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A DSGE model for Iceland

By

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Abstract

This paper presents a dynamic stochastic general equilibrium (DSGE) model for a small open economy fitted to Icelandic data. The model has been developed at the Central Bank of Iceland as a tool for policy analysis and forecasting purposes in support of inflation targeting. As the existing macroeconometric model at the Central Bank, the model is a dynamic quarterly model. But it differs by being fully founded on well-defined microeconomic decision problems of agents in the economy. This allows for a structural interpretation of shocks to the economy. The model features endogenous capital accumulation subject to investment adjustment costs, variable capacity utilisation, habit formation in consumption, monopolistic competition in goods and labour markets, as well as sticky prices and wages. The home economy engages freely in international trade, while international financial intermediation is subject to endogenous costs. Monetary policy is conducted by an inflation targeting central bank. The model is fitted to Icelandic data for the sample period 1991-2005 through a combination of calibration and formal Bayesian estimation. The paper presents the estimation results, and it discusses the model's properties. Finally, first applications are shown to illustrate the model's potential in guiding monetary policy.

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1 Introduction

This paper presents a dynamic stochastic general equilibrium (DSGE) model for Iceland. The model is parameterised to fit Icelandic data through a combination of calibration and Bayesian estimation. The model is New Keynesian in the sense that goods and labour markets feature imperfect competition and nominal rigidities. This gives the model Keynesian features in the short run and classical ones in the long run. In particular, nominal rigidities imply that monetary policy has real effects in the short but not in the long run. The central bank affects the economy by setting a short-term interest rate. This influences aggregate demand and therefore the marginal costs of firms. As the prices set by firms are determined by current and expected future marginal costs, the central bank therefore controls inflation through its current and expected future interest rate decisions. In addition, by affecting the return to domestic financial assets relative to foreign ones, the central bank's interest rate affects the exchange rate, which passes through to inflation via the prices of imported goods.

The specification of the home economy is based on the closed-economy models by Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003, 2007). At its core is a neoclassical growth model with technology-driven growth and optimising economic agents. But in addition to this, it features a number of frictions to make it suitable for business cycle and policy analysis. Besides monopolistic competition and nominal rigidities, it features endogenous capital accumulation subject to investment adjustment costs, variable capacity utilisation, and habit formation in consumption. Moreover, open economy aspects are introduced along the lines suggested by Clarida, Galí and Gertler (2002). The home economy is assumed to be a small open economy, which is modelled by letting its relative size go to zero in a general two-country model. International financial markets are incomplete and international financial intermediation is subject to endogenous costs as in Laxton and Pesenti (2003). Monetary policy is conducted by an inflation-targeting central bank that sets the short-term interest rate endogenously according to a monetary policy rule. Each period, the economy is hit by a number of structural shocks that are propagated through the economy to generate fluctuations in macroeconomic variables.

The model is similar to a number of DSGE models used for policy analysis in central banks around the world. With the rise of inflation targeting and the associated emphasis on communication in monetary policy making, many central banks have moved towards a more formally structural approach to economic analysis.[1] At the centre of this shift has been the development and implementation of DSGE models and the numerical and econometric methods needed to analyse them. As the models represent the general equilibrium of an economy with intertemporally optimising economic agents as well as economic policy makers, the models are not only inherently dynamic, but they also capture the intricate interactions between economic agents and economy policy, explicitly considering the important role played by expectations about the future in eco-

[1] See e.g. Hammond (2009) for an overview of inflation targeting regimes.

nomic decision-making. Moreover, the shocks to the economy can generally be given a structural interpretation, facilitating the understanding of the driving forces of business cycle fluctuations. Particular inspiration for the DSGE model for Iceland has been found in the DSGE models developed by the International Monetary Fund, Norges Bank and Sveriges Riksbank, cf. Laxton and Pesenti (2003), Brubakk et al. (2006) and Adolfson et al. (2007, 2008) respectively.[2]

The model is parameterised to fit quarterly Icelandic data for the period 1991 to 2005. The objective of this exercise is twofold. First, the objective is to investigate how far a fairly standard medium-sized, open-economy DSGE model can go in terms of accounting for developments in the Icelandic economy. Iceland is a particularly interesting test case for the DSGE approach given its small size, its openness, the volatility of its economy, and the frequent structural changes in economic policy. Second, and most importantly, the objective is to develop a tool for economic and policy analysis in support of inflation targeting at the Central Bank of Iceland to be used along with the Central Bank's existing macroeconometric model *QMM*.[3] The model presented in this paper is analysed using Dynare version 4 for Matlab, cf. Adjemian et al. (2010).

The paper is organised as follows. Section 2 presents the model. First, the decision problems of agents in the economy are presented and the general equilibrium conditions are derived. Second, the log-linearisation of the model is presented. Section 3 presents the data and the parameterisation through calibration and Bayesian estimation, and it provides a discussion of the model fit. Section 4 investigates the model's properties by analysing impulse response functions from the log-linearised model. Section 5 illustrate two applications of the model in the form of shock decompositions and forecasts of key macroeconomic variables. Section 5 concludes.

2 The model

The model is a New Keynesian dynamic stochastic general-equilibrium model of a small open economy. It features endogenous accumulation of capital, variable capital utilisation and investment-adjustment costs. Both prices and wages are sticky with indexing to allow for both forward- and backward-looking behaviour in the setting of prices and wages. Employment adjusts along the intensive margin only.

[2] A non-exhaustive list of other central bank DSGE models is: Murchison and Rennison (2006) at the Bank of Canada, Harrison and Oomen (2010) at the Bank of England, Kilponen and Ripatti (2005) at the Suomen Pankki, Andrés et al. (2006) at the Banco de España, Christoffel et al. (2008) at the European Central Bank, Jääskelä and Nimark (2008) at the Reserve Bank of Australia, Beneš et al. (2009) at the Reserve Bank of New Zealand, and Edge et al. (2008) and Erceg et al. (2006) at the US Federal Reserve. Textbook treatments of the modeling framework are given by Galí (2008) and Woodford (2003), and of the empirical approach by Canova (2007) and DeJong with Dave (2007). Sbordone et al. (2010) illustrate the use of DSGE models in policy analysis.

[3] A small New Keynesian model estimated using Icelandic data (following a Bayesian approach) is presented in Hunt (2006). The *QMM* is documented in Daníelsson et al. (2009).

The home economy consists of a continuum of firms, a continuum of households, and an inflation-targeting central bank. Fiscal policy is passive in that government spending is exogenous and financed fully by lump-sum taxes each period. There is monopolistic competition in goods and labour markets, and perfect competition in the rental market for capital.

Using Cobb-Douglas technology, each firm combines rented capital with an aggregate of the differentiated labour services supplied by individual households to produce a differentiated intermediate good. It sets the price of its good according to a Calvo price-setting mechanism and stands ready to satisfy demand at the chosen price. Given this demand, and given wages and rental rates, the firm chooses the relative factor inputs to production to minimise its costs. To allow for incomplete pass-through of exchange rate developments into prices in the short run, firms are assumed to engage in international price discrimination and goods are priced in the currency of the country in which they are sold.

Each household consumes a bundle of the intermediate goods produced by individual firms at home and abroad. Each period, it chooses how much to consume of this final good (in addition to its composition) and how much to invest in state-contingent domestic bonds (denominated in domestic currency) and non-state-contingent foreign bonds (denominated in foreign currency) subject to an international financial intermediation cost. It also chooses how much to invest in new capital available for rent in the next period subject to investment adjustment costs, and it chooses the rate of utilisation of its existing capital stock. Finally, the household chooses the hourly wage rate for its labour service. It then stands ready to meet demand for its labour at the chosen wage.

Each period – thought of as a quarter – begins by the realisation of shocks to the economy. The model has 15 structural shocks. Three shocks originate abroad (to foreign output, inflation and interest rates), four shocks are to technology (a permanent total factor productivity shock, a temporary labour-augmenting technology shock, an internationally asymmetric technology shock, and an investment-specific technology shock), while four shocks are to mark-ups (for domestic goods sold at home, imported goods, exported goods, and in the labour market). Finally, one shock is to household preferences, one to monetary policy, one to government spending, and one to the home country risk premium.

2.1 Monopolistic competition

The world economy is populated by a continuum of households and a continuum of firms. Home firms (denoted by subscript H) sell differentiated products to households at home and abroad in competition with firms abroad (denoted by subscript F). Each continuum of agents has unit mass. Agents in the interval $[0, n]$ where $n \in [0, 1]$ belong to the home economy, while agents in the interval $(n, 1]$ reside abroad. Initially, a general two-country model is considered. Then we take the limit as $n \to 0$ to analyse the small open economy.

2.1.1 Factor markets

The labour used in production in each domestic firm $i \in [0,n]$ denoted by $N_t(i)$, is a Dixit-Stiglitz aggregate of the differentiated labour services supplied by domestic households

$$N_t(i) = \left(\left(\frac{1}{n}\right)^{\frac{1}{\varepsilon_{W,t}}} \int_0^n N_t(i,j)^{\frac{\varepsilon_{W,t}-1}{\varepsilon_{W,t}}} dj \right)^{\frac{\varepsilon_{W,t}}{\varepsilon_{W,t}-1}} \tag{1}$$

where $N_t(i,j)$ represents the hours worked by domestic household $j \in [0,n]$ in the production process of domestic firm i. The elasticity of substitution between individual labour services are given by $\varepsilon_{W,t} > 1$ so that the desired mark-up is given as $\mathcal{M}_{W,t} = \varepsilon_{W,t}/(\varepsilon_{W,t} - 1)$. The elasticity of substitution and so the desired mark-up are subject to exogenous shocks.

Denoting the wage rate demanded by household j by $W_t(j)$, cost minimisation by firms (for a given level of total labour input) leads to a downward-sloping demand schedule for the labour service offered by this particular households. Firm i's demand for household j's labour is given as

$$N_t(i,j) = \frac{1}{n} \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_{W,t}} N_t(i) \tag{2}$$

Aggregating over firms gives the economy-wide demand for the work hours offered by household j

$$N_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_{W,t}} N_t \tag{3}$$

where $\varepsilon_{W,t}$ now represents the elasticity of demand, and

$$N_t = \frac{1}{n} \int_0^n N_t(i)\, di \tag{4}$$

represents total hours worked in firms across the economy (in per capita terms). W_t is the wage index defined as

$$W_t = \left(\frac{1}{n} \int_0^n W_t(j)^{1-\varepsilon_{W,t}} dj\right)^{\frac{1}{1-\varepsilon_{W,t}}} \tag{5}$$

This wage index has the property that the minimum (per capita) cost of employing workers for N_t hours is given by $W_t N_t$.

The capital rental market is competitive. Aggregate effective capital per capita is given as

$$K_t = \frac{1}{n} \int_0^n K_t(i)\, di \tag{6}$$

2.1.2 Goods

The final consumption good that enters domestic household j's utility function is an aggregate of home and foreign goods

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

where $\eta > 0$ is the elasticity of subsitution between domestically produced and imported goods, and $(1-\bar{\alpha}) = (1-n)\alpha$. The parameter $\alpha \in [0,1]$ is related to the degree of openness, while $(1-\alpha)$ can be interpreted as the degree of home bias.[4] Home and foreign tradable goods are, in turn, combined according to Dixit-Stiglitz indices of the differentiated goods produced by firms at home and abroad:

$$C_{H,t}(j) = \left(\left(\frac{1}{n}\right)^{\frac{1}{\varepsilon_{H,t}}} \int_0^n C_{H,t}(i,j)^{\frac{\varepsilon_{H,t}-1}{\varepsilon_{H,t}}} di\right)^{\frac{\varepsilon_{H,t}}{\varepsilon_{H,t}-1}} \tag{7}$$

$$C_{F,t}(j) = \left(\left(\frac{1}{1-n}\right)^{\frac{1}{\varepsilon_{F,t}}} \int_n^1 C_{F,t}(i,j)^{\frac{\varepsilon_{F,t}-1}{\varepsilon_{F,t}}} di\right)^{\frac{\varepsilon_{F,t}}{\varepsilon_{F,t}-1}} \tag{8}$$

where $C_{H,t}(i,j)$ represents the consumption by domestic household $j \in [0,n]$ of the good produced by domestic producer $i \in [0,n]$, and $C_{F,t}(i,j)$ represents the consumption by domestic household $j \in [0,n]$ of the good produced by foreign producer $i \in (n,1]$. Here, $\varepsilon_{H,t}, \varepsilon_{F,t} > 1$ are the elasticities of substitution between individual goods so that desired mark-ups are given as $\mathcal{M}_{H,t} = \varepsilon_{H,t}/(\varepsilon_{H,t}-1)$ and $\mathcal{M}_{F,t} = \varepsilon_{F,t}/(\varepsilon_{F,t}-1)$. The elasticities and so the desired mark-ups are subject to exogenous shocks.

Similarly, the final good entering a foreign household's utility function is given by

$$C_t^*(j) = \left[(\bar{\alpha}^*)^{\frac{1}{\eta}} C_{H,t}^*(j)^{\frac{\eta-1}{\eta}} + (1-\bar{\alpha}^*)^{\frac{1}{\eta}} C_{F,t}^*(j)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{9}$$

with $\bar{\alpha}^* = n\alpha^*$. The subindices are given by

$$C_{H,t}^*(j) = \left(\left(\frac{1}{n}\right)^{\frac{1}{\varepsilon_{H,t}^*}} \int_0^n C_{H,t}^*(i,j)^{\frac{\varepsilon_{H,t}^*-1}{\varepsilon_{H,t}^*}} di\right)^{\frac{\varepsilon_{H,t}^*}{\varepsilon_{H,t}^*-1}} \tag{10}$$

and

$$C_{F,t}^*(j) = \left(\left(\frac{1}{1-n}\right)^{\frac{1}{\varepsilon_{F,t}^*}} \int_n^1 C_{F,t}^*(i,j)^{\frac{\varepsilon_{F,t}^*-1}{\varepsilon_{F,t}^*}} di\right)^{\frac{\varepsilon_{F,t}^*}{\varepsilon_{F,t}^*-1}} \tag{11}$$

[4] When $\alpha = 1$, there is no home bias in consumption. In the limit as $n \to 0$, that is, for the small open economy, only a negligible, infinitesimally small part of the consumption bundle consists of domestically produced goods in this case.

Here $C^*_{H,t}(i,j)$ represents the consumption by foreign household $j \in (n,1]$ of the good produced by domestic producer $i \in [0,n]$, and $C^*_{F,t}(i,j)$ represents the consumption by foreign household $j \in (n,1]$ of the good produced by foreign producer $i \in (n,1]$.

2.1.3 Prices

Let the price in home currency demanded by home producer $i \in [0,n]$ in the domestic market be $P_{H,t}(i)$, and let the price in foreign currency demanded by the same producer in the foreign market be $P^*_{H,t}(i)$. Similarly, let the price in home currency demanded by foreign tradables producer $i \in (n,1]$ in the home market be $P_{F,t}(i)$, and let the price in foreign currency demanded by the same producer in the foreign market be $P^*_{F,t}(i)$. Then, we may define the index of domestically produced goods as

$$P_{H,t} = \left[\frac{1}{n}\int_0^n P_{H,t}^{1-\varepsilon_{H,t}}(i)\,di\right]^{\frac{1}{1-\varepsilon_{H,t}}} \tag{12}$$

while

$$P_{F,t} = \left[\frac{1}{1-n}\int_n^1 P_{F,t}^{1-\varepsilon_{F,t}}(i)\,di\right]^{\frac{1}{1-\varepsilon_{F,t}}} \tag{13}$$

is an index of imported goods prices. Corresponding price indices are defined for the foreign economy.

The consumer price index (CPI) is defined as

$$P_t = \left[\bar{\alpha}P_{H,t}^{1-\eta} + (1-\bar{\alpha})\,P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{14}$$

This price indix has the property that the minimum expenditure required to purchase C_t units of the composite good is given by P_tC_t.

Generally the law of one price does not hold because of local-currency pricing, i.e., $P_{H,t} \neq \mathcal{E}_tP^*_{H,t}$ and $P_{F,t} \neq \mathcal{E}_tP^*_{F,t}$. Therefore, and because of home bias, purchasing power parity does not hold. We therefore define the real exchange rate as

$$S_t = \frac{\mathcal{E}_tP^*_t}{P_t} \tag{15}$$

where $\mathcal{E}_t$ is the nominal exchange rate giving the home-currency price of one unit of foreign currency. We also define the terms of trade as

$$T_t = \frac{P_{F,t}}{\mathcal{E}_tP^*_{H,t}} \tag{16}$$

Note that in the limit as $n \to 0$, $P^*_t = P^*_{F,t}$.

2.1.4 Demand

Expenditure minimisation by a household (for a given level of final goods consumption) leads to a downward-sloping demand schedule for the intermediate good produced by a particular firm. Domestic household j's demand for the product produced by domestic producer i is given by

$$\begin{aligned} & C_{H,t}(i,j) \\ = \;& \frac{1}{n}\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon_{H,t}} C_{H,t}(j) \\ = \;& \frac{1}{n}\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon_{H,t}} \bar{\alpha}\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t(j) \end{aligned} \tag{17}$$

Aggregating over domestic households gives domestic consumption demand for domestic producer i's product

$$C_{H,t}(i) = \bar{\alpha}\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon_{H,t}}\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \tag{18}$$

where $C_t = \frac{1}{n}\int_0^n C_t(j)\,dj$ is aggregate domestic consumption (per capita). Similarly, domestic consumption demand for the product produced by foreign tradables firm $i \in (n,1]$ is given by

$$C_{F,t}(i) = (1-\bar{\alpha})\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\varepsilon_{F,t}}\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} \frac{n}{1-n} C_t \tag{19}$$

Corresponding demand relations hold for the foreign economy. Hence, foreign demand for a home good i is given by

$$C^*_{H,t}(i) = \bar{\alpha}^*\left(\frac{P^*_{H,t}(i)}{P^*_{H,t}}\right)^{-\varepsilon^*_{H,t}}\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\eta} \frac{1-n}{n} C^*_t \tag{20}$$

and foreign demand for a foreign good by

$$C^*_{F,t}(i) = (1-\bar{\alpha}^*)\left(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\varepsilon^*_{F,t}}\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\eta} C^*_t \tag{21}$$

For simplicity, we assume that the elasticities of substitution between varieties of goods are the same regardless of the use of the final good. Consequently, we may derive demand relations for the good produced by any firm i corresponding to the private consumption demand relations above for public consumption, investment and maintenance of machinery.

Aggregate demand for home good $i \in [0,n]$ is then given by

$$Y^d_{H,t}(i) \equiv A_{H,t}(i) + A^*_{H,t}(i) \tag{22}$$

where

$$A_{H,t}(i) = C_{H,t}(i) + I_{H,t}(i) + M_{H,t}(i) + G_{H,t}(i) \tag{23}$$

and $I_{H,t}(i)$ represents goods produced by firm i devoted to investment, $M_{H,t}(i)$ denotes those devoted to covering capital utilisation costs, which we may think of as maintenance of the existing capital stock, and $G_{H,t}(i)$ represents government consumption of good i. Substituting the demand relations into (22) and taking the limit as $n \to 0$ gives

$$\begin{aligned} Y_{H,t}^{d}(i) \;\equiv\; & (1-\alpha)\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon_{H,t}}\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} A_t \\ & +\alpha^{*}\left(\frac{P_{H,t}^{*}(i)}{P_{H,t}^{*}}\right)^{-\varepsilon_{H,t}^{*}}\left(\frac{P_{H,t}^{*}}{P_t^{*}}\right)^{-\eta} A_t^{*} \end{aligned} \tag{24}$$

where

$$A_t = C_t + I_t + M_t + G_t \tag{25}$$

is per capita absorption. Similarly for foreign goods we have (for $n \to 0$)

$$Y_{F,t}^{d}(i) = \left(\frac{P_{F,t}^{*}(i)}{P_{F,t}^{*}}\right)^{-\varepsilon_{F,t}^{*}}\left(\frac{P_{F,t}^{*}}{P_t^{*}}\right)^{-\eta} A_t^{*} \tag{26}$$

Hence, the domestic economy has no influence on aggregate demand abroad, while foreign demand affects aggregate demand in the domestic economy.

2.1.5 Resource constraints

Labour and capital rental markets clear when

$$N_t = \frac{1}{n}\int_0^n N_t(j)\,dj \tag{27}$$

and

$$K_t = \frac{1}{n}\int_0^n K_t(j)\,dj \tag{28}$$

where $N_t(j)$ represents total hours worked, and $K_t(j)$ the effective capital let to firms, by household $j \in [0, n]$.

Let $Y_{H,t}^{h}(i)$ represent the production of home firm i for the domestic market and $Y_{H,t}^{f}(i)$ the production of the same firm for exports so that total production of the firm is $Y_{H,t}(i) = Y_{H,t}^{h}(i) + Y_{H,t}^{f}(i)$. Then aggregate domestic output per capita can be defined as

$$Y_{H,t} = Y_{H,t}^{h} + EX_t \tag{29}$$

where

$$Y_{H,t}^{h} \equiv \frac{1}{n}\left(\left(\frac{1}{n}\right)^{\frac{1}{\varepsilon_{H,t}}}\int_0^n Y_{H,t}^{h}(i)^{\frac{\varepsilon_{H,t}-1}{\varepsilon_{H,t}}}\,di\right)^{\frac{\varepsilon_{H,t}}{\varepsilon_{H,t}-1}} \tag{30}$$

and

$$EX_t \equiv \frac{1}{n}\left(\left(\frac{1}{n}\right)^{\frac{1}{\varepsilon^*_{H,t}}}\int_0^n Y^f_{H,t}(i)^{\frac{\varepsilon^*_{H,t}-1}{\varepsilon^*_{H,t}}}di\right)^{\frac{\varepsilon^*_{H,t}}{\varepsilon^*_{H,t}-1}} \tag{31}$$

represent production for the home market and for exports, respectively. Then the resource constraints are given by

$$Y^h_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} A_t \tag{32}$$

and

$$EX_t = \alpha^*\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\eta} A^*_t \tag{33}$$

so that

$$Y_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} A_t + \alpha^*\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\eta} A^*_t \tag{34}$$

Per capita net exports (measured in terms of home goods) is defined as

$$NX_t = EX_t - \frac{P_{F,t}}{\mathcal{E}_t P^*_{H,t}} IM_t = EX_t - T_t IM_t \tag{35}$$

where per capita imports are given as

$$IM_t = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} A_t \tag{36}$$

from the demand relations described above.

Nominal gross domestic product (GDP) per capital is defined as

$$GDP_t = P_{H,t}Y^h_{H,t} + \mathcal{E}_t P^*_{H,t} EX_t \tag{37}$$

Real GDP per capital in consumption units is therefore

$$Y_t \equiv \frac{GDP_t}{P_t} = \frac{P_{H,t}}{P_t}Y^h_{H,t} + \frac{\mathcal{E}_t P^*_{H,t}}{P_t} EX_t \tag{38}$$

or

$$\begin{aligned} Y_t &= (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{1-\eta} A_t + \frac{\mathcal{E}_t P^*_{H,t}}{P_t} EX_t \\ &= \left[1-\alpha\left(\frac{P_{F,t}}{P_t}\right)^{1-\eta}\right] A_t + \frac{\mathcal{E}_t P^*_{H,t}}{P_t} EX_t \\ &= A_t + \frac{\mathcal{E}_t P^*_{H,t}}{P_t} EX_t - \frac{P_{F,t}}{P_t} IM_t \end{aligned} \tag{39}$$

Hence, we may write real GDP per capita in consumption units as domestic absorption plus net exports (transformed to consumption units):

$$Y_t = A_t + \frac{\mathcal{E}_t P^*_{H,t}}{P_t} NX_t \tag{40}$$

2.2 Households

2.2.1 Utility

Each domestic household $j \in [0, n]$ maximises its expected discounted life-time utility given by

$$E_t \sum_{k=0}^{\infty} \beta^k \mathcal{U}\left(C_{t+k}(j), N_{t+k}(j)\right) \tag{41}$$

where $\beta \in (0,1)$ is the subjective discount factor and the instantaneous utility function is given by

$$\mathcal{U}\left(C_t(j), N_t(j)\right) = Z_{C,t} \ln\left(C_t(j) - hC_{t-1}\right) - \chi \frac{N_t(j)^{1+\varphi}}{1+\varphi} \tag{42}$$

The marginal utilities of consumption and labour are

$$MU_{C,t}(j) = Z_{C,t}\left(C_t(j) - hC_{t-1}\right)^{-1} \tag{43}$$

and

$$MU_{N,t}(j) = -\chi N_t(j)^{\varphi} \tag{44}$$

respectively. The utility function is subject to a preference shock in the form of a shock to the marginal utility of consumption, $Z_{C,t}$.

2.2.2 Capital

Households own the capital stock and let this capital to firms in a perfectly competitive rental market at the nominal rental rate R_t^K. Each household chooses the rate at which its capital is utilised, $U_t(j)$, which transforms the accumulated capital stock, $K_{S,t}(j)$, into effective capital in period t, $K_t(j)$, according to

$$K_t(j) = U_t K_{S,t}(j) \tag{45}$$

Following Christiano, Eichenbaum and Evans (2005), the cost of capital utilisation is given by the increasing and convex function $\Gamma_U(.)$ so that

$$M_t(j) = \Gamma_U(U_t(j)) K_{S,t}(j) \tag{46}$$

By assumption, $\Gamma_U(1) = 0$.

The capital accumulation equation is given by

$$K_{S,t+1}(j) = (1-\delta) K_{S,t}(j) + Z_{I,t}\left(1 - \Gamma_I\left(\frac{I_t(j)}{I_{t-1}(j)}\right)\right) I_t(j) \tag{47}$$

where $I_t(j)$ is the amount of the final good acquired by the household for investment purposes, and $\Gamma_I(.)$ is a function representing investment-adjustment costs. We assume that $\Gamma_I(\Pi_Z) = \Gamma_I^{'}(\Pi_Z) = 0$ and $\Gamma_I^{''}(\Pi_Z) > 0$ where Π_Z is technology growth in steady state (see below). $Z_{I,t}$ is an investment-specific technology shock, which affects the extent to which resources allocated to investment (net of investment-adjustment costs) increase the capital stock available for use in production next period.

2.2.3 Budget constraint

Household maximisation is subject to a sequence of budget constraints taking the following form

$$\begin{aligned}
& P_t\left(C_t(j)+I_t(j)+\Gamma_U(U_t(j))K_{S,t}(j)\right) \\
& +\mathcal{E}_t B^*_{H,t+1}(j)+E_t\left(\Lambda_{t,t+1}B_{H,t+1}(j)\right)+TA_t(j) \\
= \quad & R^*_{t-1}\left(1-\Gamma_{B,t-1}\right)\mathcal{E}_t B^*_{H,t}(j)+B_{H,t}(j) \\
& +W_t(j)N_t(j)+R^K_t U_t(j)K_{S,t}(j)+DIV_t(j)
\end{aligned} \tag{48}$$

The left-hand side gives the allocation of resources to consumption, investment, capital adjustment costs, foreign bonds, $B^*_{H,t+1}(j)$, earning the gross risk-free foreign interest rate, R^*_t, to a portfolio of domestic bonds, $E_t\left(\Lambda_{t,t+1}B_{H,t+1}(j)\right)$, where $\Lambda_{t,t+1}$ is the stochastic discount factor and $B_{H,t+1}(j)$ represents contingent claims, and to lump-sum taxes, $TA_t(j)$.[5] Hence, the risk-free (gross) nominal interest rate is defined by $R_t=\left(E_t\Lambda_{t,t+1}\right)^{-1}$. The right-hand side gives available resources as the sum of holdings of foreign and domestic bonds, labour income, rental income from capital, and real dividends from firms, denoted by DIV_t. Following Laxton and Pesenti (2003), an international financial friction is introduced to induce stationarity in net asset positions (cf. Schmitt-Grohé and Uribe, 2003) by specifying the transaction cost function

$$\Gamma_{B,t-1}=\phi_1\frac{\exp\left\{\phi_2\frac{\mathcal{E}_{t-1}B^*_{Ht}}{P_{t-1}Y_{t-1}}\right\}-1}{\exp\left\{\phi_2\frac{\mathcal{E}_{t-1}B^*_{Ht}}{P_{t-1}Y_{t-1}}\right\}+1}+\ln Z_{B,t-1}$$

where $\phi_1\in[0,1]$, $\phi_2>0$ and $B^*_{H,t}=\frac{1}{n}\int_0^n B^*_{H,t}(j)\,dj$ is aggregate per capita holdings of foreign bonds by domestic households (taken as given by the individual household). With this specification, the country risk premium increases in the ratio of its foreign debt to GDP. $Z_{B,t-1}$ represents a risk-premium shock to the transaction cost function.

2.2.4 First order conditions

First-order conditions with respect to consumption and domestic bond holdings gives rise to an Euler equation summarising the intertemporal consumption allocation choice of households. It takes the form

$$1=R_tE_t\Lambda_{t,t+1}. \tag{49}$$

with the stochastic discount factor given as

$$\Lambda_{t,t+1}=\beta\frac{MU_{C,t+1}}{MU_{C,t}}\frac{P_t}{P_{t+1}} \tag{50}$$

[5] The stochastic discount factor $\Lambda_{t,t+1}$ is defined as the period-t price of a claim to one unit of currency in a particular state in period $t+1$, divided by the period-t probability of that state occuring.

where $MU_{C,t}$ is the marginal utility of consumption as specified above. The assumption of complete domestic financial markets allows us to drop household indices in this expression (and in many of those that follow). First-order conditions imply that domestic risk-sharing is complete in consumption and investment under the complete market assumption as long as initial endowments are identical. That is, $C_t(j) = C_t$, $I_t(j) = I_t$, $K_{S,t}(j) = K_{S,t}$, $U_t(j) = U_t$ and $B^*_{H,t}(j) = B^*_{H,t}$ for all $j \in [0, n]$.

The first-order condition with respect to foreign bonds is given by

$$1 = R^*_t (1 - \Gamma_{B,t}) E_t \left(\Lambda_{t,t+1} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right) \tag{51}$$

which represents an uncovered interest rate parity condition.

First-order conditions with respect to investment and capital equates marginal cost and benefits of additional investment and capital

$$\begin{aligned} 1 &= Q_t Z_{I,t} \left[1 - \Gamma_I \left(\frac{I_t}{I_{t-1}} \right) - \Gamma'_I \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] \\ &\quad + E_t \left[\Lambda_{t,t+1} Q_{t+1} \frac{P_{t+1}}{P_t} Z_{I,t+1} \Gamma'_I \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right] \end{aligned} \tag{52}$$

$$Q_t = E_t \left[\Lambda_{t,t+1} \frac{P_{t+1}}{P_t} \left(\frac{R^K_{t+1}}{P_{t+1}} U_{t+1} - \Gamma_U (U_{t+1}) + Q_{t+1} (1 - \delta) \right) \right] \tag{53}$$

The variable Q_t, representing Tobin's q, is equal to the ratio of the Lagrange multipliers attached to the capital accumulation equation and the budget constraint, respectively.

Similarly, the first-order condition with respect to capital utilisation

$$\frac{R^K_t}{P_t} = \Gamma'_U (U_t) \tag{54}$$

equates the the marginal benefit of raising capital utilisation with the marginal cost of doing so.

2.2.5 Wage setting

Households set wages following a Calvo mechanism. Each period a measure $(1 - \theta_W)$ of randomly selected households get to set a new wage rate, while remaining households' wages are partially indexed to past inflation as in Smets and Wouters (2003) and technology growth as in Adolfson et al. (2007). A household allowed to reoptimise at time t sets $W_t(j) = \tilde{W}_t$ to maximise its expected life-time utility, (41), subject to its budget constraint, (48), the demand for its labour service, (3), and the restriction from the Calvo mechanism that

$$W_{t+k+1}(j) = \begin{cases} \tilde{W}_{t+k+1} & \text{w.p.} (1 - \theta_W) \\ \Pi^{\gamma_w}_{P,t+k} \Pi_{Z,t+k+1} W_{t+k}(j) & \text{w.p.} \theta_W \end{cases} \tag{55}$$

where $\gamma_w \in [0,1]$ is the degree of wage indexation to the CPI, and $\Pi_{P,t} \equiv P_t/P_{t-1}$ is gross CPI inflation. Technology is represented by Z_t so that $\Pi_{Z,t} \equiv Z_t/Z_{t-1}$ represents technology growth. The first-order condition is given by

$$\sum_{k=0}^{\infty} (\beta_t \theta_w)^k E_t \left\{ N_{t+k}(j) (1-\varepsilon_{W,t+k}) \left[\frac{\tilde{W}_t}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\gamma_W} \frac{Z_{t+k}}{Z_t} MU_{C,t+k} \right.\right. \\ \left.\left. + \mathcal{M}_{W,t+k} MU_{N,t+k}(j) \right] \right\} = 0 \tag{56}$$

where $\mathcal{M}_{W,t} \equiv \varepsilon_{W,t}(\varepsilon_{W,t}-1)^{-1}$ is the household's desired mark-up of the real wage over the marginal rate of substitution. This condition reflects the forward-looking nature of wage-setting; households take not only current but also future expected marginal rates of substitution into account when setting wages.

The law of motion of the wage index is given as

$$W_t^{1-\varepsilon_{W,t}} = \theta_w \left(W_{t-1} \Pi_{P,t-1}^{\gamma_w} \Pi_{Z,t} \right)^{1-\varepsilon_{W,t}} + (1-\theta_w) \left(\tilde{W}_t \right)^{1-\varepsilon_{W,t}} \tag{57}$$

For future reference, we define wage inflation as $\Pi_{W,t} \equiv W_t/W_{t-1}$.

2.3 Firms

2.3.1 Production

Each home firm $i \in [0,n]$ produces a differentiated good, $Y_{H,t}(i)$, according to

$$Y_{H,t}(i) = K_t(i)^{\psi_H} (Z_t Z_{H,t} N_t(i))^{1-\psi_H} \tag{58}$$

where $K_t(i)$ denotes the period-t capital stock rented by firm i, $N_t(i)$ is the number of hours worked in the production process, and the capital share parameter satisfies $0 \leq \psi_H \leq 1$. Z_t is a permanent economy-wide total factor productivity shock with the growth rate $\Pi_{Z,t} = Z_t/Z_{t-1}$, while $Z_{H,t}$ is a stationary technology shock.

Firm i's nominal marginal cost in period t can be found as the Lagrangian to the cost minimisation problem:

$$\begin{aligned} MC_t(i) &= \frac{W_t}{(1-\psi_H)(Z_t Z_{H,t})^{1-\psi_H}} \left(\frac{N_t(i)}{K_t(i)} \right)^{\psi_H} \\ &= \frac{R_t^K}{\psi_H (Z_t Z_{H,t})^{1-\psi_H}} \left(\frac{K_t(i)}{N_t(i)} \right)^{1-\psi_H} \end{aligned} \tag{59}$$

Conditional factor demand implies that firm i will choose factor inputs such that

$$\frac{K_t(i)}{N_t(i)} = \frac{\psi_H}{1-\psi_H} \frac{W_t}{R_t^K} \tag{60}$$

This equation implies that, on the margin, the cost of increasing capital in production equals the cost of increasing labour. Since all firms have to pay the same wage for the labour they employ, and the same rental rate for the capital they rent, it follows from (59) and (60) that marginal costs (of increasing output) are equalised across firms regardless of any heterogeneity in output induced by differences in prices. Hence, $MC_t(i) = MC_t \ \forall i$ where

$$MC_t = \frac{1}{1-\psi_H}\left(\frac{\psi_H}{1-\psi_H}\right)^{-\psi_H}\frac{W_t^{1-\psi_H}\left(R_t^K\right)^{\psi_H}}{\left(Z_t Z_{H,t}\right)^{1-\psi_H}} \tag{61}$$

2.3.2 Price-setting

Firms follow a Calvo price-setting mechanism when setting prices. Each period, a measure $(1-\theta_H)$ of randomly selected firms get to post new prices at home, while remaining firms partially index their prices to past domestic price inflation. Similarly, a measure $(1-\theta_H^*)$ of randomly selected firms get to post new prices abroad, while remaining firms partially index their prices to past export price inflation. A firm allowed to choose new price at time t sets $P_{H,t}(i) = \tilde{P}_t$ respectively $P_{H,t}^*(i) = \tilde{P}_{H,t}^*$ to maximise the value of the firm to its owners, the households. At time t, this value is given by

$$\begin{aligned}&\sum_{k=0}^{\infty} E_t\Big\{\Lambda_{t,t+k}\Big[P_{H,t+k}(i)\,Y_{H,t+k}^h(i) + \mathcal{E}_{t+k}P_{H,t+k}^*(i)\,Y_{F,t+k}^f(i)\\&-\Psi\left(Y_{H,t+k}(i)\right)\Big]\Big\}\end{aligned} \tag{62}$$

where $\Psi(.)$ is the cost function, i.e., the value function from the cost minimisation problem above.

Optimisation is subject to the demand for the firm's product at home and abroad, its production technology, and the restrictions from the Calvo mechanism that

$$P_{H,t+k+1}(i) = \begin{cases} \tilde{P}_{H,t+k+1} & \text{w.p.}\,(1-\theta_H) \\ \left(\frac{P_{H,t+k}}{P_{H,t+k-1}}\right)^{\gamma_H} P_{H,t+k}(i) & \text{w.p.}\theta_H \end{cases} \tag{63}$$

and

$$P_{H,t+k+1}^*(i) = \begin{cases} \tilde{P}_{H,t+k+1}^* & \text{w.p.}\,(1-\theta_H^*) \\ \left(\frac{P_{H,t+k}^*}{P_{H,t+k-1}^*}\right)^{\gamma_H^*} P_{H,t+k}^*(i) & \text{w.p.}\theta_H^* \end{cases}$$

where $\gamma_H \in [0,1]$ and $\gamma_H^* \in [0,1]$ are the degrees of price indexation to the CPI. The first-order condition with respect to the home price is given as

$$\begin{aligned}&\sum_{k=0}^{\infty}\theta_H^k E_t\Big\{\Lambda_{t,t+k}Y_{H,t+k}^h(i)\left(1-\varepsilon_{H,t+k}\right)\Big[\tilde{P}_{H,t}\left(\frac{P_{H,t+k-1}}{P_{H,t-1}}\right)^{\gamma_H}\\&-\mathcal{M}_{H,t+k}MC_{t+k}\Big]\Big\} = 0\end{aligned} \tag{64}$$

where $\mathcal{M}_{H,t} \equiv \varepsilon_{H,t}\left(\varepsilon_{H,t}-1\right)^{-1}$ as the desired mark-up of price over nominal marginal cost. This condition reflects the forward-looking nature of price-setting; firms take not only current but also future expected marginal costs into account when setting prices. Similarly, the first-order condition for the price of exported goods becomes

$$\sum_{k=0}^{\infty} (\theta_H^*)^k E_t \left\{ \Lambda_{t,t+k} Y_{H,t+k}^f (i) \left(1 - \varepsilon_{H,t+k}^*\right) \left[\mathcal{E}_{t+k} \tilde{P}_{H,t}^* \left(\frac{P_{H,t+k-1}^*}{P_{H,t-1}^*} \right)^{\gamma_H^*} \right.\right.$$
$$\left.\left. - \mathcal{M}_{H,t+k}^* MC_{H,t+k} \right] \right\} = 0 \tag{65}$$

where $\mathcal{M}_{H,t}^* \equiv \varepsilon_{H,t}^* \left(\varepsilon_{H,t}^* - 1\right)^{-1}$.

The law of motion of the domestic price index is given as

$$P_{H,t}^{1-\varepsilon_{H,t}} = \theta_H \left(P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\gamma_H} \right)^{1-\varepsilon_{H,t}} + (1-\theta_H) \left(\tilde{P}_{H,t} \right)^{1-\varepsilon_{H,t}} \tag{66}$$

and of export prices

$$\left(P_{H,t}^*\right)^{1-\varepsilon_{H,t}} = \theta_H^* \left(P_{H,t-1}^* \left(\frac{P_{H,t-1}^*}{P_{H,t-2}^*} \right)^{\gamma_H^*} \right)^{1-\varepsilon_{H,t}} + (1-\theta_H^*) \left(\tilde{P}_{H,t}^* \right)^{1-\varepsilon_{H,t}} \tag{67}$$

Note that a law of motion for the import price index, $P_{F,t}$, and a first-order condition for the prices of imported goods corresponding to (67) and (65), respectively, follow from the price setting decisions of foreign producers.

2.4 Monetary policy

The central bank follows a monetary policy rule, by which it responds to a number of endogenous variables in the economy. We follow Brubakk et al. (2006) and Adolfson et al. (2007) by specifying the general rule

$$\begin{aligned} \frac{R_t}{R} &= Z_{R,t} \left(\frac{R_{t-1}}{R} \right)^{\xi_R} \left[\left(\frac{\Pi_{P,t-1}}{\Pi_P} \right)^{\phi_P} \left(\frac{Y_{t-1}}{Z_{t-1}} \frac{Z}{Y} \right)^{\phi_Y} \left(\frac{S_{t-1}}{S} \right)^{\phi_S} \right]^{(1-\xi_R)} \\ & \quad \cdot \left(\frac{\Pi_{P,t}}{\Pi_{P,t-1}} \right)^{\phi_{\Delta P}} \left(\frac{Y_t / Y_{t-1}}{\Pi_{Z,t}} \right)^{\phi_{\Delta Y}} \left(\frac{S_t}{S_{t-1}} \right)^{\phi_{\Delta S}} \end{aligned} \tag{68}$$

where $0 < \xi_R < 1$ governs monetary policy inertia and $Z_{R,t}$ is a monetary policy shock. The parameters $\phi_\iota \geq 0$ for $\iota \in \{P, Y, S, \Delta P, \Delta Y, \Delta S\}$ are such that determinacy of the equilibrium is ensured.

As argued by Adolfson et al. (2008) for Sweden, a Taylor rule of this kind may provide a good approximation to the actual conduct of monetary policy in Iceland even if the formal monetary regime was exchange rate rather than inflation targeting in parts of the sample period. This is because the peg allowed the Icelandic króna to fluctuate within a band, leaving some scope for responses to macroeconomic variables for the monetary decision makers, who, at the time, may have had a politically motivated emphasis on short-term output stabilisation.[6]

In contrast to monetary policy, fiscal policy is passive in that G_t is driven solely by exogenous shocks. The public budget is balanced each period.

2.5 Log-linearisation of stationary model

Variables in the model are generally non-stationary. Nominal variables have unit roots because monetary policy targets inflation and not the price level, while real variables have unit roots because the model is subject to permanent technology shocks. The economy therefore evolves around a stochastic growth path. The growth path is balanced in the sense that hours worked are stationary.

To solve the model, nominal variables are first detrended with the CPI index to express the model in terms of real variables. Then, non-stationary real variables are detrended with the permanent technology shock Z_t to render the model stationary. An upper bar indicates that a variable has been expressed in real terms and detrended if necessary. Appendix A lists the equations of the stationary model.

The stationary model is log-linearised around the flexible-price steady state characterised and solved in appendix B. Steady-state variables are indicated by omission of time subscripts. For all exogenous shocks ι, we have $Z_\iota = 1$ in the steady state. We further impose the normalisation $U = 1$, and assume that $R = R^*$, $\beta = \beta^*$ and $\Pi_P = \Pi_P^*$ (allowing a constant steady state real exchange rate). The steady state is solved under the assumptions that wage and price inflation as well as output growth are zero so that $\Pi_P = \Pi_W = \Pi_Z = 1$, and that trade is balanced in that $B_H^* = NX = 0$. We also assume that $G/Y = \gamma_G \in [0, 1]$.

Given a specification of the foreign economy, the following 44 equations (71)-(114) with 44 endogenous variables constitute the detrended model in log-linear form. Lower-case letters generally denote deviations of corresponding upper case variables from their values in the steady state. But bars over detrended variables are omitted to ease the notation. Hence, for the generic variable X_t we have

$$x_t \equiv \frac{d\overline{X}_t}{\overline{X}} = \frac{\overline{X}_t - \overline{X}}{\overline{X}} \approx \ln \overline{X}_t - \ln \overline{X} = \ln X_t - \ln Z_t - \ln \frac{X}{Z} \tag{69}$$

if X_t is non-stationary and

$$x_t \equiv \frac{dX_t}{X} = \frac{X_t - X}{X} \approx \ln X_t - \ln X \tag{70}$$

if it is stationary. Exceptions are net exports and net foreign assets, which are expressed in deviation from steady-state output, i.e., $nx_t \equiv d\overline{NX}_t/\overline{Y}$ and $b_{H,t}^* \equiv d\overline{B}_{H,t}^*/\overline{Y}$. Also, we define $\gamma_{B,t} \equiv d\Gamma_{B,t}$.

[6] Adolfson et al. (2008) allow for a structural break when Sweden went from exchange rate to inflation targeting. They find similar estimates regardless of the presence of a break.

2.5.1 Prices

The linearised CPI (14) is

$$0 = (1 - \alpha) p_{H,t} + \alpha p_{F,t} \tag{71}$$

where $p_{\iota,t}$ denotes the relative price for $\iota \in \{H, F\}$ in terms of the final good. The relation for the real exchange rate (15) can be written as

$$s_t - s_{t-1} = \pi_{\mathcal{E},t} + \pi^*_{P,t} - \pi_{P,t} \tag{72}$$

where $\pi_{\mathcal{E},t}$ is the nominal depreciation rate of the home currency. The terms of trade relation (16) becomes

$$t_t = p_{F,t} - s_t - p^*_{H,t} \tag{73}$$

2.5.2 Resource constraints

The resource constraints (29), (32) and (33) become

$$y_{H,t} = (1 - \alpha) y^h_{H,t} + \alpha e x_t \tag{74}$$

$$y^h_{H,t} = -\eta p_{H,t} + a_t \tag{75}$$

$$e x_t = -\eta p^*_{H,t} + a^*_t - z_{D,t} \tag{76}$$

where $z_{D,t}$ reflects permanent international growth differences (see below).

The definition of net exports (35) gives a relation

$$n x_t = \alpha (e x_t - i m_t - t_t) \tag{77}$$

where nx_t is the deviation of net exports from steady state in percentage of steady state real GDP. From (36), imports are

$$i m_t = -\eta p_{F,t} + a_t \tag{78}$$

Real GDP per capita (40) becomes

$$y_t = a_t + n x_t \tag{79}$$

where absorption follows from (25) and (46)

$$a_t = \frac{\overline{C}}{\overline{Y}} c_t + \frac{\overline{I}}{\overline{Y}} i_t + \gamma_g g_t + \frac{\overline{K}_H}{\overline{Y}} \Gamma'_U (1) u_t \tag{80}$$

2.5.3 Households

The relation between the stock of capital and effective capital, (45), becomes

$$k_t = u_t + k_{S,t} - \zeta_t \tag{81}$$

while the capital accumulation equation (47) in log-linear form is given by

$$k_{S,t+1} = (1-\delta)(k_{S,t} - \zeta_t) + \delta(i_t + z_{I,t}) \tag{82}$$

The aggregate budget constraint (48) gives a relation for the evolution of the home country's real net asset position (in per cent deviation from steady-state output)[7]

$$b^*_{H,t+1} = \beta^{-1} b^*_{H,t} + nx_t \tag{83}$$

The consumption Euler equation derived from (43), (49) and (50) takes the form

$$\begin{aligned} c_t = {} & \frac{h}{1+h} c_{t-1} + \frac{1}{1+h} E_t c_{t+1} - \frac{1-h}{1+h}(r_t - E_t \pi_{P,t+1}) \\ & - \frac{1-h}{1+h}(E_t z_{C,t+1} - z_{C,t}) + \frac{1}{1+h} E_t \zeta_{t+1} - \frac{h}{1+h}\zeta_t \end{aligned} \tag{84}$$

The uncovered interest rate parity condition (51) becomes

$$s_t = E_t s_{t+1} - (r_t - E_t \pi_{P,t+1}) + \left(r^*_t - E_t \pi^*_{P,t+1}\right) - \gamma_{B,t} \tag{85}$$

where the international transaction costs (in absolute deviation from steady state) is given by

$$\gamma_{B,t} = \phi_B b^*_{H,t+1} + z_{B,t} \tag{86}$$

where $\phi_B = \phi_1 \phi_2 / 2$. The linearised first-order conditions with respect to investment (52) and capital (53) read

$$i_t = \frac{1}{1+\beta}\left(\beta E_t \left(i_{t+1} + \zeta_{t+1}\right) + i_{t-1} - \zeta_t + \lambda_I (q_t + z_{I,t})\right) \tag{87}$$

and

$$q_t = -(r_t - E_t \pi_{P,t+1}) + (1 - \beta(1-\delta)) E_t r^k_{t+1} + \beta(1-\delta) E_t q_{t+1} \tag{88}$$

where the value of $\lambda_I^{-1} \equiv \Gamma''_I(1) > 0$ governs investment-adjustment costs. The first-order condition with respect to capital utilisation (54) is

$$r^k_t = \lambda_U u_t \tag{89}$$

in its log-linear form where

$$\lambda_U \equiv \frac{\Gamma''_U(U)\,U}{\Gamma'_U(U)} = \frac{\Gamma''_U(1)}{\Gamma'_U(1)}$$

[7] This uses the definition of GDP in (38) and (40), the assumption of a balanced public budget so that $TA = P \cdot G$, and an appropriate definition of DIV_t as revenues over costs.

is the elasticity of the marginal costs of capital utilisation.

By combining the first-order condition for wages (56) with the law of motion of the wage index (57) and the labour demand relation (3), a New Keynesian Phillips curve for wage inflation, $\pi_{W,t}$, is derived as

$$\begin{aligned}\pi_{W,t} &= \beta E_t \pi_{W,t+1} + \kappa_W \left(mrs_t - w_t + \mu_{W,t} \right) &(90)\\ &\quad + \gamma_W \left(\pi_{P,t-1} - \beta \pi_{P,t} \right) + \left(1 - \beta \rho \right) \zeta_t &(91)\end{aligned}$$

where

$$\pi_{W,t} - \pi_{P,t} = w_t - w_{t-1} + \zeta_t \tag{92}$$

and

$$mrs_t = \varphi n_t + \frac{1}{1-h} \left(c_t - h c_{t-1} \right) - z_{C,t} + \frac{h}{1-h} \zeta_t \tag{93}$$

is defined as the economy's average marginal rate of substitution, cf. (43) and (44). The slope is given by

$$\kappa_W = \frac{\left(1 - \beta \theta_W \right) \left(1 - \theta_W \right)}{\theta_W \left(1 + \varphi \varepsilon_W \right)}$$

2.5.4 Firms

Up to a first-order approximation, aggregate production, (58), is given by

$$y_{H,t} = \psi_H k_t + \left(1 - \psi_H \right) \left(z_{H,t} + n_t \right) \tag{94}$$

The factor input relation (60) becomes

$$r_t^k = w_t + n_t - k_t \tag{95}$$

and from (61) marginal costs become

$$mc_t = \left(1 - \psi_H \right) w_t + \psi_H r_t^k - \left(1 - \psi_H \right) z_{H,t} \tag{96}$$

By combining the first-order condition for prices (64) with the law of motion of the price index (66), a New Keynesian Phillips curve for the sector's domestic price inflation is derived as

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \gamma_H \left(\pi_{P,t-1} - \beta \pi_{P,t} \right) + \kappa_H \left(\mu_{H,t} + mc_t - p_{H,t} \right) \tag{97}$$

with

$$\pi_{H,t} - \pi_{P,t} = p_{H,t} - p_{H,t-1} \tag{98}$$

and

$$\kappa_H = \frac{\left(1 - \beta \theta_H \right) \left(1 - \theta_H \right)}{\theta_H}$$

Similarly, a New Keynesian Phillips curve for export price inflation is derived as

$$\pi_{H,t}^* = \beta E_t \pi_{H,t+1}^* + \gamma_H^* \left(\pi_{P,t-1}^* - \beta \pi_{P,t}^* \right) + \kappa_H^* \left(\mu_{H,t}^* + mc_t - s_t - p_{H,t}^* \right) \tag{99}$$

where

$$\pi^*_{H,t} - \pi^*_{P,t} = p^*_{H,t} - p^*_{H,t-1} \tag{100}$$

and

$$\kappa^*_H = \frac{(1-\beta\theta^*_H)(1-\theta^*_H)}{\theta^*_H}$$

2.5.5 Imports

By analogy with home price setting, a New Keynesian Phillips curve for import prices is given as

$$\pi_{F,t} = \beta E_t \pi_{F,t+1} + \gamma_F (\pi_{P,t-1} - \beta\pi_{P,t}) + \kappa_F \left(\mu_{F,t} + mc^*_t + s_t - p_{F,t}\right) \tag{101}$$

with

$$\pi_{F,t} - \pi_{P,t} = p_{F,t} - p_{F,t-1} \tag{102}$$

and the slope

$$\kappa_F = \frac{(1-\beta\theta_F)(1-\theta_F)}{\theta_F} \frac{1-\psi_F}{1-\psi_F+\psi_F\varepsilon_F}$$

where θ_F is the Calvo parameter determining the price setting of foreign exporters. The composite slope parameter differs from the ones for domestic and exported inflation by the assumption that the foreign economy can be well represented by a model that excludes endogenous capital accumulation.[8] This introduces a strategic complementarity in price-setting, or a real rigidity in the Ball and Romer (1990) sense, which reduces the slope of the Phillips curve for a given Calvo parameter.[9]

2.5.6 Monetary policy

The monetary policy rule (68) becomes

$$\begin{aligned} r_t \;=\; & z_{R,t} + \xi_R r_{t-1} + (1-\xi_R)\left[\phi_P \pi_{P,t-1} + \phi_Y y_{t-1} + \phi_S s_{t-1}\right] \\ & + \phi_{\Delta P}(\pi_{P,t} - \pi_{P,t-1}) + \phi_{\Delta Y}(y_t - y_{t-1}) + \phi_{\Delta S}(s_t - s_{t-1}) \end{aligned} \tag{103}$$

2.5.7 Shock processes

The economy is subject to a number of exogenous shocks. The mark-up shocks evolve according to

$$\mu_{W,t} = \rho_{\mu,W}\mu_{W,t-1} + \epsilon_{\mu,W,t} \tag{104}$$

$$\mu_{H,t} = \rho_{\mu,H}\mu_{H,t-1} + \epsilon_{\mu,H,t} \tag{105}$$

$$\mu^*_{H,t} = \rho^*_{\mu,H}\mu^*_{H,t-1} + \epsilon^*_{\mu,H,t} \tag{106}$$

[8] This will allow us to replace the simple structure assumed for the foreign economy below with a basic New Keynesian DSGE model.

[9] This is without consequence in the estimation exercise below, however, as we can only hope to identify the slope of the Phillips curve, κ_F.

and

$$\mu_{F,t} = \rho_{\mu,F}\mu_{F,t-1} + \epsilon_{\mu,F,t} \tag{107}$$

where for $\iota \in \{W, H, F\}$, $\mu_{\iota,t} \equiv \ln \mathcal{M}_{\iota,t} - \ln \mathcal{M}_i$ for some $\varepsilon_\iota > 1$, $0 < \rho_{\mu,\iota} < 1$, and $\epsilon_{\mu,\iota,t} \backsim \left(0, \sigma^2_{\mu,\iota}\right)$ is white noise (similarly for $\mu^*_{H,t}$).

Processes for the shocks to household relations are given as

$$z_{C,t} = \rho_C z_{C,t-1} + \epsilon_{C,t} \tag{108}$$

$$z_{I,t} = \rho_I z_{I,t-1} + \epsilon_{I,t} \tag{109}$$

and

$$z_{B,t} = \rho_B z_{B,t-1} + \epsilon_{B,t} \tag{110}$$

where for $\iota \in \{C, I, B\}$, $z_{\iota,t} \equiv \ln Z_{\iota,t}$, $0 < \rho_\iota < 1$, and $\epsilon_{\iota,t} \backsim \left(0, \sigma^2_\iota\right)$ is white noise.

The permanent technology shock evolves according to

$$\zeta_t = \rho\zeta_{t-1} + \epsilon_t \tag{111}$$

where $\zeta_t \equiv \ln \Pi_{Z,t} - \ln \Pi_Z$ for some $\Pi_Z \geq 0$, $0 < \rho < 1$, and $\epsilon_t \backsim \left(0, \sigma^2\right)$ is white noise. Differences in growth at home and abroad are captured by the shock

$$z_{D,t} = \rho_D z_{D,t-1} + \epsilon_{D,t}$$

where $z_{D,t} = z_t - z^*_t$ and $\epsilon_{D,t} \backsim \left(0, \sigma^2_D\right)$. The labour-augmenting technology shock has the proces

$$z_{H,t} = \rho_H z_{H,t-1} + \epsilon_{H,t} \tag{112}$$

where $z_{H,t} \equiv \ln Z_{H,t}$, $0 < \rho_H < 1$, and $\epsilon_{H,t} \backsim \left(0, \sigma^2_H\right)$.

The monetary policy shock evolves as

$$z_{R,t} = \rho_R z_{R,t-1} + \epsilon_{R,t} \tag{113}$$

where $z_{R,t} \equiv \ln Z_{R,t}$, $0 < \rho_R < 1$, and $\epsilon_{R,t} \backsim \left(0, \sigma^2_R\right)$ is white noise. Finally, government spending is given as

$$g_t = \rho_G g_{t-1} + \epsilon_{G,t} \tag{114}$$

where $0 < \rho_G < 1$, and $\epsilon_{G,t} \backsim \left(0, \sigma^2_G\right)$.

2.5.8 The foreign economy

By the assumption that $n \to 0$, the home economy has no influence on foreign variables. We may therefore treat the foreign economy as exogenous to the small open home economy. As we are interested in the impact of economic developments abroad on the home economy rather than in the details of the dynamics of the trading partners' economies, we simplify the analysis considerably by replacing the foreign economy part of the model with a vector autoregression. Following Adolfson et al. (2007), we represent the foreign economy as

$$\Xi_0 x^*_t = \Xi_1 x^*_{t-1} + \Xi_2 x^*_{t-2} + \Xi_3 x^*_{t-3} + \Xi_4 x^*_{t-4} + \varepsilon^*_t \tag{115}$$

where $x_t^* = \left[\begin{array}{ccc} \pi_{P,t}^* & y_t^* & R_t^* \end{array} \right]'$, $\varepsilon_t^* = \left[\begin{array}{ccc} \varepsilon_{P,t}^* & \varepsilon_{Y,t}^* & \varepsilon_{R,t}^* \end{array} \right]'$ with $\varepsilon_t^* \tilde{} N(0, \Sigma^*)$, and

$$\Xi_0 = \left[\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\xi_{0,\pi} & -\xi_{0,y} & 1 \end{array} \right]$$

We further assume that foreign marginal costs are proportional to foreign output so that

$$mc_t^* = \eta_{mc,y}^* y_t^* \tag{116}$$

where $\eta_{mc,y}^* > 0$.

Finally, to allow for a smaller sensitivity of export than import volumes, we replace the export relation (76) with

$$ex_t = -\frac{\eta}{1 + \phi_M^* \eta} p_{H,t}^* + y_t^* + \frac{\phi_M^* \eta}{1 + \phi_M^* \eta} \left(y_{t-1}^* - ex_{t-1} \right) - z_{D,t} \tag{117}$$

where $\phi_M^* \geq 0$. A relation of this kind can be motivated by the presence of quadratic import adjustment costs in the foreign economy, cf. Laxton and Pesenti (2003). In Iceland's case, however, the main motivation for this specification is the importance of resource goods such as fish and aluminium in exports, a feature not explicitly taken into account in the model.[10] Notice in relation to this that the asymmetric technology shock effectively works as an exogenous shock to exports in the model.

3 Parameterisation

The model is parameterised through a combination of calibration and formal estimation. Parameters that effect the steady state of the model are calibrated to reproduce the sample means of the great ratios. Also, a number of weakly identified parameters are fixed at values that are common in the literature. Thus, 19 domestic parameters are fixed prior to estimation. In addition, we follow Adolfson et al. (2007) in estimating the government spending process and the foreign economy VAR separately. This leaves 36 parameters, of which 21 govern the shock processes, to be estimated formally.

We estimate these parameters using a Bayesian approach. Following the seminal work of Smets and Wouters (2003), this has become standard practice in the literature. The Bayesian approach essentially falls in between classical maximum likelihood estimation and simple calibration. The approach requires the specification of prior distributions of the parameters to be estimated. The priors reflect our pre-estimation beliefs about reasonable parameter values based, e.g., on microeconomic studies or evidence from other countries. Using Bayes' formula, we then update our prior beliefs using the sample information contained in the likelihood function. This gives us the posterior distributions

[10] Moreover, restricting ϕ_M to zero gives much too volatile exports in the estimated model. Marginal likelihood comparisons also favour the model with $\phi_M > 0$.

of the parameters, and we take the posterior means to be the point parameter estimates.

In practice, the likelihood function is evaluated by applying the Kalman filter to the solution of the model. We find this solution for a given set of parameter values using the default method in Dynare, which is based on a generalised Schur decomposition of the model's structural parameter matrices, cf. Klein (2000). Combining the evaluation of the likelihood function with the prior distribution, we obtain an evaluation of the posterior distribution. We then find the mode of this posterior distribution using a standard numerical optimisation routine. Specifically, we use the *fmincon* algorithm from Matlab's Optimization toolbox. Finally, we generate 250,000 draws from the posterior distribution around the posterior mode using the Metropolis-Hastings algorithm. The normal distribution is used as a proposal distribution, and we scale the proposal co-variance matrix to obtain an acceptance ratio of about 25 per cent. For details on the Bayesian approach to the estimation of DSGE models, see e.g. An and Schorfheide (2006), Canova (2007) or Fernández-Villaverde (2009).

3.1 Data

The model is estimated using 14 dataseries covering the period 1991Q1 through 2005Q4. Data for consumption, consumer price inflation, exports, government spending, GDP, investment, imports, the real exchange rate, interest rates, wage inflation, foreign inflation, foreign GDP, and foreign interest rates are taken from the Central Bank of Iceland's *QMM* database, cf. Daníelsson et al. (2009).[11] Hours worked are taken from Statistic Iceland's labour force survey. Prior to 2003, this survey was conducted only twice a year. Quarterly data are therefore constructed using ECOTRIM with employment as a related series for this period. Relevant series are seasonally adjusted using X-12-ARIMA prior to use, and we also remove the irregular component from domestic series to alleviate measurement problems. While relatively short and containing a structural break in monetary policy regime, the sample period excludes the disinflation taking place in the 1980s as well as the final stages of the unsustainable boom leading up the financial collapse in the autumn of 2008.

As the linear model is expressed in terms of detrended per capita variables in deviations from the steady state, cf. (69) and (70), we fit the linear model to the data using transformations of the dataseries. For the real variables for consumption, exports, government spending, GDP, investment, imports, and hours worked, we use the demeaned transformation

$$\widehat{X}_t = \ln \frac{X_t^{QMM}}{\text{Þ}_t} - \ln \frac{X_{t-1}^{QMM}}{\text{Þ}_{t-1}} \tag{118}$$

where X_t^{QMM} is the (seasonally adjusted) empirical counterpart from the database to the generic model variable X_t, and Þ_t is the size of the working-age

[11] The QMM mnemonics are C, CPI, EX, G, GDP, I, IMP, REX, RS, W, WCPI, WGDP, and WRS. As real GDP is measured in consumption units in the model, we divide nominal GDP from the QMM database by the CPI to get the model-consistent real GDP.

population at time t.[12]

For consumption, exports, government spending, GDP and imports, we then add the measurement equation

$$\widehat{X}_t = x_t - x_{t-1} + \zeta_t \tag{119}$$

to the model. For investment, we observe aggregate investment and assume that the investment series includes maintenance costs. Hence we observe INV_t^{QMM} as a counterpart to $INV_t \equiv I_t + M_t$. This gives the measurement equation

$$\widehat{INV}_t = inv_t - inv_{t-1} + \zeta_t \tag{120}$$

where

$$inv_t = i_t + \frac{1}{\delta}\left(\beta^{-1} - 1 + \delta\right) u_t \tag{121}$$

The measurement equations for hours worked and the real exchange rate (both stationary) are given as

$$\widehat{X}_t = x_t - x_{t-1} \tag{122}$$

where, for the real exchange rate, we use the demeaned transformation[13]

$$\widehat{S}_t = \ln S_t^{QMM} - \ln S_{t-1}^{QMM} \tag{123}$$

For the nominal interest and inflation rates, demeaned empirical variables coincide with model variables. For home and foreign interest rates,[14] we add the transition equation

$$\widehat{R}_t = r_t \tag{124}$$

with

$$\widehat{R}_t = \ln R_t^{QMM}$$

Quarterly inflation rates (home and foreign as well as wage inflation) are calculated directly from database indices, P_t^{QMM}, as

$$\widehat{\Pi}_t = \ln P_t^{QMM} - \ln P_{t-1}^{QMM} \tag{125}$$

with the transition

$$\widehat{\Pi}_t = \pi_t \tag{126}$$

for the generic model inflation rate π_t.

Foreign GDP is detrended using the Hodrick-Prescott filter and we let

$$\widehat{Y}_t^* = y_t^* \tag{127}$$

[12] Given the limited number of Greek letters available, we found it appropriate to let the Old Norse letter *thorn* represent the Icelandic population.

[13] Note that $S_t^{QMM} = 1/REX_t$, where REX is the QMM mnemonic for the real exchange rate (indirect quotation).

[14] Note that $R_t^{QMM} = 1 + RS_t/4$, where RS is the QMM mnemonic for the annualised short-term interest rate expressed as a fraction.

where $\widehat{Y}_t^*$ represents the detrended series.

Figures 1-3 show the data series used in the estimation. The figures show the data from the QMM database (black lines), seasonally adjusted series (blue lines), and adjusted series with both the seasonal and the irregular component removed (red lines). In figures 1-2, the left panels represent the empirical domestic real variables, while the right panels represent the growth transformations just describes. Figure 3 shows the nominal variables, interest rates and the cyclical component of foreign output.

3.2 Calibrated parameters

Table 1 summarises values chosen for the parameters calibrated before estimation. First, all the parameters that affect the steady state are fixed before estimation. Second, we also fix a number of weakly identified parameters to facilitate the estimation of remaining parameters.

To guide the calibration of parameters affecting the steady state, figure 4 presents ratios of demand components to GDP in the sample period 1991Q1 through 2005Q4. On average, the current account has been in deficit during the period. Therefore, the private consumption ratio is supplemented with a consumption residual, defined as $1 - INV/Y - G/Y$.

The ratio of investment to capital suggests that $\delta = 0.02$ (or more precisely between 0.015 and 0.02). Following the discussion in Daníelsson (2009), the capital share is set to $\psi_H = 0.33$, and we set $\varepsilon_H = 7$ implying that the desired mark-up in goods markets is about 17 per cent. The subjective discount factor is fixed at $\beta = 0.9915$ implying that the annual interest rate is about 3.5 per cent in steady state. These values imply that $INV/Y = 0.198$ or slightly less than the 0.1995 average investment ratio in the 1991-2005 sample. Reducing δ to 0.015, as suggested by the QMM database, would reduce the share to 0.18, while increasing the steady-state interest rate to 4 per cent would reduce the ratio to below 0.19. In accordance with the average ratio of government spending to GDP in the sample, the government consumption share is set to $\gamma_g = 0.24$ implying that $C/Y = 1 - INV/Y - \gamma_g = 0.562$. This is somewhat lower than the average consumption-output ratio in the sample, but slightly larger than the calculated consumption residual. The degree of openness is set to $\alpha = 0.34$, which is equal to the export share in the sample period.

As we can only hope to identify the composite slope parameters of the Phillips curves rather than the individual parameters entering them, we fix ε_F, ε_W and ψ_F leaving the estimation procedure to find values for the Calvo parameters. We choose $\varepsilon_F = 7$ and $\psi_F = 0.33$ as for the home economy, while we let the elasticity of substitution for differentiated labour services be $\varepsilon_W = 6$. This value is similar to the one chosen by Brubakk et al. (2006) for Norway on the grounds that it implies a degree of competition in the labour market that falls in between those typically assumed for the US and Europe.

Fitting a first-order autoregressive process for detrended government spending suggest that $\rho_G = 0.8$ and $\sigma_G = 0.0051$. Similarly, an estimation of the foreign economy VAR suggest that $\sigma^*_{P,t} = 0.0026$, $\sigma^*_{Y,t} = 0.0033$ and $\sigma^*_{R,t} = 0.0028$, besides giving estimates of Ξ_ι for $\iota = 0, 1, ..., 4$.[15] We let $\eta^*_{mc,y} = 2.7$. In a simple New Keynesian model with a labour share of one third and a unit labour supply elasticity, this would be the proportionality factor linking marginal costs and the output gap, cf. Galí (2007).

To reduce the dimensionability of the estimation problem, we fix the price and wage index parameters to unity, i.e., $\gamma_W = \gamma_H = \gamma^*_H = \gamma_F = 1$. The implicit assumption is that wage and price setting agents that are prevented from adjusting nominal variables through the Calvo mechanism fully index to past inflation levels. We also restrict monetary policy shocks to be purely temporary by setting $\rho_r = 0$. This is to reduce the endogenous response of monetary policy to prevent a fall in the interest rate on impact of a positive policy shock.

Finally, we choose to fix three parameters based on results from initial estimation rounds. The values for the international elasticity of substitution, η, the inverse of the labour supply elasticity, φ, and the elasticity of the capacity utilisation costs are all driven to high values when included in the estimation. As argued by Adolfson et al. (2007), who get similar results for η, a high estimate of the international elasticity of substitution is driven by the estimation procedure's attempt to reconcile the high volatility of imports relative to consumption with the import relation (36). The nominal rigidities needed to generate plausible responses to monetary policy shocks, for example, will only allow this relation to add up if η is very high (given the relatively small investment share). Our initial estimation suggests a value of η of aproximately 10. This is much higher than the values typically assumed for this parameter, and it would seem to be a very high number indeed for the highly specialised production structure of Iceland, which produces few substitutes for most of its imports. We therefore follow Adolfson et al. (2007) by fixing a smaller value for this parameter, specifically we set $\eta = 4.5$. Similarly, we follow Brubakk et al. (2006) in fixing $\varphi = 3$, which is close to initial estimates, even if this value is substantially higher than values typically assumed in the literature. Finally, the elasticity of the cost of changing the utilisation of capital is driven to high values (with large confidence bands), suggesting that variable capacity utilisation is not an important adjustment mechanism in the economy. We therefore set $\lambda_U = 99,999$, which essentially keeps capacity utilisation fixed. These choices have only small effects on the marginal likelihood, while they help generate convergence of the Metropolis-Hastings algorithm for other parameters. The actual estimated values for the other parameters are not greatly affected, however.

3.3 Prior distributions of estimated parameters

The prior distributions of the estimated dynamic parameters are summarised in table 2 (along with the posterior distributions to be discussed below), while table 3 provides similar information for the estimated shock parameters. We use

[15] In practice, we estimate the standard deviations of all shocks to the model, but we specify very tight priors around the values stated here for the foreign shocks and the government spending shock.

four different families of distributions for the priors, i.e., the beta, the inverted gamma, the normal, and the uniform distributions.

Parameters restricted by theory to fall in the unit interval are given beta distributions. This includes the habit persistence parameter, the Calvo parameters, the shock persistence parameters, and the degree of interest rate smoothing in the monetary policy rule. The habit persistence parameter is given a prior mean of $h = 0.8$ with a standard deviation of 0.1. This choice reflects the high degree of habit persistence estimated for Norway in Brubakk et al. (2006). For the Calvo parameters θ_ι for $\iota \in \{F, H, W\}$ and θ_H^* we set the prior mean to 0.75 with a standard deviation of 0.1. This choice implies an average duration of price and wage contracts of four quarters. This is longer than the estimated duration of prices found for Iceland by Gudmundsson et al. (2010). But as strategic complementarities are absent from domestic price setting in the model, we expect that higher values of the Calvo parameters are needed to match the slopes of the Phillips curves. Regarding the persistence of the shocks, we set the prior means to 0.75 with a standard deviation of 0.1.

We use the inverse gamma distribution for the priors of dynamic parameters in the model that are restricted to be positive. We let the inverse of the second derivative of the investment adjustment cost function, λ_I, have a prior mean of 0.15 with a standard deviation of 0.1. This is in line with priors and estimates in Adolfson et al. (2007) and Smets and Wouters (2007). The prior for the parameter of the international financial cost is also an inverted gamma distribution, and we set its mean to be 0.03, but with a standard deviation of 0.05. This strikes a balance between the values suggested by Adolfson et al. (2007) and Laxton and Pesenti (2003), while allowing the data to speak relatively freely on this parameter. Similarly, we specify a relatively loose prior for the export adjustment cost parameter ϕ_M^*. We set its prior mean to 0.75 with a standard deviation of 0.15.

Following Adolfson et al. (2007), we let the parameters entering the Taylor rule have normal prior distributions, and we set similar values for the prior means and variances. Finally, we are agnostic about the size of the structural shocks, and so we let their prior distributions be uniform on the unit interval.

3.4 Posterior distributions of estimated parameters

The estimation results in the form of the posterior modes, means and confidence intervals are shown along with information on the prior distributions in tables 2 and 3. Figures 5-9 convey the same information graphically. The grey lines present the prior distributions and the black lines the estimated posterior distributions. The posterior modes are represented by the vertical green lines. Generally speaking, the data appears to quite informative about the parameter values as the posterior distributions tend to have thinner tales and different means than the prior distributions. Exceptions to this are the international transaction cost parameter and some of the parameters entering the Taylor rule. They do not seem to be well identified by the estimation procedure, and posterior means are very close to priors. This possibly reflects the lack of monetary stability in the estimation period.

The estimation drives the value of habit persistence in consumption to a high value, while the investment adjustment cost parameter is estimated to be lower than the prior mean. This reflects the volatile nature of quarterly investments in the Icelandic data. In contrast, the updating of prior beliefs through the likelihood function leads us to a posterior distribution of the export adjustment costs with a much higher mean. This reflects the relatively low variability of exports in comparison with imports.

The estimated Calvo parameters suggest a high degree of domestic nominal rigidity with $\theta_H = 0.91$ and $\theta_W = 0.77$. The Calvo parameters for import and particular export prices are estimated to be considerably lower with $\theta_F = 0.61$ and $\theta_H^* = 0.19$. In comparision, Adolfson et al. (2008) estimate import and export prices in Sweden to have degrees of stickiness as high as domestic prices. This difference suggests that the pass-through of exchange rate developments into prices of imported goods are particularly high for Iceland, while the low degree of stickiness in export prices is likely to be related to the high content of goods with highly volatile prices (fish and aluminium) in Icelandic exports. We note that a high value for η plays an important role in these estimates. Lowering the value of η to 1.1 (the value chosen by Brubakk et al., 2006), reduces the estimated degree of domestic price stickiness, while increasing the degree of stickiness in export prices.

The shock processes are generally estimated to be very persistent with persistence parameters exceeding 0.8. Exceptions are the domestic and imported price mark-up shocks that are moderately persistent with values of 0.56 and 0.65, respectively. This is in line with the findings of Brubakk et al. (2006).

3.5 Model fit

To assess the model's ability to account for the dynamics in the Icelandic economy, table 4 presents unconditional moments of the observable variables in the data and their model counterparts. We present standard deviations, first-order autocorrelation coefficients, and correlations with output growth and CPI inflation.

Based on the statistics considered here, it appears that the model is able to replicate the moments for consumption and investment growth quite well, roughly replicating the volatility, persistence and business cycle co-movements in the data. Similarly, the model seems capable of capturing the output growth and inflation moments reasonably well, though it overestimates the volatilities. The reason for this may be that growth in exports and hours are too volatile in the model. For exports, this is despite of the introduction of export adjustment costs. But without them, the fit of the model worsens considerably as exports become much too volatile. This, in turn, increases the output growth volatility further, while reducing output growth persistence markedly. Along similar lines, we may speculate that the introduction of habit persistence in leisure (as well as in consumption goods) as in Pesenti (2008), or labour adjustment costs in production as in Juillard et al. (2006), may improve the fit of the model by slowing down the response of hours to shocks in the economy. In some dimension, however, the model does not perform well. It struggles to reproduces the correlations of the real exchange rate, and it produces countercyclical imports.

In sum, we believe the model provides a decent, though by no means perfect, representation of the data. We note, however, that the moments considered here are only a small subset of the features which the estimation routine attempts to match. Essentially, the Bayesian estimation procedure sets out to fit the model to all the variation in the data (standard deviations, autocorrelations and cross-correlations), which necessarily requires the algorithm to make compromises along several dimensions of the estimation problem. Some of these are represented by the impulse response functions to shocks, to which we turn next.

4 Impulse responses to shocks

This section turns to the properties of the estimated model by presenting the responses of key variables to the domestic exogenous shocks. This analysis is conditional in the sense that one shock is considered at a time. Throughout, monetary policy responds endogenously to the shock by following the monetary policy rule. By construction, the response is sufficiently strong so as to anchor inflation expectations and thereby avoid multiplicity of equilibria. The purpose of this exercise is to describe the model's propagation mechanism.

4.1 Monetary policy shock

Figure 10 presents responses to a typical monetary policy shock that increases the nominal interest rate on impact (a shock to $z_{R,t}$). In keeping with conventional wisdom, such a monetary policy shock has a contractionary effect in the model.

The transmission is as follows. The increase in the *nominal* interest rate also leads to an increase in the *real* interest rate as prices are sticky. This decreases aggregate demand through a fall in consumption and investment. Because of habit persistence and investment adjustment costs, the responses of consumption and investment are hump-shaped. Effectively, households need time to adjust to lower levels of consumption when habits are persistent. By the Euler equation, they therefore adjust their consumption gradually. Similarly, they reduce investment gradually due to the costs of such adjustments. With nominal price rigidity, output is determined by demand. Therefore, output falls gradually along with demand. This reduces firms' marginal costs, which makes a subset of the firms – those that are allowed to reset their prices through the Calvo price-setting mechanism – respond by reducing prices. Thus, domestic inflation falls. The decline in demand also translate into a fall in the demand for labour, which puts downward pressure on wages. Because of nominal rigidities, however, the response of the real wage is muted.

Further to this interest-rate transmission channel of monetary policy, there is an open-economy channel working through the exchange rate, by which monetary policy has real effects in the economy. The more open the economy and the higher the pass-through of exchange rate movements into the prices of imported goods, the more important is this exchange-rate transmission channel. Through the uncovered interest rate parity condition, the higher interest rate leads to an appreciation of both the real and the nominal exchange rate. This reduces the prices of imported goods, especially if pass-through is high, which leads to a larger fall in CPI inflation than in domestic price inflation. This works to both increase the impact response of CPI inflation and to lower its persistence in response to the monetary policy shock. The appreciation of the real exchange rate also induces expenditure switching away from domestic goods. The effect is a fall in exports and in increase in imports. Hence, net exports and the net asset position fall. As domestic demand falls, imports will eventually fall as well despite the expenditure switching effect. The fall in net exports further depresses output. As the response of the real exchange rate is immediate, a common feature of open-economy DSGE models, the open-economy transmission channel works to limit both the persistence and the hump in output's response to the monetary policy shock.[16]

As agents in the economy are forward-looking with households that optimise expected life-time utility and firms that maximise their value rather than simply current-period profits, expectations naturally play an important role in the transmission of monetary policy be it through the interest-rate or the exchange-rate channel. Hence, it is essentially the expected future path of the central bank's interest rates induced by the shock that agents respond to. In turn, the future path of interest rates is determined by the central bank's endogenous response to the actions of private agents. This emphasises the general-equilibrium nature of the model's dynamics.

The responses to a monetary policy shock are qualitatively similar to those found by Brubakk et al. (2006) for Norway and Adolfson et al. (2008) for Sweden, but the responses of inflation and output are somewhat less persistent. CPI inflation reaches its trough in the third quarter, while domestic inflation bottoms out one to two quarters later. The peak effect on output is reached in the third or forth quarter. In comparison, Adolfson et al. (2008) find troughs in inflation as well as output after between four to six quarters, while Brubakk et al. (2006) find a peak effect on output after about a year and on CPI inflation after two years with a quite persistent return to the steady state. This reflects both differences in the estimated degree of domestic price stickiness and in the extent of exhange-rate pass-through in the Icelandic economy. We find that the exchange rate channel of monetary policy is particularly important in Iceland.[17]

[16] See Adolfson et al. (2008) for a discussion of this issue. We have also estimated a version of our model with the ad-hoc specification of the uncovered interest rate parity condition suggested in that paper (with a forward-looking term in the real exchange rate). The main effect on the impulse responses to a monetary policy shock is to make the hump in output smoother. The marginal likelihood comparion favours this specification slightly, but an inspection of the unconditional moments does not suggest that the fit of the model is improved.

[17] However, if empirical impulse responses to monetary policy shocks are more persistent, parameterising the model by minimising the distance between empirical impulse responses and the model equivalents as in Christiano, Eichenbaum and Evans (2005) may result in

The responses in figure 10 are also broadly in line with those generated in the Central Bank of Iceland's *QMM,* cf. Daníelsson et al. (2009). While domestic demand components are more persistent in the DSGE model, inflation returns to the baseline in approximately the same time, while it takes somewhat longer for the output gap to close in the *QMM* than for output to break its steady-state level in the DSGE model. Also, the peak effects on output and inflation occur one to two quarters later in the *QMM* model. In both models, real and nominal exchange rates appreciate, but in the *QMM*, a small trade surplus is generated in the first couple of quarters before the expenditure switching effect comes to dominate the demand effect in the following periods. In the DSGE model, the timing of this is reversed. In the first six quarters after a monetary policy shock, the model generates a trade deficit, followed by trade surpluses to bring the net asset position back to its steady state level.

4.2 Technology shocks

Figure 11 shows responses to a temporary, labour-augmenting technology shock (a shock to $z_{H,t}$). As we would expect from a supply shock of this kind, the shock works to reduce inflation and increase domestic output. On impact, the shock reduces the marginal costs of firms, a subset of which respond by reducing prices. This leads to a fall in domestic inflation and an increase in demand as the central bank reduces interest rates. Consumption, investment and aggregate output all increase. As the reduction in prices is gradual due to the Calvo price-setting mechanism, and as habit persistence and investment-adjustment costs imply gradual demand responses, inflation and output respond in a more hump-shaped fashion. But as firms cannot fully adjust prices, the limited demand response induces a fall in hours worked as firms have become more productive. Effectively, they can produce the same output with less labour. The fall in domestic prices works to increase the term of trade, which shifts demand from foreign to domestic goods. By increasing exports, this further stimulates domestic production. In the estimated model with costly export adjustments, the deterioration of the terms of trade is so strong (and the response of exports so weak) that GDP measured in consumption units actually falls slightly on impact of the shock.

Figure 12 shows responses to an investment-specific technology shock (a shock to $z_{I,t}$). An investment-specific technology shock increases the marginal efficiency of investment in the sense that a given amount of resources devoted to investment increases productive capital more following a positive shock, cf. (82). In other words, the relative price of investment falls, driving up the rate of return to investment. This induces intertemporal substitution from consumption to

more persistant responses to monetary policy shocks also in the model. By using the full-information Bayesian approach, we attempt to fit the model to all the variation in the data as discussed above, not just monetary policy shocks. This may require us to compromise on the model's ability to capture certain features of the data to allow for plausible responses to other shocks. For an analysis of the effects of monetary policy innovations in Iceland, see Pétursson (2001a,b).

investment. The investment boom leads to an increase in aggregate demand and output in the economy, to which firms respond by increasing prices. The central bank therefore increases the interest rate to dampen demand. The expansion in the economy drives up imports, while exports suffer from higher prices caused by increasing domestic marginal costs. Hence, the trade balance moves into deficit.

Figure 13 shows responses to an asymmetric technology shocks (a shock to $z_{D,t}$). As noted above, this shock essentially works as an exogenous shock to exports in the model. A positive shock means that the foreign economy now grows relatively slowly. It therefore wants to import less. By reducing demand for domestic goods, production in the home economy falls. Domestic firms respond by reducing prices and the real exchange rate depreciates. This drives up the prices of imported goods. The net effect is an increase in CPI inflation, to which the central bank soon responds by increasing interest rates. This dampens aggregate demand, further reducing activity in the home economy.

Figure 14 shows responses to a permanent total factor technology shocks (a shock to ζ_t). The interpretion of the responses is complicated by the fact that real variables are expressed in efficiency units. However, we see that output growth increases on impact of the shock, while it takes time for output itself to rise to its new potential.

4.3 Mark-up shocks

Figure 15 shows responses to a domestic mark-up shock (a shock to $\mu_{H,t}$). This shock can be seen as in increase in the market power of domestic firms in the home market, or alternatively as a shock to the marginal cost of production for domestic firms. The firms therefore respond to this shock by increasing prices as their desired mark-ups over marginal costs (or the costs themselves) have increased. This drives up CPI inflation through its effects on domestic inflation. The central bank, in turn, responds by increasing interest rates with adverse effects on the components of aggregate demand. As output is determined by demand in this economy with monopolistically competitive price-setters, production in the economy falls. The recession also leads to a fall in the demand for labour, and hours fall along with output putting downward pressure on wages. Because of wage stickiness, the response of wages is gradual. Moreover, the increase in domestic inflation and the monetary tightening lead to a gradual real exchange rate appreciation and a fall in net exports driven by expenditure switching from the more expensive domestic goods towards foreign goods.

Figure 16 shows responses to an imported mark-up shock (a shock to $\mu_{F,t}$). This shock increases the market power of foreign firms exporting goods to the home economy. Hence, the prices of imported goods increase as foreign exporters have higher desired mark-ups over marginal costs. Households at home respond to this increase in the prices of foreign goods by importing less. Nevertheless, the increase in imported inflation also drives up CPI inflation. The central bank therefore dampens demand in the economy by increasing interest rates to bring CPI inflation back to target. This has a contractionary effect on production, but because foreign goods are now more expensive relative to domestic ones, expenditure switching towards domestic goods works to expand the home economy. As domestic firms see marginal costs go up, they increase their prices and domestic inflation increases. This has an adverse effect on exports, though the net effect is an increase in net exports and the net asset position.

Figure 17 shows responses to an exported mark-up shock (a shock to $\mu^*_{H,t}$). By increasing the market power of home firms abroad, this shock works to reduce export volumes as firms increase prices abroad. As fewer goods have to be exported, domestic firms produce less output. This reduces marginal costs allowing them to reduce prices on goods sold in the home market. The fall in domestic inflation works to reduce CPI inflation, and the central bank responds by reducing interest rates. Consequently, domestic demand components increase countering the fall in output somewhat. But the increase in domestic demand is not sufficient to off-set the fall in exports, even in this economy with export adjustment costs. The fall in interest rates causes an exchange rate depreciation. Import goods therefore become more expensive, and imported inflation rises. This moderates the fall in CPI inflation.[18]

Figure 18 shows responses to a wage mark-up shock (a shock to $\mu_{W,t}$). This shock increases the market power of households in wage setting, i.e., the desired mark-up of the real wage over the marginal rate of substitution increases. The shock is therefore equivalent to an adverse labour supply shock. As we should expect from such a shock, hours decline and the real wage increases on impact. This increases firms' marginal costs, which makes them increase prices. As inflation gradually rises, the central bank increases interest rates. Through the usual aggregate demand effects, the result is a recession in the economy to the effect of bringing inflation back down from its elevated levels. As the interest rate increases, the real exchange rate will eventually appreciate with adverse effects on net exports and the net asset position.

4.4 Risk-premium shock

Figure 19 shows how a shock to the cost of international financial intermediation (a shock to $z_{B,t}$) is propagated through the economy. By increasing the cost of financial intermediation, the shock decreases the return to holding international bonds. As foreign bonds become less attractive to domestic households, the exchange rate appreciates. This makes imported goods cheaper relative to domestic ones. Consequently, net exports fall along with imported inflation. The central bank responds to a lower inflation rate by reducing interest rates. This stimulates demand, and the increases in consumption and investment eventually off-set the fall in output brought about by the fall in net exports. As the trade deficit worsens the country's net asset position, the shock is amplified through

[18] Note that the dynamic effects from an exported mark-up shock are very similar to those following an asymmetric technology shock, $z_{D,t}$. The shocks only differ in the net effect on CPI inflation from a fall in domestic and an increase in imported inflation. This then explains the different responses of aggregate demand components through the endogenous response of monetary policy.

the endogenous response of the risk premium to the foreign indebtedness of the economy, cf. (86).

Note that the *positive* shock to the cost of financial intermediation just described is equivalent to a *negative* shock to the home country's risk premium. An exogenous increase in the risk premium for Iceland would therefore have the opposite effects in the model: An increase in the risk premium would lead to an export-driven boom in the economy through an exchange rate depreciation. In fact, by increasing the endogenous response of the risk premium, the expansion in the economy would be larger the more indebted the economy. While this suggests an important channel through which a country may recover from financial crisis, it clearly indicates that the model in its current form has little to say about the difficult policy dilemmas facing Iceland during the financial crisis that hit the country with full force in the autumn of 2008. Besides abstracting from confidence issues, it features none of the balance sheet effects that were at the centre of policy deliberations during the crisis. In other words, the model is not constructed to account for the recent boom-bust cycle of the Icelandic economy.[19]

4.5 Other shocks

Figure 20 shows responses to a household preference shock (a shock to $z_{C,t}$). The shock increases the current marginal utility of consumption. This makes households value consumption more, and they respond by substituting intertemporally from investment to consumption. The net effect is an increase in aggregate demand driven by an expansion in consumption, and so output increases. Firms therefore face rising marginal costs, and they respond by increasing prices. This, in turn, induces the central bank to increase interest rates to counter the expansion in the economy and bring inflation back to target.

Finally, Figure 21 shows responses to a government spending shock (a shock to g_t). The shock has an expansionary effect on output, hours and inflation as the expansion in public spending provides extra aggregate demand in the economy. The expansion in demand drives up output and marginal costs, and firms increase prices. The central bank responds to the rising inflation by increasing interest rates. This then crowds out private consumption and investment. Importantly, the responses of households and the contraction in private demand are not sensitive to the assumption of balanced public budgets as household behaviour is fully Ricardian in the model. Non-Ricardian behaviour, for instance in the form of rule-of-thumb consumption behaviour as in Galí (2007), would enable the model to generate positive responses of consumption to deficit-financed increases in government spending.

[19] The policy dilemmes have been described in detail in various issues of the Central Bank of Iceland's *Monetary Bulletin*. See Gertler et al. (2007) for an analysis of balance sheet effects in an open-economy DSGE model.

5 Applications

In this section, we briefly present two applications in the form of variance decompositions and forecasting to illustrate the model's potential in structural business cycle analysis.

One of the main advantages of the DSGE approach is the explicit specification of structural shocks to the economy. This allows us to study the transmission of these shocks through the economy as in the previous section. But the model can give us further insights about business cycle fluctuations by detailing the contribution of each shock to the fluctuations in the endogenous variables. We may then potentially single out a subset of the model's shocks as the prime drivers of business cycles. This is the objective of variance decompositions. Moreover, we can estimate time series for the shock processes and the unobservable endogenous variables to give us information about the drivers of specific economic developments at specific points in time during the sample period.[20] In turn, this may guide the conduct of monetary policy given our knowledge about the transmission of individual shocks through the economy. This is the idea behing historical shock decompositions, where we first simulate the model using the estimated or *smoothed* time series for one shock at a time. This tells us how the economy would have evolved if this shock were the only one operating. We then add up the contributions of individual shocks to gives us a complete historical decomposition of the fluctuations in endogenous variables in the model during the sample period.

The estimation of time series for the shock processes and the other unobservable variables has the further benefit that it gives us a starting point for forecasting. If we start our projections in the steady state, and unless we add deterministic effects, our forecasts would be flat with ever increasing confidence bands caused by uncertainty about the shocks that will hit the economy in the future. The smoothed time series allow us to project the dynamics of the model into the future and to assess the uncertainty of our forecasts due to uncertainty about future shocks as well as uncertainty about parameter estimates.[21]

5.1 Variance decompositions

Table 5 presents the unconditional (infinite-horizon) variance decomposition of a selected subset of variables, where we have grouped the foreign shocks, the technology shocks, and the mark-up shocks. The purpose of this exercise is to gauge the importance of different shocks in generating fluctuations in endogenous variables.

[20] During estimation, the Kalman filter works its way through the sample to produce one-step ahead, conditional predictions of the unobservable variables. It is the prediction errors from this process that allows us to evaluate the likelihood function. To arrive at estimated time series for the unobservable variables, we combine the Kalman filter with a *smoothing* algorithm that updates the predictions from the Kalman filter with all the information contained in the sample. For details, see e.g. Harvey (1989).

[21] A recent review of forecasting methodologies in the DSGE framework is given by Christoffel et al. (2010).

While technology shocks alone appear to be very important drivers of the fluctuations in the Icelandic economy explaining about 50 per cent of the variation in output (of which 27 per cent is explained by the investment-specific technology shock, making it the single most important shock, and 15 per cent by temporary labour-augmenting shocks), the model does not support the view that technology shocks are the only dominant forces of business cycle fluctuations. Mark-up shocks, in particular in the domestic goods and labour markets, are also important source of fluctuations explaining about 35 per cent of the variation in output. Also, the risk premium shock alone account for a substantial part of output fluctuations. Together with foreign shocks, this open economy shock explains more than 11 per cent of output fluctuations.

Considering the sources of variation in output growth, it is clear that the open-economy shocks are even more important in generating fluctuations at short horizons. Hence, close to 30 per cent of output growth variability is assigned to the open-economy shocks. Moreover, the asymmetric technology shock, working as a shock to exports in the model, and the exported mark-up shock together account for about 10 per cent of the variation in output and 15 per cent of the variation in output growth.

A similar picture emerges when considering the other variables. Together, technology and mark-up shocks account for about 75 per cent of the variation in investment and inflation, and 65 per cent of consumption. Their share in generating fluctuations in net exports, the real exchange rate and the interest rate are somewhat smaller, however, as the open-economy shocks explain a larger share of fluctuations in these variables. Also, the open-economy shocks, affecting the economy through the exchange rate, account for about 18 per cent of the variation in CPI inflation. Preference shocks are mainly driving consumption and investment fluctuations, reflecting the role played by these shocks in generating substitution between consumption and investment. The short-run behaviour of consumption, in particular, is to a large extent driven by preference shocks. Policy shocks are not found to be important drivers of the business cycle, though monetary policy plays some role for the variation in growth rates.

To further assess the importance of various shocks at particular points in time, figures 22 and 23 show the historical decomposition of GDP and CPI inflation, respectively. Similar figures can be generated for all the other variables in the model, but we emphasise the responses of output and inflation as an illustration of the model's ability to provide structural information on business cycle developments. The decompositions are based on the smoothed shocks from the estimated model, i.e., the estimated time series of the exogenous shocks to the model in the sample period. The historical decomposition therefore provides estimates of the shocks driving the endogenous variables at particular points in time during the sample period.

Figure 22 suggests that adverse technology shocks, in particular investment-specific and temporary labour-augmenting technology shocks, have worked in the direction of reducing output below its efficient level throughout the sample period. Domestic shocks to mark-ups worked in the same direction in the early period of the sample, where they were countered by labour supply shocks. In the later part of the sample, mark-up shocks and risk-premium shocks appear to have contributed in the direction of expanding output above its efficient level.

From figure 23, we see that the estimated model explains the above-average inflation rates in the latter half of the sample with adverse technology shocks in combination with risk-premium shocks, while mark-up shocks worked to reduce inflation. In earlier parts of the sample, inflation fell slightly below average for about 20 quarters. The estimated model suggests that this was driven mostly by labour supply and risk-premium shocks.

Hence, figures 22 and 23 confirm the importance of technology, mark-up and risk-premium shocks in driving the business cycle from table 5. But additionally, they provide an estimate of the points in time at which these shocks were important as well as an estimate of the direction in which they have affected the economy at a given point in time. This may allow us to explain specific events in the business cycle using the structural model.

5.2 Forecasting

Finally, figure 24 shows forecasts of key endogenous variables in the model along with up to 90 per cent confidence bands illustrating the uncertainty about the forecast due to the estimated parameter uncertainty.[22] Note that the variables are expressed as in the model, i.e., in efficiency units and in deviation from the steady state. To arrive at actual growth forecasts, we would have to add the mean, trend effect of permanent technology, and seasonal components. The forecast takes the smoothed time series of exogenous shocks and endogenous variables as a starting point. From that starting point, the model's transmission mechanism drives the forecast and no deterministic factors have been added.

The starting point of the forecast is one in which domestic demand components are high, and the trade balance is in deficit. Also, domestic and CPI inflation are high, but the model does not suggest that domestic output is far from its growth potential. The forecast predicts a soft landing of the economy, by which consumption and investment gradually fall to sustainable levels, enabling the trade balance to recover through a real depreciation. In addition, the central bank is forecasted to keep interest rates high facilitating a return of inflation to its steady state level.

It its clear from figure 24 that the model predicts a relatively smooth return to the steady state. To increase forecasting accuracy, it may therefore be necessary to provide the model with additional information on short-run developments in the economy. Further testing of the forecasting abilities of the model will be needed to establish the horizon at which the model dynamics should take over from other short-run forecasting procedures in generating an actual forecast of the economy for policy decision making.

[22] We can also compute confidence intervals that take the uncertainty about future shocks into account. These confidence intervals will be considerably larger than the ones reported here.

6 Conclusion

This paper has presented an estimated DSGE model for Iceland. The model has been developed at the Central Bank of Iceland as a tool in support of inflation targeting. The model provides a reasonable fit to the Icelandic data. The estimation suggests that nominal rigidities play an important role in the propagation mechanism of the Icelandic economy, but that the pass-through of exchange rate movements to domestic prices is high in comparison with other Nordic countries. This suggests that the exchange rate channel of monetary policy is particularly important in Iceland. According to the model, the most important drivers of the Icelandic business cycle are technology shocks, mark-up shocks and risk-premium shocks. In future work, the model will have to be further tested in particular as a tool in the forecasting process. This may result in adjustments to the model specification with non-trivial implication for the propagation mechanism and estimated parameters. However, we believe that the current model provides a useful representation of the Icelandic economy.

A Stationary model

We define $\overline{X}_{R,t} = X_{R,t}/Z_t$ for most real variables $X_{R,t}$ and $\overline{X}_{N,t} = X_{N,t}/P_t$ for most nominal variables $X_{N,t}$ (respectively $\overline{X}^*_{N,t} = X^*_{N,t}/P^*_t$ for $X^*_{N,t}$). Exceptions are $\overline{W}_t = W_t/P_tZ_t$, $\overline{MU}_{C,t} = MU_{C,t}Z_t$, $\overline{B}_{H,t} = B_{H,t}/P_{t-1}Z_{t-1}$, $\overline{B}^*_{H,t} = B^*_{H,t}/P^*_{t-1}Z_{t-1}$ and $\overline{K}_{S,t} = K_{S,t}/Z_{t-1}$. Hence, real variables are detrended with the level of technology in the period in which they are determined. Note also that hours worked is stationary, while the real wage is non-stationary. In constrast, the capital stock is non-stationary, while the real rental rate is stationary. We let $\Pi_{\mathcal{E},t} = \mathcal{E}_t/\mathcal{E}_{t-1}$ represent the nominal depreciation rate of the home currency and we define $\Pi_{\iota,t,t+k} \equiv \Pi_{\iota,t+1} \cdot \Pi_{\iota,t+2} \cdot \ldots \cdot \Pi_{\iota,t+k}$ for $\iota \in \{\mathcal{E}, H, P\}$. Then, the stationary model is given by the following equations (128)-(161).

A.1 Prices

$$1 = \left[(1-\alpha)\left(\overline{P}_{H,t}\right)^{1-\eta} + \alpha\left(\overline{P}_{F,t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{128}$$

$$\frac{S_t}{S_{t-1}} = \frac{\Pi_{\mathcal{E},t}\Pi^*_{P,t}}{\Pi_{P,t}} \tag{129}$$

$$T_t = \frac{\overline{P}_{F,t}}{S_t\overline{P}^*_{H,t}} \tag{130}$$

A.2 Resource constraints

$$\overline{Y}_{H,t} = \overline{Y}^h_{H,t} + \overline{EX}_t \tag{131}$$

$$\overline{Y}^h_{H,t} = (1-\alpha)\,\overline{P}^{-\eta}_{H,t}\overline{A}_t \tag{132}$$

$$\overline{EX}_t = \alpha^*\left(\overline{P}^*_{H,t}\right)^{-\eta}\overline{A}^*_t\frac{Z^*_t}{Z_t} \tag{133}$$

$$\overline{NX}_t = \overline{EX}_t - \frac{\overline{P}_{F,t}}{S_t\overline{P}^*_{H,t}}\overline{IM}_t = \overline{EX}_t - T_t\overline{IM}_t \tag{134}$$

$$\overline{IM}_t = \alpha\overline{P}^{-\eta}_{F,t}\overline{A}_t \tag{135}$$

$$\overline{Y}_t = \overline{P}_{H,t}\overline{Y}^h_{H,t} + S_t\overline{P}^*_{H,t}\overline{EX}_t \tag{136}$$

$$\overline{A}_t = \overline{C}_t + \overline{I}_t + \overline{M}_t + \overline{G}_t \tag{137}$$

$$\overline{Y}_t = \overline{A}_t + S_t\overline{P}^*_{H,t}\overline{NX}_t \tag{138}$$

A.3 Household relations

$$\overline{MU}_{C,t} = Z_{C,t}\left(\overline{C}_t - h\frac{\overline{C}_{t-1}}{\Pi_{Z,t}}\right)^{-1} \tag{139}$$

$$MU_{N,t}(j) = -\chi N_t(j)^{\varphi} \tag{140}$$

$$\overline{K}_t = U_t\frac{\overline{K}_{S,t}}{\Pi_{Z,t}} \tag{141}$$

$$\overline{M}_t = \Gamma_U(U_t)\frac{\overline{K}_{S,t}}{\Pi_{Z,t}} \tag{142}$$

$$\overline{K}_{S,t+1} = (1-\delta)\frac{\overline{K}_{S,t}}{\Pi_{Z,t}} + Z_{I,t}\left(1-\Gamma_I\left(\frac{\overline{I}_t}{\overline{I}_{t-1}}\Pi_{Z,t}\right)\right)\overline{I}_t \tag{143}$$

$$\begin{aligned}
&\overline{C}_t + \overline{I}_t + \Gamma_U(U_t)\frac{\overline{K}_{S,t}}{\Pi_{Z,t}} + S_t\overline{B}^*_{H,t+1} + E_t\left(\Lambda_{t,t+1}\overline{B}_{H,t+1}(j)\right) + \overline{TA}_t \\
= \;& R^*_{t-1}(1-\Gamma_{B,t-1})\frac{S_t}{\Pi_{Z,t}\Pi^*_{P,t}}\overline{B}^*_{H,t} + \frac{\overline{B}_{H,t}(j)}{\Pi_{Z,t}\Pi_{P,t}} + \overline{W}_tN_t(j) \\
&+\overline{R}^K_tU_t\frac{\overline{K}_{S,t}}{\Pi_{Z,t}} + \overline{DIV}_t
\end{aligned} \tag{144}$$

$$\Gamma_{B,t-1} = \phi_1\frac{\exp\left\{\phi_2S_{t-1}\frac{\overline{B}^*_{Ht}}{\overline{Y}_{t-1}}\right\}-1}{\exp\left\{\phi_2S_{t-1}\frac{\overline{B}^*_{Ht}}{\overline{Y}_{t-1}}\right\}+1} + \ln Z_{B,t-1} \tag{145}$$

$$1 = R_tE_t\Lambda_{t,t+1}. \tag{146}$$

$$\Lambda_{t,t+1} = \frac{\beta}{\Pi_{Z,t+1}\Pi_{P,t+1}}\frac{\overline{MU}_{C,t+1}}{\overline{MU}_{C,t}} \tag{147}$$

$$1 = R^*_t(1-\Gamma_{B,t})E_t\left(\Lambda_{t,t+1}\frac{S_{t+1}}{S_t}\frac{\Pi_{P,t+1}}{\Pi^*_{P,t+1}}\right) \tag{148}$$

$$\begin{aligned}
1 = \;& Q_tZ_{I,t}\left[1-\Gamma_I\left(\frac{\overline{I}_t}{\overline{I}_{t-1}}\Pi_{Z,t}\right) - \Gamma'_I\left(\frac{\overline{I}_t}{\overline{I}_{t-1}}\Pi_{Z,t}\right)\frac{\overline{I}_t}{\overline{I}_{t-1}}\Pi_{Z,t}\right] \\
&+E_t\left[\Lambda_{t,t+1}Q_{t+1}\Pi_{P,t+1}Z_{I,t+1}\Gamma'_I\left(\frac{\overline{I}_{t+1}}{\overline{I}_t}\Pi_{Z,t+1}\right)\left(\frac{\overline{I}_{t+1}}{\overline{I}_t}\Pi_{Z,t+1}\right)^2\right]
\end{aligned} \tag{149}$$

$$Q_t = E_t\left[\Lambda_{t,t+1}\Pi_{P,t+1}\left(\overline{R}^K_{t+1}U_{t+1} - \Gamma_u(U_{t+1}) + Q_{t+1}(1-\delta)\right)\right] \tag{150}$$

$$\overline{R}^K_t = \Gamma'_U(U_t) \tag{151}$$

$$\sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left\{ N_{t+k}(j)(1-\varepsilon_{W,t+k}) \left[\frac{\overline{\tilde{W}}_t}{\Pi_{P,t,t+k}} (\Pi_{P,t-1,t+k-1})^{\gamma_w} \overline{MU}_{C,t+k} \right.\right.$$
$$\left.\left. + \mathcal{M}_{W,t+k} MU_{N,t+k}(j) \right] \right\} = 0 \tag{152}$$

$$\left(\overline{W}_t\right)^{1-\varepsilon_{W,t}} = \theta_w \left(\frac{\overline{W}_{t-1}}{\Pi_{P,t}} \Pi_{P,t-1}^{\gamma_w} \right)^{1-\varepsilon_{W,t}} + (1-\theta_w) \left(\overline{\tilde{W}}_t \right)^{1-\varepsilon_{W,t}} \tag{153}$$

A.4 Firm relations

$$\overline{Y}_{H,t}(i) = \overline{K}_t^{\psi_H}(i) \left(Z_{H,t} N_t(i) \right)^{1-\psi_H} \tag{154}$$

$$\frac{\overline{K}_t(i)}{N_t(i)} = \frac{\psi_H}{1-\psi_H} \frac{\overline{W}_t}{\overline{R}_t^K} \tag{155}$$

$$\overline{MC}_t = \frac{1}{1-\psi_H} \left(\frac{\psi_H}{1-\psi_H} \right)^{-\psi_H} \frac{\overline{W}_t^{1-\psi_H} \left(\overline{R}_t^K \right)^{\psi_H}}{Z_{H,t}^{1-\psi_H}} \tag{156}$$

$$\sum_{k=0}^{\infty} \theta_H^k E_t \left\{ \Lambda_{t,t+k} \overline{Y}^h_{H,t+k}(i) \Pi_{Z,t,t+k} (1-\varepsilon_{H,t+k}) \left[\overline{\tilde{P}}_{H,t} (\Pi_{H,t-1,t+k-1})^{\gamma_H} \right.\right.$$
$$\left.\left. - \mathcal{M}_{H,t+k} \overline{MC}_{H,t+k} \Pi_{P,t,t+k} \right] \right\} = 0 \tag{157}$$

$$\sum_{k=0}^{\infty} (\theta_H^*)^k E_t \left\{ \Lambda_{t,t+k} \overline{Y}^f_{H,t+k}(i) \Pi_{Z,t,t+k} \left(1-\varepsilon^*_{H,t+k}\right) \left[\Pi_{\mathcal{E},t,t+k} S_t \overline{\tilde{P}}^*_{H,t} \left(\Pi^*_{H,t-1,t+k-1}\right)^{\gamma_H^*} \right.\right.$$
$$\left.\left. - \mathcal{M}^*_{H,t+k} \overline{MC}_{H,t+k} \Pi_{P,t,t+k} \right] \right\} = 0 \tag{158}$$

$$\overline{P}_{H,t}^{1-\varepsilon_{H,t}} = \theta_H \left(\overline{P}_{H,t-1} \frac{\Pi_{H,t-1}^{\gamma H}}{\Pi_{H,t}} \right)^{1-\varepsilon_{H,t}} + (1-\theta_H) \left(\overline{\tilde{P}}_{H,t} \right)^{1-\varepsilon_{H,t}} \tag{159}$$

$$\left(\overline{P}^*_{H,t} \right)^{1-\varepsilon_{H,t}} = \theta_H^* \left(\overline{P}^*_{H,t-1} \frac{\left(\Pi^*_{H,t-1}\right)^{\gamma_H^*}}{\Pi^*_{H,t}} \right)^{1-\varepsilon_{H,t}} + (1-\theta_H^*) \left(\overline{\tilde{P}}^*_{H,t} \right)^{1-\varepsilon_{H,t}} \tag{160}$$

A.5 Monetary policy

$$\frac{R_t}{R} = Z_{R,t} \left(\frac{R_{t-1}}{R} \right)^{\xi_R} \left[\left(\frac{\Pi_{P,t-1}}{\Pi_P} \right)^{\phi_P} \left(\frac{\overline{Y}_{t-1}}{\overline{Y}} \right)^{\phi_Y} \left(\frac{S_{t-1}}{S} \right)^{\phi_S} \right]^{(1-\xi_R)}$$
$$\cdot \left(\frac{\Pi_{P,t}}{\Pi_{P,t-1}} \right)^{\phi_{\Delta P}} \left(\frac{\overline{Y}_t}{\overline{Y}_{t-1}} \right)^{\phi_{\Delta Y}} \left(\frac{S_t}{S_{t-1}} \right)^{\phi_{\Delta S}} \tag{161}$$

B Steady state

Steady-state variables are indicated by omission of time subscripts. The steady state of the model is given by the following equations (162)-(189).

B.1 Prices and resource constraints

$$1 = \left[(1-\alpha)\left(\overline{P}_H\right)^{1-\eta} + \alpha\left(\overline{P}_F\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{162}$$

$$1 = \frac{\Pi_{\mathcal{E}}\Pi_P^*}{\Pi_P} \tag{163}$$

$$T = \frac{\overline{P}_F}{S\overline{P}_H^*} \tag{164}$$

$$\overline{Y}_H = \overline{Y}_H^h + \overline{EX} \tag{165}$$

$$\overline{Y}_H^h = (1-\alpha)\,\overline{P}_H^{-\eta}\overline{A} \tag{166}$$

$$\overline{EX} = \alpha^*\left(\overline{P}_H^*\right)^{-\eta}\overline{A}^* \tag{167}$$

$$\overline{IM} = \alpha\overline{P}_F^{-\eta}\overline{A} \tag{168}$$

$$\overline{NX} = \overline{EX} - \frac{\overline{P}_F}{S\overline{P}_H^*}\overline{IM} \tag{169}$$

$$\overline{Y} = \overline{P}_H\overline{Y}_H^h + S\overline{P}_H^*\overline{EX} \tag{170}$$

$$\overline{A} = \overline{C} + \overline{I} + \overline{G} \tag{171}$$

$$\overline{Y} = \overline{A} + S\overline{P}_H^*\overline{NX} \tag{172}$$

B.2 Household relations

$$\overline{K} = \frac{\overline{K}_S}{\Pi_Z} \tag{173}$$

$$\frac{\overline{I}}{\overline{K}} = 1 - \frac{1-\delta}{\Pi_Z} \tag{174}$$

$$\overline{C} + \overline{I} + S\overline{B}_H^* + \overline{TA} = R^*\left(1-\Gamma_B\right)\frac{S\overline{B}_H^*}{\Pi_Z\Pi_P} + \overline{W}N + \overline{R}^K\frac{\overline{K}_S}{\Pi_Z} + \overline{DIV} \tag{175}$$

$$1 = R\frac{\beta}{\Pi_Z\Pi_P} \tag{176}$$

$$1 = R^*\frac{\beta}{\Pi_Z\Pi_P} \tag{177}$$

$$1 = Q \tag{178}$$

$$\overline{R}^K = \beta^{-1}\Pi_Z - 1 + \delta \tag{179}$$

$$\overline{R}_t^K = \Gamma'_u(1) \tag{180}$$

$$\overline{\tilde{W}} = \mathcal{M}_W \chi N^{\varphi} \left(1 - \frac{h}{\Pi_Z}\right) \overline{C} \tag{181}$$

$$\overline{W} = \overline{\tilde{W}} \tag{182}$$

B.3 Firm relations

$$\overline{Y}_H = \overline{K}^{\psi_H} N^{1-\psi_H} \tag{183}$$

$$\overline{MC} = \frac{\overline{R}^K}{\psi_H} \left(\frac{\overline{K}}{N}\right)^{1-\psi_H} \tag{184}$$

$$\frac{\overline{K}}{N} = \frac{\psi_H}{1-\psi_H} \frac{\overline{W}}{\overline{R}^K} \tag{185}$$

$$\overline{\tilde{P}}_H = \mathcal{M}_H \overline{MC}_H \tag{186}$$

$$\overline{P}_H = \overline{\tilde{P}}_H \tag{187}$$

$$S\overline{\tilde{P}}_H^* = \mathcal{M}_H^* \overline{MC}_H \tag{188}$$

$$\overline{P}_H^* = \overline{\tilde{P}}_H^* \tag{189}$$

B.4 Solution

To solve for the steady state, let $\Pi_P = \Pi_W = \Pi_Z = 1$, $B_H^* = NX = 0$ and $G/Y = \gamma_g \in [0,1]$. By (163), this means that $\Pi_{\mathcal{E}} = 1$, and it follows directly from (176)-(180) that

$$R = R^* = \beta^{-1} \tag{190}$$

$$Q = 1 \tag{191}$$

and

$$\overline{R}^K = \Gamma'_U(1) = \beta^{-1} - 1 + \delta \tag{192}$$

From (173) and (174) we get

$$\overline{K} = \overline{K}_S \tag{193}$$

$$\overline{I} = \delta \overline{K} \tag{194}$$

The relations (162), (165)-(170) and (172) represents a system of equations, a solution to which is given by

$$\overline{P}_H = S = \overline{P}_H^* = \overline{P}_F = 1 \tag{195}$$

$$\overline{Y} = \overline{A} \tag{196}$$

$$\overline{Y}_H = \overline{Y} \tag{197}$$

$$\overline{Y}_H^h = (1-\alpha)\overline{Y} \tag{198}$$

$$\frac{\overline{EX}}{\overline{Y}} = \frac{\overline{IM}}{\overline{Y}} = \alpha \tag{199}$$

It then follows from (164) that $T = 1$ and from (167)-(169) that $\alpha Y = \alpha^* Y^*$.

The firm relations (183)-(189)

$$\frac{\overline{K}}{\overline{Y}} = \frac{\psi_H}{\mathcal{M}_H \left(\beta^{-1} - 1 + \delta\right)} \tag{200}$$

so that

$$\frac{\overline{I}}{\overline{Y}} = \delta \frac{\overline{K}}{\overline{Y}} \tag{201}$$

Then from (171)

$$\frac{\overline{C}}{\overline{Y}} = 1 - \frac{\overline{I}}{\overline{Y}} - \gamma_g \tag{202}$$

From (183) we get

$$\overline{Y} = N \left(\frac{\overline{I}}{\overline{Y}} \delta^{-1} \right)^{\frac{\psi_H}{1-\psi_H}} \tag{203}$$

For a given N, we therefore have

$$\overline{C} = \frac{\overline{C}}{\overline{Y}} \overline{Y} \tag{204}$$

$$\overline{I} = \frac{\overline{I}}{\overline{Y}} \overline{Y} \tag{205}$$

$$\overline{K} = \frac{\overline{I}}{\delta} \tag{206}$$

and from (185)

$$\overline{W} = \frac{1 - \psi_H}{\psi_H} \frac{\overline{K}}{N} \overline{R}^K \tag{207}$$

Finally, (181) and (182) give a restriction on the parameter χ to ensure the existence of a solution

$$\chi = \frac{\overline{W}}{\mathcal{M}_W N^{\varphi} (1 - h) \overline{C}} \tag{208}$$

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Parameter		**Value**
Openness	α	0.34
Discount factor	β	0.9915
Depreciation rate	δ	0.02
Elasticity of substitution of imports	ε_F	7
Elasticity of substitution of domestic goods	ε_H	7
Elasticity of substitution of labour services	ε_W	6
Government spending share	γ_G	0.24
Capital share	ψ_H	0.33
Capital share abroad	ψ_F	0.33
Persistence of monetary policy shock	ρ_R	0
Foreign marginal cost to output factor	$\eta^*_{mc,y}$	2.7
Indexing of import good prices	γ_F	1
Indexing of domestic good prices	γ_G	1
Indexing of exported good prices	γ^*_H	1
Indexing of wages	γ_N	1
Persistence of government spending shock	ρ_G	0.8
International elasticity of substitution	η	4.5
Inverse of labour supply elasticity	φ	3
Elasticity of capital utilisation costs	λ_U	99999

Table 1: Calibrated parameters

Parameter		**Prior**			**Posterior**			
		Family	Mean	Std.dev.	Mode	Mean	5%	95%
Habit	h	Beta	0.80	0.1000	0.9154	0.9212	0.8855	0.9584
Investment adj. cost	λ_I	Inv.gam.	0.15	0.1000	0.0657	0.0721	0.0454	0.0978
Risk premium elast.	ϕ_B	Inv.gam.	0.03	0.0500	0.0144	0.0204	0.0830	0.0343
Export adjustment	ϕ_M^*	Inv.gam.	0.75	0.1500	2.3465	2.4657	1.6890	3.2455
Diff. inflation resp.	$\phi_{\Delta P}$	Normal	0.30	0.1000	0.3776	0.3690	0.2455	0.5032
Diff. output resp.	$\phi_{\Delta Y}$	Normal	0.06	0.0500	0.0543	0.0676	0.0123	0.1243
Diff. exch. resp.	$\phi_{\Delta S}$	Normal	0.00	0.1000	-0.0050	-0.0020	-0.0293	0.0273
Inflation response	ϕ_P	Normal	1.50	0.2000	1.5780	1.5334	1.2628	1.8042
Output response	ϕ_Y	Normal	0.13	0.0500	0.0452	0.0576	0.0013	0.1118
Exch. response	ϕ_S	Normal	0.00	0.0500	-0.0014	0.0102	-0.0331	0.0514
Import Calvo	θ_F	Beta	0.75	0.1000	0.5892	0.6103	0.5016	0.7736
Domestic Calvo	θ_H	Beta	0.75	0.1000	0.8925	0.9091	0.8655	0.9536
Export Calvo	θ_H^*	Beta	0.75	0.1000	0.1636	0.1853	0.1148	0.2485
Wage Calvo	θ_W	Beta	0.75	0.1000	0.7421	0.7718	0.6963	0.8539
Int. rate smoothing	ξ_R	Beta	0.80	0.1000	0.7548	0.7711	0.6943	0.8493

Table 2: Prior and posterior distributions of dynamic parameters

Parameter		Prior			Posterior			
		Family	Mean	Std.dev.	Mode	Mean	5%	95%
Permanent techn.	ρ	Beta	0.75	0.1000	0.8003	0.7812	0.6783	0.8867
Risk premium	ρ_B	Beta	0.75	0.1000	0.9100	0.8817	0.8082	0.9616
Preference	ρ_C	Beta	0.75	0.1000	0.8378	0.8302	0.7642	0.8957
Asymmetric techn.	ρ_D	Beta	0.75	0.1000	0.8587	0.8335	0.7274	0.9430
Temporary techn.	ρ_H	Beta	0.75	0.1000	0.9214	0.9029	0.8468	0.9615
Inv.-spec. techn.	ρ_I	Beta	0.75	0.1000	0.8343	0.8201	0.7406	0.9009
Import mark-up	$\rho_{\mu,F}$	Beta	0.75	0.1000	0.6958	0.6513	0.4806	0.8220
Domestic mark-up	$\rho_{\mu,H}$	Beta	0.75	0.1000	0.6091	0.5559	0.3987	0.7198
Export mark-up	$\rho^*_{\mu,H}$	Beta	0.75	0.1000	0.7470	0.7194	0.5820	0.8593
Wage mark-up	$\rho_{\mu,W}$	Beta	0.75	0.1000	0.7954	0.7867	0.7070	0.8730
Permanent techn.	σ	Uniform	0.50	0.0833	0.0024	0.0025	0.0017	0.0034
Risk premium	σ_B	Uniform	0.50	0.0833	0.0065	0.0082	0.0054	0.0110
Preference	σ_C	Uniform	0.50	0.0833	0.0817	0.0983	0.0529	0.1408
Asymmetric techn.	σ_D	Uniform	0.50	0.0833	0.0152	0.0156	0.0123	0.0186
Temporary techn.	σ_H	Uniform	0.50	0.0833	0.0186	0.0194	0.0162	0.0226
Inv.-spec. techn.	σ_I	Uniform	0.50	0.0833	0.1167	0.1253	0.0756	0.1743
Import mark-up	$\sigma_{\mu,F}$	Uniform	0.50	0.0833	0.0769	0.1122	0.0363	0.2027
Domestic mark-up	$\sigma_{\mu,H}$	Uniform	0.50	0.0833	0.1467	0.2754	0.0438	0.5182
Export mark-up	$\sigma^*_{\mu,H}$	Uniform	0.50	0.0833	0.0374	0.0418	0.0304	0.0533
Wage mark-up	$\sigma_{\mu,W}$	Uniform	0.50	0.0833	0.3617	0.5213	0.2172	0.8883
Monetary policy	σ_R	Uniform	0.50	0.0833	0.0032	0.0034	0.0028	0.0039

Table 3: Prior and posterior distributions of shock parameters

Observable		Std.dev. (%)		Autocorr.		Corr. $\widehat{Y}_t$		Corr. $\widehat{\Pi}_{P,t}$	
		Data	Model	Data	Model	Data	Model	Data	Model
Consumption	$\widehat{C}_t$	1.33	1.05	0.89	0.79	0.42	0.21	-0.44	-0.34
CPI inflation	$\widehat{\Pi}_{P,t}$	0.59	1.30	0.78	0.95	-0.06	-0.12	1.00	1.00
Exports	$\widehat{EX}_t$	1.56	3.23	0.63	0.77	0.32	0.29	0.05	-0.06
GDP	$\widehat{Y}_t$	1.28	2.06	0.55	0.59	1.00	1.00	-0.06	-0.12
Investment	$\widehat{I}_t$	4.27	4.14	0.83	0.78	0.45	0.28	-0.16	-0.19
Imports	$\widehat{IM}_t$	3.53	4.84	0.74	0.86	0.05	-0.45	-0.51	-0.19
Real exch. rate	$\widehat{S}_t$	2.76	3.77	0.19	-0.04	0.01	0.30	0.09	-0.13
Interest rate	$\widehat{R}_t$	0.94	1.63	0.86	0.96	-0.31	-0.11	0.59	0.84
Wage inflation	$\widehat{\Pi}_{W,t}$	0.95	1.44	0.83	0.87	0.44	0.11	0.25	0.77
Hours	$\widehat{N}_t$	1.17	3.07	0.62	0.50	0.16	0.74	-0.14	-0.07

Table 4: Unconditional moments

Shocks	y_t	$y_{H,t}$	c_t	i_t	nx_t	s_t	r_t	$\pi_{P,t}$	$\pi_{H,t}$
Foreign	2.85	2.98	0.76	0.83	10.69	6.44	4.60	3.76	2.82
Mark-up	34.70	32.33	15.09	14.33	31.81	38.18	40.40	51.21	54.76
Technology	49.96	52.49	51.92	70.33	16.07	18.24	21.65	24.12	22.33
Preferences	3.19	2.93	28.80	10.48	2.09	0.05	9.10	6.43	6.00
Monetary pol.	0.86	0.69	0.28	0.06	1.03	2.62	5.72	0.62	0.64
Government	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00
Risk premium	8.43	8.57	3.17	3.95	38.31	34.47	18.51	13.86	13.48
Shocks	$\pi_{F,t}$	$\pi_{w\,t}$	$\widehat{C}_t$	$\widehat{EX}_t$	$\widehat{Y}_t$	$\widehat{I}_t$	$\widehat{IM}_t$	$\widehat{S}_t$	$\widehat{N}_t$
Foreign	7.16	3.83	0.73	5.25	8.60	0.70	8.29	9.84	8.21
Mark-up	55.62	47.67	11.12	46.47	46.84	11.47	62.24	16.04	33.17
Technology	18.59	30.19	10.50	35.23	19.84	81.08	12.82	6.48	39.00
Preferences	3.58	4.41	73.43	0.14	2.06	3.05	0.86	0.03	1.41
Monetary pol.	0.66	0.78	1.10	0.94	2.71	0.19	0.48	6.51	1.91
Government	0.00	0.00	0.00	0.00	0.14	0.00	0.05	0.00	0.11
Risk premium	14.39	13.12	3.11	11.97	19.82	3.51	15.25	61.10	16.21

Table 5: Variance decomposition in per cent

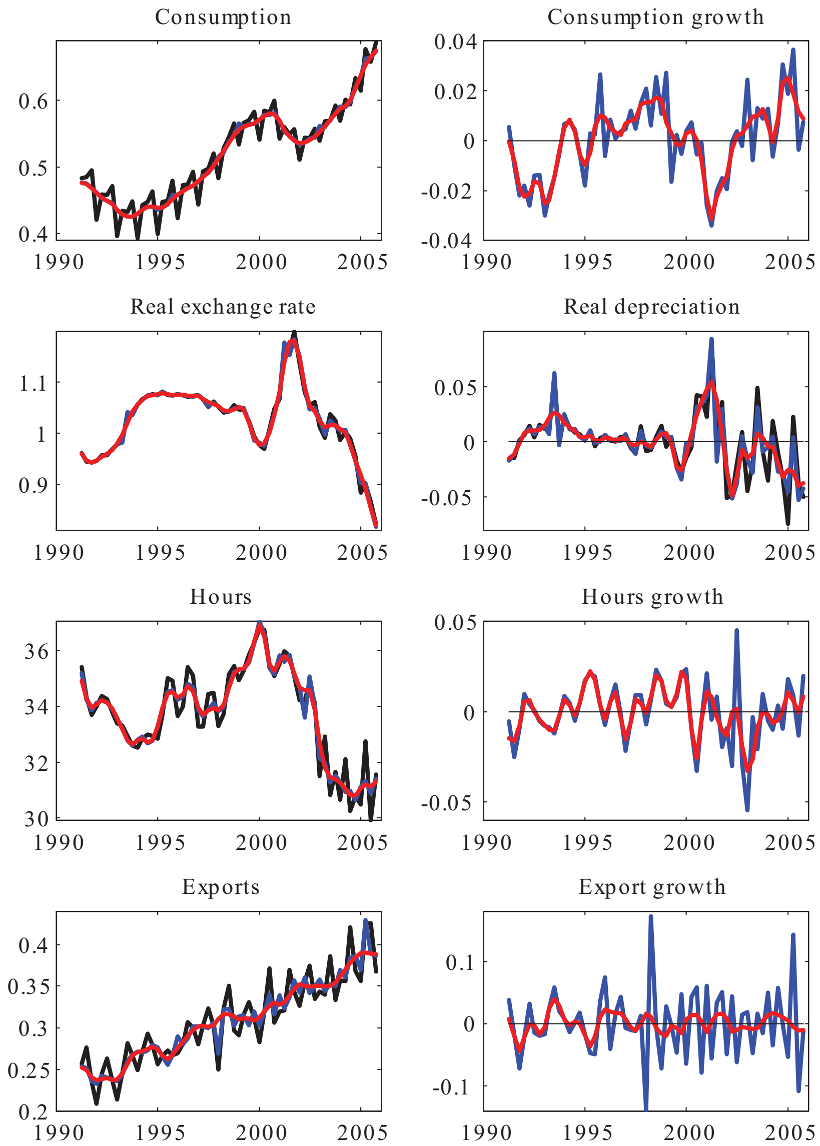

Figure 1: Data from the QMM database (levels and growth transformations). Black lines show raw data, blue lines show seasonally adjusted data, and red lines show data adjusted for both seasonal and irregular components. Source: QMM database, Statistics Iceland.

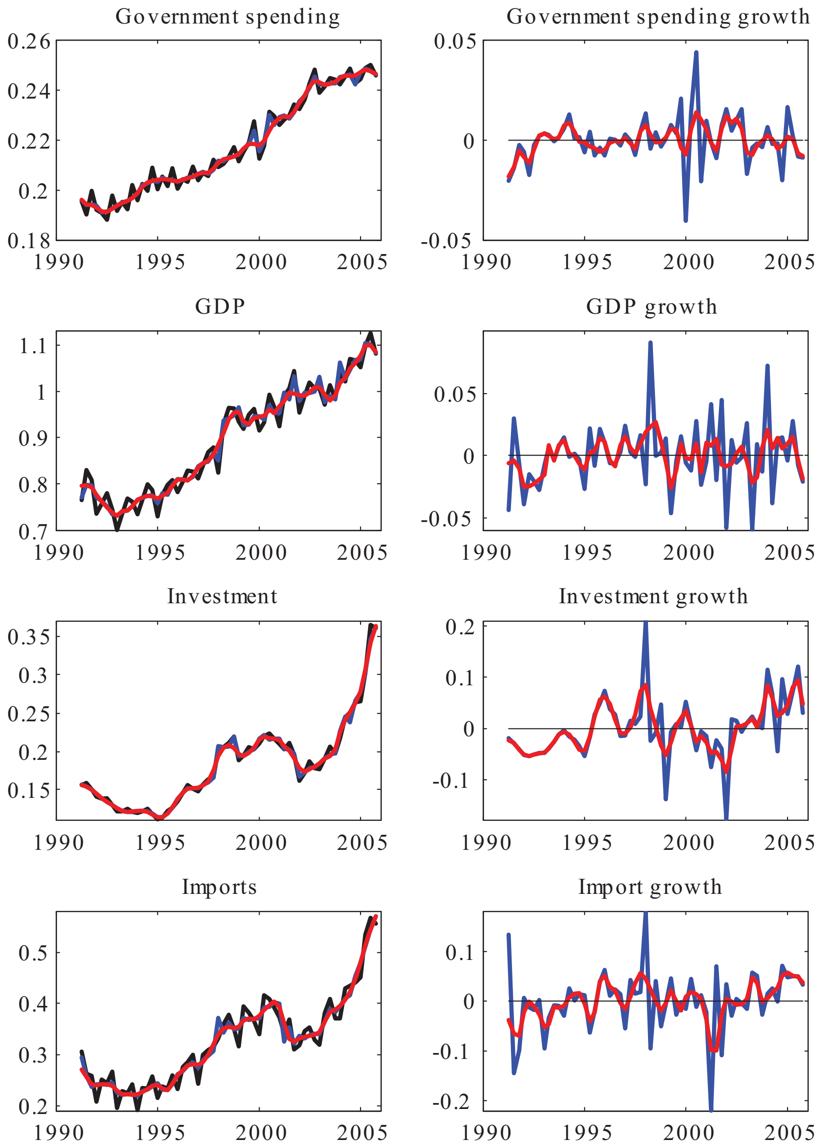

Figure 2: Data from the QMM database (levels and growth transformations). Black lines show raw data, blue lines show seasonally adjusted data, and red lines show data adjusted for both seasonal and irregular components. Source: QMM database.

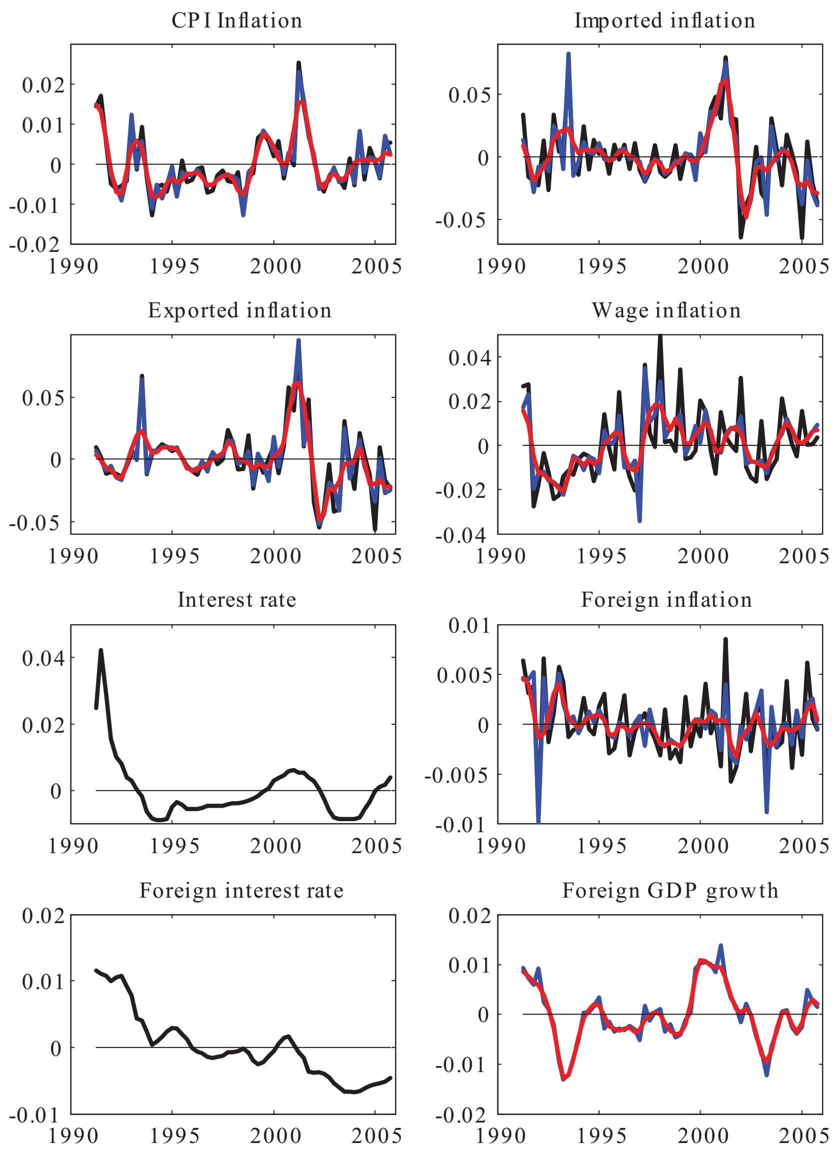

Figure 3: Data from the QMM database. Black lines show raw data, blue lines show seasonally adjusted data, and red lines show data adjusted for both seasonal and irregular components. Source: QMM database.

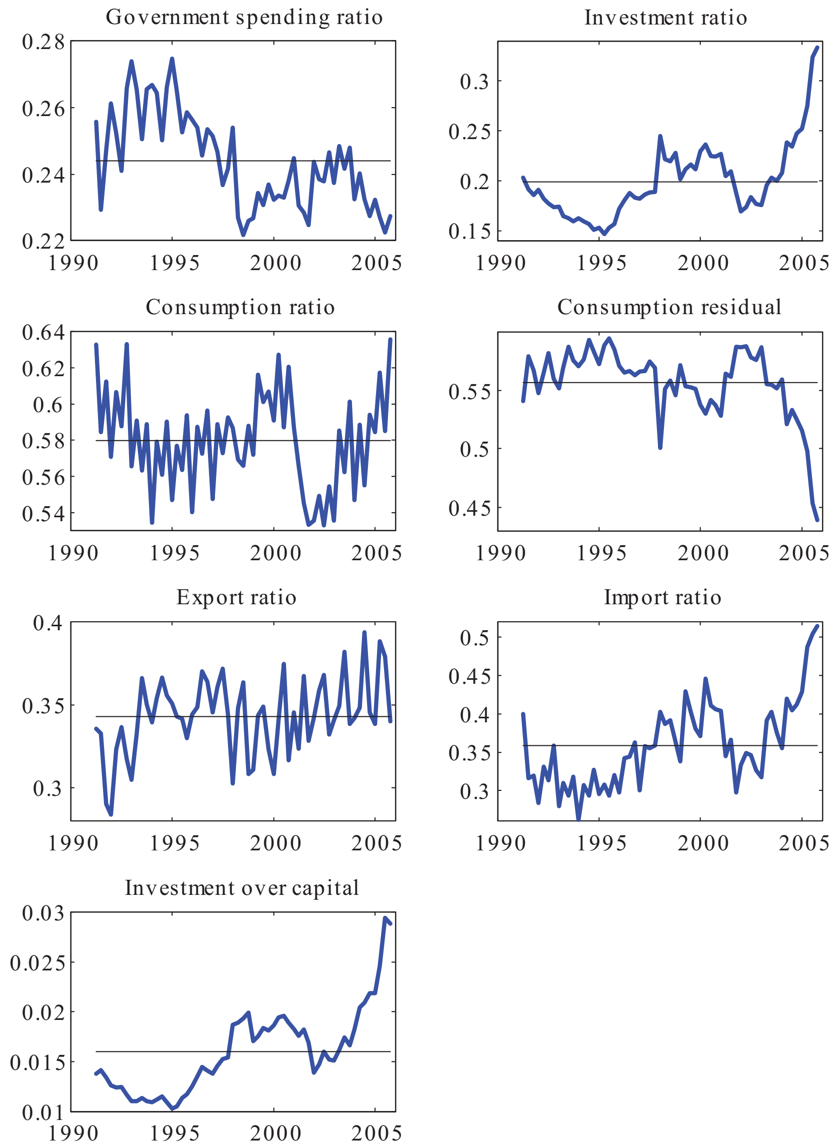

Figure 4: Ratios of demand components to gross domestic product from 1991 to 2005. Source: QMM database.

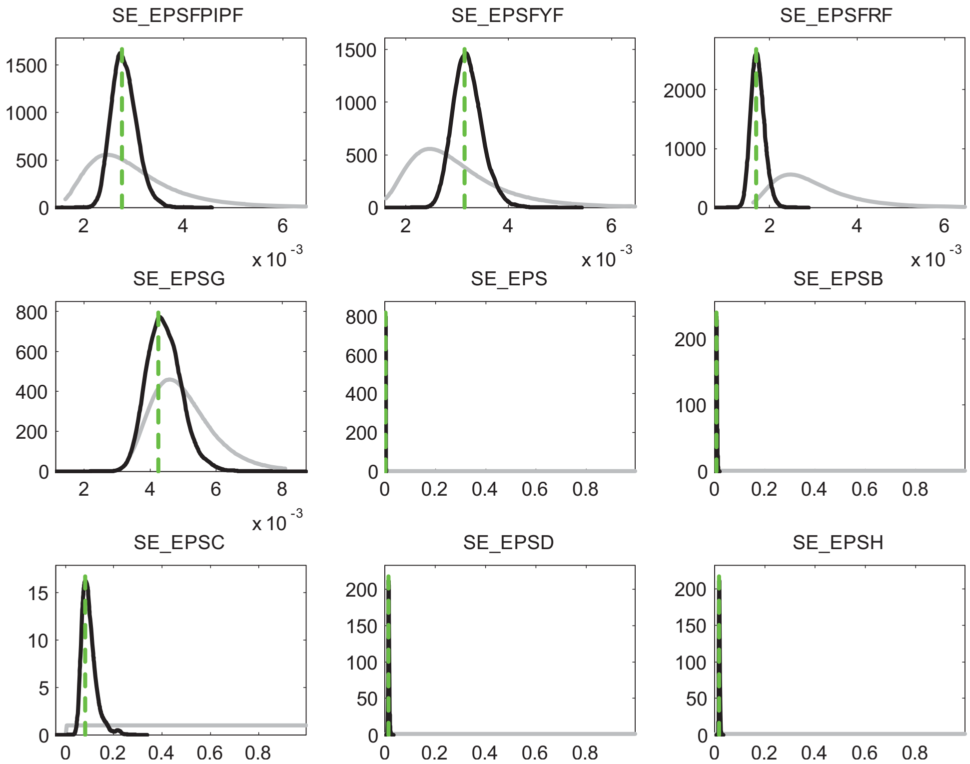

Figure 5: Priors and posteriors for σ_P^* (SE_EPSFPIPF), σ_Y^* (SE_EPSFYF), σ_R^* (SE_EPSFRF), σ_G (SE_EPSG), σ (SE_EPS), σ_B (SE_EPSB), σ_C (SE_EPSC), σ_D (SE_EPSD) and σ_H (SE_EPSH).

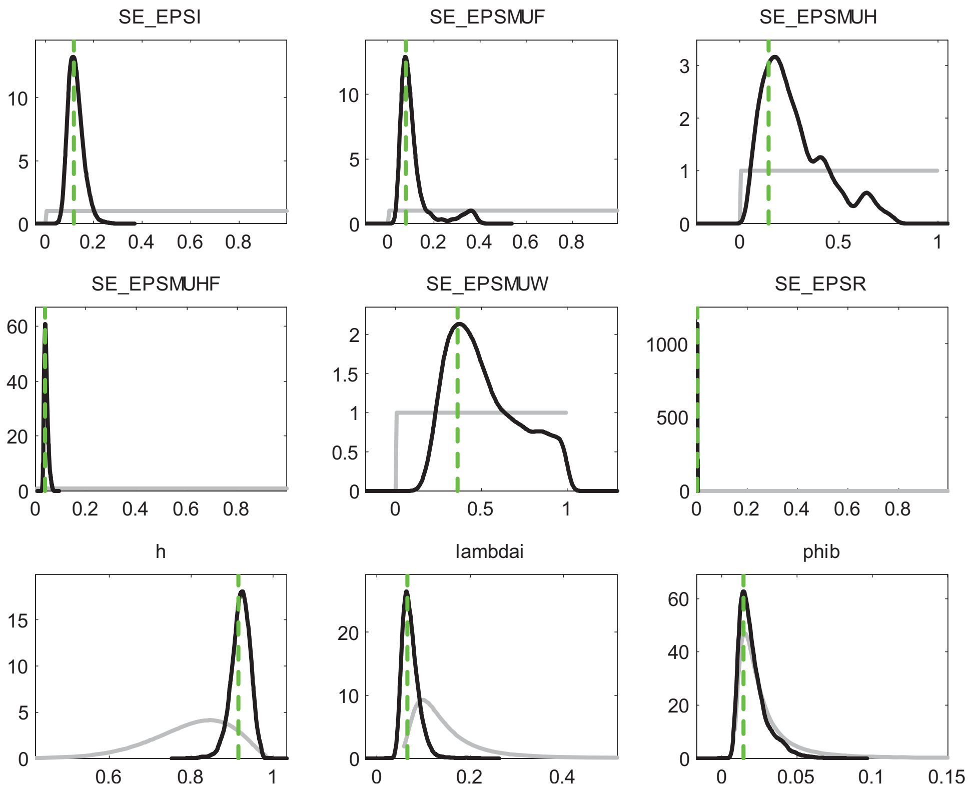

Figure 6: Priors and posteriors for σ_I (SE_EPSI), $\sigma_{\mu,F}$ (SE_EPSMUF), $\sigma_{\mu,H}$ (SE_EPSMUF), $\sigma^*_{\mu,H}$ (SE_EPSMUHF), $\sigma_{\mu,W}$ (SE_EPSMUW), σ_R (SE_EPSR), h (h), λ_I (lambdai) and ϕ_B (phib).

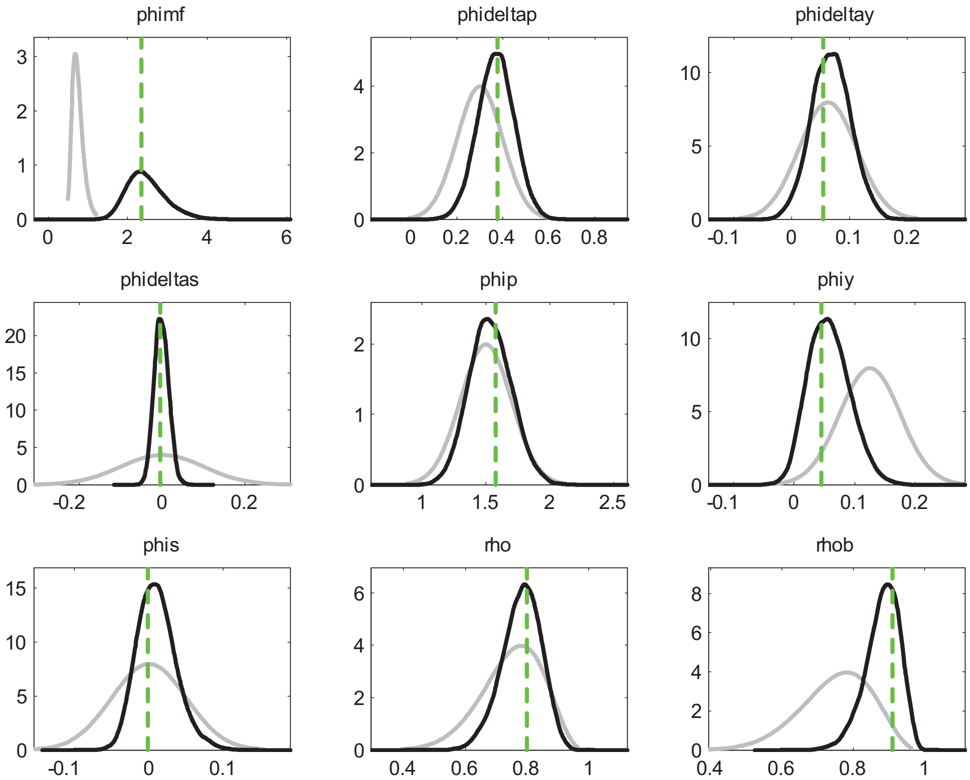

Figure 7: Priors and posteriors for ϕ_M^* (phimf), $\phi_{\Delta P}$ (phideltap), $\phi_{\Delta Y}$ (phideltay), $\phi_{\Delta S}$ (phideltas), ϕ_P (phip), ϕ_Y (phiy), ϕ_S (phis), ρ (rho), and ρ_B (rhob).

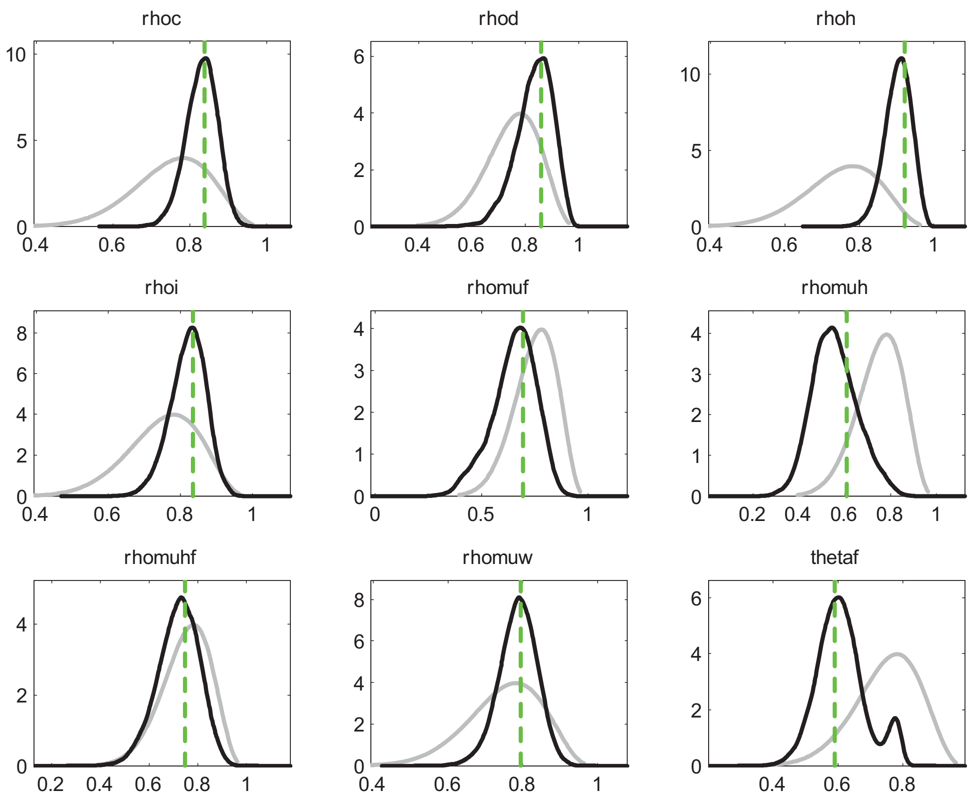

Figure 8: Priors and posteriors for ρ_C (rhoc), ρ_D (rhod), ρ_H (rhoh), ρ_I (rhoi), $\rho_{\mu,F}$ (rhomuf), $\rho_{\mu,H}$ (rhomuh), $\rho^*_{\mu,H}$ (rhomuhf) $\rho_{\mu,W}$ (rhomuw), and θ_F (thetaf).

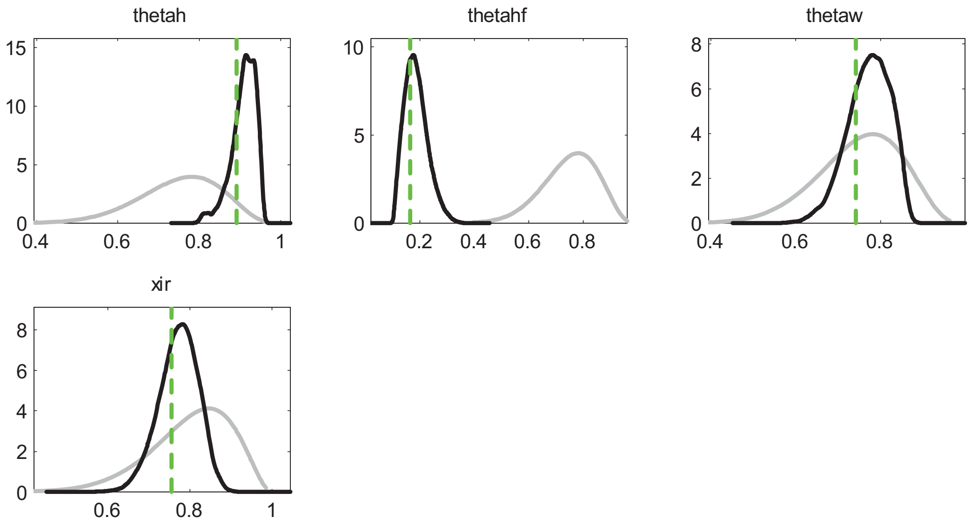

Figure 9: Priors and posteriors for θ_H (thetah), θ_H^* (thetahf), θ_W (thetaw), and ξ_R (xir).