign market, which use it

[4] The flexible price problem is relevant for the steady state we are linearzing around, and can be described in the following way. Let $\tilde{P}_{i,t}^{m,j}$ denote the optimal flexible price of firm i, $i\epsilon[0,1]$ on imported good j, $j\epsilon\{c,i\}$. In a flexible price environment the imported goods firms solve the following problem

$$\max_{\tilde{P}_{i,t}^{m,c},\tilde{P}_{i,t}^{m,i}} \tilde{P}_{i,t}^{m,c}C_{i,t}^m + \tilde{P}_{i,t}^{m,i}I_{i,t}^m - S_tP_t^*\left(C_{i,t}^m + I_{i,t}^m\right)$$

subject to the demand functions (2.27) and (2.29). As outlined earlier, we assume that the import firms pay the same price for imported goods in the world market regardless if they are used for domestic consumption and investment. Carrying out the maximization yields the first-order conditions (after rearranging, and dropping the subscript i, since all firms are alike)

$$\tilde{P}_t^{m,c} = \frac{\eta_t^{m,c}}{\eta_t^{m,c}-1}S_tP_t^*, \tag{2.37}$$

$$\tilde{P}_t^{m,i} = \frac{\eta_t^{m,i}}{\eta_t^{m,i}-1}S_tP_t^*. \tag{2.38}$$

Here we notice that if the substitution elasticities among foreign and domestic consumption and investment goods are the same, the price charged by the import firm would coincide. But when they are different, the import firm exploit the downward-sloping demand curve for each type of goods. The steady state markup for imported consumption and investment goods are thus allowed to be different. In contrast, note that as $\eta_t^{m,j} \to \infty$ $(j\epsilon\{c,i\})$, implying a horizontal demand curve for imported goods, the markup over the world market price goes to zero. Incomplete exchange rate pass-through occurs due to nominal rigidities in the import sector rather than through an explicit model of dynamic price differentiation (i.e., where, for example, the markup is dependent on the exchange rate development).

for consumption and investment purposes. The marginal cost is thus the price of the domestic good P_t. The exporting firms face the following demand $\tilde{X}_{i,t}$ for each product i:

$$\tilde{X}_{i,t} = \left(\frac{P_{i,t}^x}{P_t^x}\right)^{-\frac{\lambda_{x,t}}{\lambda_{x,t}-1}} \tilde{X}_t, \tag{2.39}$$

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

$$\lambda_{x,t} = (1 - \rho_{\lambda_x}) \lambda_x + \rho_{\lambda_x} \lambda_{x,t-1} + \varepsilon_{\lambda_x,t}. \tag{2.40}$$

Note that we allow for different elasticities between the differentiated goods abroad and at home. The steady state markup thus differs between the domestic and the export market (λ_f and $\lambda_x = 1$, respectively).

Furthermore, following the Calvo model, we assume that export prices are sticky in the foreign currency so that there will be incomplete exchange rate pass-through in the export market. When setting their prices, the export firms care about the relative price between the firms' own price and the aggregate export price, as well as the price of the domestic good since this is the export firms' marginal cost. Hence when an export firm is not allowed to optimize its price, the firm is assumed to index the price to last period's (export price) inflation and the domestic inflation target. The price in period $t+1$ is thus $P_{t+1}^x = (\pi_t^x)^{\kappa_x} \left(\bar{\pi}_{t+1}^c\right)^{1-\kappa_x} P_t^{x,new}$. The export firms maximize profits (denoted in the local currency) taking into account that there might not be a chance to optimally change the price:

$$\begin{gathered}\max_{P_i^{x,new}} \mathrm{E}_t \sum_{s=0}^{\infty} (\beta\xi^x)^s \upsilon_{t+s}[\left(\left(\pi_t^x \pi_{t+1}^x ... \pi_{t+s-1}^x\right)^{\kappa_x} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_x} P_t^{x,new}\right) \times \\ \left(\tfrac{1}{P_{t+s}^x} \left(\pi_t^x \pi_{t+1}^x ... \pi_{t+s-1}^x\right)^{\kappa_x} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_x} P_t^{x,new}\right)^{-\frac{\lambda_{x,t+s}}{\lambda_{xt+s}-1}} \tilde{X}_{t+s} \\ -\tfrac{P_{t+s}}{S_{t+s}} \left(\tfrac{1}{P_{t+s}^x} \left(\pi_t^x \pi_{t+1}^x ... \pi_{t+s-1}^x\right)^{\kappa_x} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_x} P_t^{x,new}\right)^{-\frac{\lambda_{x,t+s}}{\lambda_{xt+s}-1}} \tilde{X}_{t+s} - \tfrac{P_{t+s}}{S_{t+s}} z_{t+s}\phi^x].\end{gathered} \tag{2.41}$$

The linearized first order condition of this problem implies that the aggregate export inflation is given by (noting that all export firms are alike in equilibrium)

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

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

Note that by letting $\kappa_x = 1$, this boils down to

$$\widehat{\pi}_t^x = \frac{\beta}{1+\beta}\mathrm{E}_t\widehat{\pi}_{t+1}^x + \frac{1}{1+\beta}\widehat{\pi}_{t-1}^x + \frac{(1-\xi^x)(1-\beta\xi^x)}{\xi^x(1+\beta)}\left(\widehat{mc}_t^x + \widehat{\lambda}_{x,t}\right).$$

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

$$C_t^x = \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} C_t^*, \tag{2.42}$$

where C_t^* and P_t^* is the foreign consumption and price level, respectively. We allow for the possibility that the elasticity of substitution between final consumption goods η_f may be different in the world economy than in the domestic economy (η_c). Also, notice that the specification in (2.42) allows for short run deviations from the law of one price which occur because export prices (in the local currency) are sticky. There is thus incomplete exchange rate pass-through in the foreign market.

Assuming that aggregate foreign investment also follows a CES function, foreign investment demand for the domestic good, I_t^x, is given by

$$I_t^x = \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} I_t^*, \tag{2.43}$$

where I_t^* is foreign investment, and where we allow for the elasticity of substitution between investment goods η_f to be different in the world economy than in the domestic economy (η_i). Notice that we assume that the elasticity is the same in (2.43) as in (2.42), in order to be able to use foreign output when log-linearizing the aggregate resource constraint.

2.2. Households

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

$$\mathrm{E}_0^j \sum_{t=0}^{\infty} \beta^t \left[\zeta_t^c U\left(C_{j,t} - bC_{j,t-1}\right) - \zeta_t^h L(h_{j,t}) + \zeta_t^q V\left(\frac{Q_{j,t}}{z_t P_t}\right)\right], \tag{2.44}$$

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

$$\begin{aligned}
\hat{\zeta}_t^c &= \rho_{\zeta^c}\hat{\zeta}_{t-1}^c + \varepsilon_{\zeta^c,t}, \\
\hat{\zeta}_t^h &= \rho_{\zeta^h}\hat{\zeta}_{t-1}^h + \varepsilon_{\zeta^h,t}, \\
\hat{\zeta}_t^q &= \rho_{\zeta^q}\hat{\zeta}_{t-1}^h + \varepsilon_{\zeta^q,t},
\end{aligned}$$

where $\mathrm{E}(\zeta_t^i) = 1$ and $\hat{\zeta}_t^i = (\zeta_t^i - 1)/1$, $i \in \{c, h, q\}$. We will refer to ζ_t^c as consumption preference shocks, ζ_t^h as labour supply shocks and ζ_t^q as household money demand shocks.

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

$$C_t = \left[(1-\omega_c)^{1/\eta_c}\left(C_t^d\right)^{(\eta_c-1)/\eta_c} + \omega_c^{1/\eta_c}\left(C_t^m\right)^{(\eta_c-1)/\eta_c}\right]^{\eta_c/(\eta_c-1)}, \tag{2.45}$$

where C_t^d and C_t^m are consumption of the domestic and imported good, respectively. ω_c is the share of imports in consumption, and η_c is the elasticity of substitution across consumption goods. By maximizing (2.45) subject to the budget constraint

$$P_t C_t^d + P_t^{m,c} C_t^m = P_t^c C_t,$$

we obtain the following consumption demand functions

$$\begin{aligned} C_t^d &= (1-\omega_c)\left[\frac{P_t}{P_t^c}\right]^{-\eta_c} C_t, \\ C_t^m &= \omega_c \left[\frac{P_t^{m,c}}{P_t^c}\right]^{-\eta_c} C_t, \end{aligned} \tag{2.46}$$

where the aggregate price index (the CPI) is given by

$$P_t^c = \left[(1-\omega_c)(P_t)^{1-\eta_c} + \omega_c (P_t^{m,c})^{1-\eta_c}\right]^{1/(1-\eta_c)}. \tag{2.47}$$

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

$$\begin{aligned} & M_{j,t+1} + S_t B_{j,t+1}^* + P_t^c C_{j,t}(1+\tau_t^c) + P_t^i I_{j,t} + P_t\left(a(u_{j,t})\overline{K}_{j,t} + P_{k',t}\Delta_t\right) \\ = & \\ & R_{t-1}(M_{j,t} - Q_{j,t}) + Q_{j,t} + \left(1-\tau_t^k\right)\Pi_t + (1-\tau_t^y)\frac{W_{j,t}}{1+\tau_t^w} h_{j,t} \\ & + \left(1-\tau_t^k\right) R_t^k u_{j,t}\overline{K}_{j,t} + R_{t-1}^* \Phi\left(\frac{A_{t-1}}{z_{t-1}}, \widetilde{\phi}_{t-1}\right) S_t B_{j,t}^* \\ & -\tau_t^k\left[(R_{t-1}-1)(M_{j,t}-Q_{j,t}) + \left(R_{t-1}^*\Phi\left(\frac{A_{t-1}}{z_{t-1}}, \widetilde{\phi}_{t-1}\right) - 1\right) S_t B_{j,t}^*\right] \\ & + TR_t + D_{j,t}, \end{aligned}$$

where the subscript j denotes household choice variables and upper-case variables without subscripts denote economy wide-averages. The terms on the LHS of the equality show how the household use their resources, while the terms on the RHS show what resources the households have at their disposal. $P_t^i I_{j,t}$ is nominal resources spent by the household on investment goods. All interest rates are expressed as gross rates, i.e. $R_t = 1 + r_t$. The households hold their financial wealth in form of cash balances, domestic bank deposits and foreign bonds. The household earns interest on the amount of its nominal domestic assets that are not held as cash, i.e. $M_{j,t} - Q_{j,t}$.[5] The interest rate they earn is R_{t-1}, since we think of the deposits paying out a nominal amount with certainty (i.e., it can be thought of as a zero coupon bond).[6] They can also save in foreign bonds, which pay a risk-adjusted pre-tax gross interest rate of $R^*_{t-1}\Phi(A_{t-1}/z_{t-1}, \widetilde{\phi}_{t-1})$.

Following Benigno (2001), the term $\Phi(\frac{A_t}{z_t}, \widetilde{\phi}_t)$ is a premium on foreign bond holdings, which depends on the real aggregate net foreign asset position of the domestic economy, defined as

$$A_t \equiv \frac{S_t B^*_{t+1}}{P_t}. \tag{2.48}$$

The function $\Phi(\frac{A_t}{z_t}, \widetilde{\phi}_t)$ is assumed to be strictly decreasing in A_t and satisfying $\Phi(0,0) = 1$. Consequently, this function captures imperfect integration in the international financial markets. If the domestic economy as a whole is a net borrower (so $B^*_{t+1} < 0$), domestic households are charged a premium on the foreign interest rate. If the domestic economy is a net lender ($B^*_{t+1} > 0$), households receive a lower remuneration on their savings. The introduction of this risk-premium is needed in order to ensure a well defined steady-state in the model. $\widetilde{\phi}_t$, in turn, is a time varying shock to the risk premium.

Rather than having the firms pay the adjustment costs of capital, they are paid by the households, which explains the presence of $a(u_t)P_t$ in the budget constraint. Here, $a(u)$ is the utilization cost function, with $a(1) = 0$, $u = 1$ and $a' = \left(1 - \tau^k\right) r^k$ in steady state, and $a'' \geq 0$. u_t is the utilization rate, that is $u_t = K_t/\bar{K}_t$. The presence of $P_{k',t}\Delta_t$ is to be able to compute the price of capital in the model. Notice that we will set ϕ so that profits, Π_t, are zero in steady state. τ^c_t is a consumption tax, τ^w_t is a pay-roll tax (assumed for simplicity to be paid by the households), τ^y_t is a labour income-tax, and τ^k_t is capital income-tax. TR_t are lump-sum transfers from the government and $D_{j,t}$ is the household's net cash income from participating in state contingent securities at time t.

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

$$\bar{K}_{t+1} = (1-\delta)\bar{K}_t + \Upsilon_t F(I_t, I_{t-1}) + \Delta_t \tag{2.49}$$

and is assumed to be identical for all households.[7] $F(I_t, I_{t-1})$ is a function which turns investment into physical capital. We will adopt the specification of Christiano, Eichenbaum and Evans (2001) and assume that

$$F(I_t, I_{t-1}) = \left(1 - \tilde{S}\left(I_t/I_{t-1}\right)\right) I_t \tag{2.50}$$

[5] Note that the end of period after-tax net interest income on funds deposited at the financial intermediary at the beginning of the period (i.e. $m_t - q_t$) is $\left(1 - \tau^k_t\right)(R_{t-1} - 1)(m_t - q_t)$ and that the resources for this type of assets that the household has at its disposal are $\left(1 - \tau^k_t\right)(R_{t-1} - 1)(m_t - q_t) + m_t$.

[6] To see this, assume that a zero coupon bond paying out B_{t+1} in period *t+1* can be bought at price $1/R_t$ in period t. The households pay a tax (τ^k_t) on the interest income from this bond. The following resource constraint must then hold for the bonds ; $\frac{B_{t+1}}{R_t} = B_t - \tau^k_t (R_{t-1} - 1)\frac{B_t}{R_{t-1}}$. Now define $\widetilde{B}_{t+1} = \frac{B_{t+1}}{R_t}$,which implies that this can be rewritten as $\widetilde{B}_{t+1} = \widetilde{B}_t R_{t-1} - \tau^k_t (R_{t-1} - 1)\widetilde{B}_t$, so the interest earnings of period *t+1* are known with certainty in period t (i.e., $\tau^k_{t+1}(R_t - 1)\frac{B_{t+1}}{R_t}$). This is not equivalent to, for example, Christiano et al. (2001) which assume $B_{t+1} = B_t R_t - \tau^k_t (R_t - 1) B_t$, since they think of the deposits as a risky asset where the nominal income in period *t+1* is unknown (R_{t+1} is not determined in period t).

[7] The variable, Δ_t, reflects that households have access to a market where they can purchase new, installed capital, $\bar{K}_{t+1}$. Households wishing to sell $\bar{K}_{t+1}$ are the only suppliers in this market, while households wishing to buy $\bar{K}_{t+1}$ are the only source of demand. Since all households are identical, the only equilibrium is one in which $\Delta_t = 0$. We nevertheless introduce this variable as a convenient way to define the price of capital, $P_{k',t}$. See Christiano, Eichenbaum and Evans (2001) for further details.

where the functional form of $\tilde{S}$ is given by

$$\tilde{S}(x) = g_3 \left\{ \exp\left[g_1(x-\mu_z)\right] + \frac{g_1}{g_2}\exp\left[-g_2(x-\mu_z)\right] - (1+\frac{g_1}{g_2}) \right\}. \tag{2.51}$$

Recalling that real investment grows at rate μ_z in the steady state, it follows from (2.51) that the investment adjustment costs in steady state have the properties

$$\begin{aligned} \tilde{S}(\mu_z) &= 0, \\ \tilde{S}'(\mu_z) &= g_1 g_3 \left\{\exp\left[g_1(\mu_z-\mu_z)\right] - \exp\left[-g_2(\mu_z-\mu_z)\right]\right\} = 0, \\ \tilde{S}''(\mu_z) &\equiv \tilde{S}'' = g_1 g_3 \left\{g_1+g_2\right\} > 0, \end{aligned}$$

since g_1, g_2 and g_3 are all positive constants. Note that only the parameter $\tilde{S}''$ is identified and will be used in the model. Moreover, (2.50) implies

$$\begin{aligned} F_1(I_t, I_{t-1}) &\equiv \frac{\partial F(I_t, I_{t-1})}{\partial I_t} = -\tilde{S}'(I_t/I_{t-1})I_t/I_{t-1} + \left(1-\tilde{S}(I_t/I_{t-1})\right), \qquad (2.52) \\ F_2(I_t, I_{t-1}) &\equiv \frac{\partial F(I_t, I_{t-1})}{\partial I_{t-1}} = \tilde{S}'(I_t/I_{t-1})\left(\frac{I_t}{I_{t-1}}\right)^2 \end{aligned}$$

so that, using (2.52), the following holds true in steady state:

$$\begin{aligned} F_1(I, I) &= -\tilde{S}'(\mu_z)\mu_z + \left(1-\tilde{S}(\mu_z)\right) = 1, \qquad (2.53) \\ F_2(I, I) &= \tilde{S}'(\mu_z)\mu_z^2 = 0. \end{aligned}$$

In (2.49), Υ_t is a stationary investment-specific technology shock, given by the following exogenous AR(1)-process

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

where $\hat{\Upsilon}_t = (\Upsilon_t - 1)/1$.[8]

In a similar way as in consumption, total investment is assumed to be given by a CES aggregate of domestic and imported investment goods (I_t^d and I_t^m, respectively) according to

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

where ω_i is the share of imports in investment, and η_i is the elasticity of substitution across investment goods. We assume that the prices of the domestically produced investment goods coincide with the prices of the domestically produced consumption goods, which implies the following investment demand functions

$$I_t^d = (1-\omega_i)\left[\frac{P_t}{P_t^i}\right]^{-\eta_i} I_t, \tag{2.54}$$

$$I_t^m = \omega_i\left[\frac{P_t^{m,i}}{P_t^i}\right]^{-\eta_i} I_t, \tag{2.55}$$

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

where the implicit investment price deflator P_t^i is given by

$$P_t^i = \left[(1-\omega_i)\,(P_t)^{1-\eta_i} + \omega_i \left(P_t^{m,i} \right)^{1-\eta_i} \right]^{1/(1-\eta_i)}. \quad (2.56)$$

By using (2.44), (2.48) and (2.49), households solve the following Lagrangian problem:

$$\max_{C_{j,t},M_{j,t+1},\Delta_t,\overline{K}_{j,t+1},I_{j,t},u_{j,t},Q_{j,t},B^*_{j,t+1},h_{j,t}} \mathrm{E}_0^j \sum_{t=0}^{\infty} \beta^t \left[\widetilde{L}_t \right].$$

$$\widetilde{L}_t = \left\{ \begin{array}{c} \left[\zeta_t^c U\left(C_{j,t} - bC_{j,t-1}\right) - \zeta_t^h L(h_{j,t}) + \zeta_t^q V(\frac{Q_{j,t}}{z_t P_t}) \right] \\ +\upsilon_t [R_{t-1}\left(M_{j,t} - Q_{j,t}\right) + Q_{j,t} + \left(1-\tau_t^k\right)\Pi_t + \left(1-\tau_t^y\right)\frac{W_{j,t}}{1+\tau_t^w} h_{j,t} \\ + \left(1-\tau_t^k\right) R_t^k u_{j,t}\overline{K}_{j,t} + R_{t-1}^* \Phi(a_{t-1},\widetilde{\phi}_{t-1}) S_t B_{j,t}^* \\ -\tau_t^k \left[(R_{t-1}-1)\left(M_{j,t} - Q_{j,t}\right) + \left(R_{t-1}^* \Phi(a_{t-1},\widetilde{\phi}_{t-1}) - 1 \right) S_t B_{j,t}^* \right] + TR_{j,t} + D_{j,t} \\ - \left(M_{j,t+1} + S_t B_{j,t+1}^* + P_t^c C_{j,t}\left(1+\tau_t^c\right) + P_t^i I_{j,t} + P_t \left(a(u_{j,t})\overline{K}_{j,t} + P_{k',t}\Delta_t \right) \right)] \\ +\omega_t [(1-\delta)\overline{K}_{j,t} + \Upsilon_t F(i_t, i_{t-1}) + \Delta_t - \overline{K}_{j,t+1}]\} \end{array} \right\}$$

We will now state the first-order conditions for the households' problem, where we make use of the fact that the households average (aggregate) choices coincide in equilibrium. To render stationarity of all variables, we need to divide all the volume variables with the trend level of technology z_t (see 2.12), and multiply the Lagrangian multiplier $\psi_t \equiv \upsilon_t P_t$ with it. Throughout the paper we let small letters indicate that a variable have been stationarized(i.e., real variables are stationarized as $x_t = \frac{X_t}{z_t}$), and for the multiplier, we introduce the notation $\psi_{z,t} \equiv z_t \psi_t$. After scaling with the technology level, and using the assumption that the $U\left(.\right)$, $L\left(.\right)$, and $V\left(.\right)$ functions are given by

$$\begin{aligned} U\left(.\right) &= \ln\left(.\right), \quad (2.57) \\ L\left(.\right) &= A_L \frac{\left(.\right)^{1+\sigma_L}}{1+\sigma_L}, \\ V\left(.\right) &= A_q \frac{\left(.\right)}{1-\sigma_q}^{1-\sigma_q} \end{aligned}$$

we obtain the following set of first-order conditions

$$\text{w.r.t. } c_t \quad : \quad \frac{\zeta_t^c}{c_t - bc_{t-1}\frac{1}{\mu_{z,t}}} - \beta b \mathrm{E}_t \frac{\zeta_{t+1}^c}{c_{t+1}\mu_{z,t+1} - bc_t} - \psi_{z,t}\frac{P_t^c}{P_t}\left(1+\tau_t^c\right) = 0, \tag{2.58}$$

$$\text{w.r.t. } m_{t+1} \quad : \quad -\psi_{z,t} + \beta \mathrm{E}_t\left[\frac{\psi_{z,t+1}}{\mu_{z,t+1}}\frac{R_t}{\pi_{t+1}} - \frac{1}{\mu_{z,t+1}}\frac{\psi_{z,t+1}}{\pi_{t+1}}\tau_{t+1}^k\left(R_t - 1\right)\right] = 0, \tag{2.59}$$

$$\text{w.r.t. } \Delta_t \quad : \quad -\psi_t P_{k',t} + \omega_t = 0, \tag{2.60}$$

$$\text{w.r.t. } \bar{k}_{t+1} \quad : \quad -P_{k',t}\psi_{z,t} + \beta \mathrm{E}_t\left[\frac{\psi_{z,t+1}}{\mu_{z,t+1}}\left(\begin{array}{c}(1-\delta)P_{k',t+1}\\ +\left(\left(1-\tau_{t+1}^k\right)r_{t+1}^k u_{t+1} - a\left(u_{t+1}\right)\right)\end{array}\right)\right] = 0, \tag{2.61}$$

$$\text{w.r.t. } i_t \quad : \quad \begin{array}{l}-\psi_{z,t}\frac{P_t^i}{P_t} + P_{k',t}\psi_{z,t}\Upsilon_t F_1(i_t, i_{t-1})\\ \quad + \beta \mathrm{E}_t\left[P_{k',t+1}\frac{\psi_{z,t+1}}{\mu_{z,t+1}}\Upsilon_{t+1}F_2(i_{t+1}, i_t)\right] = 0,\end{array} \tag{2.62}$$

$$\text{w.r.t. } u_t \quad : \quad \psi_{z,t}\left(\left(1-\tau_t^k\right)r_t^k - a'(u_t)\right) = 0, \tag{2.63}$$

$$\text{w.r.t. } q_t \quad : \quad \zeta_t^q A_q q_t^{-\sigma_q} - \left(1-\tau_t^k\right)\psi_{z,t}\left(R_{t-1} - 1\right) = 0, \tag{2.64}$$

$$\text{w.r.t. } b_{t+1}^* \quad : \quad -\psi_{z,t}S_t + \beta \mathrm{E}_t\left[\frac{\psi_{z,t+1}}{\mu_{z,t+1}}\frac{S_{t+1}}{\pi_{t+1}}\left(R_t^*\Phi(a_t, \widetilde{\phi}_t) - \tau_{t+1}^k\left(R_t^*\Phi(a_t, \widetilde{\phi}_t) - 1\right)\right)\right] = 0, \tag{2.65}$$

$$\text{w.r.t. } h_{j,t} \quad : \quad -\zeta_t^h A_L H_t^{\sigma_L} + \left(1-\tau_t^y\right)\psi_{z,t}\frac{\bar{w}_{j,t}}{1+\tau_t^w} = 0, \tag{2.66}$$

where the investment variables in the first-order condition associated with i_t has been scaled using the expression given by (2.52).[9] By combining the households' first order conditions for domestic and foreign bond holdings (2.59 and 2.65, respectively) we obtain, after log-linearization, the following modified uncovered interest rate parity condition:

$$\widehat{R}_t - \widehat{R}_t^* = \frac{\pi\mu_z}{\pi\mu_z - \tau^k\beta}\mathrm{E}_t\Delta\widehat{S}_{t+1} - \widetilde{\phi}\widehat{a}_t + \widehat{\widetilde{\phi}}_t. \tag{2.67}$$

Since the capital tax initiates that $\frac{\pi\mu_z}{\pi\mu_z-\tau^k\beta} > 1$, this interest rate parity condition is slightly different compared to the standard case without taxes. The tax on capital income causes the households to require an extra interest rate premium on their domestic bond holdings. The reason is that there is no tax paid on expected exchange rate profits. Consequently, when the exchange rate is expected to depreciate the households anticipate larger gains from holding foreign bonds compared to holding domestic bonds since the *effective* tax rate differs between these positions. To make the expected earnings on the domestic and foreign bond holdings equivalent, the domestic-foreign interest rate differential must thus be larger than one when the capital tax is positive.

2.2.1. Wage setting equation

Each household is a monopoly supplier of a differentiated labour service requested by the domestic firms. This implies that the households can determine their own wage. In modeling this wage equation we follow Erceg et al. (2000) and Christiano et al. (2001), and introduce wage stickiness à la Calvo. The household sells its labour ($h_{j,t}$) to a firm which transforms household labour into a homogeneous

[9]Notice that, with the exception of b_{t+1}^*, all first order conditions above coincide with those reported in the technical appendix to Altig et al. (2003) when the tax-rates equal nil and when relative prices $\frac{P_t^c}{P_t}$, $\frac{P_t^i}{P_t}$ for consumption and investment equal unity.

input good H using the following production function:

$$H_t = \left[\int_0^1 (h_{j,t})^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w}, \ 1 \leq \lambda_w < \infty, \tag{2.68}$$

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

$$h_{j,t} = \left[\frac{W_{j,t}}{W_t} \right]^{\frac{\lambda_w}{1-\lambda_w}} H_t. \tag{2.69}$$

In every period each household face a random probability $1 - \xi_w$ that she can change her nominal wage. The j^{th} household's reoptimized wage is set to $W_{j,t}^{new}$, taking into account the probability ξ_w that the wage will not be reoptimized in the future. The households that can not reoptimize set their wages according to

$$W_{j,t+1} = (\pi_t^c)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \right)^{(1-\kappa_w)} \mu_{z,t+1} W_{j,t}^{new},$$

where

$$\mu_{z,t+1} = \frac{z_{t+1}}{z_t}.$$

Consequently, the non-optimizing households index their wage rate to last period's CPI inflation rate, the current inflation target, as well as adding a technology growth factor to their wage. The wage in period $t+s$ is $W_{j,t+s} = \left(\pi_t^c ... \pi_{t+s-1}^c \right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c ... \bar{\pi}_{t+s}^c \right)^{(1-\kappa_w)} \left(\mu_{z,t+1} ... \mu_{z,t+s} \right) W_{j,t}^{new}$. The j^{th} household that can reoptimize its wage faces the following optimization problem (where irrelevant terms have been neglected in the household's objective function (2.57))

$$\max_{W_{j,t}^{new}} \quad \mathrm{E}_t \sum_{s=0}^{\infty} (\beta \xi_w)^s \left[\begin{array}{c} -\zeta_{t+s}^h L(h_{j,t+s}) + \upsilon_{t+s} \frac{\left(1-\tau_{t+s}^y\right)}{\left(1+\tau_{t+s}^w\right)} \times \\ \left(\left(\pi_t^c ... \pi_{t+s-1}^c \right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c ... \bar{\pi}_{t+s}^c \right)^{(1-\kappa_w)} \left(\mu_{z,t+1} ... \mu_{z,t+s} \right) W_{j,t}^{new} \right) h_{j,t+s} \end{array} \right]. \tag{2.70}$$

Inserting the relevant expressions for $h_{j,t+s}$ in the optimization problem above yields the following first order condition

$$\mathrm{E}_t \sum_{s=0}^{\infty} (\xi_w \beta)^s h_{j,t+s} \left[\frac{W_t^{new}}{z_t P_t} \frac{z_{t+s} \upsilon_{t+s} P_{t+s}}{\lambda_w} \frac{\left(1-\tau_{t+s}^y\right)}{\left(1+\tau_{t+s}^w\right)} \frac{\left(\frac{P_{t+s-1}^c}{P_{t-1}^c} \right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c ... \bar{\pi}_{t+s}^c \right)^{(1-\kappa_w)}}{\frac{P_{t+s}^d}{P_t^d}} + \zeta_{t+s}^h L^{'} \left(h_{j,t+s} \right) \right] = 0, \tag{2.71}$$

which is the Euler equation for the wage rate, and where $L^{'}\left(h_{j,t+s}\right)$ is the marginal disutility of labour. When wages are fully flexible ($\xi_w = 0$), the real wage is set as a markup λ_w over the current ratio of the marginal disutility of labour and the marginal utility of additional income. Note also that $\xi_w = 0$ implies that the households' wage decision is equivalent to the first order condition for their choice of labour input.

2.3. Government

The government budget constraint in this economy equals

$$\begin{aligned} P_t G_t + TR_t \quad = \quad & R_{t-1} \left(M_{t+1} - M_t \right) + \tau_t^c P_t^c C_t + \frac{\left(\tau_t^y + \tau_t^w\right) W_t}{1 + \tau_t^w} H_t + \\ & \tau_t^k \left[\left(R_{t-1} - 1 \right) \left(M_t - Q_t \right) + R_t^k u_t \bar{K}_t + \left(R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_{t-1}) - 1 \right) S_t B_t^* + \Pi_t \right], \end{aligned}$$

and accordingly TR_t has the interpretation of a budget deficit. Consequently, there is no government debt, but as long as the households and the government pay the same interest rate, this has no consequence for the dynamics in this economy. One way to understand that (2.72) is correct is to insert it into the households budget constraint (2.48, evaluated at the aggregate level), which implies that all the tax-terms except $P_t G_t$ and $R_{t-1}(M_{t+1} - M_t)$ will cancel as they should.

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

$$\Gamma_0 \tau_t = \Gamma(L)\,\tau_{t-1} + \varepsilon_{\tau,t},\ \varepsilon_{\tau,t} \sim N(0, \Sigma_\tau) \tag{2.72}$$

When estimating this process in the data, we tested whether we could reject the assumption that the off-diagonal terms in Γ_0 were zero. Since we could not reject this hypothesis, we are able to identify the various fiscal policy shocks and separate their different effects. We are thus able to study the effects of a disturbance to a particular fiscal policy variable, not just assessing their total importance for how the economy evolves.

2.4. More open economy aspects

We will now discuss the various stationary relative prices that enter in the model. There are two different types of *domestic* relative prices. One is defined in terms of the imported consumption goods and one in terms of the investment goods. That is, the relative prices between domestic goods and imported consumption, or investment, goods perceived by the domestic agents. The two (domestic) relative prices occur since the domestic agents face different prices on the imported consumption goods and the imported investment goods;

$$\gamma_t^{mc,d} \equiv \frac{P_t^{m,c}}{P_t}, \tag{2.73}$$

$$\gamma_t^{mi,d} \equiv \frac{P_t^{m,i}}{P_t}. \tag{2.74}$$

There is also the relative price between the domestically produced goods (home exports) and the foreign goods;

$$\gamma_t^{x,*} \equiv \frac{P_t^x}{P_t^*}, \tag{2.75}$$

which is the relative price observed by the foreign agents (as well as the domestic exporters). Deviations from the law of one price for the export goods are given by

$$mc_t^x \equiv \frac{P_t}{S_t P_t^x}. \tag{2.76}$$

We can then make use of the above to define the following relative prices which are used by the exporting and importing firms

$$\begin{aligned} \gamma_t^f &\equiv \frac{P_t}{S_t P_t^*} \\ &= mc_t^x \gamma_t^{x,*}. \end{aligned} \tag{2.77}$$

$$
\begin{aligned}
mc_t^{m,c} &\equiv \frac{S_t P_t^*}{P_t^{m,c}} \\
&= \frac{1}{\left(\gamma_t^f\right)\left(\gamma_t^{mc,d}\right)} \\
&= \frac{1}{\left(mc_t^x \gamma_t^{x,*}\right)\left(\gamma_t^{mc,d}\right)}
\end{aligned} \tag{2.78}
$$

$$
\begin{aligned}
mc_t^{m,i} &\equiv \frac{S_t P_t^*}{P_t^{m,i}} \\
&= \frac{1}{\left(\gamma_t^f\right)\left(\gamma_t^{mi,d}\right)} \\
&= \frac{1}{\left(mc_t^x \gamma_t^{x,*}\right)\left(\gamma_t^{mi,d}\right)}
\end{aligned} \tag{2.79}
$$

2.5. The central bank

The policy maker is assumed to adjust the short run interest rate in response to deviations of CPI inflation from the inflation target $\left(\hat{\pi}^c - \widehat{\bar{\pi}}^c\right)$, the output gap $(\hat{y})$ and the real exchange rate $(\hat{x})$. We allow for some persistence (ρ_R) to make the instrument rule consistent with the empirical data. In addition, note that the nominal interest rate adjusts directly to the inflation target, so that an increase in the target raises the nominal interest rate.

Based on the estimation results of simple OLS regressions and following Smets and Wouters (2003a), monetary policy is approximated with the following instrument rule

$$
\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left(\widehat{\bar{\pi}}_t^c + r_\pi\left(\hat{\pi}_{t-1}^c - \widehat{\bar{\pi}}_t^c\right) + r_y \hat{y}_{t-1} + r_x \hat{x}_{t-1}\right) + r_{\Delta\pi}\Delta\hat{\pi}_t^c + r_{\Delta y}\Delta\hat{y}_t + \varepsilon_{R,t} \tag{2.80}
$$

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

$$
\hat{x}_t = \Delta\hat{S}_t + \hat{\pi}_t^* - \hat{\pi}_t^c + \hat{x}_{t-1} = -\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} - \hat{\gamma}_t^{x,*} - \widehat{mc}_t^x.
$$

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

$$
\hat{\pi}_t^c = \left((1-\omega_c)\left(\gamma^{d,c}\right)^{1-\eta_c}\right)\hat{\pi}_t^d + \left((\omega_c)\left(\gamma^{mc,c}\right)^{(1-\eta_c)}\right)\hat{\pi}_t^{m,c}. \tag{2.81}
$$

$\widehat{\bar{\pi}}_t^c$ is a time-varying inflation target and $\varepsilon_{R,t}$ is an interest rate shock. We will refer to the first as an inflation target shock and the latter as a monetary policy shock. The inflation target follows the process

$$
\bar{\pi}_t^c = (1-\rho_\pi)\bar{\pi} + \rho_\pi \bar{\pi}_{t-1}^c + \varepsilon_{\widehat{\bar{\pi}}^c,t}, \tag{2.82}
$$

which in its log-linearized version is

$$
\widehat{\bar{\pi}}_t^c = \rho_\pi \widehat{\bar{\pi}}_{t-1}^c + \varepsilon_{\widehat{\bar{\pi}}^c,t}. \tag{2.83}
$$

2.6. Market clearing conditions

In equilibrium the final goods market, the loan market, the bond market and the labour market must clear. The final goods market (for consumption and investment goods) clears when the demand from the households, the government and the foreign market can be met by the production of the intermediate domestic firms. The loan market, in turn, clears when the demand for liquidity from the firms (financing their wage bills) equals the supplied deposits of the households. The foreign bond market is in equilibrium when the positions of the export and importing firms equals the households' choice of foreign bond holdings. Lastly, after having set their wages, the households inelastically supply the firms' demand for labour at the going wage rate.

2.6.1. The aggregate resource constraint

The equilibrium resource constraint from the production perspective follows

$$C_t^d + I_t^d + G_t + C_t^x + I_t^x \leq \epsilon_t z_t^{1-\alpha} K_t^{\alpha} H_t^{1-\alpha} - z_t\phi - a(u_t)\bar{K}_t \tag{2.84}$$

where u_t is the utilization rate (i.e. $u_t = K_t/\bar{K}_t$), K_t capital services, and $\overline{K}_t$ physical capital. By substituting (2.46), (2.42), (2.54) and (2.43) into (2.84) , we obtain

$$(1-\omega_c)\left[\frac{P_t^c}{P_t^d}\right]^{\eta_c} c_t + (1-\omega_i)\left[\frac{P_t^i}{P_t^d}\right]^{\eta_i} i_t + g_t + \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} y_t^* \frac{z_t^*}{z_t} \leq \epsilon_t \left(\frac{1}{\mu_{z,t}}\right)^{\alpha} k_t^{\alpha} H_t^{1-\alpha} - \phi - a(u_t)\bar{k}_t \frac{1}{\mu_{z,t}}, \tag{2.85}$$

where we have introduced the notation that $Y_t^* = C_t^* + I_t^*$, scaled K_t and $\bar{K}_t$ with z_{t-1}, and stationarized the other real variables with z_t. Note that Y_t^* has been scaled with z_t^* which is the reason why $\frac{z_t^*}{z_t}$ appears in the formula. Suppose that z_t^* follows a similar process as z_t. Then we have that $\frac{z^*}{z} = 1$ in steady state even if $\mu_z < \mu_z^*$ (since $\Sigma_{i=0}^{\infty}\mu_{z,-i}^*/\Sigma_{i=0}^{\infty}\mu_{z,-i} = \infty/\infty$). This implies that the long-term steady-state growth rate in the foreign economy can be higher than in the domestic economy (but not the converse, of course, because then the domestic open economy would be the only economy in steady state). However, we will maintain the assumption throughout the analysis that $\mu_z = \mu_z^*$, and treat $\tilde{z}_t^* = \frac{z_t^*}{z_t}$ as a stationary shock which measures the degree of asymmetry in the technological progress in the domestic economy versus the rest of the world. We assume that this relative technology shock follows the process (log-linearized, note $\tilde{z}^* = 1$ by assuming $z_0^* = z_0 = 1$)

$$\widehat{\tilde{z}}_{t+1}^* = \rho_{\tilde{z}^*}\widehat{\tilde{z}}_t^* + \varepsilon_{\tilde{z}^*,t+1}. \tag{2.86}$$

Totally differentiating equation (2.85) and evaluating in steady state, we obtain

$$\begin{aligned}
&(1-\omega_c)\left(\gamma^{c,d}\right)^{\eta_c} c\left(\frac{dc_t}{c} + \eta_c\frac{d\gamma_t^{c,d}}{\gamma^{c,d}}\right) + (1-\omega_i)\left(\gamma^{i,d}\right)^{\eta_i} i\left(\frac{di_t}{i} + \eta_i\frac{d\gamma_t^{i,d}}{\gamma^{i,d}}\right)\\
&+g\frac{dg_t}{g} + \left(\gamma^{x,*}\right)^{-\eta_f} y^*\left(\frac{dy_t^*}{y^*} - \eta_f\frac{d\gamma_t^{x,*}}{\gamma^{x,*}} + \frac{d\tilde{z}_t^*}{\tilde{z}^*}\right)\\
=&\\
&\left(\frac{1}{\mu_z}\right)^{\alpha} k^{\alpha}H^{1-\alpha}\left(d\epsilon_t - \alpha\frac{d\mu_{z,t}}{\mu_z} + \alpha\frac{dk_t}{k} + (1-\alpha)\frac{dH_t}{H}\right)\\
&-a'(u)du_t\bar{k}\frac{1}{\mu_z} + a(u)d\bar{k}_t\frac{1}{\mu_z} - a(u)\bar{k}\frac{1}{\mu_z}\frac{d\mu_{z,t}}{\mu_z},
\end{aligned}$$

where we note that $(\gamma^{x,*})^{-\eta_f} y^* = y^*$ equals the value of export in steady state (since $\gamma^{x,*} = 1$ in steady state). If we make use of that and the following relationships

$$\begin{aligned}
\left(\frac{1}{\mu_z}\right)^{\alpha} k^{\alpha} H^{1-\alpha} &= y + \phi = y + (\lambda_f - 1) y = \lambda_f y, \\
a(u) &= 0, \\
a'(u) &= \left(1 - \tau^k\right) r^k, \\
\hat{u}_t &= du_t = \hat{k}_t - \hat{\bar{k}}_t, \\
d\epsilon_t &= \hat{\epsilon}_t,
\end{aligned}$$

and introduce the notation $\hat{x}_t = dx_t / x$, we can, after dividing through with y, rewrite the log-linearized resource constraint as

$$\begin{aligned}
& (1-\omega_c)\left(\gamma^{c,d}\right)^{\eta_c} \frac{c}{y}\left(\hat{c}_t + \eta_c \widehat{\gamma}_t^{c,d}\right) + (1-\omega_i)\left(\gamma^{i,d}\right)^{\eta_i} \frac{i}{y}\left(\hat{\imath}_t + \eta_i \widehat{\gamma}_t^{i,d}\right) \\
& + \frac{g}{y}\hat{g}_t + \frac{y^*}{y}\left(\hat{y}_t^* - \eta_f \widehat{\gamma}_t^{x,*} + \hat{\tilde{z}}_t^*\right) \\
= \; & \lambda_f\left(\hat{\epsilon}_t + \alpha\left(\hat{k}_t - \hat{\mu}_{z,t}\right) + (1-\alpha)\hat{H}_t\right) - \left(1-\tau^k\right) r^k \frac{\bar{k}}{y}\frac{1}{\mu_z}\left(\hat{k}_t - \hat{\bar{k}}_t\right).
\end{aligned} \tag{2.87}$$

2.6.2. Evolution of net foreign assets

The evolution of net foreign assets at the aggregate level satisfies

$$S_t B_{t+1}^* = S_t P_t^x \left(C_t^x + I_t^x\right) - S_t P_t^* \left(C_t^m + I_t^m\right) + R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_{t-1}) S_t B_t^*, \tag{2.88}$$

where we notice that $R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_t)$ is the risk-adjusted gross nominal interest rate. Note that the definition of a_t is given by

$$a_t \equiv \frac{S_t B_{t+1}^*}{P_t z_t}.$$

Multiplying through with $1/(P_t z_t)$, we obtain

$$\frac{S_t B_{t+1}^*}{P_t z_t} = \frac{S_t P_t^x}{P_t}\left(\frac{C_t^x}{z_t} + \frac{I_t^x}{z_t}\right) - \frac{S_t P_t^*}{P_t}\left(\frac{C_t^m}{z_t} + \frac{I_t^m}{z_t}\right) + R_{t-1}^* \Phi(a_{t-1}, \widetilde{\phi}_{t-1}) \frac{S_{t-1} B_t^*}{P_{t-1} z_{t-1}} \frac{S_t P_{t-1} z_{t-1}}{S_{t-1} P_t z_t}.$$

Note that there are deviations from the law of one price for the export and import goods. Note also that $\tilde{x}_t = \frac{C_t^x}{z_t} + \frac{I_t^x}{z_t} = \left[\frac{P_t^x}{P_t^*}\right]^{-\eta_f} \frac{Y_t^*}{z_t^*}\frac{z_t^*}{z_t}$. Using this, and our definition of a_t, we have

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

where we allow for an asymmetric technology shock $\tilde{z}_t^* = \frac{z_t^*}{z_t}$ (see the discussion in the subsection above), and where $mc_t^x = \frac{P_t}{S_t P_t^x}$. Totally differentiating this expression, and evaluating in the steady state where $a = 0$, $\Phi(0,0) = 1$, $R^* = R$, $\frac{\bar{S}_t}{\bar{S}_{t-1}} = 1$, $\gamma^f = \frac{P}{SP^*} = 1$, $mc^x = \frac{P}{SP^x} = \frac{P}{S(P/S)} = 1$, and

$\gamma^{x,*} = \frac{P^x}{P^*} = \frac{P}{SP^*} = 1$, we derive the log-linearized equation for net foreign assets as

$$\begin{aligned} \hat{a}_t &= -y^* \widehat{mc}_t^x - \eta_f y^* \hat{\gamma}_t^{x,*} + y^* \hat{y}_t^* + y^* \widehat{\tilde{z}}_t^* \\ &\quad + (c^m + i^m) \hat{\gamma}_t^f \\ &\quad - \left(\begin{array}{c} c^m \left(-\eta_c (1-\omega_c) \left(\gamma^{c,d}\right)^{-(1-\eta_c)} \widehat{\gamma}_t^{mc,d} + \widehat{c}_t \right) + \\ i^m \left(-\eta_i (1-\omega_i) \left(\gamma^{i,d}\right)^{-(1-\eta_i)} \widehat{\gamma}_t^{mi,d} + \widehat{i}_t \right) \end{array} \right) + \frac{R}{\pi \mu_z} \hat{a}_{t-1}, \end{aligned}$$

where we have used the expressions for $\hat{c}_t^m$ and $\hat{i}_t^m$.

2.6.3. Loan market clearing

We also have the money market clearing condition, which reads

$$\nu_t W_t H_t = \mu_t M_t - Q_t, \tag{2.89}$$

or equivalently, in its stationarized form,

$$\nu_t \bar{w}_t H_t = \frac{\mu_t \bar{m}_t}{\pi_t \mu_{z,t}} - q_t.$$

Totally differentiating this expression, we have

$$\nu \bar{w} H \left(\hat{\nu}_t + \widehat{\bar{w}}_t + \hat{H}_t \right) = \frac{\mu \bar{m}}{\pi \mu_z} \left(\hat{\mu}_t + \widehat{\bar{m}}_t - \hat{\pi}_t - \hat{\mu}_{z,t} \right) - q \hat{q}_t,$$

which is the log-linearized loan market clearing condition.

2.6.4. Definitional equation for money growth

We also have a definitional equation for money growth, which is given by

$$\mu_t = \frac{M_{t+1}}{M_t} = \frac{\bar{m}_{t+1} z_t P_t}{\bar{m}_t z_{t-1} P_{t-1}} = \frac{\bar{m}_{t+1} \mu_{z,t} \pi_t}{\bar{m}_t}$$

where we notice that π_t is the gross inflation rate. Log-linearizing this expression, we have

$$\hat{\mu}_t - \hat{m}_{t+1} - \hat{\mu}_{z,t} - \hat{\pi}_t + \hat{m}_t = 0. \tag{2.90}$$

2.7. Foreign economy

Let $X_t^* \equiv \left[\begin{array}{ccc} \pi_t^* & \hat{y}_t^* & R_t^* \end{array} \right]'$ where π_t^* and R_t^* are quarterly foreign inflation and interest rates, and $\hat{y}_t^*$ foreign HP-filtered output. As a first step, we model the foreign economy as a VAR model following Lindé (2003),[10]

$$F_0 X_t^* = F(L) X_{t-1}^* + \varepsilon_{x^*,t}, \qquad \varepsilon_{x^*,t} \sim N\left(0, \Sigma_{x^*}\right). \tag{2.91}$$

In a similar way as for the fiscal policy VAR model, we will test if F_0 has the following structure

$$\left[\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\gamma_\pi^* & -\gamma_y^* & 1 \end{array} \right]$$

[10] At a later stage, we can perhaps represent the world economy with a closed-economy version of the model outlined above.

when taking the foreign VAR to the data. The above structure of F_0 is equivalent of assuming predetermined expectations in the the Phillips and output equation. Empirically, we cannot reject this structure of F_0, and hence we can identify the structural shocks to the three foreign variables from the reduced form VAR residuals, and are thus able to determine the effects of a specific foreign shock.

3. Solving the model

First, we compute the non-stochastic steady state of the model. This is described in Appendix A, where details about the determination of the steady state can be found. Second, we log-linearize the relevant first order conditions and the market clearing conditions around this steady state. Appendix B presents all the equations of the log-linearized model. To solve the log-linearized model we use the AIM algorithm developed by Anderson and Moore (1985). The fundamental difference equation solved by the Anderson and Moore algorithm for this model can be written as

$$\mathrm{E}_t \left\{ \alpha_0 \tilde{z}_{t+1} + \alpha_1 \tilde{z}_t + \alpha_2 \tilde{z}_{t-1} + \beta_0 \theta_{t+1} + \beta_1 \theta_t \right\} = 0, \tag{3.1}$$

where $\tilde{z}_t$ is a $n_{\tilde{z}} \times 1$ vector with endogenous variables and θ_t is a $n_\theta \times 1$ vector with exogenous variables which follows

$$\theta_t = \rho \theta_{t-1} + \varepsilon_t. \tag{3.2}$$

Note that if the processes for the exogenous variables are given by more than one lag, we expand θ_t with lags of the relevant exogenous variable.

The solution of the fundamental difference equation can then be written as

$$\tilde{z}_t = A \tilde{z}_{t-1} + B \theta_t \tag{3.3}$$

where A is the "feedback" matrix and B is the "feedforward" matrix.

4. Data

To estimate the model we use quarterly euro area for the period 1970:1-2002:4.[11] The data set we employ was first constructed by Fagan et al. (2001). We have chosen to match the following set of variables, the GDP deflator, the real wage, consumption, investment, the real exchange rate, the short-run interest rate, employment, GDP, exports, imports, the consumption deflator, the investment deflator, foreign output, foreign inflation and the foreign interest rate. To calculate the likelihood function of the observed variables we apply the Kalman filter.[12] As in Altig et al. (2003) the theoretical

[11] We use the period 1970:1-1979:4 to compute a good guess of the state for the unobserved variables, and then use the sample 1980:1-2002:4 to form the likelihood function.

[12] The solution of the model given by (3.3) can be transformed to the following state-space representation for the unobserved state variables ξ_t in the model

$$\xi_{t+1} = F_\xi \xi_t + v_{t+1}, \ \mathrm{E}\left(v_{t+1} v_{t+1}'\right) = Q,$$

and the observation equation can be written

$$\tilde{Y}_t = A_X' X_t + H' \xi_t + \zeta_t,$$

where $\tilde{Y}_t$ is a vector of observed variables, X_t a vector with exogenous or predetermined variables (e.g., a constant) and where the measurement errors ζ_t are assumed to follow

$$\zeta_t = M \zeta_{t-1} + u_t, \ \mathrm{E}\left(u_t u_t'\right) = R.$$

model economy evolves along a stochastic growth path. The non-stationary technology shock thus induces a trend in the real variables of the model. To make these variables stationary in the measured data we use first differences and derive the state space representation for the following vector of observed variables

$$\tilde{Y}_t = \begin{matrix} [& \pi_t^d & \Delta\ln(W_t/P_t) & \Delta\ln C_t & \Delta\ln I_t & x_t & R_t & \tilde{E}_t & \Delta\ln Y_t ... \\ & & \Delta\ln\tilde{X}_t & \Delta\ln\tilde{M}_t & \pi_t^{def,c} & \pi_t^{def,i} & \Delta\ln Y_t^* & \pi_t^* & R_t^* \ ]'. \end{matrix} \tag{4.1}$$

In comparison with the previous literature, we have chosen to work with a large number of variables, in order to be able to identify the estimated parameters in a satisfactory way.[13]

For the euro area there is no (official) data on aggregate hours worked, H_t. Due to these data limitations we use employment E_t in our empirical estimations. Since employment is likely to respond more slowly to shocks than hours worked, which is an entirely flexible variable, we model employment using Calvo-rigidity (see also Smets and Wouters (2003a)). We assume that only a fraction $(1-\xi_e)$ of the firms can adjust the level of employment to the preferred amount of total labour input. The rest of the firms ξ_e are forced to keep the level of employment they had in the last period, $E_{i,t+1} = E_{i,t}^{new}$. The difference is taken up by each worker's labour input (unobserved hours per worker). That is, each worker supplies its labour inelastically after having set his or her wage. The aggregate employment equation then follows[14]

Following Hamilton (1994), the Kalman updating equations are given by

$$\begin{aligned} \xi_{t+1|t} &= F_\xi \xi_{t|t-1} + F_\xi P_{t|t-1} H \left(H' P_{t|t-1} H + R\right)^{-1} \left(\tilde{Y}_t - A_X' X_t - H'\xi_{t|t-1}\right), \\ P_{t+1|t} &= F_\xi P_{t|t-1} F_\xi' - F_\xi P_{t|t-1} H \left(H' P_{t|t-1} H + R\right)^{-1} H' P_{t|t-1} F_\xi' + Q, \end{aligned}$$

and the log-likelihood is computed as

$$\ln L = -\frac{Tn}{2}\log 2\pi - \frac{1}{2}\sum_{t=1}^{T}\log|\Sigma_t| - \frac{1}{2}\sum_{t=1}^{T}\left(\tilde{Y}_t - A_X' X_t - H'\xi_{t|t-1}\right)' \Sigma_t^{-1}\left(\tilde{Y}_t - A_X' X_t - H'\xi_{t|t-1}\right)$$

where $\Sigma_t = H' P_{t|t-1} H + R$. In the current draft of the paper, we use $M = 0$ and set $R = 0.10$ for all "domestic" variables and $R = 0$ for the foreign variables. We allow R to be non-zero for the domestic variables because we know that the data series at hand are only at best good approximations of the true series for the domestic variables. This is true in particular for the "open-economy" variables included in $\tilde{Y}_t$, because the data does not distinguish between intra- and inter-trade. However, it should be emphazied that our choosen value of 0.10 is very small, so the fluctuations driven by the measurement errors will be tiny.

[13]We have also experimented with an alternative strategy which exploit the fact that the real variables contain the same trend as output (i.e., they grow at $\mu_{z,t}$). By allowing for cointegration relations in the measured data one does not discard any information. In this case the observed vector is as follows

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

As the inflation rates, nominal interest rates, employment, and the real exchange rate are all stationary variables, this makes the entire of $\tilde{Y}_t$ stationary. The estimation results for the model with this vector of observable variables are very similar to the ones reported on the Tables. [**We should perhaps consider reporting benchmark estimation results for this alternative strategy.**]

[14]We assume that firm i faces the following problem

$$\min_{E_{i,t}^{new}} \quad \sum_{s=0}^{\infty} (\beta\xi_e)^s \left(nE_{i,t}^{new} - H_{i,t+s}\right)^2.$$

By log-linearizing the first order condition of this optimization problem and combining that with the log-linearized employment aggregator, we obtain the aggregate employment equation in the main text.

$$\Delta\hat{E}_t = \beta \mathrm{E}_t \Delta\hat{E}_{t+1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{\xi_e}\left(\hat{H}_t - \hat{E}_t\right). \tag{4.2}$$

We have adjusted the raw data for three series. First, there is an upward trend in the employment series for the euro area, presumably reflecting an increasing degree of part-time employment. Since hours worked (and employment) is a stationary variable in the model, we decided to remove a linear trend in this variable prior to estimation. Second, the share of import and export to output are increasing during the sample, increasing from about 0.15 to 0.36 during the sample period. Although these numbers are distorted by the fact that a part of this increase reflect intra-euro trade, they also convey a clear pattern of increasing trade. In our model, import and export are assumed to grow at the same rate as output. Therefore, we decided to remove the excessive trend of import and export in the data, to render the export and import shares stationary.[15]

For all other variables in (4.1), we use the actual series (seasonally adjusted with the X12-method). It should be pointed out that the stationary variables x_t and $\tilde{E}_t$ are measured as deviations around a constant mean, i.e. $z_t = (z_t - z)/z$.

4.1. Data considerations

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

$$Y_t = \tilde{C}_t + \tilde{I}_t + G_t + \tilde{X}_t - \tilde{M}_t, \tag{4.3}$$

where we have that

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

In the theoretical model, we have the following aggregate production resource constraint

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

which can be rearranged as

$$\left(C_t^d + C_t^m\right) + \left(I_t^d + I_t^m\right) + G_t + C_t^x + I_t^x - (C_t^m + I_t^m) \leq \epsilon_t z_t^{1-\alpha} K_t^\alpha H_t^{1-\alpha} - z_t\phi - a(u_t)\bar{K}_t. \tag{4.4}$$

Our starting point for measurement are the resource constraints in the theoretical model (4.4) and in the data (4.3). Given that we work with open economy data we must take into account that we, for example, observe $\tilde{C}_t \equiv C_t^d + C_t^m$ in the data but have C_t (which is a CES aggregate of the two sub-components, C_t^d and C_t^m) in our theoretical model. Consequently, we must adjust C_t with the appropriate relative prices. Using the demand schedules (2.46 and 2.46) from the consumption CES function we we have that

$$\tilde{C}_t = C_t^d + C_t^m = \left((1-\omega_c)\left[\frac{P_t^d}{P_t^c}\right]^{-\eta_c} + \omega_c\left[\frac{P_t^{m,c}}{P_t^c}\right]^{-\eta_c}\right) C_t. \tag{4.5}$$

[15] One potential answer in our model as to why we observe these strong increases in the import and export shares is that the weights of foreign consumption/investment in the consumption/investment bundles, i.e. ω_c/ω_i, are increasing over time.

Similarly, investment is given by

$$\tilde{I}_t = I_t^d + I_t^m = \left((1-\omega_i) \left[\frac{P_t^d}{P_t^i} \right]^{-\eta_i} + \omega_i \left[\frac{P_t^{m,i}}{P_t^i} \right]^{-\eta_i} \right) I_t. \tag{4.6}$$

Total imports are given by

$$\tilde{M}_t = C_t^m + I_t^m = \omega_c \left[\frac{P_t^{m,c}}{P_t^c} \right]^{-\eta_c} C_t + \omega_i \left[\frac{P_t^{m,i}}{P_t^i} \right]^{-\eta_i} I_t, \tag{4.7}$$

while exports are defined as

$$\tilde{X}_t = C_t^x + I_t^x = \left[\frac{P_t^x}{P_t^*} \right]^{-\eta_f} Y_t^*. \tag{4.8}$$

We must also take into account that we have capital utilization costs in our theoretical model. Because of these adjustment costs, the GDP identity in the theoretical model is not directly comparable with the data, as can be seen from (4.4) and (4.3). Since the adjustment costs tends to be cyclical, we have chosen to add the adjustment costs to investment, instead of interpreting them as the residual in the real GDP identity in the data. Output is then given by

$$Y_t = \epsilon_t z_t^{1-\alpha} K_t^\alpha H_t^{1-\alpha} - z_t \phi. \tag{4.9}$$

The nominal GDP identity in the data is given by

$$P_t Y_t = (1+\tau_t^c) \left(P_t C_t^d + P_t^{m,c} C_t^m \right) + \left(P_t I_t^d + P_t^{m,i} I_t^m \right) + P_t G_t + (P_t^x C_t^x + P_t^x I_t^x) - \left(P_t^{m,c} C_t^m + P_t^{m,i} I_t^m \right).$$

Consequently, the deflators for consumption and investment are measured as

$$\begin{aligned} P_t^{def,c} &\equiv \frac{(1+\tau_t^c) \left(P_t C_t^d + P_t^{m,c} C_t^m \right)}{C_t^d + C_t^m}, \\ P_t^{def,i} &\equiv \frac{P_t I_t^d + P_t^{m,i} I_t^m}{I_t^d + I_t^m}. \end{aligned}$$

Finally, the growth rate in foreign output is measured as $\ln \mu_z + \Delta \hat{y}_t^* + \Delta \hat{\tilde{z}}_t^*$ where $\hat{\tilde{z}}_t^*$ is given by (2.86) and $\hat{y}_t^*$ is given from (2.91).

5. Calibration and estimation

5.1. Calibrated parameters

A number of parameters are kept fixed throughout the estimation procedure. Most of these parameters can be related to the steady state values of the observed variables in the model, and are therefore calibrated so as to match the sample mean of these. The money growth rate μ is related to the steady state level of inflation, $\pi = \mu/\mu_z$, and is set to 1.01 (per quarter). If the steady state growth rate of output is around 0.5 percent quarterly, this number implies a steady-state quarterly inflation rate of around 0.5 percent as well.[16] The discount factor β is set to 0.999, which implies a nominal interest of

[16] Note that since we estimate some of the parameters that determine the steady state (like μ_z), the steady state will change slightly during the estimation procedure.

5.5 percent (annually) in steady state assuming a capital tax of around 10 percent.[17] This value of β is quite high, but a lower value results in an even higher nominal interest rate, and thus an implausible high real interest rate in our view. To match the sample mean of the investment-output ratio, the depreciation rate δ is set to 0.013 and the share of capital in production α to 0.29. The constant in the labour disutility function A_L is set to 7.5, implying that the agents devote around 30 percent of their time to work in steady state. Following Christiano, Eichenbaum and Evans (2001), the labour supply elasticity σ_L is set to 1, and the markup power in the wage setting λ_w is set to 1.05.

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

The (steady state) government expenditure share, the labour income tax, the consumption tax, and the cash to money ratio (M_1/M_3) are all set equal to their sample means. This implies $g_\tau = 0.2037$, $\tau^y = 0.1771$, $\tau^c = 0.1249$, and $A_q = 0.3776$, respectively. Since we lack data on capital income taxes as well as pay-roll taxes we approximate these with the following AR(1) processes,

$$\hat{\tau}_t^k = \rho_{\tau^k} \hat{\tau}_{t-1}^k + \varepsilon_t^{\tau^k}, \tag{5.1}$$

$$\hat{\tau}_t^w = \rho_{\tau^w} \hat{\tau}_{t-1}^w + \varepsilon_t^{\tau^w}, \tag{5.2}$$

and set the persistence parameters ρ_{τ^k} and ρ_{τ^w} to 0.9. The standard deviations for the shocks $\varepsilon_t^{\tau^k}$ and $\varepsilon_t^{\tau^w}$ are set to 1 percent. Although both the persistence coefficients and standard errors in these variables are quite high, we still find that these shocks have small dynamic effects in the model, presumably because the fiscal shocks are transitory and does not generate any wealth effects for the households. There are two distinct reasons for keeping the fiscal policy shocks in the model nevertheless. First, they reduce the degree of stochastic singularity in the model. As is clear from the previous subsection, we match the model to more variables than estimated shocks, which would not be possible if we did not include the fiscal policy shocks. Second, although the dynamic effects are small, the steady state values of the fiscal policy variables matter for the dynamic effects of the other shocks in the model, which is our second reason for including them.

Given our choice of working with an interest rule (rather than a money growth rule), and not including money growth as an observable variable, the money demand shocks are badly identified since they have very small real effects (the household money demand shock, $\hat{\zeta}_t^q$ have zero effects, but the firm money demand shock $\hat{\nu}_t$ have some real effects due to its influence on the effective interest rate, see 2.11). We therefore decided not to include these shocks in the analysis.

[**Remains to be done: Report estimation results for the Foreign and Fiscal policy VARs.**]

5.2. Bayesian estimation

5.2.1. Prior distributions of the estimated parameters

The Bayesian estimation technique allows us to use the prior information from studies at both the macro and micro level in a formal way. Table 1 shows the assumptions for the prior distribution of

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

the estimated parameters. The location of the prior distribution of the 53 parameters we estimate corresponds to a large extent to those in Smets and Wouters (2003a) and the findings in Altig et al. (2003) on U.S. data. For all the parameters bounded between 0 and 1 we use the beta distribution. This consequently applies to the nominal stickiness parameters ξ, the indexation parameters κ, the habit persistence b, the tax rates τ, and the persistence parameters of the shock processes ρ. The domestic price and wage stickiness parameters are set so that the average length between price, or wage, adjustments are 3 quarters. In contrast, the stickiness parameters pertaining to the import and export prices are set lower so as to get a reasonable degree of exchange rate pass-through. The prior standard deviation of these parameters are twice as large as their domestic counterparts, reflecting a greater prior uncertainty.

For parameters assumed to be positive, such as the standard deviations of the shocks, ε, and the substitution elasticities between goods, η and λ, we use the inverse gamma distribution. Following Cooley and Hansen (1995), we set the standard deviation of the stationary technology shock to 0.7 percent. The size of the unit root technology shock, in turn, is set to 0.2, which is based on the findings of Altig et al. (2003) on US data. From Altig et al. we also take the standard deviation of the monetary policy shock $\varepsilon_{R,t}$, which is set to 0.15. The size of the risk premium shock is set to 0.05 based on an estimated UIP-equation on Swedish data, see Lindé et al. (2003). For some of the shocks, the earlier literature give less guidance and we rely on very simple regressions to pin down the prior distribution of their processes. For example, the inflation target shock $\varepsilon_{\widehat{\bar{\pi}}^c,t}$ is set to 0.05, which is the standard error of regressing HP-filtered domestic inflation on itself, setting the persistence parameter to 0.975. The size of the asymmetric technology shock $\widehat{\widetilde{z}}_t^*$ is set to 0.40. This is taken from the standard error of an autoregression of the series obtained when subtracting HP-filtered domestic output from HP-filtered foreign output. The persistence parameter in the autoregression is set to 0.85. The size of the domestic markup shock $\varepsilon_{\lambda_f,t}$ is set to 0.3. This is the resulting standard error when regressing the high frequency component left out after HP-filtering domestic inflation, on itself. The shocks to the elasticity between import goods $\varepsilon_{\eta^{m,c},t}$ and $\varepsilon_{\eta^{m,i},t}$ are set to 1.5 (i.e., five times the domestic markup shock), corresponding to the same size of markup fluctuations as in the domestic sector. Further, in the export sector we believe the markups are somewhat more volatile why the markup shock in this sector $\varepsilon_{\lambda x,t}$ is set to 0.6. For some of the disturbances we have even less information about, it is difficult to carry out similar exercises. We therefore set their standard deviations to 1.0. This pertains to the two preference shocks $\varepsilon_{\zeta^c,t}$, $\varepsilon_{\zeta^h,t}$ and the investment specific technology shock $\varepsilon_{\Upsilon,t}$, which are all set to 1.0. In order to let the data determine the importance of the disturbances, the degree of freedom is set to 2. This gives a rather uninformative prior. The substitution elasticity between imported consumption goods $\eta^{m,c}$, as well as between imported investment goods $\eta^{m,i}$, determine the markup in these two sectors. We set the prior mode to 6 which implies a markup of 20%. In order to restrict the markup to a reasonable size we set the degree of freedom to 4 for these parameters.

For the parameters in the monetary policy rule we use the normal distribution. The prior mean is set to standard values, following Smets and Wouters (2003a), trying to avoid indeterminacy when solving the model. The prior mean on the inflation coefficient is set to 1.7, on the lagged interest rate coefficient to 0.8, and the output reaction of 0.125 per quarter corresponds to a standard Taylor response of 0.5 (on annual output). Note though that we also allow for an interest rate response to the real exchange rate, but that the prior mean of this parameter is set to zero.

5.2.2. Posterior distributions of the estimated parameters

The joint posterior distribution of all estimated parameters is obtained in two steps. First, the posterior mode and Hessian matrix evaluated at the mode is computed by standard numerical optimization routines (Matlab's fmincon). Second, draws from the joint posterior are generated using the Metropolis-Hastings algorithm. The proposal distribution is taken to be the multivariate normal density centered at the previous draw with a covariance matrix proportional to the inverse Hessian at the posterior mode. See Schorfheide (2000) and Smets and Wouters (2003*a*) for details. The results are reported in Table 1. It shows the posterior mode of all the parameters along with the approximate posterior standard deviation obtained from the inverse Hessian at the posterior mode. In addition, it shows the 5th, 50th and 95th percentile of the posterior distribution.[18] Figure 1 summarizes this information visually by plotting the prior and the posterior distributions.

It is important to note that when estimating the model, we found it convenient to rescale the parameter multiplying the markup shocks in the Phillips curve for domestic/export goods with the inverse of $\frac{(1-\xi^d)(1-\beta\xi^d)}{\xi^d(1+\kappa_d\beta)}/\frac{(1-\xi^x)(1-\beta\xi^x)}{\xi^x(1+\beta)}$ so that the shocks in these two equations enters in an additive way. Similarly, we rescaled the demand elasticity shocks in the Phillips curves for the imported consumption/investment goods with the inverse of $\frac{(1-\xi^{m,j})(1-\beta\xi^{m,j})}{\xi^{m,j}(1+\beta)}\frac{1}{(\eta^{m,j}-1)}$ for $j = c, i$ so that these two shocks enter in an additive fashion as well in those equations. Although this was not of any particular importance for the baseline estimation of the model, we found it important to do this when doing the sensitivity analysis in the model because the effective prior standard deviation of the shocks changes with value of the stickiness parameters. Smets and Wouters (2003b) adopt the same strategy. So to actually figure out the size of the markup and demand elasticity shocks, you need to multiply the reported standard errors with the "Calvo" parameters (e.g. $\frac{(1-\xi^d)(1-\beta\xi^d)}{\xi^d(1+\kappa_d\beta)}$). When doing this, some quick back-of-the envelope calculations suggest that we are actually coming up with rather large values for the domestic and export markup shocks, and even larger demand elasticity shocks for imported consumption and investment goods. [**This needs to be checked further, trying to find independent evidence on the size of the mark-up shocks.**]

One very interesting aspect of the results:

- Neither variable capital utilization nor the working capital channel do not give us a lower estimate of price stickiness in the Bayesian framework.

[**Remains to be written.**]

5.3. Sensitivity analysis

Table 2 shows the estimated posterior mode when some of the frictions in the model are turned off. This is done in an attempt to assess the importance of the different frictions for matching the data. The columns report the estimated parameter vector (mode posterior) when there is, *i*) no wage stickiness, *ii*) no price stickiness, *iii*) the Law of One Price holds, *iv*) no habit formation, *v*) no investment adjustment cost, *vi*) no variable capital utilization, *vii*) no working capital channel, and *viii*) no varying inflation target. For ease of comparison the benchmark results are also reproduced.

The results indicate that

- One can obtain a lower degree of sticky domestic prices, by allowing for serially correlated markup shocks.

- Model without variable capital utilization, working capital and time-varying inflation target does as well as the benchmark model

- Sticky domestic prices important,

[18] A posterior sample of 300,000 draws was generated from the posterior of which the first 10,000 draws were discarded as burn-in.

- Sticky wages important
- Sticky import and export prices important too
- Real rigidities important

[**This should be verified by comparing marginal likelihoods. Remains to be written.**]

6. Impulse responses and variance decompositions

We report the 5th and 95th percentiles of the posterior distribution of the variance decompositions for some selected variables in Table 3. One very interesting result appears to stand out here. The shocks in the import prices for imported consumption and investment goods account for a substantial share of fluctuations in inflation and output according to the variance decompositions. Out interpretation is that the open economy frictions and shocks appear to add interesting dynamics to the closed economy setting by Smets and Wouters (2003a).

Figures 2-14 report the impulse response functions (median and 5th, 25th, 75th and 95th percentiles) for each estimated shock in the baseline model. Notice that the inflation rates and the nominal interest rates are reported as annualized quarterly rates (i.e. 4 times inflation measured in first differences).

[**Remains to be written.**]

7. Comparing the forecasting properties of the DSGE model with alternative models

[**Remains to be written.**]

8. Conclusions

[**Remains to be written.**]

Appendix A. Steady state

In this subsection, we will compute the steady state in the model. Note that the stationary first-order condition for m_{t+1} (2.59) in steady state reduce to

$$-1+\beta\left[\frac{1}{\mu_z}\frac{1}{\pi}\left(R-\tau^k\left(R-1\right)\right)\right]=0, \tag{A.1}$$

or equivalently

$$\begin{aligned} R-\tau^k\left(R-1\right) &= \frac{\pi\mu_z}{\beta} \\ &\Leftrightarrow \\ R &= \frac{\pi\mu_z-\tau^k\beta}{\left(1-\tau^k\right)\beta}. \end{aligned} \tag{A.2}$$

From the definitional equation for money growth, we have

$$\pi=\frac{\mu}{\mu_z}. \tag{A.3}$$

The stationarized version of the first-order condition for b^*_{t+1} in (2.65) is simplified to

$$-S_t+\beta\left[\frac{1}{\mu_z}\frac{1}{\pi}S_{t+1}\left(R^*\Phi(\frac{A_t}{z_t},\widetilde{\phi}_t)-\tau^k\left(R^*\Phi(\frac{A_t}{z_t},\widetilde{\phi}_t)-1\right)\right)\right]=0 \tag{A.4}$$

and if we assume that

$$R^*=R, \tag{A.5}$$

then we see by comparison of (A.1) and (A.4) that one possible steady state is characterized by

$$\begin{aligned} S_t &= S_{t+1}=1, \\ \Phi(\frac{A_t}{z_t},\widetilde{\phi}_t) &= \Phi(\frac{A}{z},\widetilde{\phi})=1, \end{aligned}$$

which with our assumption that $\Phi(\frac{A}{z},\widetilde{\phi})=\exp\left(-\widetilde{\phi}_a A/z+\widetilde{\phi}\right)$ implies that $B^*=A=0$,and $\widetilde{\phi}=0$. Thus, in steady state, the net foreign asset position is zero.[19]

The first order-condition for i_t in (2.62) simplifies to (using 2.53, i.e. $F_1=1,F_2=0,\Upsilon=1$)

$$P_{k'}=\frac{P^i}{P}. \tag{A.6}$$

[19] In contrast, letting $\pi=\pi^*$ but assuming that domestic and foreign captial income taxes are not the same; τ^k and zero, respectively), we know from the foc of m_{t+1} that $R=\frac{\pi\mu_z-\tau^k\beta}{(1-\tau^y)\beta}$. The foreign counterpart (without taxes) implies that $R^*=\frac{\pi\mu_z}{\beta}$ (given the same money growth and discounting). We consequently allow for different domestic and foreign interest rates in this example. The foc for b^*_{t+1} in equation (A.4) then implies the following in steady state; $\frac{S_t}{E_tS_{t+1}}=\beta\left[\frac{1}{\mu_z}\frac{1}{\pi}\left(R^*-\tau^k\left(R^*-1\right)\right)\right]$. Inverting this and using $R^*=\frac{\pi\mu_z}{\beta}$; $\frac{E_tS_{t+1}}{S_t}=\frac{1}{\left[1-\tau^k\beta(R^*-1)\right]}\begin{cases} >1 & iff \quad \tau^k>0 \\ =1 & iff \quad \tau^k=0 \end{cases}$. Hence, the exchange rate is depreciating in steady state if we allow for larger capital income taxes at home than abroad.

Thus, we need to pin down the relative price in steady state. We will here assume, in addition to $R = R^*$ that $\pi = \pi^*$ and that $P_0 = P_0^*$, i.e. that the steady-state price levels in the beginning of time were the same. Notice that (2.47) can be used to define the following relative prices

$$\begin{aligned} \left(\frac{P_t^c}{P_t}\right) &= \left[(1-\omega_c) + \omega_c \left(\frac{P_t^{m,c}}{P_t}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)}, \\ \left(\frac{P_t^c}{P_t^{m,c}}\right) &= \left[(1-\omega_c)\left(\frac{P_t}{P_t^{m,c}}\right)^{1-\eta_c} + \omega_c\right]^{1/(1-\eta_c)}, \end{aligned} \tag{A.7}$$

Combining (A.7) , (A.7) and (2.37) , evaluated in steady state, we derive

$$\frac{P^c}{P} = \left[(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\frac{SP_t^*}{P_t}\right)^{1-\eta_i}\right]^{1/(1-\eta_i)},$$

and

$$\left(\frac{P^c}{P^{m,c}}\right) = \left[(1-\omega_c)\left(\frac{\eta^{m,c}-1}{\eta^{m,c}}\frac{P_t}{SP_t^*}\right)^{1-\eta_i} + \omega_c\right]^{1/(1-\eta_i)}$$

and under the above assumption, we have that $\frac{SP_t^*}{P_t} = 1$ and consequently,

$$\frac{P^c}{P} = \left[(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)}, \tag{A.8}$$

and also

$$\frac{P^c}{P^{m,c}} = \left[(1-\omega_c)\left(\frac{\eta^{m,c}-1}{\eta^{m,c}}\right)^{1-\eta_c} + \omega_c\right]^{1/(1-\eta_c)}. \tag{A.9}$$

Similarly, we have that

$$\frac{P^i}{P} = \left[(1-\omega_i) + \omega_i \left(\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)^{1-\eta_i}\right]^{1/(1-\eta_i)}, \tag{A.10}$$

and

$$\frac{P^i}{P^{m,i}} = \left[(1-\omega_i)\left(\frac{\eta^{m,i}-1}{\eta^{m,i}}\right)^{1-\eta_i} + \omega_i\right]^{1/(1-\eta_i)}. \tag{A.11}$$

Here it is important to note the following. If $0 < \eta_j < \infty$ and $1 < \eta^{m,j} < \infty$, then P^j/P will be greater than unity as long as $\omega_j > 0$ because then the households will substitute between the foreign and domestic goods and the mark-up on the foreign good is higher than unity $\left(\frac{\eta^{m,j}}{\eta^{m,j}-1}\right)$ when $\eta^{m,j} < \infty$. Also, $P^j/P^{m,j}$ will be less than unity as long as $\omega_c < 1$ and $\eta^{m,j} < \infty$ because the price of the domestic good will always be lower than the charged price of the foreign good given our assumption that $\frac{SP_t^*}{P_t} = 1$. Combining equations (A.8) and (A.9) we have that:

$$\frac{P^{m,c}}{P} = \left[\frac{(1-\omega_c) + \omega_c\left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)^{1-\eta_c}}{(1-\omega_c)\left(\frac{\eta^{m,c}-1}{\eta^{m,c}}\right)^{1-\eta_c} + \omega_c}\right]^{1/(1-\eta_c)} = \frac{\eta^{m,c}}{\eta^{m,c}-1}, \tag{A.12}$$

and equations (A.10) and (A.11)

$$\frac{P^{m,i}}{P}=\left[\frac{(1-\omega_i)+\omega_i\left(\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)^{1-\eta_i}}{(1-\omega_i)\left(\frac{\eta^{m,i}-1}{\eta^{m,i}}\right)^{1-\eta_i}+\omega_i}\right]^{1/(1-\eta_i)}=\frac{\eta^{m,i}}{\eta^{m,i}-1}. \tag{A.13}$$

Finally, it is useful to note that all relative prices equal unity when $\eta^{m,j}=\infty$ irrespectively of ω_j and η_j.

Furthermore, note that the export price equals the foreign price level in steady state $P^x=P^*$, implying that the steady state markup in the export market must be one;

$$P^x=\frac{P}{S}. \tag{A.14}$$

There are thus only *short run* deviations from the law of one price.

Using (A.6) in the first-order condition for $\bar{k}_{t+1}$ in (2.61), we obtain (using our assumption that $u_t=\frac{k_t}{\bar{k}_t}=u=1\Rightarrow a(u)=a(1)=0$ in steady state)

$$\begin{aligned}\beta\left[\frac{1}{\mu_z}\left((1-\delta)P_{k'}+\left(1-\tau^k\right)r^k\right)\right] &= P_{k'}\\ &\Leftrightarrow\\ r^k &= \frac{\mu_z P_{k'}-\beta(1-\delta)P_{k'}}{(1-\tau^k)\,\beta}.\end{aligned}$$

From (2.15), we also have that

$$r^k=\frac{\alpha}{1-\alpha}\mu_z\bar{w}R^f\frac{H}{k}, \tag{A.15}$$

where from (2.9)

$$R^f\equiv\nu R+1-\nu. \tag{A.16}$$

Using that

$$P=\lambda_f MC,$$

in steady state, or equivalently,

$$\frac{MC}{P}=\frac{1}{\lambda_f}, \tag{A.17}$$

we have from (2.17) that

$$\frac{1}{\lambda_f}=\left(\frac{1}{1-\alpha}\right)^{(1-\alpha)}\left(\frac{1}{\alpha}\right)^{\alpha}\left(r^k\right)^{\alpha}\left(\bar{w}R^f\right)^{1-\alpha}. \tag{A.18}$$

We now want to solve for c, y, g, H, K, m, and q. In the end, we also want to check that all steady-state relationships are correct.

Real profits, Π^R, are given by

$$\Pi^R\equiv(\frac{P}{MC})y-r^k\frac{k}{\mu_z}-\bar{w}R^fH-\phi,$$

where y is scaled output (i.e., $\frac{Y}{z}$) given by (2.4). The first term is the (real) income from sales, the next two terms represent the (real) cost of producing y, and ϕ denotes the fixed cost (or equivalently, the firm's profit from working under monopolistic competition). Because of its monopoly power the firm is paid a markup, λ_f, over its marginal cost (see (A.17)). In contrast, under perfect competition we know that there is no markup (profits are zero), and y must equal $y = r^k \frac{k}{\mu_z} - \bar{w} R^f H$. We now want to impose $\Pi^R = 0$ in steady state also in our monopolistic case, and determine the size of the fixed cost, ϕ, such that this zero profit condition is fulfilled. From the cost side, and perfect competition, we have that the real production cost must equal y (from (2.8). Combining the two equations above, and using (A.17), the zero profit condition reduces to:

$$\Pi^R \equiv \lambda_f y - y - \phi = 0,$$

or equivalently,

$$\phi = (\lambda_f - 1) y. \tag{A.19}$$

This has a simple interpretation. $(\lambda_f - 1)y$ is the excess over what is paid to factors of production, when steady-state output is y. This is completely absorbed by the fixed costs if (A.19) is satisfied. However, ϕ is included in y, so another way to write (A.19) is to use the steady-state version of (2.4).[20] We then have

$$\phi = (\lambda_f - 1) \left(\mu_z^{-\alpha} k^\alpha H^{1-\alpha} - \phi \right),$$

or equivalently

$$\phi = \frac{\lambda_f - 1}{\lambda_f} \mu_z^{-\alpha} \left(\frac{k}{H} \right)^\alpha H \tag{A.20}$$

From the law-of-motion for capital (2.49), we have in steady state (using 2.50 and 2.52, and stationarizing $\bar{K}_{t+1}$ with z_t)

$$k = \frac{1-\delta}{\mu_z} k + i,$$

or equivalently

$$i = \left(1 - \frac{1-\delta}{\mu_z} \right) k. \tag{A.21}$$

The consumption Euler equation (2.58) is in steady state given by

$$\frac{1}{c - bc\frac{1}{\mu_z}} - \beta b \frac{1}{c\mu_z - bc} - \psi_z \frac{P^c}{P} (1 + \tau^c) = 0,$$

or equivalently

$$\psi_z = \frac{1}{c} \frac{\mu_z - \beta b}{(1+\tau^c)(\mu_z - b)} \left(\frac{P^c}{P} \right)^{-1} \tag{A.22}$$

Since the effective steady-state wage is divided by the markup λ_w, the first-order condition for the households labour decision in (2.66) reduces to in steady state

$$-A_L H^{\sigma_L} + (1 - \tau^y) \frac{\psi_z}{\lambda_w} \frac{\bar{w}}{1 + \tau^w} = 0,$$

[20] Note that the scaled version of (2.4) reads at the aggregate level $y_t = \mu_{z,t}^{-\alpha} \epsilon_t k_t^\alpha H_t^{1-\alpha} - \phi$ and in steady state we thus have $y = \mu_z^{-\alpha} k^\alpha H^{1-\alpha} - \phi$.

or equivalently

$$H=\left[\frac{\left(1-\tau^{y}\right)\frac{\psi_{z}}{\lambda_{w}}\frac{\bar{w}}{1+\tau^{w}}}{A_{L}}\right]^{1/\sigma_{L}}. \tag{A.23}$$

The resource constraint (2.84) in steady state is given by

$$c^{d}+i^{d}+c^{x}+i^{x}=\left(1-g_{r}\right)\left(\mu_{z}^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}H-\phi\right).$$

Using (2.46), (2.42), (2.54) and (2.43), (A.20), we have

$$\left(1-\omega_{c}\right)\left[\frac{P^{c}}{P}\right]^{\eta_{c}}c+\left(1-\omega_{i}\right)\left[\frac{P^{i}}{P}\right]^{\eta_{i}}i+c^{x}+i^{x}=\frac{\left(1-g_{r}\right)}{\lambda_{f}}\mu_{z}^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}H. \tag{A.24}$$

Thus, in order to proceed, we must assume something regarding c^x and i^x in steady state. Here we will adopt the assumption that export equals import in steady state, an assumption consistent with a zero foreign debt and unchanged nominal exchange rate in steady-state. From (2.88), this implies that (dividing through with z_t)

$$c^{m}+i^{m}=c^{x}+i^{x},$$

and using (2.46) and (2.55) evaluated in steady state;

$$\begin{aligned} c^{m} &= \omega_{c}\left[\frac{P^{m,c}}{P^{c}}\right]^{-\eta_{c}}c=\omega_{c}\left[\frac{P^{c}}{P^{m,c}}\right]^{\eta_{c}}c, \\ i^{m} &= \omega_{i}\left[\frac{P^{m,i}}{P^{i}}\right]^{-\eta_{i}}i=\omega_{i}\left[\frac{P^{i}}{P^{m,i}}\right]^{\eta_{i}}i, \end{aligned}$$

this can be rewritten as

$$\omega_{c}\left[\frac{P^{c}}{P^{m,c}}\right]^{\eta_{c}}c+\omega_{i}\left[\frac{P^{i}}{P^{m,i}}\right]^{\eta_{i}}i=\left(c^{x}+i^{x}\right),$$

$$\omega_{c}\left[\frac{P^{c}}{P^{m,c}}\right]^{\eta_{c}}c+\omega_{i}\left[\frac{P^{i}}{P^{m,i}}\right]^{\eta_{i}}i=\tilde{x}, \tag{A.25}$$

which thus determines the aggregate export (of consumption and investment goods), and where the relative prices are determined in equations (A.12, A.9, A.13, and A.11).

Using this and (A.21) in (A.24), we obtain

$$\begin{aligned} &\left(\left(1-\omega_{c}\right)\left[\frac{P^{c}}{P}\right]^{\eta_{c}}+\omega_{c}\left[\frac{P^{c}}{P^{m,c}}\right]^{\eta_{c}}\right)c+\left(\left(1-\omega_{i}\right)\left[\frac{P^{i}}{P}\right]^{\eta_{i}}+\omega_{i}\left[\frac{P^{i}}{P^{m,i}}\right]^{\eta_{i}}\right)\left(1-\frac{1-\delta}{\mu_{z}}\right)\left(\frac{k}{H}\right)H \\ =\; &\frac{\left(1-g_{r}\right)}{\lambda_{f}}\mu_{z}^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}H, \end{aligned}$$

or equivalently,

$$\begin{aligned} &\left(\left(1-\omega_{c}\right)\left[\frac{P^{c}}{P}\right]^{\eta_{c}}+\omega_{c}\left[\frac{P^{c}}{P^{m,c}}\right]^{\eta_{c}}\right)c \\ =\; &\left[\frac{\left(1-g_{r}\right)}{\lambda_{f}}\mu_{z}^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}-\left(\left(1-\omega_{i}\right)\left[\frac{P^{i}}{P}\right]^{\eta_{i}}+\omega_{i}\left[\frac{P^{i}}{P^{m,i}}\right]^{\eta_{i}}\right)\left(1-\frac{1-\delta}{\mu_{z}}\right)\left(\frac{k}{H}\right)\right]H. \end{aligned}$$

We now substitute out for H in this expression using (A.22) and (A.23). For convenience, we introduce the definitions

$$
\begin{aligned}
D_1 &\equiv (1-\omega_c)\left[\frac{P^c}{P}\right]^{\eta_c} + \omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c}, \\
D_2 &\equiv \left[\frac{(1-g_r-x_r)}{\lambda_f}\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha} - \left((1-\omega_i)\left[\frac{P^i}{P}\right]^{\eta_i} + \omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i}\right)\left(1-\frac{1-\delta}{\mu_z}\right)\left(\frac{k}{H}\right)\right], \\
D_3 &\equiv \left[\frac{\left(1-\tau^y\right)\frac{1}{\lambda_w}\frac{\bar{w}}{1+\tau^w}}{A_L}\right]^{1/\sigma_L}, \qquad (A.26) \\
D_4 &\equiv \frac{\mu_z-\beta b}{(1+\tau^c)(\mu_z-b)}\left(\frac{P^c}{P}\right)^{-1},
\end{aligned}
$$

since we can compute these constants using previous results. We then have the following system of equations

$$
\begin{aligned}
D_1 c &= D_2 H, \\
H &= D_3\left(\psi_z\right)^{1/\sigma_L}, \\
\psi_z &= \frac{1}{c}D_4,
\end{aligned}
$$

and the solution for H, c and ψ_z are given by

$$
\begin{aligned}
H &= \left[D_3 D_4^{1/\sigma_L}\left(\frac{D_2}{D_1}\right)^{-1/\sigma_L}\right]^{\frac{\sigma_L}{1+\sigma_L}}, \qquad (A.27) \\
c &= \frac{D_2}{D_1}H, \\
\psi_z &= \frac{1}{c}D_4.
\end{aligned}
$$

Once equipped with the solution for H, we can compute y as

$$
y = \frac{1}{\lambda_f}\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha} H \qquad (A.28)
$$

using our solution for $\frac{k}{H}$ from (A.15). ϕ is computed using (A.20) and steady state government expenditures g as

$$
g = g_r y, \qquad (A.29)
$$

The first-order condition for the capital utilization rate in (2.63) evaluated in steady state equals

$$
a'(1) = \left(1-\tau^k\right)r^k. \qquad (A.30)
$$

The first-order condition for the households cash decision in (2.64) evaluated in steady-state is given by

$$
\begin{aligned}
A_q q^{-\sigma_q} &= \left(1-\tau^k\right)\psi_z\left(R-1\right) \\
&\Leftrightarrow \\
q &= \left(\frac{A_q}{\left(1-\tau^k\right)\psi_z\left(R-1\right)}\right)^{\frac{1}{\sigma_q}},
\end{aligned}
$$

which can be used to compute q in steady state.

Finally, we can compute m using the loan market clearing condition (2.89) evaluated in steady state,

$$\begin{aligned} \nu\bar{w}H &= \frac{\mu m}{\pi\mu_z} - q \\ &\Leftrightarrow \\ m &= \nu\bar{w}H + q \end{aligned} \tag{A.31}$$

in steady state.

Using the steady-state relationships above, we can compute $P_{k'}$, r^k, $\bar{w}$, R, R^f and $\frac{H}{k}$ in the following way. First, compute R from (A.2), second, compute R^f from (A.16), third, use (A.6) and (A.15) to compute r^k, fourth use (A.18) to compute $\bar{w}R^f$ and when divide the result with R^f to obtain $\bar{w}$, and fifth, use the solutions for r^k, $\bar{w}$, and R^f in (A.15) to compute $\frac{H}{k}$.

Using these results, we can compute c, i, y, g, ϕ, ψ_z, H, K, m, $\tilde{x}$ and q in the following way. First, define the composite coefficients D_1, D_2, D_3 and D_4 defined in (A.26). Second, use (A.27) to compute c, H and ψ_z. Third, use A.20 to compute ϕ. Fourth, compute k by multiplying $\frac{k}{H}$ with H. Fifth, compute y using (A.28). Sixth, compute g from (A.29). Seventh, use (A.31) to compute q. Eighth, use (A.21) to compute i. Ninth, compute $\tilde{x}$ using (A.25). Finally, use (A.31) to compute m.

Appendix B. The log-linearized model

The log-linearized equations of the model are as follows

$$\begin{aligned}\left(\widehat{\pi}_t-\widehat{\overline{\pi}}_t^c\right) &= \frac{\beta}{1+\kappa_d\beta}\left(\mathrm{E}_t\widehat{\pi}_{t+1}-\rho_\pi\widehat{\overline{\pi}}_t^c\right)+\frac{\kappa_d}{1+\kappa_d\beta}\left(\widehat{\pi}_{t-1}-\widehat{\overline{\pi}}_t^c\right)\\ &\quad -\frac{\kappa_d\beta\left(1-\rho_\pi\right)}{1+\kappa_d\beta}\widehat{\overline{\pi}}_t^c+\frac{(1-\xi^d)(1-\beta\xi^d)}{\xi^d\left(1+\kappa_d\beta\right)}\left(\widehat{mc}_t+\widehat{\lambda}_{f,t}\right),\end{aligned} \tag{B.1}$$

$$\widehat{\pi}_t^{m,c}=\frac{\beta}{1+\beta}\mathrm{E}_t\widehat{\pi}_{t+1}^{m,c}+\frac{1}{1+\beta}\widehat{\pi}_{t-1}^{m,c}+\frac{(1-\xi^{m,c})(1-\beta\xi^{m,c})}{\xi^{m,c}(1+\beta)}\left(\widehat{mc}_t^{m,c}-\frac{1}{(\eta^{m,c}-1)}\widehat{\eta}_t^{m,c}\right), \tag{B.2}$$

$$\widehat{\pi}_t^{m,i}=\frac{\beta}{1+\beta}\mathrm{E}_t\widehat{\pi}_{t+1}^{m,i}+\frac{1}{1+\beta}\widehat{\pi}_{t-1}^{m,i}+\frac{(1-\xi^{m,i})(1-\beta\xi^{m,i})}{\xi^{m,i}(1+\beta)}\left(\widehat{mc}_t^{m,i}-\frac{1}{(\eta^{m,i}-1)}\widehat{\eta}_t^{m,i}\right), \tag{B.3}$$

$$\begin{aligned}\left(\widehat{\pi}_t^x-\widehat{\overline{\pi}}_t^c\right) &= \frac{\kappa_x}{1+\beta\kappa_x}\left(\widehat{\pi}_{t-1}^x-\widehat{\overline{\pi}}_t^c\right)+\frac{\beta}{1+\beta\kappa_x}\left(\mathrm{E}_t\widehat{\pi}_{t+1}^x-\rho_\pi\widehat{\overline{\pi}}_t^c\right)\\ &\quad +\frac{(1-\beta\xi^x)(1-\xi^x)}{\xi^x\left(1+\beta\kappa_x\right)}\left(\widehat{mc}_t^x+\widehat{\lambda}_t^x\right)-\frac{\beta\kappa_x\left(1-\rho_\pi\right)}{1+\beta\kappa_x}\widehat{\overline{\pi}}_t^c,\end{aligned} \tag{B.4}$$

$$E_t\left[\begin{array}{c}\eta_0\widehat{\overline{w}}_{t-1}+\eta_1\widehat{\overline{w}}_t+\eta_2\widehat{\overline{w}}_{t+1}+\eta_3\left(\hat{\pi}_t^d-\widehat{\overline{\pi}}_t^c\right)+\eta_4\left(\hat{\pi}_{t+1}^d-\rho_{\widehat{\overline{\pi}}^c}\widehat{\overline{\pi}}_t^c\right)\\ +\eta_5\left(\hat{\pi}_{t-1}^c-\widehat{\overline{\pi}}_t^c\right)+\eta_6\left(\hat{\pi}_t^c-\rho_{\widehat{\overline{\pi}}^c}\widehat{\overline{\pi}}_t^c\right)\\ +\eta_7\hat{\psi}_{z,t}^\tau+\eta_8\hat{H}_t+\eta_9\hat{\tau}_t^y+\eta_{10}\hat{\tau}_t^w+\eta_{11}\hat{\zeta}_t^h\end{array}\right]=0, \tag{B.5}$$

where $b_w=\frac{[\lambda_w\sigma_L-(1-\lambda_w)]}{[(1-\beta\xi_w)(1-\xi_w)]}$ and

$$\eta=\begin{pmatrix} b_w\xi_w\\ \left(\sigma_L\lambda_w-b_w\left(1+\beta\xi_w^2\right)\right)\\ b_w\beta\xi_w\\ -b_w\xi_w\\ b_w\beta\xi_w\\ b_w\xi_w\kappa_w\\ -b_w\beta\xi_w\kappa_w\\ (1-\lambda_w)\\ -(1-\lambda_w)\sigma_L\\ -(1-\lambda_w)\frac{\tau^y}{(1-\tau^y)}\\ -(1-\lambda_w)\frac{\tau^w}{(1+\tau^w)}\\ -(1-\lambda_w)\end{pmatrix}=\begin{pmatrix}\eta_0\\ \eta_1\\ \eta_2\\ \eta_3\\ \eta_4\\ \eta_5\\ \eta_6\\ \eta_7\\ \eta_8\\ \eta_9\\ \eta_{10}\\ \eta_{11}\end{pmatrix},$$

$$\mathrm{E}_t\left[\begin{array}{c}-b\beta\mu_z\hat{c}_{t+1}+\left(\mu_z^2+b^2\beta\right)\hat{c}_t-b\mu_z\hat{c}_{t-1}+b\mu_z\left(\hat{\mu}_{z,t}-\beta\hat{\mu}_{z,t+1}\right)+\\ +\left(\mu_z-b\beta\right)\left(\mu_z-b\right)\hat{\psi}_{z,t}+\frac{\tau^c}{1+\tau^c}\left(\mu_z-b\beta\right)\left(\mu_z-b\right)\hat{\tau}_t^c+\left(\mu_z-b\beta\right)\left(\mu_z-b\right)\hat{\gamma}_t^{c,d}\\ -\left(\mu_z-b\right)\left(\mu_z\hat{\zeta}_t^c-b\beta\hat{\zeta}_{t+1}^c\right)\end{array}\right]=0, \tag{B.6}$$

$$\mathrm{E}_t \left\{ \hat{P}_{k',t} + \hat{\Upsilon}_t - \hat{\gamma}_t^{i,d} - \mu_z^2 \tilde{S}'' \left[(\hat{\imath}_t - \hat{\imath}_{t-1}) - \beta (\hat{\imath}_{t+1} - \hat{\imath}_t) + \hat{\mu}_{z,t} - \beta \hat{\mu}_{z,t+1} \right] \right\} = 0, \tag{B.7}$$

$$\mathrm{E}_t \left[-\mu \hat{\psi}_{z,t} + \mu \hat{\psi}_{z,t+1} - \mu \hat{\mu}_{z,t+1} + \left(\mu - \beta \tau^k \right) \hat{R}_t - \mu \hat{\pi}_{t+1} + \frac{\tau^k}{1-\tau^k} (\beta - \mu) \hat{\tau}_{t+1}^k \right] = 0, \tag{B.8}$$

$$\mathrm{E}_t \left[\begin{array}{c} \hat{\psi}_{z,t} + \hat{\mu}_{z,t+1} - \hat{\psi}_{z,t+1} - \frac{\beta(1-\delta)}{\mu_z} \hat{P}_{k',t+1} + \hat{P}_{k',t} - \frac{\mu_z - \beta(1-\delta)}{\mu_z} \hat{r}_{t+1}^k \\ + \frac{\tau^k}{(1-\tau^k)} \frac{\mu_z - \beta(1-\delta)}{\mu_z} \hat{\tau}_{t+1}^k \end{array} \right] = 0, \tag{B.9}$$

$$\frac{\pi \mu_z}{\pi \mu_z - \tau^k \beta} \mathrm{E}_t \Delta \widehat{S}_{t+1} - \left(\widehat{R}_t - \widehat{R}_t^* \right) - \widetilde{\phi} \widehat{a}_t + \widehat{\widetilde{\phi}}_t = 0, \tag{B.10}$$

$$\begin{array}{rl} & (1-\omega_c) \left(\gamma^{c,d} \right)^{\eta_c} \dfrac{c}{y} \left(\hat{c}_t + \eta_c \widehat{\gamma}_t^{c,d} \right) + (1-\omega_i) \left(\gamma^{i,d} \right)^{\eta_i} \dfrac{i}{y} \left(\hat{\imath}_t + \eta_i \widehat{\gamma}_t^{i,d} \right) \\ & + \dfrac{g}{y} \hat{g}_t + \dfrac{y^*}{y} \left(\hat{y}_t^* - \eta_f \widehat{\gamma}_t^{x,*} + \widehat{\tilde{z}}_t^* \right) \\ = & \\ & \lambda_f \left(\hat{\epsilon}_t + \alpha \left(\hat{k}_t - \hat{\mu}_{z,t} \right) + (1-\alpha) \hat{H}_t \right) - \left(1 - \tau^k \right) r^k \dfrac{\bar{k}}{y} \dfrac{1}{\mu_z} \left(\hat{k}_t - \widehat{\bar{k}}_t \right), \end{array} \tag{B.11}$$

$$\widehat{\bar{k}}_{t+1} = (1-\delta) \frac{1}{\mu_z} \widehat{\bar{k}}_t - (1-\delta) \frac{1}{\mu_z} \hat{\mu}_{z,t} + \left(1 - (1-\delta) \frac{1}{\mu_z} \right) \hat{\Upsilon}_t + \left(1 - (1-\delta) \frac{1}{\mu_z} \right) \hat{\imath}_t, \tag{B.12}$$

$$\begin{array}{rcl} \widehat{u}_t & = & \widehat{k}_t - \widehat{\bar{k}}_t \\ & = & \dfrac{1}{\sigma_a} \widehat{r}_t^k - \dfrac{1}{\sigma_a} \dfrac{\tau^k}{(1-\tau^k)} \widehat{\tau}_t^k, \end{array} \tag{B.13}$$

$$\widehat{q}_t = \frac{1}{\sigma_q} \left[\widehat{\zeta}_t^q + \frac{\tau^k}{1-\tau^k} \widehat{\tau}_t^k - \widehat{\psi}_{z,t} - \frac{R}{R-1} \widehat{R}_{t-1} \right], \tag{B.14}$$

$$\hat{\mu}_t - \widehat{\bar{m}}_{t+1} - \hat{\mu}_{z,t} - \hat{\pi}_t + \widehat{\bar{m}}_t = 0, \tag{B.15}$$

$$\nu \bar{w} H \left(\widehat{\nu}_t + \widehat{w}_t + \hat{H}_t \right) = \frac{\mu \bar{m}}{\pi \mu_z} \left(\hat{\mu}_t + \widehat{\bar{m}}_t - \hat{\pi}_t - \hat{\mu}_{z,t} \right) - q \hat{q}_t, \tag{B.16}$$

$$\begin{array}{rcl} \hat{a}_t & = & -y^* \widehat{mc}_t^x - \eta_f y^* \hat{\gamma}_t^{x,*} + y^* \hat{y}_t^* + y^* \widehat{\tilde{z}}_t^* \\ & & + (c^m + i^m) \hat{\gamma}_t^f \\ & & - \left(\begin{array}{c} c^m \left(-\eta_c (1-\omega_c) \left(\gamma^{c,d} \right)^{-(1-\eta_c)} \widehat{\gamma}_t^{mc,d} + \widehat{c}_t \right) + \\ i^m \left(-\eta_i (1-\omega_i) \left(\gamma^{i,d} \right)^{-(1-\eta_i)} \widehat{\gamma}_t^{mi,d} + \widehat{\imath}_t \right) \end{array} \right) + \dfrac{R}{\pi \mu_z} \hat{a}_{t-1}, \end{array} \tag{B.17}$$

$$\widehat{\gamma}_t^{mc,d} = \widehat{\gamma}_{t-1}^{mc,d} + \widehat{\pi}_t^{m,c} - \widehat{\pi}_t^{d}, \tag{B.18}$$

$$\widehat{\gamma}_t^{mi,d} = \widehat{\gamma}_{t-1}^{mi,d} + \widehat{\pi}_t^{m,i} - \widehat{\pi}_t^{d}, \tag{B.19}$$

$$\widehat{\gamma}_t^{x,*} \equiv \widehat{\gamma}_{t-1}^{x,*} + \widehat{\pi}_t^{x} - \widehat{\pi}_t^{*}, \tag{B.20}$$

$$\widehat{x}_t = -\omega_c \left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \widehat{\gamma}_t^{mc,d} - \widehat{\gamma}_t^{x,*} - \widehat{mc}_t^{x}, \tag{B.21}$$

$$\widehat{mc}_t^{x} = \widehat{mc}_{t-1}^{x} + \widehat{\pi}_t - \widehat{\pi}_t^{x} - \Delta\widehat{S}_t, \tag{B.22}$$

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left(\widehat{\bar{\pi}}_t^c + r_\pi \left(\hat{\pi}_{t-1}^c - \widehat{\bar{\pi}}_t^c\right) + r_y \hat{y}_{t-1} + r_x \hat{x}_{t-1}\right) + r_{\Delta\pi}\left(\hat{\pi}_t^c - \hat{\pi}_{t-1}^c\right) + r_{\Delta y}\Delta\hat{y}_t + \varepsilon_{R,t}, \tag{B.23}$$

where

$$\begin{aligned}
\widehat{\pi}_t^c &= \left((1-\omega_c)\left(\gamma^{d,c}\right)^{1-\eta_c}\right)\widehat{\pi}_t^d + \left((\omega_c)\left(\gamma^{mc,c}\right)^{(1-\eta_c)}\right)\widehat{\pi}_t^{m,c}, \\
\hat{y}_t &= \lambda_f \left(\hat{\epsilon}_t + \alpha\left(\hat{k}_t - \hat{\mu}_{z,t}\right) + (1-\alpha)\hat{H}_t\right), \\
\widehat{x}_t &= -\omega_c \left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \widehat{\gamma}_t^{mc,d} - \widehat{\gamma}_t^{x,*} - \widehat{mc}_t^{x}.
\end{aligned}$$

To write the equations above plus the exogenous process on the form given by equations (3.1) and (3.2) in the main text, we define $\tilde{z}_t$ and θ_t as follows

$$\tilde{z}_t = \begin{bmatrix} \hat{\pi}_t & \hat{\pi}_t^{m,c} & \hat{\pi}_t^{m,i} & \hat{\pi}_t^{x} & \hat{w}_t & \hat{c}_t & \hat{\imath}_t & \hat{\psi}_{z,t} & \hat{P}_{k',t} & \Delta\hat{S}_t & \hat{H}_t & ... \\ \widehat{\bar{k}}_{t+1} & \widehat{k}_t & \hat{q}_t & \widehat{\bar{m}}_{t+1} & \hat{\mu}_t & \hat{a}_t & \widehat{\gamma}_t^{mc,d} & \widehat{\gamma}_t^{mi,d} & \hat{\gamma}_t^{x,*} & \widehat{mc}_t^{x} & \hat{R}_t \end{bmatrix}'$$

$$\theta_t = \begin{bmatrix} \theta_t^s & \theta_t^\tau & \theta_t^* \end{bmatrix}',$$

where

$$\begin{aligned}
\theta_t^s &= \begin{bmatrix} \widehat{\epsilon}_t & \widehat{\epsilon}_{t-1} & \hat{\mu}_{z,t} & \hat{\mu}_{z,t-1} & \hat{\nu}_t & \hat{\zeta}_t^c & \hat{\zeta}_t^h & \hat{\zeta}_t^q & \hat{\lambda}_t^f & \hat{\eta}_t^{m,c} & \hat{\eta}_t^{m,i} & \widetilde{\phi}_t & \hat{\Upsilon}_t & \widehat{\tilde{z}}_t^* & \hat{\lambda}_t^x & \epsilon_{R,t} & \widehat{\bar{\pi}}_t^c \end{bmatrix}, \\
\theta_t^\tau &= \begin{bmatrix} \hat{\tau}_t^k & \hat{\tau}_t^y & \hat{\tau}_t^c & \hat{\tau}_t^w & \hat{g}_t & \hat{\tau}_{t-1}^k & \hat{\tau}_{t-1}^y & \hat{\tau}_{t-1}^c & \hat{\tau}_{t-1}^w & \hat{g}_{t-1} \end{bmatrix}, \\
\theta_t^* &= \begin{bmatrix} \hat{\pi}_t^* & \hat{y}_t^* & \hat{R}_t^* & \hat{\pi}_{t-1}^* & \hat{y}_{t-1}^* & \hat{R}_{t-1}^* & \hat{\pi}_{t-2}^* & \hat{y}_{t-2}^* & \hat{R}_{t-2}^* & \hat{\pi}_{t-3}^* & \hat{y}_{t-3}^* & \hat{R}_{t-3}^* \end{bmatrix},
\end{aligned}$$

and where the parameter matrices α_0, α_1, α_2, β_0 and β_1 corresponds to the equations $(B.1 - B.23)$.

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Table 1: Estimated parameters

Parameter		Prior distribution type	Prior distribution mean*	Prior distribution std. err./df	Estimated posterior mode	Estimated posterior std. err. (Hessian)	Posterior distribution 5%	Posterior distribution 50%	Posterior distribution 95%	Posterior distribution mean
Calvo wages	ξ_w	beta	0.675	0.050	0.653	0.045	0.582	0.655	0.724	0.654
Calvo domestic prices	ξ_d	beta	0.675	0.050	0.933	0.009	0.896	0.919	0.943	0.919
Calvo import cons. prices	$\xi_{m,c}$	beta	0.500	0.100	0.391	0.031	0.262	0.327	0.403	0.329
Calvo import inv. prices	$\xi_{m,i}$	beta	0.500	0.100	0.494	0.034	0.430	0.490	0.547	0.489
Calvo export prices	ξ_x	beta	0.500	0.100	0.663	0.048	0.533	0.629	0.721	0.629
Calvo employment	ξ_e	beta	0.675	0.100	0.779	0.030	0.708	0.763	0.805	0.761
Indexation domestic prices	κ_d	beta	0.500	0.150	0.204	0.087	0.902	0.199	0.338	0.205
Indexation wages	κ_w	beta	0.500	0.150	0.323	0.139	0.174	0.378	0.617	0.384
Indexation export prices	κ_x	beta	0.500	0.150	0.169	0.086	0.078	0.191	0.379	0.205
Real cash balances utility	σ_q	normal	10.620	3.500	10.620	1.000	4.207	9.905	15.407	9.757
Capital utilization adj. cost	σ_a	inv. gamma	0.049	4	0.056	0.024	0.042	0.095	0.311	0.127
Investment adj. cost	SS''	normal	7.694	1.500	7.945	1.097	6.191	8.591	10.986	8.591
Habit formation	b	beta	0.650	0.100	0.763	0.051	0.691	0.791	0.874	0.788
Markup domestic	λ_f	inv. gamma	1.200	2	1.145	0.041	1.107	1.162	1.264	1.170
Subst. elasticity consump.	η_c	inv. gamma	1.500	4	5.287	0.812	5.605	11.953	19.340	12.060
Subst. elasticity invest.	η_i	inv. gamma	1.500	4	2.481	0.568	1.536	2.056	2.932	2.120
Subst. elasticity foreign	η_f	inv. gamma	1.500	4	1.376	0.075	1.263	1.354	1.491	1.363
Subst. elast. import cons.	$\eta_{m,c}$	inv. gamma	6.000	4	3.409	0.290	3.186	3.809	4.858	3.877
Subst. elast.import invest.	$\eta_{m,i}$	inv. gamma	6.000	4	5.534	0.907	4.889	6.962	11.280	7.406
Technology growth	μ_z	normal	1.006	0.001	1.005	0.001	1.004	1.005	1.005	1.005
Capital tax	τ_k	beta	0.120	0.050	0.185	0.041	0.121	0.189	0.252	0.188
Labour tax	τ_w	beta	0.200	0.050	0.175	0.052	0.109	0.181	0.270	0.184
Risk premium	$\tilde{\phi}$	beta	0.010	0.005	0.039	0.011	0.030	0.047	0.069	0.048
Unit root tech. shock	ρ_{μ_z}	beta	0.850	0.050	0.855	0.036	0.724	0.816	0.885	0.812
Stationary tech. shock	ρ_{ε}	beta	0.850	0.050	0.943	0.029	0.864	0.915	0.951	0.912
Invest. spec. tech shock	ρ_{Υ}	beta	0.850	0.050	0.807	0.035	0.739	0.802	0.855	0.800
Risk premium shock	$\rho_{\tilde{\phi}}$	beta	0.850	0.050	0.940	0.025	0.898	0.938	0.968	0.936
Cons. pref. shock	ρ_{ζ_c}	beta	0.850	0.050	0.835	0.053	0.775	0.869	0.922	0.861
Labour supply shock	ρ_{ζ_h}	beta	0.850	0.050	0.938	0.019	0.819	0.887	0.941	0.885
Asymm. tech. shock	$\rho_{\tilde{z}*}$	beta	0.850	0.050	0.875	0.037	0.837	0.981	0.990	0.956
Exp. markup shock	ρ_{λ_x}	beta	0.850	0.050	0.887	0.035	0.796	0.873	0.926	0.869
Imp. cons. elasticity shock	$\rho_{\eta_{m,c}}$	beta	0.850	0.050	0.969	0.010	0.952	0.971	0.984	0.970
Imp. invest. elast. shock	$\rho_{\eta_{m,i}}$	beta	0.850	0.050	0.984	0.006	0.964	0.978	0.987	0.977
Unit root tech. shock	ε_z	inv. gamma	0.200	2	0.129	0.026	0.098	0.132	0.177	0.134
Stationary tech. shock	$\varepsilon_{\varepsilon}$	inv. gamma	0.700	2	0.446	0.083	0.360	0.469	0.613	0.476
Imp. cons. elasticity shock	$\varepsilon_{\eta_{m,c}}$	inv. gamma	1.500	2	2.036	0.307	2.048	4.326	7.814	4.541
Imp. invest. elast. shock	$\varepsilon_{\eta_{m,i}}$	inv. gamma	1.500	2	0.927	0.161	0.671	0.889	1.244	0.915
Domestic markup shock	ε_{λ}	inv. gamma	0.300	2	0.133	0.013	0.115	0.134	0.157	0.135
Invest. spec. tech. shock	ε_{Υ}	inv. gamma	1.000	2	5.403	0.918	4.275	5.955	7.948	6.027
Risk premium shock	$\varepsilon_{\tilde{\phi}}$	inv. gamma	0.050	2	0.137	0.031	0.102	0.144	0.207	0.148
Consumption pref. shock	ε_{ζ_c}	inv. gamma	1.000	2	1.363	0.318	1.145	1.639	2.459	1.700
Labour supply shock	ε_{ζ_h}	inv. gamma	1.000	2	5.299	1.728	4.039	6.961	13.704	7.629
Monetary policy shock	ε_R	inv. gamma	0.150	2	0.134	0.015	0.110	0.132	0.157	0.133
Asymmetric tech. shock	$\varepsilon_{\tilde{z}*}$	inv. gamma	0.400	2	0.185	0.028	0.160	0.206	0.268	0.208
Export markup shock	ε_{λ_x}	inv. gamma	0.600	2	0.920	0.175	0.778	1.070	1.530	1.101
Inflation target shock	$\varepsilon_{\bar{\pi}^c}$	inv. gamma	0.050	2	0.038	0.011	0.025	0.038	0.061	0.040
Interest rate smoothing	ρ_R	beta	0.800	0.050	0.911	0.016	0.858	0.899	0.933	0.897
Inflation response	r_{π}	normal	1.700	0.100	1.613	0.094	1.459	1.621	1.788	1.623
Diff. infl response	$r_{\Delta\pi}$	normal	0.300	0.100	0.316	0.063	0.205	0.314	0.426	0.315
Real exch. rate response	r_x	normal	0.000	0.050	-0.020	0.007	-0.035	-0.020	-0.010	-0.021
Output response	r_y	normal	0.125	0.050	0.051	0.024	0.048	0.103	0.165	0.104
Diff. output response	$r_{\Delta\pi}$	normal	0.0625	0.050	0.177	0.026	0.102	0.150	0.203	0.151

*Note: For the inverse gamma distribution. the mode and the degrees of freedom are reported.

Table 2: Sensitivity analysis

Parameter		Posterior mode: Bench-mark	No wage stickiness $\xi_w = 0.01$	No price stickiness $\xi_d = 0.01$	No habit $b = 0.05$	No invest.adj. cost $SS'' = 0.1$	No variable cap. utiliz. $\sigma_a = 1e+6$	No working cap. channel $\nu = 0.01$	No varying inflation target $\varepsilon_{\bar{\pi}^c} = 0.0001$	Persis-tent markup shock $\rho_{\lambda} \neq 0$
Calvo wages	ξ_w	0.653		0.633	0.635	0.60	0.649	0.652	0.651	0.633
Calvo domestic prices	ξ_d	0.933	0.858		0.935	0.931	0.935	0.930	0.927	0.679
Calvo import cons. prices	$\xi_{m,c}$	0.391	0.282	0.320	0.257	0.318	0.284	0.390	0.386	0.288
Calvo import inv. prices	$\xi_{m,i}$	0.494	0.435	0.461	0.437	0.281	0.488	0.496	0.497	0.483
Calvo export prices	ξ_x	0.663	0.656	0.654	0.650	0.658	0.663	0.664	0.662	0.657
Calvo employment	ξ_e	0.779	0.731	0.746	0.761	0.754	0.830	0.780	0.776	0.802
Indexation domestic prices	κ_d	0.204	0.185	0.583	0.180	0.173	0.224	0.205	0.218	0.346
Indexation wages	κ_w	0.323	0.499	0.506	0.324	0.329	0.325	0.322	0.318	0.223
Indexation export prices	κ_x	0.169	0.142	0.153	0.139	0.161	0.142	0.169	0.169	0.148
Real cash balances utility	σ_q	10.620	10.620	10.620	10.625	10.620	10.621	10.620	10.620	10.622
Capital utilization adj. cost	σ_a	0.056	0.063	0.088	0.062	0.056		0.055	0.054	2.524
Investment adj. cost	SS''	7.945	8.188	7.727	8.498		7.518	7.902	7.816	7.391
Habit formation	b	0.763	0.740	0.703		0.790	0.754	0.766	0.767	0.713
Markup domestic	λ_f	1.145	1.129	1.108	1.140	1.138	1.145	1.144	1.140	1.140
Subst. elasticity consump.	η_c	5.287	14.491	12.788	13.303	4.764	11.949	5.304	5.374	11.400
Subst. elasticity invest.	η_i	2.481	1.891	1.805	1.681	3.502	1.924	2.473	2.429	1.969
Subst. elasticity foreign	η_f	1.376	1.336	1.351	1.337	1.356	1.375	1.377	1.378	1.370
Subst. elast. import cons.	$\eta_{m,c}$	3.409	3.697	3.656	3.522	3.538	3.637	3.392	3.435	3.565
Subst. elast.import invest.	$\eta_{m,i}$	5.534	5.887	6.005	6.568	5.729	6.230	5.512	5.451	6.281
Technology growth	μ_z	1.005	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.005
Capital tax	τ_k	0.185	0.204	0.193	0.238	0.197	0.170	0.185	0.170	0.181
Labour tax	τ_w	0.175	0.175	0.180	0.175	0.168	0.177	0.175	0.175	0.178
Risk premium	$\tilde{\phi}$	0.039	0.038	0.031	0.039	0.071	0.043	0.039	0.039	0.039
Unit root tech. shock	ρ_{μ_z}	0.855	0.779	0.830	0.821	0.862	0.845	0.855	0.854	0.833
Stationary tech. shock	ρ_{ε}	0.943	0.981	0.987	0.927	0.941	0.874	0.947	0.958	0.919
Invest. spec. tech shock	ρ_{Υ}	0.807	0.775	0.812	0.755	0.913	0.849	0.811	0.806	0.824
Risk premium shock	$\rho_{\tilde{\phi}}$	0.940	0.957	0.961	0.954	0.935	0.949	0.941	0.938	0.955
Cons. pref. shock	ρ_{ζ_c}	0.835	0.871	0.914	0.909	0.879	0.878	0.831	0.831	0.927
Labour supply shock	ρ_{ζ_h}	0.938	0.926	0.890	0.928	0.940	0.936	0.936	0.935	0.902
Asymm. tech. shock	$\rho_{\tilde{z}*}$	0.875	0.903	0.935	0.870	0.876	0.882	0.874	0.870	0.874
Exp. markup shock	ρ_{λ_x}	0.887	0.852	0.882	0.855	0.876	0.893	0.887	0.888	0.890
Imp. cons. elasticity shock	$\rho_{\eta_{m,c}}$	0.969	0.973	0.978	0.968	0.969	0.974	0.969	0.969	0.977
Imp. invest. elast. shock	$\rho_{\eta_{m,i}}$	0.984	0.982	0.983	0.985	0.984	0.979	0.984	0.983	0.979
Domestic markup shock	ρ_{λ}									0.980
Unit root tech. shock	ε_z	0.129	0.110	0.142	0.106	0.130	0.136	0.127	0.131	0.140
Stationary tech. shock	$\varepsilon_{\varepsilon}$	0.446	0.415	0.225	0.454	0.452	0.572	0.442	0.433	0.400
Imp. cons elasticity shock	$\varepsilon_{\eta_{m,c}}$	2.036	7.970	5.317	8.281	2.898	5.655	2.055	2.090	5.352
Imp. inv. elast. shock	$\varepsilon_{\eta_{m,i}}$	0.927	1.109	0.991	1.094	2.789	0.882	0.919	0.917	0.905
Domestic markup shock	ε_{λ}	0.133	0.140	0.270	0.135	0.134	0.134	0.133	0.134	0.106
Invest. spec. tech. shock	ε_{Υ}	5.403	5.702	4.905	6.128	1.047	5.172	5.328	5.353	4.936
Risk premium shock	$\varepsilon_{\tilde{\phi}}$	0.137	0.123	0.112	0.129	0.145	0.123	0.136	0.138	0.120
Consumption pref. shock	ε_{ζ_c}	1.363	1.261	1.066	0.762	1.277	1.576	1.398	1.365	1.408
Labour supply shock	ε_{ζ_h}	5.299	0.977	2.454	5.214	4.912	5.491	5.352	5.337	5.000
Monetary policy shock	ε_R	0.134	0.134	0.140	0.150	0.142	0.138	0.135	0.133	0.134
Asymmetric tech. shock	$\varepsilon_{\tilde{z}*}$	0.185	0.196	0.218	0.190	0.185	0.182	0.185	0.183	0.183
Export markup shock	ε_{λ_x}	0.920	1.013	0.976	1.019	0.961	0.921	0.914	0.919	0.949
Inflation target shock	$\varepsilon_{\bar{\pi}^c}$	0.038	0.036	0.045	0.039	0.034	0.049	0.039		0.039
Interest rate smoothing	ρ_R	0.911	0.794	0.808	0.887	0.900	0.888	0.910	0.900	0.841
Inflation response	r_{π}	1.613	1.764	1.743	1.545	1.607	1.633	1.615	1.611	1.717
Diff. infl response	$r_{\Delta\pi}$	0.316	0.415	0.370	0.345	0.338	0.334	0.319	0.332	0.336
Real exch. rate response	r_x	-0.020	-0.012	-0.011	-0.014	-0.020	-0.013	-0.021	-0.019	-0.013
Output response	r_y	0.051	0.021	0.001	0.071	0.042	0.034	0.053	0.041	0.020
Diff. output response	$r_{\Delta\pi}$	0.177	0.104	0.116	0.226	0.239	0.164	0.174	0.179	0.137
Marginal likelihood		-1974.0	-2024.6	-2035.5	-2013.4	-2062.1	-1960.6	-1917.4	-1970.6	-1995.4

Table 3: Variance decompositions. 5th and 95th percentiles and median (bold).

1 Q	Domestic inflation			Real exchange rate			Interest rate			GDP			Exports			Import		
Stationary technology	0,04	**0,06**	0,10	0,00	**0,00**	0,01	0,04	**0,06**	0,08	0,04	**0,05**	0,07	0,00	**0,00**	0,00	0,00	**0,00**	0,01
Nonstationary technology	0,00	**0,01**	0,02	0,00	**0,01**	0,02	0,00	**0,01**	0,02	0,06	**0,08**	0,11	0,01	**0,02**	0,03	0,02	**0,03**	0,04
Consumtion preference	0,00	**0,01**	0,02	0,02	**0,03**	0,05	0,03	**0,05**	0,06	0,04	**0,06**	0,09	0,01	**0,02**	0,03	0,03	**0,04**	0,05
Labour supply	0,12	**0,15**	0,20	0,01	**0,02**	0,03	0,04	**0,06**	0,09	0,01	**0,03**	0,04	0,00	**0,01**	0,01	0,00	**0,01**	0,01
Domestic goods mark-up	0,30	**0,37**	0,45	0,00	**0,01**	0,01	0,02	**0,06**	0,10	0,04	**0,05**	0,06	0,00	**0,01**	0,01	0,04	**0,05**	0,06
Imp. invest. elast. shock	0,00	**0,03**	0,07	0,20	**0,25**	0,29	0,04	**0,07**	0,11	0,02	**0,04**	0,07	0,10	**0,13**	0,15	0,18	**0,21**	0,25
Imp. cons. elasticity shock	0,03	**0,07**	0,10	0,18	**0,21**	0,24	0,06	**0,08**	0,11	0,02	**0,05**	0,08	0,10	**0,12**	0,15	0,00	**0,02**	0,05
Risk premium shock	0,01	**0,01**	0,02	0,08	**0,10**	0,12	0,04	**0,06**	0,08	0,05	**0,06**	0,08	0,03	**0,05**	0,06	0,11	**0,13**	0,16
Invest. Spec. technology	0,04	**0,06**	0,09	0,03	**0,05**	0,08	0,09	**0,12**	0,15	0,10	**0,14**	0,16	0,02	**0,03**	0,06	0,16	**0,19**	0,23
Asymmetric technology	0,00	**0,00**	0,00	0,00	**0,00**	0,01	0,01	**0,01**	0,01	0,01	**0,01**	0,01	0,03	**0,03**	0,04	0,00	**0,01**	0,01
Export goods mark-up	0,00	**0,01**	0,03	0,06	**0,07**	0,09	0,04	**0,06**	0,09	0,07	**0,09**	0,11	0,34	**0,39**	0,46	0,06	**0,08**	0,10
Monetary policy	0,04	**0,06**	0,10	0,07	**0,08**	0,10	0,13	**0,18**	0,25	0,10	**0,13**	0,16	0,03	**0,04**	0,05	0,04	**0,05**	0,07
Inflation target	0,08	**0,11**	0,16	0,02	**0,03**	0,04	0,04	**0,05**	0,07	0,02	**0,04**	0,05	0,01	**0,01**	0,02	0,00	**0,01**	0,02
Fiscal variables	0,01	**0,01**	0,02	0,01	**0,01**	0,01	0,04	**0,05**	0,06	0,06	**0,07**	0,08	0,00	**0,00**	0,01	0,00	**0,01**	0,01
Foreign variables	0,01	**0,01**	0,02	0,10	**0,11**	0,13	0,06	**0,08**	0,11	0,08	**0,10**	0,11	0,11	**0,13**	0,16	0,13	**0,15**	0,18

4 Q	Domestic inflation			Real exchange rate			Interest rate			GDP			Exports			Import		
Stationary technology	0,04	**0,08**	0,14	0,00	**0,00**	0,01	0,03	**0,04**	0,07	0,01	**0,02**	0,03	0,00	**0,00**	0,00	0,00	**0,00**	0,00
Nonstationary technology	0,00	**0,01**	0,03	0,01	**0,01**	0,03	0,00	**0,01**	0,04	0,11	**0,14**	0,18	0,02	**0,03**	0,04	0,03	**0,05**	0,07
Consumtion preference	0,01	**0,02**	0,03	0,02	**0,03**	0,05	0,05	**0,08**	0,10	0,05	**0,07**	0,09	0,01	**0,02**	0,03	0,02	**0,03**	0,04
Labour supply	0,18	**0,24**	0,31	0,00	**0,00**	0,01	0,08	**0,11**	0,14	0,01	**0,02**	0,05	0,00	**0,00**	0,01	0,00	**0,00**	0,01
Domestic goods mark-up	0,01	**0,02**	0,03	0,01	**0,01**	0,01	0,00	**0,00**	0,01	0,02	**0,03**	0,04	0,00	**0,01**	0,01	0,00	**0,00**	0,01
Imp. invest. elast. shock	0,00	**0,05**	0,11	0,23	**0,30**	0,35	0,01	**0,05**	0,11	0,00	**0,03**	0,06	0,13	**0,15**	0,18	0,12	**0,15**	0,19
Imp. cons. elasticity shock	0,06	**0,11**	0,17	0,21	**0,25**	0,29	0,06	**0,10**	0,14	0,03	**0,06**	0,10	0,13	**0,16**	0,19	0,06	**0,11**	0,16
Risk premium shock	0,01	**0,02**	0,03	0,06	**0,07**	0,09	0,05	**0,07**	0,11	0,05	**0,07**	0,09	0,03	**0,04**	0,06	0,12	**0,14**	0,17
Invest. Spec. technology	0,06	**0,10**	0,14	0,05	**0,08**	0,12	0,16	**0,22**	0,27	0,13	**0,18**	0,22	0,03	**0,05**	0,08	0,16	**0,20**	0,24
Asymmetric technology	0,00	**0,00**	0,00	0,00	**0,00**	0,01	0,00	**0,00**	0,00	0,00	**0,00**	0,00	0,01	**0,01**	0,01	0,00	**0,01**	0,01
Export goods mark-up	0,00	**0,02**	0,04	0,06	**0,07**	0,10	0,07	**0,10**	0,13	0,07	**0,09**	0,12	0,34	**0,39**	0,46	0,08	**0,10**	0,13
Monetary policy	0,07	**0,10**	0,16	0,05	**0,06**	0,08	0,00	**0,02**	0,06	0,12	**0,15**	0,19	0,03	**0,04**	0,05	0,03	**0,04**	0,05
Inflation target	0,12	**0,17**	0,25	0,01	**0,02**	0,03	0,06	**0,09**	0,13	0,03	**0,05**	0,07	0,01	**0,01**	0,02	0,01	**0,01**	0,02
Fiscal variables	0,01	**0,02**	0,03	0,00	**0,01**	0,01	0,01	**0,01**	0,02	0,01	**0,02**	0,02	0,00	**0,00**	0,01	0,00	**0,00**	0,01
Foreign variables	0,01	**0,02**	0,03	0,06	**0,07**	0,09	0,05	**0,07**	0,10	0,05	**0,07**	0,09	0,05	**0,07**	0,09	0,12	**0,15**	0,18

8 Q	Domestic inflation			Real exchange rate			Interest rate			GDP			Exports			Import		
Stationary technology	0,02	**0,06**	0,12	0,00	**0,01**	0,01	0,02	**0,04**	0,08	0,00	**0,00**	0,01	0,00	**0,00**	0,01	0,00	**0,00**	0,01
Nonstationary technology	0,00	**0,01**	0,03	0,01	**0,02**	0,03	0,00	**0,01**	0,05	0,17	**0,22**	0,28	0,05	**0,06**	0,08	0,07	**0,09**	0,12
Consumtion preference	0,01	**0,02**	0,03	0,01	**0,02**	0,03	0,07	**0,08**	0,10	0,06	**0,07**	0,09	0,01	**0,01**	0,03	0,00	**0,01**	0,01
Labour supply	0,17	**0,23**	0,31	0,00	**0,02**	0,03	0,09	**0,13**	0,17	0,00	**0,01**	0,03	0,00	**0,01**	0,02	0,01	**0,02**	0,02
Domestic goods mark-up	0,02	**0,02**	0,03	0,00	**0,01**	0,01	0,00	**0,01**	0,01	0,02	**0,03**	0,04	0,00	**0,00**	0,01	0,00	**0,01**	0,01
Imp. invest. elast. shock	0,01	**0,06**	0,13	0,23	**0,30**	0,36	0,00	**0,02**	0,06	0,00	**0,01**	0,04	0,14	**0,17**	0,21	0,07	**0,10**	0,13
Imp. cons. elasticity shock	0,07	**0,13**	0,19	0,25	**0,30**	0,35	0,10	**0,14**	0,20	0,05	**0,09**	0,13	0,17	**0,21**	0,25	0,14	**0,18**	0,24
Risk premium shock	0,01	**0,01**	0,03	0,03	**0,04**	0,06	0,01	**0,02**	0,05	0,02	**0,03**	0,06	0,02	**0,03**	0,04	0,07	**0,10**	0,16
Invest. Spec. technology	0,06	**0,10**	0,15	0,09	**0,12**	0,17	0,20	**0,26**	0,32	0,15	**0,20**	0,25	0,06	**0,08**	0,12	0,16	**0,23**	0,29
Asymmetric technology	0,00	**0,00**	0,00	0,00	**0,00**	0,01	0,00	**0,00**	0,00	0,00	**0,00**	0,00	0,00	**0,00**	0,01	0,00	**0,01**	0,02
Export goods mark-up	0,00	**0,02**	0,04	0,03	**0,06**	0,08	0,07	**0,09**	0,11	0,06	**0,08**	0,10	0,25	**0,31**	0,39	0,06	**0,09**	0,13
Monetary policy	0,07	**0,11**	0,17	0,04	**0,05**	0,07	0,00	**0,02**	0,07	0,11	**0,15**	0,19	0,03	**0,03**	0,05	0,01	**0,02**	0,03
Inflation target	0,12	**0,18**	0,26	0,01	**0,01**	0,02	0,07	**0,11**	0,16	0,03	**0,04**	0,07	0,01	**0,01**	0,02	0,00	**0,01**	0,01
Fiscal variables	0,01	**0,02**	0,03	0,00	**0,00**	0,01	0,01	**0,01**	0,02	0,01	**0,01**	0,01	0,00	**0,00**	0,00	0,00	**0,00**	0,01
Foreign variables	0,01	**0,01**	0,03	0,03	**0,05**	0,07	0,02	**0,03**	0,05	0,02	**0,04**	0,06	0,02	**0,03**	0,04	0,09	**0,12**	0,16

20 Q	Domestic inflation			Real exchange rate			Interest rate			GDP			Exports			Import		
Stationary technology	0,00	**0,02**	0,08	0,00	**0,01**	0,02	0,00	**0,02**	0,07	0,01	**0,02**	0,04	0,00	**0,01**	0,02	0,00	**0,01**	0,01
Nonstationary technology	0,00	**0,01**	0,03	0,01	**0,01**	0,03	0,00	**0,02**	0,05	0,26	**0,35**	0,45	0,10	**0,13**	0,17	0,17	**0,22**	0,27
Consumtion preference	0,00	**0,02**	0,03	0,00	**0,00**	0,01	0,01	**0,02**	0,05	0,01	**0,03**	0,04	0,00	**0,00**	0,01	0,02	**0,03**	0,05
Labour supply	0,06	**0,13**	0,24	0,03	**0,04**	0,07	0,06	**0,11**	0,20	0,05	**0,08**	0,12	0,02	**0,04**	0,05	0,00	**0,01**	0,03
Domestic goods mark-up	0,01	**0,02**	0,03	0,00	**0,01**	0,01	0,01	**0,01**	0,02	0,01	**0,02**	0,02	0,00	**0,00**	0,01	0,01	**0,01**	0,01
Imp. invest. elast. shock	0,01	**0,07**	0,16	0,18	**0,26**	0,35	0,00	**0,04**	0,10	0,00	**0,02**	0,04	0,13	**0,18**	0,24	0,00	**0,02**	0,06
Imp. cons. elasticity shock	0,13	**0,21**	0,30	0,33	**0,40**	0,46	0,22	**0,28**	0,37	0,12	**0,15**	0,20	0,27	**0,32**	0,39	0,14	**0,19**	0,24
Risk premium shock	0,00	**0,01**	0,03	0,01	**0,02**	0,02	0,00	**0,01**	0,01	0,00	**0,01**	0,02	0,01	**0,01**	0,02	0,03	**0,08**	0,11
Invest. Spec. technology	0,06	**0,11**	0,17	0,11	**0,14**	0,20	0,10	**0,17**	0,23	0,09	**0,13**	0,18	0,09	**0,12**	0,17	0,10	**0,14**	0,18
Asymmetric technology	0,00	**0,00**	0,00	0,00	**0,00**	0,00	0,00	**0,00**	0,00	0,00	**0,00**	0,00	0,00	**0,00**	0,00	0,00	**0,01**	0,01
Export goods mark-up	0,00	**0,02**	0,04	0,00	**0,02**	0,04	0,02	**0,03**	0,05	0,01	**0,03**	0,05	0,04	**0,10**	0,19	0,04	**0,06**	0,10
Monetary policy	0,07	**0,11**	0,19	0,03	**0,04**	0,06	0,03	**0,06**	0,12	0,07	**0,11**	0,16	0,02	**0,03**	0,05	0,04	**0,05**	0,07
Inflation target	0,13	**0,21**	0,29	0,01	**0,01**	0,02	0,11	**0,17**	0,23	0,01	**0,03**	0,04	0,00	**0,01**	0,01	0,01	**0,02**	0,02
Fiscal variables	0,01	**0,02**	0,03	0,00	**0,00**	0,00	0,01	**0,01**	0,02	0,00	**0,01**	0,01	0,00	**0,00**	0,00	0,00	**0,00**	0,01
Foreign variables	0,00	**0,01**	0,02	0,02	**0,02**	0,03	0,01	**0,02**	0,03	0,01	**0,02**	0,03	0,02	**0,02**	0,03	0,10	**0,13**	0,18

Figure 1: Prior and posterior distributions. The solid/dashed line is the posterior/prior.

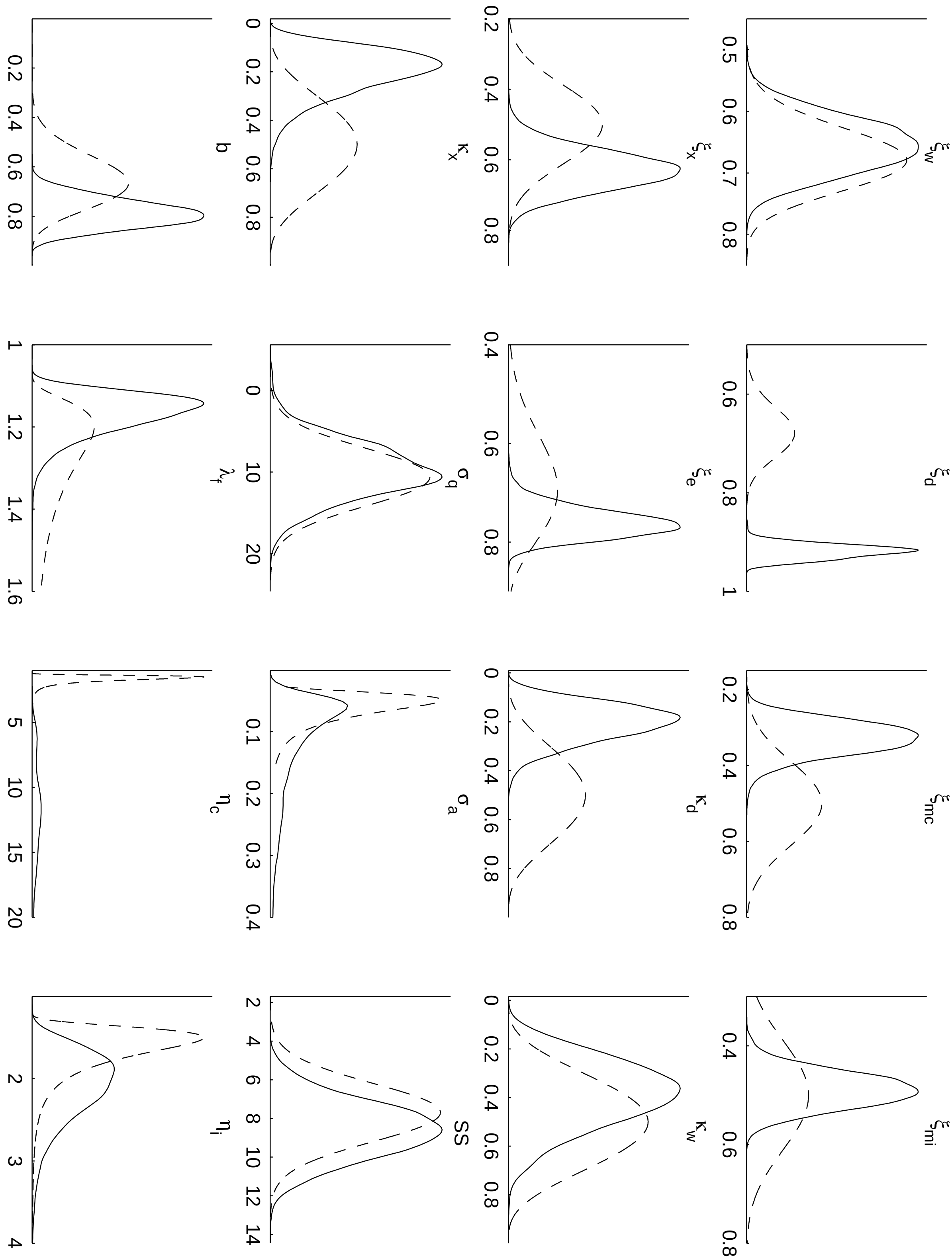

Figure 1 (cont.): Prior and posterior distributions. The solid/dashed line is the posterior/prior.

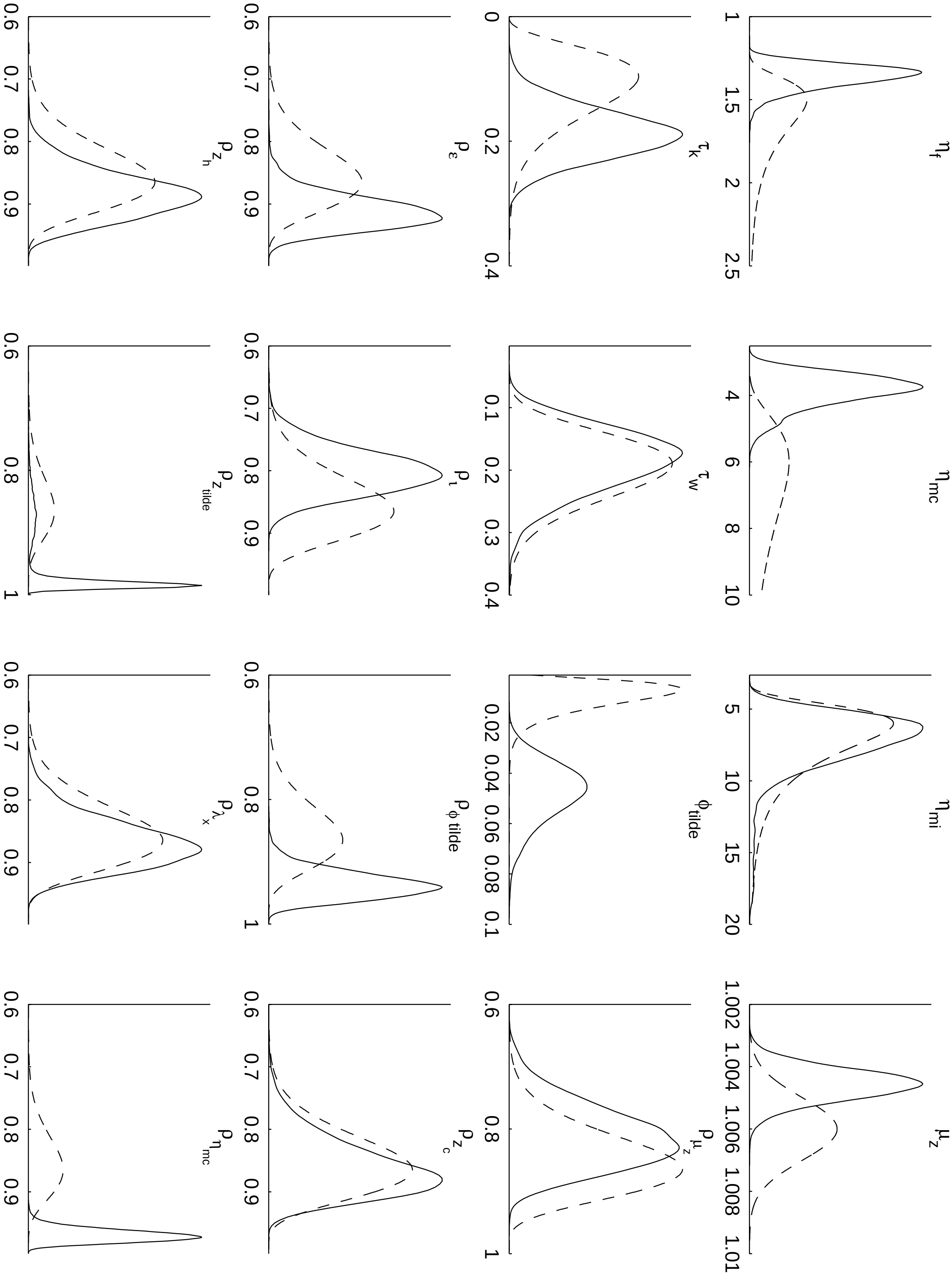

Figure 1 (cont.): Prior and posterior distributions. The solid/dashed line is the posterior/prior.

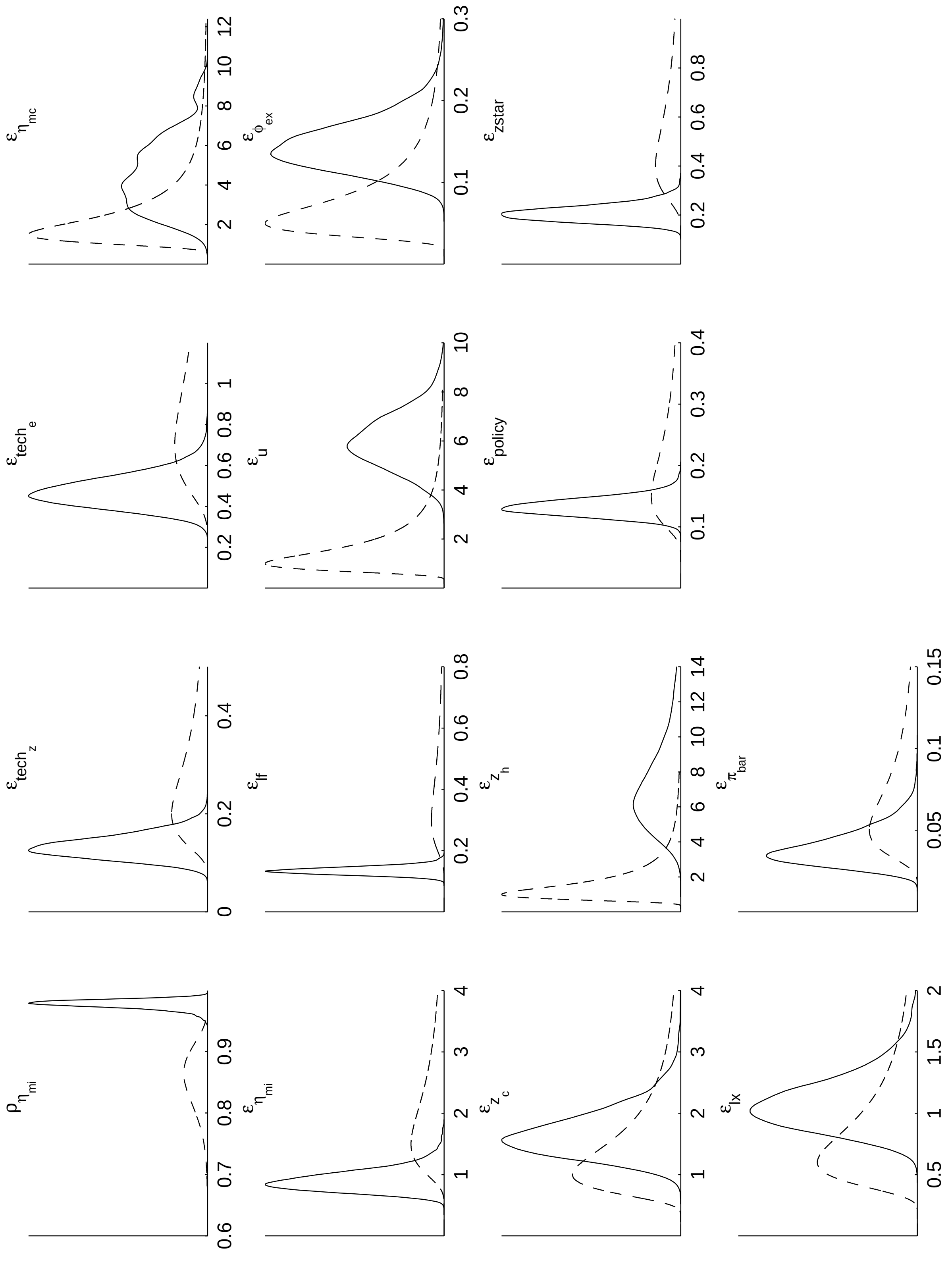

Figure 1 (cont.): Prior and posterior distributions. The solid/dashed line is the posterior/prior.

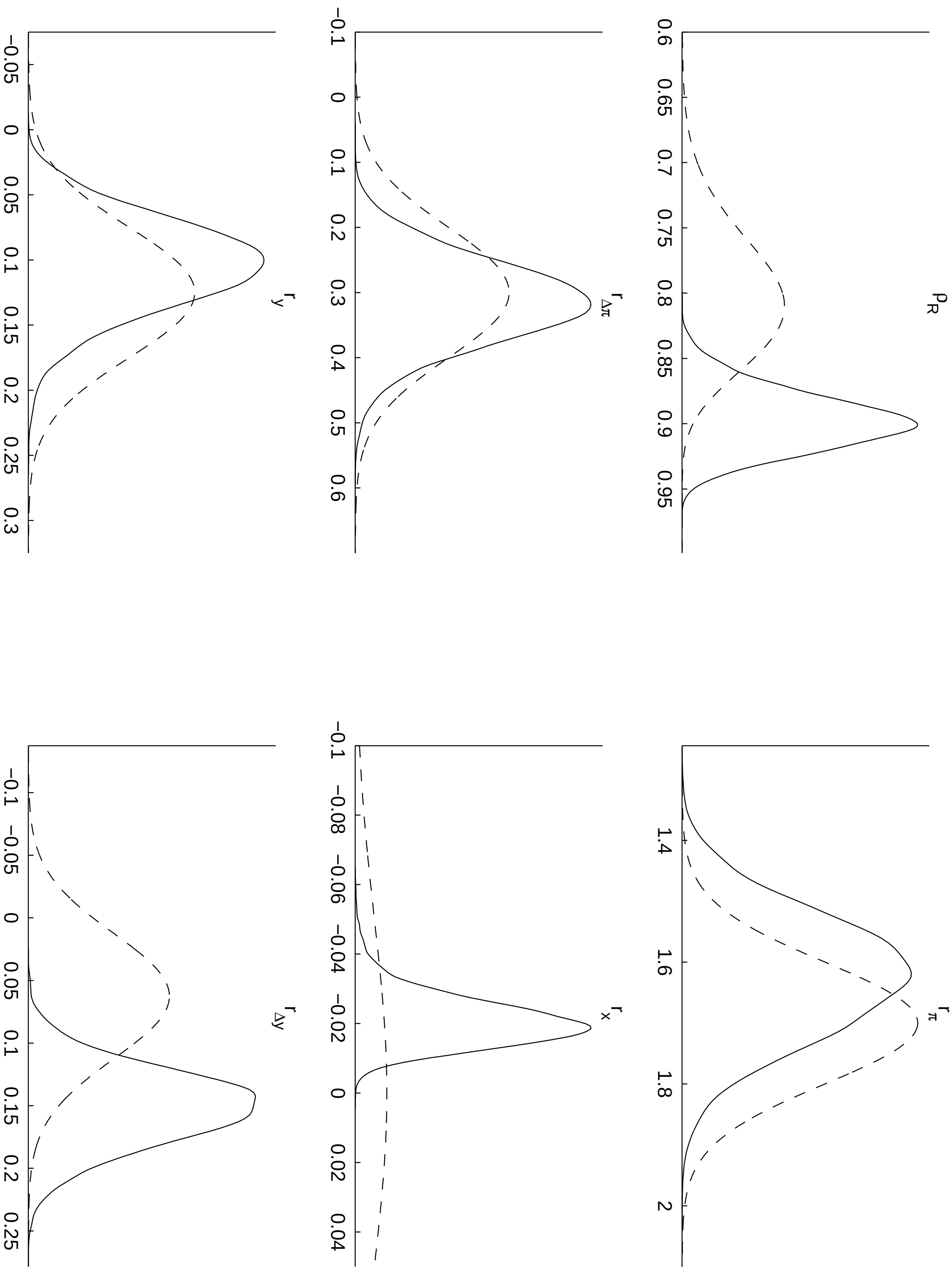

Figure 2. Response to a permanent technology shock.

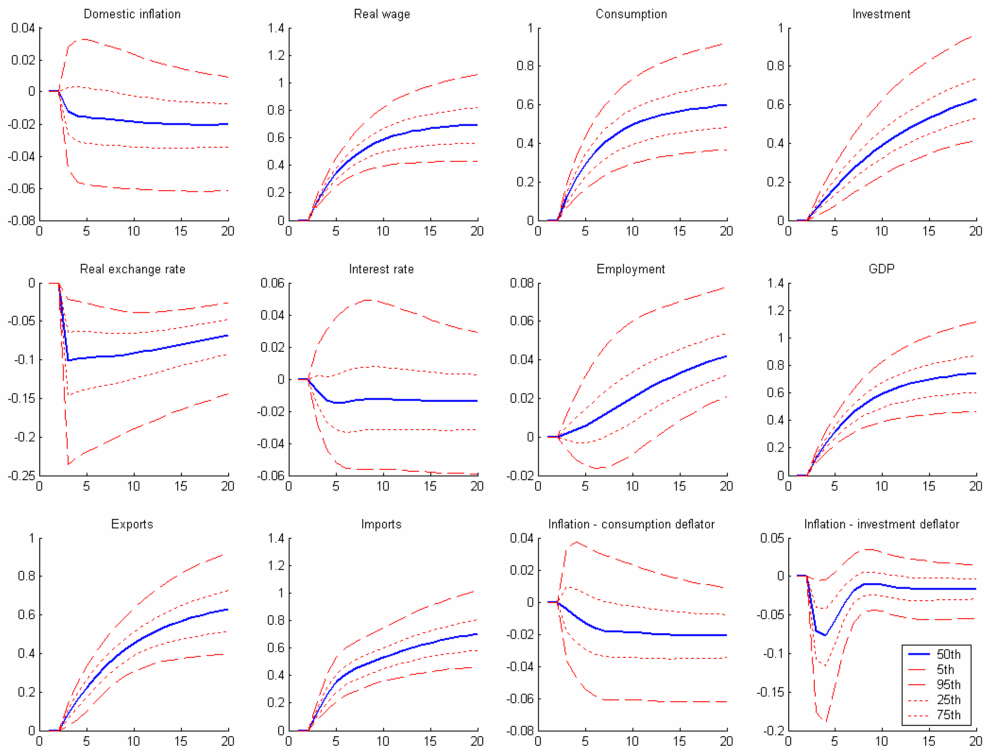

Figure 3. Response to a stationary technology shock.

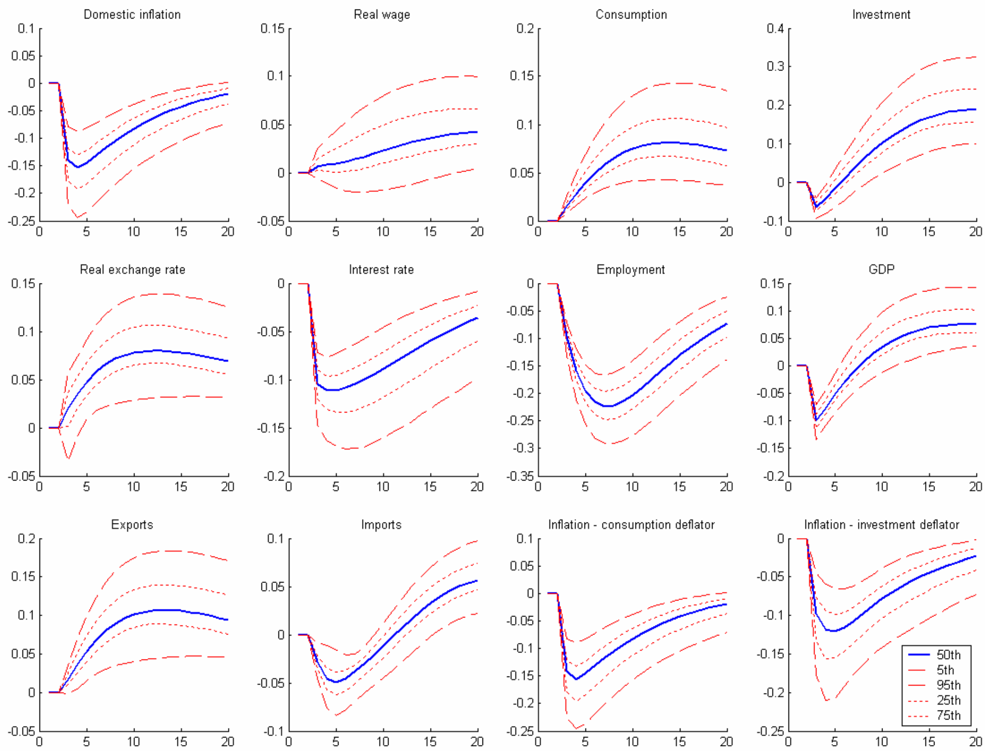

Figure 4. Response to a consumption preference shock.

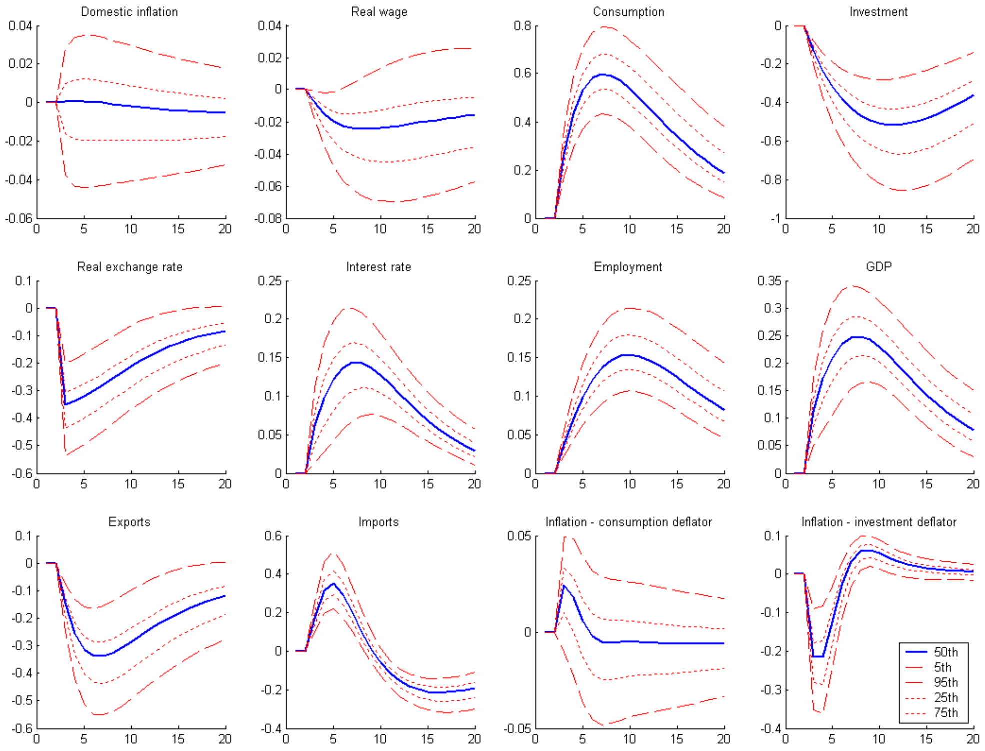

Figure 5. Response to a (negative) labour supply shock.

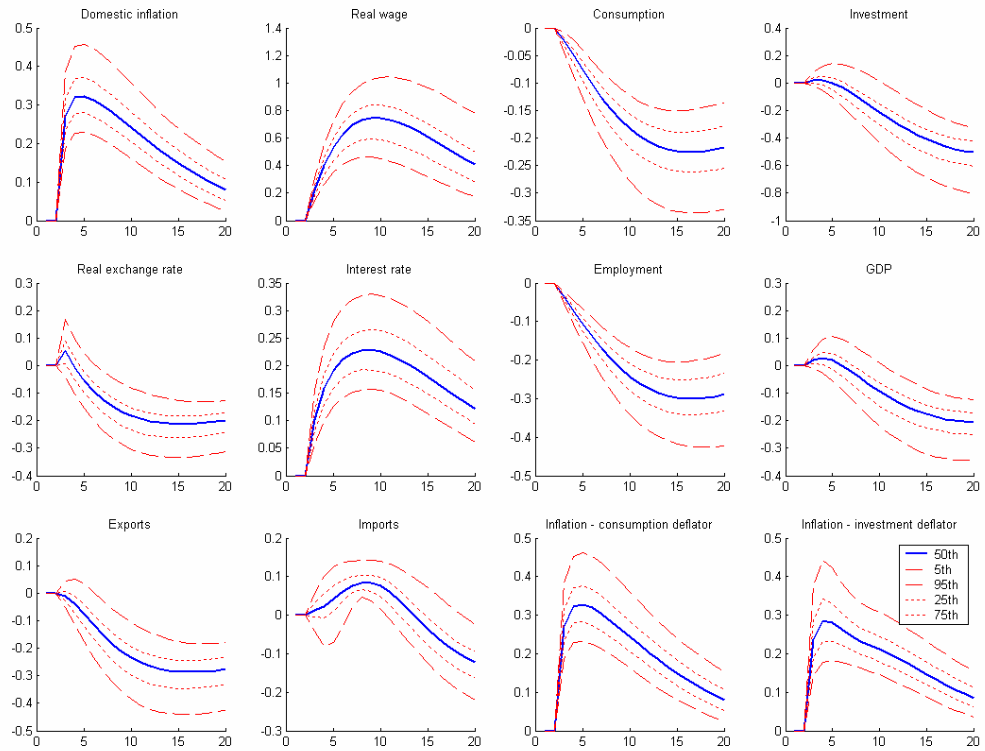

Figure 6. Response to a mark-up shock - domestic goods market.

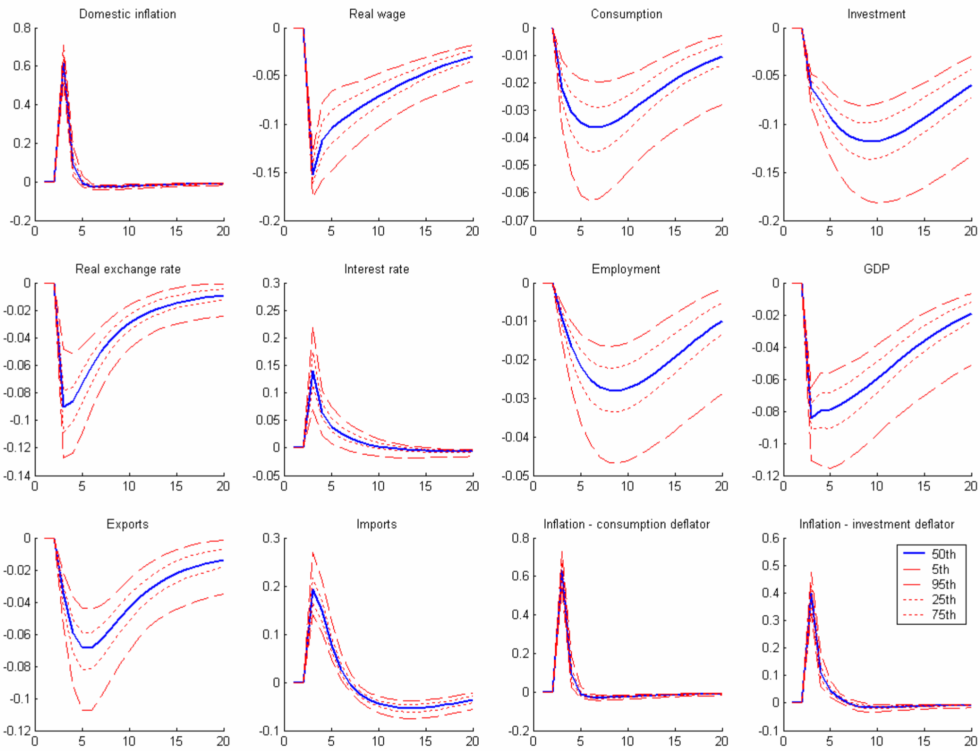

Figure 7. Response to an elasticity shock – importing investment goods.

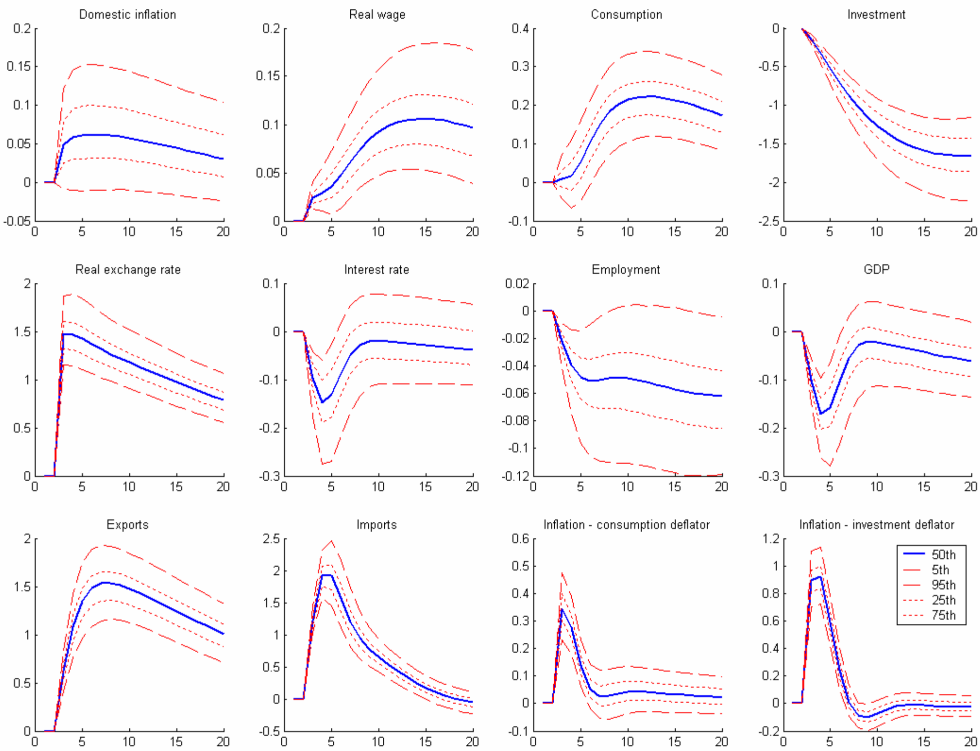

Figure 8. Response to an elasticity shock – importing consumption goods.

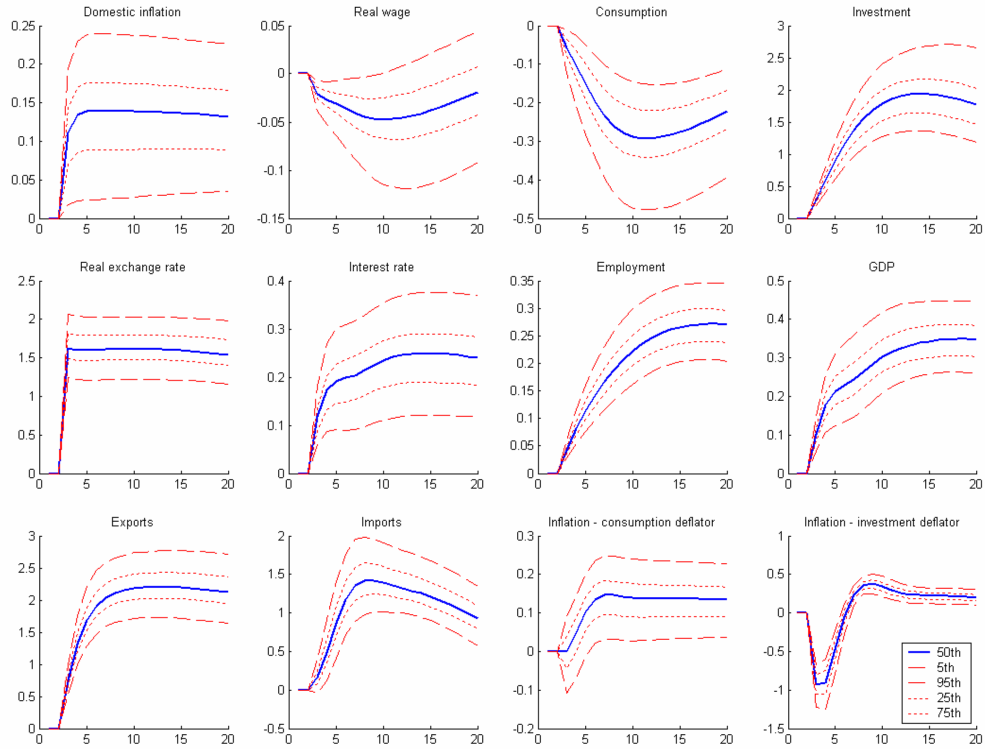

Figure 9. Response to a risk premium shock.

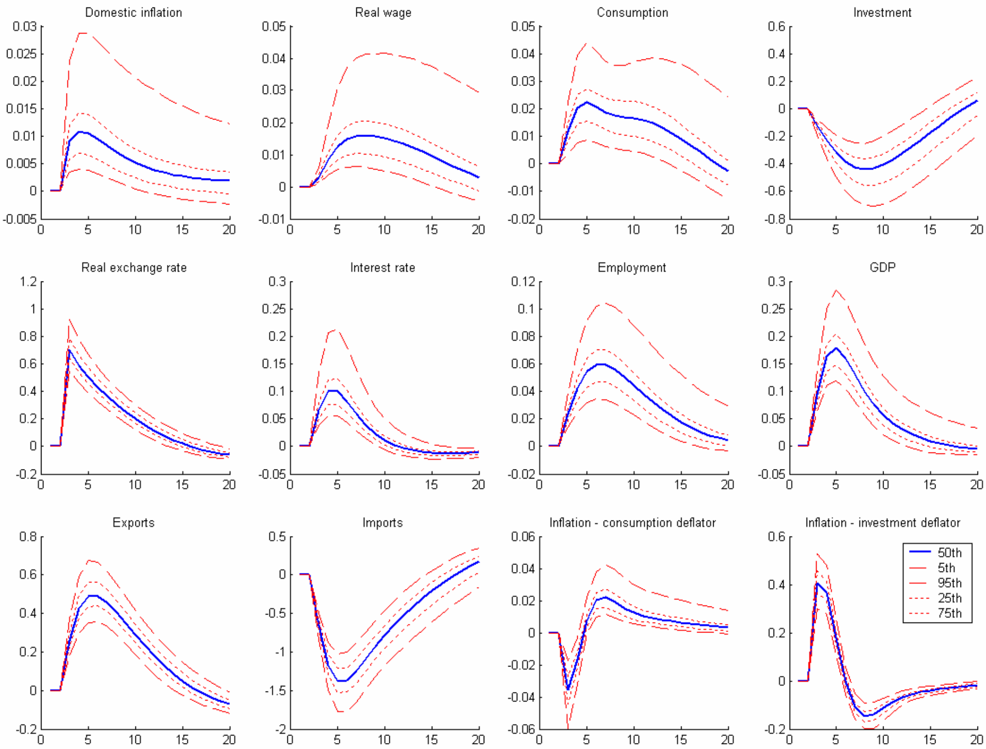

Figure 10. Response to an investment specific technology shock.

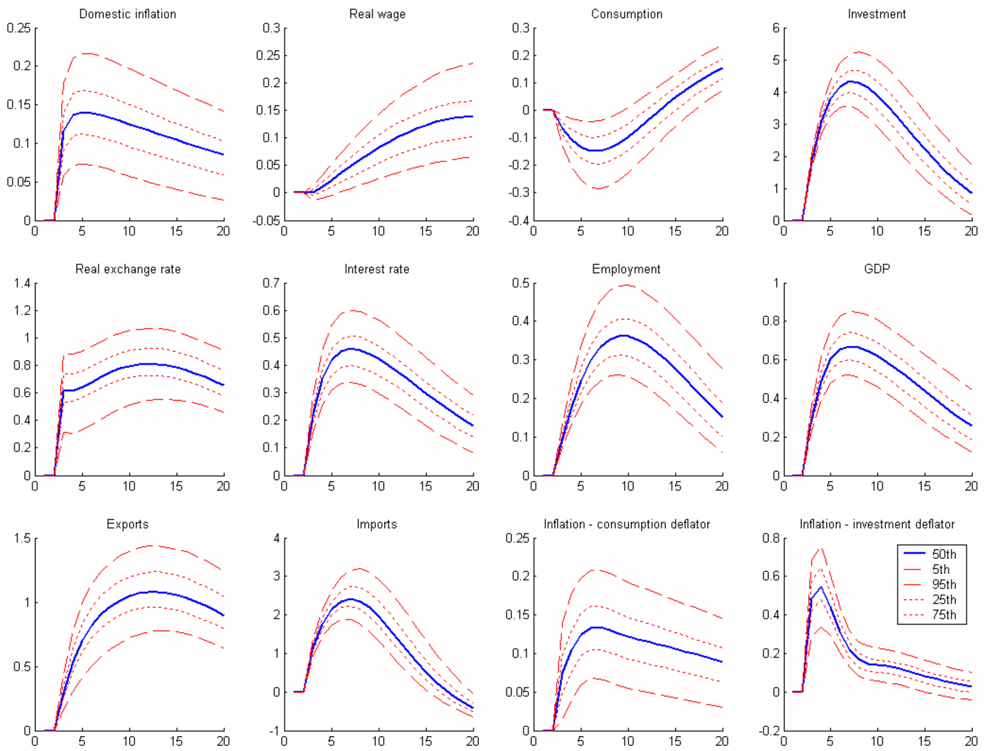

Figure 11. Response to an asymmetric technology shock.

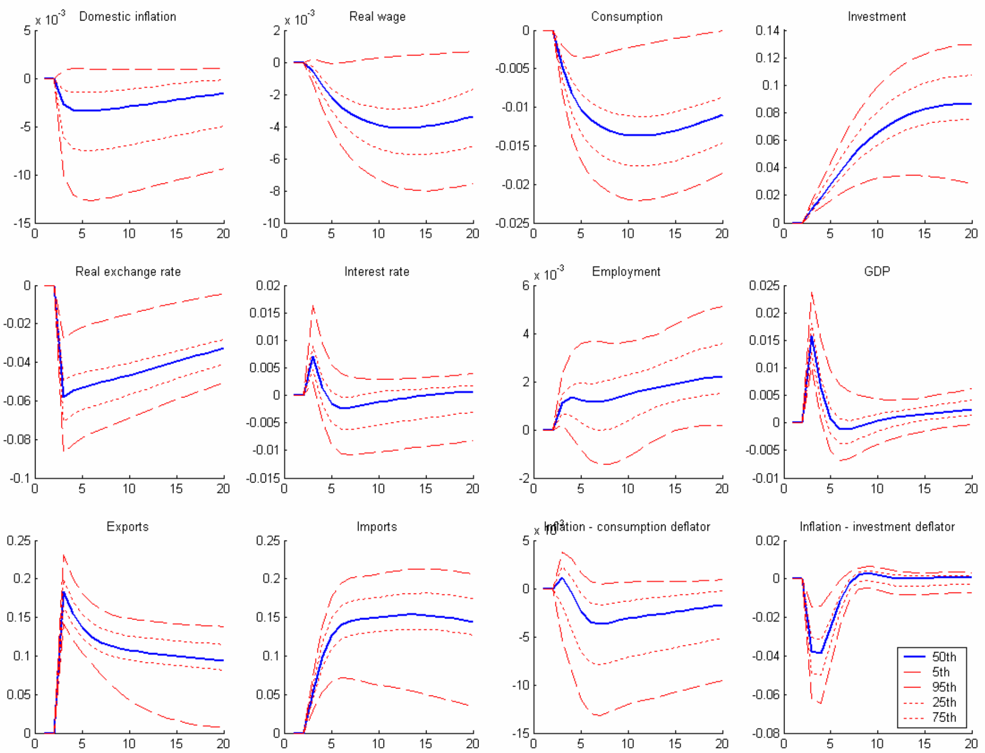

Figure 12. Response to a mark-up shock - export goods market.

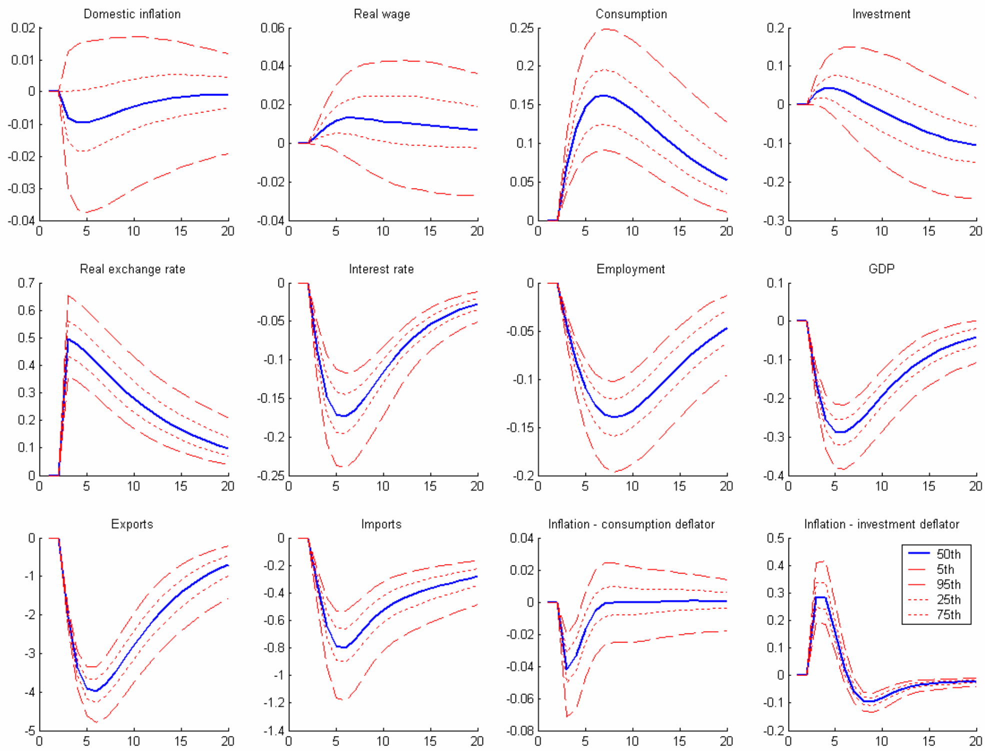

Figure 13. Response to a monetary policy shock.

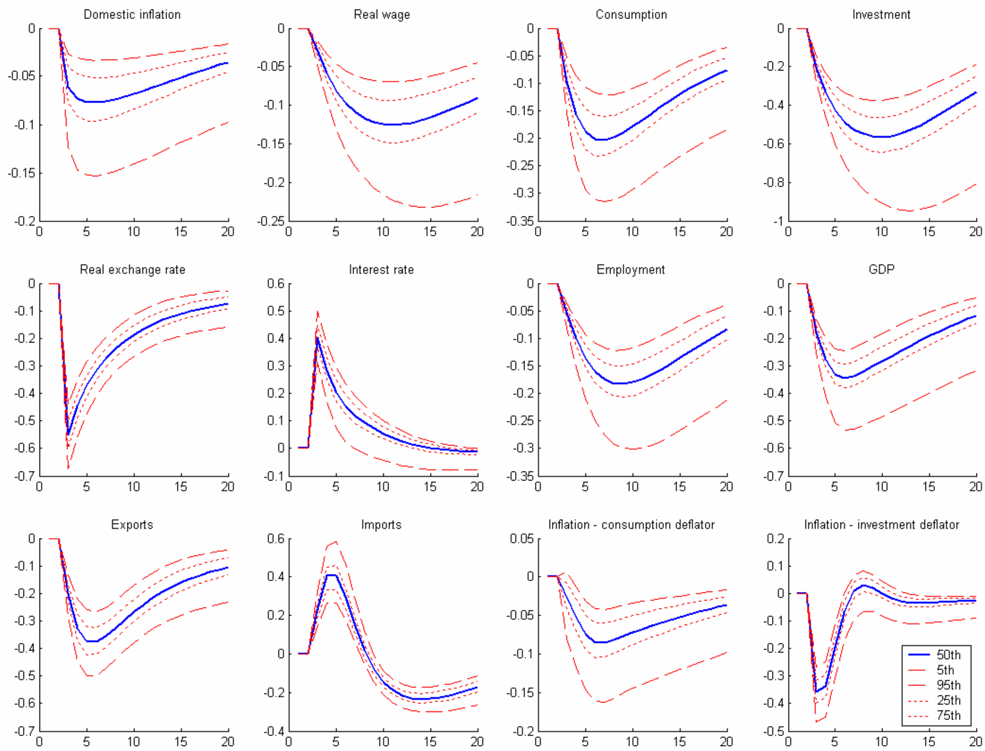

Figure 14. Response to an inflation target shock.