Model for Analysis and Simulations: A Small Open Economy DSGE for Chile*

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Abstract

The paper presents the Model for Analysis and Simulations (MAS), a new dynamic stochastic general equilibrium (DSGE) model for the Chilean economy. Model's parameters are jointly estimated using a Bayesian approach. We study the properties of the model by analyzing some impulse-responses to different shocks and we provide a recount of the historical evolution of some macro variables through the lens of the estimated model. Our results confirm the relevance of nominal and real rigidities to account for the Chilean data.

JEL Classification E37, E47, E52

1 Introduction

The paper presents the Model for Analysis and Simulations (MAS), a new dynamic stochastic general equilibrium (DSGE) model for the Chilean economy. We describe the main building blocks of the model and discuss the results of the joint estimation of key parameters. Also, we provide a recount of the historical evolution of some macro variables through the lens of the estimated model. This paper is frame in a broader agenda to develop a micro-founded general equilibrium model for the Chilean economy.

The objective of MAS is twofold: To serve as a tool for policy analysis, and to serve as a tool for forecasting key macro variables on a medium-term horizon. As a tool for policy analysis, MAS allows performing a robust and complete analysis of alternative scenarios. It allows understanding not only first-round effects of different shocks, but also second-round effects as it is a general equilibrium

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model with flow-stock consistency. Moreover, deep parameters are, in principle, invariant to policy changes. Therefore, policy analysis is robust to policy shocks. As a forecasting model, MAS allows coherent story-telling to explain the expected path for different variables conditional on the information available.

Dynamic stochastic general equilibrium models with nominal stickiness have become popular tools for monetary policy analysis in recent years.[1] The main advantage of this type of models, over more traditional reduce-form macro models, is that the structural interpretation of their parameters allows to overcome the Lucas' (1976) critique. This is clearly an advantage for policy analysis. However, the fact that DSGE models have been perceived to perform poorly, in terms of quantitative predictions, has been one of the reasons why policymakers have made little use of them. In fact, many central banks around the world still rely on macro-econometric models that lack micro-foundations.[2]

Over the past few years, key theoretical and empirical contributions have given a new status to DSGE models as useful tools for forecasting and policy analysis.[3] The research agenda around this type of models has also brought new insights on the relative empirical importance of different frictions and shocks in explaining macroeconomic data. Currently, several central banks and policy institutions are developing this type of models to support analysis and policy decisions.[4]

The MAS is meant to characterize the main features of the Chilean economy, a small open economy that exports commodities based on natural resources. The main characteristics of the model are the following: prices and wages are sticky and partially indexed to past inflation; there are adjustment costs in investment and habit persistence in consumption; the exchange rate pass-through to import prices is imperfect in the short run. On the supply side, the model includes two main productive sectors: A domestic sector where firms produce tradable varieties of intermediate goods, and a commodity export sector. There are also different layers of assemblers that utilize domestic and imported intermediate varieties to produce final goods. We assume that production in the commodity sector is completely exogenous and requires no inputs. This sector is mean to characterize Copper production, a particularly relevant sector in the Chilean economy. Some of the parameters of the model are calibrated in order to match long-run features of the Chilean data. Others are estimated using a Bayesian approach as in Smets and Wouters (2003a,b), Lubik and Shorfheide (2005), Adolfson et al (2005).

Our results confirm the relevance of nominal and real rigidities to account for the Chilean data.[5] According to our estimated parameters, wages are set optimally on average every eight quarters. The

[1] See, for instance, Goodfriend and King (1997), Rotemberg and Woodfoord (1997), Clarida, Gali and Getler (1999), Altig et al. (2004), Benigno and Benigno (2003), Christiano, Eichenbaum and Evans (2005), Gali and Monacelli (2005), Schmitt-Grohé and Uribe (2001).

[2] The current macro-model used by the Chilean central bank (MEP) is a semi-structural model that combines elements of micro-founded dynamic models, with reduced form equations with no clear structural interpretation. For a complete description of the MEP, see CBC (2003).

[3] Recent contributions in estimating monetary general equilibrium models are Ireland (2004), Smets and Wouters (2003a,b), Del Negro et al. (2004). Additionally, Schorfheide (2000) and Del Negro and Schorfheide (2004) propose methodologies to evaluate the fit of the general equilibrium models. A good review of different methods is provided by Ruge-Murcia (2003).

[4] One of the most ambitious projects along these lines is the GEM model at the IMF. See IMF (2004)

[5] Our results are related to those of Caputo *et al* (2006) who estimate the relative fit of general equilibrium models with different sources of rigidities to explain Chilean business cycles.

average length of the time span between optimal price adjustments for domestic goods sold in the domestic markets is several years. Prices of imported goods and domestic goods sold abroad are optimally reset on average every three quarters. The estimated degree of substitution between domestic and imported goods is moderate, with an elasticity close to one. Our estimates also show that habit persistent in consumption and adjustments cost in investment are relevant features of the Chilean economy. When looking at the complete posterior distributions we observe that most of the structural parameters are identified in the data.

We study the properties of the model by analyzing some impulse-responses functions to different shocks. A commodity price shock, for instance, generates a mild boom in consumption and investment, and a GDP expansion. It also produce a real appreciation of the exchange rate that lowers inflation and reduces employment. Similar responses are obtained after a foreign output shock. However, unlike the commodity price shock, this type of shock fosters employment. A monetary policy shock generates hump-shaped positive responses of GDP, consumption and investment, and a fall in inflation. The transmission mechanisms to this shock implicit in the model imply responses in GDP and inflation that are faster than the ones obtained from VAR evidence.[6]

The historical decomposition of the model shows that copper price increases, foreign interest rate reductions, foreign output expansions and decreases in the foreign interest premium have generated important real exchange appreciations and decreases in inflation over the last sixteen years. However, the effects of these shocks on GDP seems to have had a minor role, at least when compared to other empirical studies.[7] Finally, the large monetary shock of 1998 explains a important part of the reduction on GDP and inflation around that year. Nevertheless, this shock had no persistent effect after 1999.

The paper is organized as follows. The next section presents the model, describing the main equations that characterize the economy. Section 3 describes the Bayesian methodology utilized to estimate the parameters of the model and discusses some of the results. Section 4 analyzes the dynamic of the estimated model by describing the responses of the main endogenous variables to three exogenous shocks. Section 5 presents the historical decomposition of key variables. Finally, section 6 concludes.

2 Model Economy

The model is closely related to the models developed by Christiano *et al* (2005), Altig *et al.* (2004), and Smets and Wouters (2003a, 2003b). There is a continuum of households and different types of firms in the economy. Households live infinitely, take decisions on consumption and savings, and set wages in a staggered way. There is a set of firms that produce differentiated varieties of tradable intermediate goods using labor and capital. They have monopoly power over the varieties they produce and set prices in a staggered way. Another set of firms are importers that distribute domestically different varieties of foreign intermediate varieties. These firms have monopoly power over the varieties they distribute, and also set prices in a staggered fashion. There is a third single firm that produces a commodity good which is completely exported abroad. This firm has no market power: it the international price of the

[6]See Valdés (1998) and Parrado (2001).

[7]See Franken *et al* (2006).

commodity good as given. Production by this firm is exogenously determined and requires no inputs. Its revenues are owned by the government and by foreign investors.

Domestic and foreign intermediate varieties are used to assemble two final goods: *home* and *foreign* goods. These two final goods are combined into a bundle consumed by household, another bundle consumed by the government and a third bundle that corresponds to new capital goods that are accumulated to increase the capital stock.

The model exhibits a balanced growth path. We assume that in steady-state labor productivity grows at rate g_y. All quantities are expressed in per-capita terms.

2.1 Households

The domestic economy is inhabited by a continuum of households indexed by $j \in [0,1]$. The expected present value of the utility of household j is given by:

$$U_t = E_t \left\{ \sum_{i=0}^{\infty} \beta^i \zeta_{C,t+i} \left[\frac{\left(C_{t+i}(j) - \tilde{h} H_{t+i} \right)^{\frac{\sigma_C - 1}{\sigma_C}}}{1 - 1/\sigma_C} - \zeta_{L,t+i} \frac{l_{t+i}(j)^{1+\sigma_L}}{1+\sigma_L} + \frac{\zeta_{\mathcal{M}}}{\mu} \left(\frac{\mathcal{M}_{t+i}(j)}{P_{C,t+i}} \right)^{\mu} \right] \right\} \tag{1}$$

where $l_t(j)$ is labor effort, $C_t(j)$ is its total consumption, and $\mathcal{M}_t(j)$ corresponds to nominal balances held at the beginning of period t. Parameters σ_C and σ_L are the inter-temporal elasticity of substitution for consumption, and the inverse real-wage elasticity of labor supply, respectively. Variable $\zeta_{C,t}$ is a preference shock that shifts consumption; $\zeta_{L,t}$ is a labor supply shock.

Preferences display habit formation measured by parameter $\tilde{h}$.[8] The external habit is defined by $H_t = C_{t-1}$, where C_t is the aggregate per capita consumption in period t. The consumption bundle is given by the following CES aggregator of *home* and *foreign* goods,

$$C_t(j) = \left[\gamma_C^{1/\eta_C} \left(C_{H,t}(j) \right)^{\frac{\eta_C - 1}{\eta_C}} + (1-\gamma_C)^{1/\eta_C} \left(C_{F,t}(j) \right)^{\frac{\eta_C - 1}{\eta_C}} \right]^{\frac{\eta_C}{\eta_C - 1}}$$

where η_C is the elasticity of substitution between *home* and *foreign* goods in the bundle and γ_C defines their respective weights. The optimal composition of this bundle is obtained by minimizing its cost. This minimization problem determines the demands for *home* and *foreign* goods by the household, $C_{H,t}(j)$ and $C_{F,t}(j)$ respectively, which are given by

$$C_{H,t}(j) = \gamma_C \left(\frac{P_{H,t}}{P_{C,t}} \right)^{-\eta_C} C_t(j), \qquad C_{F,t}(j) = (1-\gamma_C) \left(\frac{P_{F,t}}{P_{C,t}} \right)^{-\eta_C} C_t(j), \tag{2}$$

where $P_{H,t}$ and $P_{F,t}$ are the price indices of *home* and *foreign* goods, and $P_{C,t}$ is the price index of the consumption bundle, defined as: $P_{C,t} = \left(\gamma_C P_{H,t}^{1-\eta_C} + (1-\gamma_C) P_{F,t}^{1-\eta_C} \right)^{\frac{1}{1-\eta_C}}$.

[8] Since the economy grows in the steady state, we adjust the habit formation parameter in the preferences to $\tilde{h} = h(1+g_y)$ where h corresponds to the habit formation parameter in an economy without steady-state growth.

2.1.1 Consumption-savings decisions

Domestic households have access to three different types of assets: money $\mathcal{M}_t(j)$, one-period non-contingent foreign bonds (denominated in foreign currency) $B_t^*(j)$, and one-period domestic contingent bonds $d_{t+1}(j)$ which pays out one unit of domestic currency in a particular state (state contingent securities). The budget constraint of households j is given by:

$$P_{C,t}C_t(j) + E_t\{q_{t,t+1}d_{t+1}(j)\} + \frac{\mathcal{E}_t B_t^*(j)}{(1+i_t^*)\Theta\left(\mathcal{E}_t B_t^*/P_{Y,t}Y_t\right)\zeta_{\Theta,t}} + \mathcal{M}_t(j) =$$
$$W_t(j)l_t(j) + \Pi_t(j) - T_t(j) + d_t(j) + \mathcal{E}_t B_{t-1}^*(j) + \mathcal{M}_{t-1}(j),$$

where $\Pi_t(j)$ are profits received from domestic firms, $W_t(j)$ is the nominal wage set by the household, $T_t(j)$ are per-capita lump-sum net taxes from the government, and $\mathcal{E}_t$ is the nominal exchange rate.

The term $\Theta(.)$ determines the premium domestic households have to pay each time they borrow from abroad. It is a function of the aggregate net foreign asset position to GDP ratio, $\mathcal{E}_t B_t^*/P_{Y,t}Y_t$. Variable $\zeta_{\Theta,t}$ represents a stochastic component to this premium. The fact that the premium depends on the aggregate net asset position –and not the individual position– implies that households take it as an exogenous variable when optimizing.[9]

Variable $q_{t,t+1}$ is the period t price of domestic contingent bonds normalized by the probability of the occurrence of the state. Assuming the existence of a full set of contingent bonds ensures that consumption of all households is the same, independently of the labor income they receive each period.

Each household chooses a consumption path and the composition of its portfolio by maximizing (1) subject to its budget constraint. Since consumption is equalized across households, in what follows we omit index j from consumption. The first order conditions on different contingent claims over all possible states define the following Euler equation for consumption:

$$\beta E_t\left\{(1+i_t)\frac{P_{C,t}}{P_{C,t+1}}\frac{\zeta_{C,t+1}}{\zeta_{C,t}}\left(\frac{C_{t+1}-\tilde{h}C_t}{C_t-\tilde{h}C_{t-1}}\right)^{-\frac{1}{\sigma_C}}\right\} = 1, \tag{3}$$

where we have used the fact that in equilibrium $1+i_t = 1/E_t[q_{t,t+1}]$. From this expression and the first order condition with respect to foreign bonds we obtain the following expression for the uncovered interest parity (UIP) condition:

$$\frac{(1+i_t)}{(1+i_t^*)\Theta\left(\frac{\mathcal{E}_t B_t^*}{P_{Y,t}Y_t}\right)\zeta_{\Theta,t}} = \frac{E_t\left\{\frac{P_{C,t}}{P_{C,t+1}}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\frac{\zeta_{C,t+1}}{\zeta_{C,t}}\left(\frac{C_{t+1}-\tilde{h}C_t}{C_t-\tilde{h}C_{t-1}}\right)^{-\frac{1}{\sigma_C}}\right\}}{E_t\left\{\frac{P_{C,t}}{P_{C,t+1}}\frac{\zeta_{C,t+1}}{\zeta_{C,t}}\left(\frac{C_{t+1}-\tilde{h}C_t}{C_t-\tilde{h}C_{t-1}}\right)^{-\frac{1}{\sigma_C}}\right\}}. \tag{4}$$

[9] This premium is introduced mainly as a technical devise to ensure stationarity (see Schmitt-Grohé and Uribe, 2001). In the steady state we assume that $\Theta(.) = \Theta$ (constant), and $\frac{\Theta'(.)}{\Theta(.)}\frac{\mathcal{E}B^*}{P_Y Y} = \varrho$. When the country as a whole is a net debtor, ϱ is the elasticity of the upward slopping supply of international funds. The stochastic component of the premium is needed if the estimation of the model requires to make a quantitative assessment of the UIP (*uncovered interest parity*) condition.

2.1.2 Labor supply and wage setting

Each household j is a monopolistic supplier of a differentiated labor service. There is a set of perfect competitive labor service assemblers that hire labor from each household and combine it into an aggregate labor service unit,

$$l_t = \left(\int_0^1 l_t(j)^{\frac{\epsilon_L - 1}{\epsilon_L}} dj \right)^{\frac{\epsilon_L}{\epsilon_L - 1}} \tag{5}$$

This labor unit is then used as an input in production of domestic intermediate varieties. Parameter ϵ_L corresponds to the elasticity of substitution among different labor services.

The optimal composition of this labor service unit is obtained by minimizing its cost, subject to the wages set by different households. The demand for the labor service provided by household j is given by:

$$l_t(j) = \left(\frac{W_t(j)}{W_t} \right)^{-\epsilon_L} l_t, \tag{6}$$

where W_t is an aggregate wage index.

Following Erceg *et al.* (2000) we assume that wage setting is subject to a nominal rigidity à la Calvo (1983). In each period, each type of household faces a probability $(1 - \phi_L)$ of being able to re-optimize its nominal wage. In this set-up, parameter ϕ_L is a measure of the degree of nominal rigidity. The larger is this parameter the less frequent wages are adjusted (i.e. the more sticky they are).

We assume that all those households that cannot re-optimize their wages follow an updating rule: If a household cannot re-optimize during i periods between t and $t+i$, then its wage at time $t+i$ is given by $W_{t+i}(j) = \Gamma^i_{W,t} W_t(j)$, where

$$\Gamma^i_{W,t} = (1 + g_y)(1 + \pi_{C,t+i-1})^{\chi_L} (1 + \overline{\pi}_{t+i})^{1-\chi_L} \Gamma^{i-1}_{W,t}, \tag{7}$$

This "passive" adjustment rule implies that workers who do not optimally reset their wages, update them by considering a geometric weighted average of past CPI inflation, $\pi_{C,t} = P_{C,t}/P_{C,t-1} - 1$, and the inflation target set by the authority, $\overline{\pi}_t$. Parameter χ_L is the weight given to past inflation in this updating rule. Once a household has set its wage, it must supply any quantity of labor service demanded at that wage. A particular household j that is able to re-optimize its wage at t must solve the following problem:

$$\max_{W_t(j)} = E_t \left\{ \sum_{i=0}^{\infty} \phi^i_L \Lambda_{t,t+i} \left[\frac{\Gamma^i_{W,t} W_t(j)}{P_{C,t+i}} l_{t+i}(j) - \zeta_{L,t+i} \frac{l_{t+i}(j)^{1+\sigma_L}}{1+\sigma_L} \left(C_{t+i} - \tilde{h} C_{t+i-1} \right)^{1/\sigma_C} \right] \right\}$$

subject to the labor demand (6) and the updating rule for the nominal wage (7). Variable $\Lambda_{t,t+i}$ is the relevant discount factor between periods t and $t+i$.[10]

[10] Since utility exhibits habit formation in consumption the relevant discount factor is given by $\Lambda_{t,t+i} = \beta^i \left(\frac{C_t - \tilde{h} C_{t-1}}{C_{t+i} - \tilde{h} C_{t+i-1}} \right)^{1/\sigma_C}$.

2.2 Domestic production

There is a large set of firms that use a CES technology to assemble *home* goods using domestic intermediate varieties. These firms sell these *home* goods in the domestic market and also abroad. Let $Y_{H,t}$ be quantity of *home* goods sold domestically, and $Y^*_{H,t}$ the quantity sold abroad. The demands for a particular intermediate variety z_H by these assemblers are given by

$$Y_{H,t}(z_H) = \left(\frac{P_{H,t}(z_H)}{P_{H,t}}\right)^{-\epsilon_H} Y_{H,t}, \qquad Y^*_{H,t}(z_H) = \left(\frac{P^*_{H,t}(z_H)}{P^*_{H,t}}\right)^{-\epsilon_H} Y^*_{H,t}, \tag{8}$$

where $P_H(z_H)$ is the price of the variety z_H when used to assemble *home* goods sold in the domestic market, and $P^*_{H,t}(z_H)$ is the foreign-currency price of this variety when used to assemble *home* goods sold abroad. Variables $P_{H,t}$ and $P^*_{H,t}$ are the corresponding aggregate price indices.

Intermediate varieties are produced by firms that have monopoly power over each of them. These firms maximize profits by choosing the prices of their variety subject to the corresponding demands, and the available technology. Let $\mathbf{Y}_{H,t}(z_H)$ be the total quantity produced of a particular variety z_H. The available technology is given by

$$\mathbf{Y}_{H,t}(z_H) = A_{H,t}\left[\eta_H{}^{\frac{1}{\theta_H}}\left((1+g_y)^t l_t(z_H)\right)^{\frac{\theta_H-1}{\theta_H}} + (1-\eta_H)^{\frac{1}{\theta_H}} K_t(z_H)^{\frac{\theta_H-1}{\theta_H}}\right]^{\frac{\theta_H}{\theta_H-1}}, \tag{9}$$

where $l_t(z_H)$ is the amount of labor utilized, and $K_t(z_H)$ is the amount of physical capital rented. Variable $A_{H,t}$ represents a stationary productivity shock common to all firms. Parameter θ_H is the elasticity of substitution between labor and capital services and η_H defines their corresponding shares in production.

Following Calvo (1983) we assume that firms adjust their prices in an optimal way only infrequently when receiving a signal. Firms are able to price discriminate according to the market in which their variety are going to be sold. We also assume that the price charged when a variety is sold in the foreign market is invoiced in foreign currency.

In every period, the probability that a firm receives a signal for adjusting its price for the domestic market is $1-\phi_{H_D}$, and the probability of adjusting its price for the foreign market is $1-\phi_{H_F}$. These probabilities are the same for all firms, independently of their history. If a firm does not receive a signal, it updates its price following a simple rule. In particular, if the firm does not adjust its price for the domestic market between t and $t+i$, then the price it charges at $t+i$ will be $P_{H,t+i}(z_H) = \Gamma^i_{H_D,t,s} P_{H,t}(z_H)$, where $\Gamma^i_{H_D,t} = \Gamma^{i-1}_{H_D,t}(1+\bar{\pi}_{t+i})^{1-\chi_{H_D}}(P_{H,t+i}/P_{H,t+i-1})^{\chi_{H_D}}$. If the firm does not adjust its price for the foreign market, then the price charged at $t+i$ will be $P^*_{H,t+i}(z_H) = \Gamma^i_{H_F,t,s} P^*_{H,t}(z_H)$, where $\Gamma^i_{H_F,t}$ $= \Gamma^{i-1}_{H_F,t}\left(P^*_{F,t}/P^*_{F,t-1}\right)^{1-\chi_{H_F}}\left(P^*_{H,t+i}/P^*_{H,t+i-1}\right)^{\chi_{H_F}}$. Thus, when a firm receives a signal to adjust its price for the domestic market it must solve:

$$\max_{P_{H,t}(z_H)} E_t\left\{\sum_{i=0}^{\infty}\Lambda_{t,t+i}\phi^i_{H_D}\frac{\Gamma^i_{H_D,t}P_{H,t}(z_H) - MC_{H,t+i}}{P_{C,t+i}} Y_{H,t+i}(z_H)\right\},$$

subject to (8) and the updating rule for prices. Analogously, if the firm receives a signal to adjust optimally its price for the foreign market, then it solves:

$$\max_{P^*_{H,t}(z_H)} E_t \left\{ \sum_{i=0}^{\infty} \Lambda_{t,t+i} \phi^i_{H_F} \frac{\mathcal{E}_{t+i} \Gamma^i_{H_F,t} P^*_{H,t}(z_H) - MC_{H,t+i}}{P_{C,t+i}} Y^*_{H,t+i}(z_H) \right\},$$

subject to (8) and the updating rule for prices.

Variable $MC_{H,t}$ corresponds to marginal costs of producing variety z_H, which are given by,

$$MC_{H,t} = W_t \frac{l_t(z_H)}{\mathbf{Y}_{H,t}(z_H)} + Z_t \frac{K_t(z_H)}{\mathbf{Y}_{H,t}(z_H)}. \tag{10}$$

Given the constant return to scale technology available to firms, and the fact that there are no adjustment cost for inputs and that they are hired in a competitive markets, marginal cost are independent from the scale of production. More precisely, $l_t(z_H)/\mathbf{Y}_{H,t}(z_H)$ and $K_t(z_H)/\mathbf{Y}_{H,t}(z_H)$ are just functions of the relative price of inputs.

2.3 Import goods retailers

We introduce local-currency price stickiness in order to allow for incomplete exchange rate pass-through into import prices. This feature of the model is important in order to mitigate the expenditure switching effect of exchange rate movements.

There is a set of competitive assemblers that use a CES technology to combine a continuum of differentiated imported varieties to produce a final *foreign* good Y_F. This good is consumed by households and used for assembling new capital goods. The optimal mix of imported varieties in the final *foreign* good defines the demands for each of them. In particular, the demand for variety z_F is given by:

$$Y_{F,t}(z_F) = \left(\frac{P_{F,t}(z_F)}{P_{F,t}} \right)^{-\epsilon_F} Y_{F,t}, \tag{11}$$

where ϵ_F is the elasticity of substitution among imported varieties, $P_{F,t}(z_F)$ is the domestic-currency price of imported variety z_F in the domestic market, and $P_{F,t}$ is the aggregate price of import goods in this market.

Different importing firms buy abroad varieties and re-sales them domestically to the assemblers. Each one of these importing firms posses monopoly power in the domestic retailing of a particular variety. They adjust the domestic price of their varieties infrequently, only when receiving a signal. The signal arrives with probability $1 - \phi_F$ each period. As in the case of domestically produced varieties, if a firm does not receive a signal it updates its price following a "passive" rule. This "passive" rule is defined by $\Gamma^i_{F,t} = \Gamma^{i-1}_{F,t}(1 + \bar{\pi}_{t+i})^{1-\chi_F}(P_{F,t+i}/P_{F,t+i-1})^{\chi_F}$. Therefore, when a generic importing firm z_F receives a signal, it chooses a new price by maximizing the following expression,

$$\max_{P_{F,t}(z_F)} E_t \left\{ \sum_{i=0}^{\infty} \Lambda_{t,t+i} \phi^i_F \frac{\Gamma^i_{F,t} P_{F,t}(z_F) - \mathcal{E}_{t+i} P^*_{F,t+i}(z_F)}{P_{C,t+i}} Y_{F,t+i}(z_F) \right\},$$

subject to the domestic demand for variety z_F (11) and the updating rule for prices. For simplicity, we assume that $P^*_{F,t}(z_F) = P^*_{F,t}$ for all z_F.

In this setup, changes in the nominal exchange rate will not immediately be pass-through into prices of imported good sold domestically. Therefore, the exchange rate pass-through will be incomplete in the short-run. In the long-run we allow for firms to freely adjust their prices. Then, the law-of-one-price prevails up to a constant.

2.4 Investment and capital goods

There is a representative firm that rents capital goods to firms producing intermediate varieties. This firm decides how much capital to accumulate each period by defining an investment plan. New capital goods are assembled using a CES technology that combines *home* and *foreign* goods as follows:

$$I_t = \left[\gamma_I^{1/\eta_I} I_{H,t}^{1-\frac{1}{\eta_I}} + (1-\gamma_I)^{1/\eta_I} I_{F,t}^{1-\frac{1}{\eta_I}} \right]^{\frac{\eta_I}{\eta_I - 1}} \tag{12}$$

where η_I is the elasticity of substitution between *home* and *foreign* goods, and where parameter γ_I defines their weights in investment. The demands for each of those goods by the firm are given by

$$I_{H,t} = \gamma_I \left(\frac{P_{H,t}}{P_{I,t}} \right)^{-\eta_I} I_t, \qquad I_{F,t} = (1-\gamma_I) \left(\frac{P_{F,t}}{P_{I,t}} \right)^{-\eta_I} I_t, \tag{13}$$

where $P_{I,t}$ is the investment price index, given by $P_{I,t} = \left[\gamma_I P_{H,t}^{1-\eta_I} + (1-\gamma_I) P_{F,t}^{1-\eta_I} \right]^{\frac{1}{1-\eta_I}}$, and where I_t is total investment.

We assume that the firm may adjust its investment plan each period. However, changing the investment plan is costly. This assumption is introduced as a way to obtain more inertia in the demand for investment (see Christiano *et al.* (2005)). It represents a short-cut to more cumbersome approaches to model investment inertia, such as time-to-build.

Let Z_t be the rental price of capital. The representative firm must solve the following problem:

$$\max_{K_{t+i}, I_{t+i}} E_t \left\{ \sum_{i=0}^{\infty} \Lambda_{t,t+i} \frac{Z_{t+i} K_{t+i} - P_{I,t+i} I_{t+i}}{P_{C,t+i}} \right\},$$

subject to the law of motion of the capital stock,

$$K_{t+1} = (1-\delta) K_t + \zeta_{I,t} S \left(\frac{I_t}{I_{t-1}} \right) I_t, \tag{14}$$

where δ is its depreciation rate. Function $S(.)$ characterizes the adjustment cost for investment. This adjustment cost satisfies: $S((1+g_y)) = 1$, $S'((1+g_y)) = 0$, $S''((1+g_y)) = -\mu_S < 0$. Variable $\zeta_{I,t}$ is a stochastic shock that shifts the cost of adjusting investment for any growth path for this variable.

The optimality conditions of the problem above are the following:

$$\frac{P_{I,t}}{P_{C,t}} = \frac{Q_t}{P_{C,t}} \left[S\left(\frac{I_t}{I_{t-1}} \right) + S'\left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] \zeta_{I,t} - E_t \left\{ \Lambda_{t,t+1} \frac{Q_{t+1}}{P_{C,t+1}} \left[S'\left(\frac{I_{t+1}}{I_t} \right) \frac{I_{t+1}}{I_t} \right] \zeta_{I,t+1} \right\}, \tag{15}$$

$$\frac{Q_t}{P_{C,t}} = E_t \left\{ \Lambda_{t,t+1} \left(\frac{Z_{t+1}}{P_{C,t+1}} + \frac{Q_{t+1}}{P_{C,t+1}} (1-\delta) \right) \right\}. \tag{16}$$

These two equations simultaneously determine the evolution of the shadow price of capital, Q_t, and real investment expenditure.

2.5 Commodity sector

We assume that a single firm produces an homogenous commodity good that is completely exported abroad. Production evolves stochastically and requires no inputs:

$$Y_{S,t} = [(1+g_y)Y_{S,t-1}]^{\rho_{y_S}} \left[(1+g_y)^t Y_{S,0}\right]^{1-\rho_{y_S}} \exp(\varepsilon_{y_S,t}),$$

where $\varepsilon_{y_S,t} \sim N(0, \sigma^2_{y_S})$ is a stochastic shock and ρ_{y_S} captures the persistence in the production process.[11] This sector is particularly relevant for the Chilean economy, as it captures the developments in the mining sector (Copper) whose production represents about 40% of total exports. To make it consistent with the features of the Chilean economy, we assume that revenues in this sector are own by the government and by foreign investors.

2.6 Government

The government is composed by the fiscal and monetary authorities. The government budget corresponds to the consolidated budget of both them. The only asset own by the government is its share in the commodity exporting firm. Government liabilities are public bonds held by the private sector, and money. Since domestic financial markets are complete, *Ricardian Equivalence* holds. Therefore, the particular mix of assets and liabilities that finance government's absorption is irrelevant. For that reason, and without lost of generality, we abstract from government debt and assume that lump-sum taxes are adjusted in every period to keep the government budget balanced.[12]

Government consumes only *home* goods. Its expenditure follows a stochastic process given by

$$G_t = [(1+g_y)G_{t-1}]^{\rho_G} \left[(1+g_y)^t G_0\right]^{(1-\rho_G)} \exp\left(\varepsilon_{g,t}\right), \tag{17}$$

where $\varepsilon_{g,t} \sim N(0, \sigma^2_g)$ is a shock to government expenditure and $\rho_G \in (0,1)$ determines its persistence.

Monetary policy is defined as a Taylor type rule for the interest rate on public bonds. According to this rule, the interest rate is adjusted in response to deviations of inflation from its target, and GDP deviations from its trend. To be consistent with the monetary policy framework in Chile during the sample period analyzed we consider the real interest rate, r_t, as the policy instrument:

$$\frac{1+r_t}{1+r} = \left(\frac{1+r_{t-1}}{1+r}\right)^{\varphi_r} \left(\frac{1+\pi_{C,t}}{1+\overline{\pi}_t}\right)^{(1-\varphi_r)\varphi_\pi} \left(\frac{Y_t}{\overline{Y}_t}\right)^{(1-\varphi_r)\varphi_y} \zeta_{m,t}, \tag{18}$$

Parameter φ_r captures the degree of interest rate smoothing by the authority. Parameters φ_π and φ_y are the weights given to inflation and GDP deviations in the policy rule. Variable $\zeta_{m,t}$ is a monetary policy shock that satisfy $\ln\zeta_{m,t} \sim N(0, \sigma^2_m)$.

2.7 Foreign sector

Foreign agents demand both the commodity good and *home* goods. The demand for the commodity good is completely elastic at the international price $P^*_{S,t}$. The law of one price holds for this good.

[11] Production in this sector could be interpreted as the exogenous evolution of a stock of natural resources.

[12] In an application of the model, Medina and Soto (2006) analyze the effects of Copper price shocks under alternative fiscal rules assuming the existence of non-Ricardian households.

Therefore, its domestic-currency price is given by,

$$P_{S,t} = \mathcal{E}_t P^*_{S,t}, \tag{19}$$

We assume that the real price of the commodity good abroad, $Pr^*_{S,t} = P^*_{S,t}/P^*_t$ follows an autorregresive process of order one. Variable P^*_t is the foreign price index –i.e. the price of a "representative" bundle abroad.

The real exchange rate is defined as the relative price of the foreign "representative" bundle and the price of the consumption bundle in the domestic economy:

$$RER_t = \frac{\mathcal{E}_t P^*_t}{P_{C,t}}. \tag{20}$$

We assume that the foreign price index P^*_t is not necessarily equal to $P^*_{F,t}$, the CIF price of imported goods. However, we assume that both prices co-integrate. Thus, we have that:

$$P^*_{F,t} = P^*_t \zeta^*_{F,t}, \tag{21}$$

where $\zeta^*_{F,t}$ is a stationary transitory shock to the relative price of imports abroad. This shock may be related to changes in the relative productivity across sector in the foreign economy.

Foreign demand for *home* goods depends on its relative price and the total foreign aggregate demand, Y^*_t:

$$Y^*_{H,t} = \varpi^* \left(\frac{P^*_{H,t}}{P^*_t} \right)^{-\eta^*} Y^*_t, \tag{22}$$

where ϖ^* corresponds to the share of domestic intermediate goods in the consumption basket of foreign agents, and η^* is the price elasticity of the demand. This demand function can be obtained from a CES utility function with an elasticity of substitution across varieties equal to η^*.

2.8 Aggregate equilibrium

Firms producing varieties must satisfy demand at the current price. Therefore, the market clearing condition for each variety implies that:

$$\mathbf{Y}_{H,t}(z_H) = \left(\frac{P_{H,t}(z_H)}{P_{H,t}} \right)^{-\epsilon_H} Y_{H,t} + \left(\frac{P^*_{H,t}(z_H)}{P^*_{H,t}} \right)^{-\epsilon_H} Y^*_{H,t}$$

where $Y_{H,t} = C_{H,t} + I_{H,t} + G_t$, and where $Y^*_{H,t}$ is defined in (22). Equilibrium in the labor market implies that total labor demand by producers of by intermediate varieties must be equal to labor supply: $\int_0^1 l_t(z_H) dz_H = l_t$, where l_t is defined by (5).

Since the economy is open and there is no international reserves accumulation by the central bank, the current account is equal to the capital account. Using the equilibrium conditions in the goods and labor markets, and the budget constraint of households and the government, we obtain the following expression for the evolution of the net foreign asset position, B^*_t:

$$\frac{\mathcal{E}_t B^*_t / P_{Y,t} Y_t}{(1+i^*_t)\Theta\left(\frac{\mathcal{E}_t B^*_t}{P_{Y,t} Y_t}\right)\zeta_{\Theta,t}} = \frac{\mathcal{E}_{t-1} B^*_{t-1}}{P_{Y,t} Y_t} - (1-\chi)\frac{P_{S,t} Y_{S,t}}{P_{Y,t} Y_t} + \frac{P_{X,t} X_t}{P_{Y,t} Y_t} - \frac{P_{M,t} M_t}{P_{Y,t} Y_t},$$

where χ is the share of the government in the revenues from the commodity sector ($(1-\chi)$ is the share of foreigners) and $P_{Y,t}Y_t = P_{C,t}C_t + P_{H,t}G_t + P_{I,t}I_t + P_{X,t}X_t - P_{M,t}M_t$ is the nominal GDP –measured from demand side. Nominal imports and exports are given by $P_{M,t}M_t = \mathcal{E}_t P^*_{F,t} Y_{F,t}$ and $P_{X,t}X_t = \mathcal{E}_t \left(P^*_{H,t} Y^*_{H,t} + P^*_{S,t} Y_{S,t} \right)$, respectively.

3 Model estimation

The model is estimated by using a Bayesian approach (see DeJong, Ingram, and Whiteman (2000), Lubik and Schorfheide (2005)).[13] The Bayesian methodology is a full information approach to jointly estimate the parameters of a DSGE model. The estimation is based on the likelihood function obtained from the solution of the log-linear version of the model. Prior distributions for the parameters of interest are used to incorporate additional information into the estimation.[14]

Appendix B presents the log-linearized version of the model developed in the previous section. The system of linearized equations form a linear rational expectation system that can be written in canonical form as follows,

$$\Gamma_0 (\vartheta) \mathbf{z}_t = \Gamma_1 (\vartheta) \mathbf{z}_{t-1} + \Gamma_2 (\vartheta) \boldsymbol{\varepsilon}_t + \Gamma_3 (\vartheta) \boldsymbol{\xi}_t,$$

where $\mathbf{z}_t$ is a vector containing the model's variables expressed as log-deviation from their steady-state values. It includes not only endogenous variables but also the thirteen exogenous processes, $\zeta_{C,t}$, $\zeta_{L,t}$, i^*_t, $\zeta_{\Theta,t}$, $A_{H,t}$, $\zeta_{I,t}$, $Y_{S,t}$, $Pr^*_{S,t}$, G_t, $\zeta_{m,t}$, $\zeta^*_{F,t}$, Y^*_t, and π^*_t.[15] In their log-linear form, each of these variables is assumed to follow an autoregressive process of order one. Vector $\boldsymbol{\varepsilon}_t$ contains white noise innovations to these shocks, and $\boldsymbol{\xi}_t$ is a vector containing rational expectation forecast errors. Matrices Γ_1 Γ_2 and Γ_3 are non-linear functions of the structural parameters contained in vector ϑ.

The solution to this system can be expressed as follows

$$\mathbf{z}_t = \Omega_z (\vartheta) \mathbf{z}_{t-1} + \Omega_{\boldsymbol{\varepsilon}} (\vartheta) \boldsymbol{\varepsilon}_t, \tag{23}$$

where Ω_z and $\Omega_{\boldsymbol{\varepsilon}}$ are function of the structural parameters. Let $\mathbf{y}_t$ be a vector of observable variables. This vector is related to the variables in the model through a measurement equation:

$$\mathbf{y}_t = H \mathbf{z}_t \tag{24}$$

where H is a matrix that selects elements from $\mathbf{z}_t$. Equations (23) and (24) correspond to the state-space form representation of $\mathbf{y}_t$. If we assume that the white noise innovations are normally distributed we can compute the conditional likelihood function for the structural parameters using the Kalman filter, $L(\vartheta \mid \mathcal{Y}^T)$, where $\mathcal{Y}^T = \{\mathbf{y}_1, ..., \mathbf{y}_T\}$. Let $\mathbf{p}(\vartheta)$ a prior density on the structural parameters. We can

[13] Fernández-Villaverde and Rubio-Ramírez (2004) and Lubik and Schorfheide (2005) discuss in deep the advantages of this approach to estimate DSGE models.

[14] One of the advantages of the Bayesian approach is that it can cope with potential model mis-specification and possible lack of identification of the parameters of interest (Lubik and Shorfheide, 2005).

[15] These variables correspond to a preference shock, a labor supply shock, a foreign interest shock, a foreign premium shock, a productivity shock, an investment adjustment cost shock, a commodity production shock, a commodity price shock, a government expenditure shock, a monetary shock, a foreign output shock and a foreign inflation shock, respectively.

use data on the observable variables $\mathcal{Y}^T$ to update the priors through the likelihood function. The joint posterior density of the parameters is computed using the Bayes theorem

$$\mathbf{p}\left(\vartheta \mid \mathcal{Y}^T\right) = \frac{L(\vartheta \mid \mathcal{Y}^T)\mathbf{p}\left(\vartheta\right)}{\int L(\vartheta \mid \mathcal{Y}^T)\mathbf{p}\left(\vartheta\right) d\vartheta} \tag{25}$$

An approximated solution for the posterior distribution is computed by using the Metropolis-Hastings algorithm (see Lubik and Schorfheide (2005)).

The parameter vector to be estimated is $\vartheta = \{\sigma_L,\ h,\ \phi_L,\ \chi_L,\ \eta_C,\ \eta_I,\ \mu_S,\ \phi_{H_D},\ \chi_{H_D},\ \phi_{H_F},\ \chi_{H_F},\ \phi_F,\ \chi_F,\ \varphi_r,\ \varphi_\pi,\ \varphi_y,\ \eta^*,\ \varrho,\ \rho_{a_H},\ \rho_{y_S},\ \rho_{y^*},\ \rho_{i^*},\ \rho_{\pi^*},\ \rho_{\zeta_L},\ \rho_{\zeta_C},\ \rho_g,\ \rho_{\zeta_I},\ \rho_{\zeta_F^*},\ \rho_{\zeta_\Theta},\ \sigma_{a_H},\ \sigma_{y_S},\ \sigma_{y^*},\ \sigma_{i^*},\ \sigma_{\pi^*},\ \sigma_m,\ \sigma_{\zeta_L},\ \sigma_{\zeta_C},\ \sigma_g,\ \sigma_{\zeta_I},\ \sigma_{\zeta_F^*},\ \sigma_{\zeta_\Theta}\}$. Other parameters of the model are not estimated but chosen so as to match the steady-state of the model with some long-run trend data in the Chilean economy. In particular, we assume an annual long run labor productivity growth, g_y, of 3.5%.[16] The long-run annual inflation rate is set to 3%, which is consistent with the midpoint target value for headline inflation defined by the CBC since 1999. The subjective discount factor, β, is set to 0.99 (annual basis) in order to get an annual nominal interest rate around 7.0 % in the steady state. The share of *home* goods in the consumption and investment baskets, γ_C and γ_I, are set to 70% and 40%, respectively. These figures imply that investment is more intensive in *foreign* goods than consumption. The share of the commodity sector in total GDP is set to 10%.[17] The net export to GDP ratio, $\frac{X-M}{Y}$, in steady state is equal to 2% which is consistent with its average value in the sample period analyzed. The government share on commodity production, χ , is set to 40% which is consistent with the average fraction of CODELCO (the state owned company) in the total production of copper in Chile. Consistent with the fact that Chile is a net debtor in the international financial markets, we calibrate the steady-state current account GDP ratio to -1.8%.

We calibrate some other parameters to make them consistent with previous empirical studies. For instance, the intertemporal elasticity of substitution, σ_C is calibrated to one which is consistent with the evidence in Duncan (2000). The depreciation rate of capital is set to 2.2% in annual basis. For the production function of domestic producers we assume that it is Cobb-Douglas ($\theta_H = 1$) and that the labor share is about two thirds ($\eta_H = 0.66$). We do not have information on prices and wages markups. Therefore, we use values consistent with those utilized by other studies. In particular, we set $\epsilon_L = \epsilon_{H_D} = \epsilon_{H_F} = \epsilon_F = 11$.[18] We use the OLS estimates of the whole sample period for the underlying parameters governing the AR(1) process of the international copper price. The point estimates for $\rho_{p_S^*}$ is 0.97 and its normal innovations have standard deviation equal to 8.9%. Finally, we assume that monetary shocks are i.i.d., which implies that ρ_m is zero.

[16] This is consistent with 5% long run GDP growth and 1.5% of labor force growth.

[17] Value-added of the mining sector accounts for 10% of total GDP in Chile.

[18] Christiano *et al* (2005) use $\epsilon_L = 21$ and $\epsilon_H = 6$ for a closed economy model calibrated for US. Adolfson *et al* (2005) use the same values for an open economy model calibrated for Euro area. Brubakk *et al* (2005) use $\epsilon_L = 5.5$ and $\epsilon_H = 6$ for a calibrated model of the Norwegian economy. Jacquinot *et al* (2005) calibrate $\epsilon_L = 2.65$ and $\epsilon_H = 11$ for a model of the Euro Area.

3.1 Data

To estimate the model we use Chilean quarterly data for the period 1990:Q1 to 2005:Q4. We choose the following observable variables in vector $\mathbf{y}_t$: real GDP, real consumption, real investment, total real exports, commodity production —using natural-resources based GDP as a proxy—, short-run real interest rate, a measure of *core* inflation computed by the Central Bank ("IPCX1") as a proxy for inflation, the real exchange rate, nominal devaluation, and real wages. We also include as observable variables a measure of real foreign GDP –constructed as a weighted average of the GDP of the main trade partners–, foreign inflation –also a weighted average of inflation in trade partners–, foreign interest rate –the Libo rate– and the international price of Copper (in dollars, deflated by a proxy of the foreign price index) as a proxy for the real price of the commodity good. In total, we have thirteen observable variables.

In order to work with stationary series we demean all variables. In the case of real wages, GDP, consumption, investment, exports, commodity production and foreign GDP we de-trend and demean the series using a linear trend. The short-run real interest rate correspond to the monetary policy rate. This was an indexed rate from the beginning of the sample until July 2001. After July 2001 the monetary policy has been conducted by using a nominal interest rate. Therefore, for the later period we construct a series for the real interest rate computing the difference between the nominal monetary policy rate and the expected inflation implicit in the main forecast model of the Central Bank.[19]

3.2 Prior distributions

Priors' density functions reflect our beliefs about parameters values. In general, we choose priors based on evidence from previous studies for Chile. When the evidence on a particular parameter is weak or non-existent we impose more diffuse priors by setting a relatively large standard deviation for the corresponding density function. In Table 1 we present the prior distribution for each parameter contained in ϑ, its mean and an interval containing 90% of probability.

For the inverse elasticity of labor supply, σ_L, we assume a gamma distribution with mode equal to 1.0 and one degree of freedom. This implies that with 90% of probability σ_L takes values between 0.05 and 3.0. This is a wide range and reflects the uncertainty we have regarding the value of this parameter.

The habit formation parameter, h, is constrained to be between zero and one. We assume it has a beta distribution with mean 0.5 and a standard deviation of 0.25. Therefore, a 90% confidence interval for this coefficients lies between 0.1 and 0.9. This range is much wider than the one considered by Adolfson *et al* (2005) for the same coefficient in the Euro area, reflecting again our uncertainty on the value for this parameter. The elasticity of substitution between *home* and *foreign* goods in consumption, η_C, and the elasticity of substitution between these goods in investment, η_I, are assumed to have an inverse gamma distribution with a unitary mode and 5 degrees of freedom. This implies that, with 90% of probability, each of these elasticities lie between 0.66 and 3.05. The price elasticity of foreign demand for domestic goods, η^*, has also an inverse gamma distribution with a unitary mode. For this parameter

[19] This variable presents a downtrend in the sample, which can be due to a permanent reduction in the long-run interest rate after 1999. For that reason, we use a Hodrick-Prescott filter to obtain the cyclical part of the interest rate.

we choose 4 degrees of freedom to set our prior. This implies a wider range for this parameter: with 90% of probability it takes values between 0.64 and 3.66. These values are pretty much in line with Adolfson *et al* (2005).

The parameter μ_S has an inverse gamma distribution with mode 2.0 and 3 degrees of freedom. As a consequence, this parameter can take values between 1.3 and 9.8 with 90% of probability. This is a wide range reflecting, again, the uncertainty we have with respect to μ_S. The elasticity of the international supply funds, ϱ, is assumed to have an inverse gamma distribution with mode 0.01 and four degrees of freedom.

The prior distributions of each parameter in the policy rule take into account values that have been reported in other empirical studies[20]. In particular, the policy inertia parameter, φ_r, has a beta distribution with mean 0.75 and a standard deviation of 0.15. The combined parameter defining the policy response to inflation –when the policy instrument is the nominal interest rate–, $1+\varphi_\pi$, has a gamma distribution with mode 1.50 and standard deviation equal to 0.15. These values are coherent with parameter φ_π lying between 0.26 and 0.75 with 90% of probability. The parameter defining the policy response to output, φ_y, also follows a gamma distribution with mean 0.5 and a standard deviation of 0.15.

Parameters defining the probability of resetting nominal wages and prices are assumed to have distributions with support in the $[0,1]$ interval. Parameters ϕ_L, ϕ_{H_D}, ϕ_{H_F} and ϕ_F have beta distributions with means 0.75 and standard deviations of 0.1. Those values imply that the probabilities of resetting nominal wages and prices can take values between 0.57 and 0.90 with 90% of probability. These numbers are coherent with wages and prices that can be optimally reset every 2.3 and 10 quarters. Parameters χ_L, χ_{H_D}, χ_{H_F} and χ_F have also beta distributions with means 0.50 and standard deviations of 0.25. These distribution cover a range of values between 0.1 and 0.9 with 90% of probability. Hence, we do not impose very strong priors to the degree of inertia in wages and prices.

The autoregressive parameters of the stochastic shocks, ρ_{a_H}, ρ_{y_S}, ρ_{y^*}, ρ_{ζ_L}, ρ_{ζ_I}, ρ_{i^*}, ρ_{π^*}, $\rho_{\zeta_F^*}$, ρ_{y_S}, ρ_g, ρ_{ζ_Θ} have beta distributions. We do not impose tight priors on these distributions. For all these parameters we set the prior mean to 0.7 and the standard deviation to 0.20. Therefore, with 90% of probability the values of these parameters lie between 0.32 to 0.96. The variances of the shocks are assumed to be distributed as an inverse gamma with 3 degrees of freedom. This distribution implies rather diffuse priors for these parameters. The corresponding means and modes are set based on previous estimations and on trials with weak priors. In particular, σ_{a_H}, σ_{ζ_C}, σ_{ζ_L}, σ_{ζ^I}, σ_{C^*}, $\sigma_{\zeta_F^*}$, σ_{y_S} and σ_g have a prior mode of 1.0 which implies, with 90% of probability, values between 0.64 and 4.89. For σ_{i^*} the mode is set to 0.5 implying values that go from 0.32 to 2.45, whereas for σ_{π^*}, σ_{ζ_Θ} and σ_m the mode is set to 0.25, 0.25 and 0.20, respectively.

3.3 Posteriors

Table 2 presents the mean, mode and standard deviations of the posterior distribution of parameters. Figures 1 to 4 display the corresponding full posterior distributions. The mode of parameter σ_L is

[20] See Schmidt-Hebbel and Tapia (2002), Caputo (2005) and Céspedes and Soto (2005).

estimated to be close to 0 and its posterior distribution concentrates most of its mass of probability on that point. This estimated value is consistent with theory of indivisible labor at the microeconomic level (see Hansen, 1985).[21] The habit formation parameter has a posterior mode of 0.72, which is coherent with an auto-regressive coefficient for consumption in its log-linear representation, $h/(1+h)$, of 0.43. This coefficient reflects a degree of consumption inertia in Chile that is larger than the one estimated for the Euro area by Adolfson *et al*(2005).

The mode of the elasticity of substitution between *home* and *foreign* goods in consumption, η_C, is 0.99.[22] The mode of the elasticity of substitution between these two goods in investment, η_I, is 1.0. When looking at the complete distribution we notice that these two elasticities might not be well identified in the data (Figure 1). In fact, the posterior distributions of η_C and η_I resemble quite close our priors, which means that the observable variables have no additional information to identify them. The mode of the price-elasticity foreign demand for domestically produced goods, η^*, is estimated to be 0.5. This value implies that Chilean exports have a small response to movement in the relevant relative price. However, one would expect that the degree of substitution of Chilean exports in the foreign basket would be larger than the degree of substitution of imports in the domestic basket. In the data, exports seem not to be very sensitive to real exchange rate movements. To conciliate this fact, and given the structure of the model –where no rigidities are introduced to exports further than the nominal rigidity in price setting by exporters– the estimated model requires a rather low elasticity.

Regarding the parameters of the monetary policy reaction function, the three of them are well identified in the data. Our results indicate that there is a significant degree of policy inertia. The posterior mode of parameter φ_r is around 0.6. This value is in line with previous results for Chile and shows a degree of interest rate smoothing similar to that found in other economies (see Clarida, Galí and Gertler (1998)).[23] The combined parameter that captures the policy response to inflation , $1+\varphi_\pi$, has posterior mean of 1.35 which is also coherent with previous studies for Chile. The parameter that governs the policy response to output, φ_y, has a posterior mean of 0.27, also in line with previous estimates for Chile.

Our results show that the degrees of nominal rigidities and inflation persistence are quite large. The mean of the probability of not resetting optimally the prices of *home* goods sold domestically, ϕ_{H_D}, is 0.98, indicating that prices are not optimally adjusted for several years. This value is much above than other estimates of a similar parameter for the Chilean economy (e.g. Céspedes, Ochoa and Soto 2005, Caputo, Liendo and Medina, 2006). These prices also show almost full indexation to past inflation (χ_{H_D}=0.99). Wages also present an important degree of nominal rigidity. The duration of wage contracts is around eight quarters (ϕ_L=0.85), while the weight given to past inflation in the wage indexation mechanism, χ_L, is 0.38. In the case of *home* goods sold abroad and imported goods, the degree of nominal rigidities are moderate. In both cases, the estimated average duration of price

[21] Despite of this inelastic supply of labor at the microeconomic level, the presence of a complete domestic financial market guarantee a very elastic supply of labor at the aggregate level.

[22] Key to this results are the variables considered to be observable. When real imports –badly measured– are introduced, this parameter takes much larger values. This is required in order to generate the observable volatility of real imports.

[23] For other estimations for Chile, see Schmidt-Hebbel and Tapia (2002), Caputo (2005), Caputo *et al* (2006) and Céspedes and Soto (2006).

contracts is around three quarters, very much in line with the estimated values in other countries. In turn, the updating passive rules for these prices assigns a negligible weight to past inflation.

4 Impulse-response analysis

In this section we analyze the response of the model to three types of exogenous fluctuations: (i) a shock to the US$ real price of the exported commodity good (pr_S^*); (ii) a shock to foreign output (y^*); and (iii) a monetary policy shock (ζ_m). For each shock we compute the responses of a selected set of variables. The responses are computed using the estimated posterior mode of the parameters.

4.1 Exported commodity good price shock

Figure 5 shows the responses to a one standard deviation innovation in the real price of the exported commodity good –the real price of Copper. As described in section 3, the standard deviation of the innovation to this variable is estimated to be 8.9%; its autoregressive coefficient is 0.97.

Since the government owns a stake in the firm that exports this commodity, the shock implies an increase in fiscal revenues. Moreover, given that government spending is fixed, lump-sum taxes are decreased in order to keep the government's budget balanced. Therefore, private disposable income and private consumption rise after the shock.[24]

The expansion in aggregate demand has a positive impact on total GDP. Investment increases for two reasons. On the one hand, the expansion in output raises the marginal productivity of capital, which stimulates capital accumulation. On the other hand, the shock produces a real appreciation of the exchange rate. Since capital goods are mainly assembled from imported goods, this real appreciation makes investment cheaper. The inertia in the demand –habit formation in consumption and adjustment cost in investment– generates a hump-shaped responses in GDP.

The real appreciation of the exchange rate makes the expansion in investment and consumption to be more concentrated in imported goods. This *expenditure switching effect* is reflected in the fact that GDP increases by much less than consumption and investment.

The shock produces a rise in real wages that is explained by both a contraction of labor supply and an increase in labor demand. The expansion in labor demand is associated with the increase in the capital stock–that raises the marginal product of labor– and the expansion in output. The contraction in labor supply is due to the increase in consumption that reduces the incentive to work –an *income effect.* When wages are sticky, a certain fraction of the workers—those that can not adjust their wages—must supply any quantity of labor demanded at the given wage rate. Therefore, the magnitude of the income effect is diminished. The net effect of the shock on employment is, in principle, ambiguous. In our estimated model, the *income effect* dominates and employment falls in response to the shock.

Despite the increase in real wages, the shock causes a reduction in inflation. Although the increase in the real wage causes inflation in domestic intermediate sectors to rise (not shown), there is a nominal

[24]The *Ricardian* equivalence holds in our model. Therefore the precise timing pattern of the government deficits and surpluses does not matter for household's decisions.

appreciation of the exchange rate that pushes down foreign goods inflation. This last effect dominates the response of CPI inflation to the shock. As a consequence, monetary policy rule dictates a reduction in the interest rate.

4.2 Foreign output shock

An increase in foreign output directly rises the demand for *home* goods by foreign agents, which generates a expansion in domestic GDP (Figure 6). The increase in the demand for *home* goods also generates an increase in the demand for capital goods, which promotes investment. This expansion in investment is reinforced by the real appreciation of the exchange rate because investment goods, as it was said, are more intensive in imported goods. However, since capital goods are accumulated slowly over time, to satisfy the increase in their demand firms producing varieties of *home* goods must hire more labor. This increase in labor demand, in turn, pushes up real wages and marginal costs.

Given the expansion in output, monetary policy tightens in response to the shock. As a result, the nominal exchange rate appreciates. The real exchange rate also appreciates because of an increase in the price of *home* goods which is associated to the increase in marginal costs. As in the case of the commodity price shock, the deflationary pressures of the real appreciation, through its effect on the price of imported goods, dominates the inflationary pressure of the increase in real wage. As a result, inflation falls after the shock.

4.3 Monetary policy shock

In order to understand the transmission mechanism of the monetary policy, we analyze the effects of a monetary policy shock —an unanticipated increases in the real interest rate. A rise in the interest rate generates a fall in consumption and in investment (Figure 7). This contraction in the aggregate demand, in turn, induces a negative response of GDP which drops by 0.25% two and three quarters after the shock.

As expected, the increase in the interest rate appreciates the real exchange rate on impact. This sharp real appreciation explains the almost instantaneous contraction in GDP: Since domestic goods become relatively more expensive than foreign goods there is an expenditure switching effects that shifts demand (domestic and foreign) away from domestically produced goods. This intratemporal effect reinforces the detrimental intertemporal effect of the interest rate increase on output. The mild hump-shaped pattern in the response of GDP is explained by the presence of real rigidities in consumption and investment.

The fall of aggregate demand and output reduces labor demand. This pressures real wages down. However, given the nominal stickiness of wages an the reduction of inflation, real wages rise initially and then fall below their steady-state level. The reduction in inflation is caused by both a real appreciation of the exchange rate and a fall in wages that lowers marginal costs. The main effect of the shock on accumulated yearly inflation occurs after four quarters. However, the larger instantaneous impact occurs the first quarter after the shock. This seems to contradict the empirical evidence from VAR models in Valdés (1998) and Parrado (2001).

5 Historical decomposition

We use our estimated model to evaluate the contribution of the different structural shocks to the evolution of the endogenous variables within the sample period.

According to our model, the rise in GDP in the 90s is in part explained by aggregate efficiency (productivity) gains during this period (Figure 8). Productivity also explains the decrease is output below trend after 2000. Other two shocks that explain the rise and subsequent fall in output are the investment specific productivity shock and the demand shock captured by $\zeta_{C,t}$. External conditions had a minor role in explaining GDP fluctuations during the sample period. One exception is the shock to the relative price of imports abroad, $\zeta^*_{F,t}$, which seem to have exerted a positive effect on GDP during the last couple of years.[25] This result is somewhat contradictory with the common view on the sources of output fluctuations in Chile. Franken *et al* (2006), for example, using a VAR conclude that external demand fluctuations explains around 13% of the Chilean business cycles during the period 1950-2003. Notice also that shocks to the price of the commodity good had a negligible effect on output. This result is also surprising given that fluctuations in the Copper price have been considered a key factor behind the Chilean business cycles.[26] A possible explanation for the lack of significance of Copper price shocks in the model lies in the assumptions regarding the asset structure in the economy and the behavior of the fiscal authority. In the model, the government completely rebates extra revenues from higher Copper price to households. Moreover, households in the model have no restrictions to smooth consumption intertemporally. Therefore, a Copper price shock, although persistent, will induce an increase in savings. This fact, together with the leakage in demand produced by the real appreciation that accompanies Copper price increases, results in a diminished effect of this type of shocks on output.[27]

In general, monetary shocks have not play a significant role in explaining output fluctuations during the last sixteen years. Only the monetary contraction of 1998 seem the have had significant impact on activity around 1999. However, and despite of the real rigidities of aggregate demand in the model, the effect of this shock on GDP was short lived and it disappeared before year 2000. Céspedes *et al* (2006) have argued that a mix of negative external shocks and this contractionary monetary policy shock resulted in a poor GDP growth during 1998 and 1999. They do not provide a quantitative assessment of the impact of this monetary shock on output. However, they conclude that a Taylor-type monetary rule cannot account for the magnitude of the increases in the real interest rate during 1998. Our estimated model complements their findings by providing a quantitative assessment of the effect of this monetary policy shock on output.

Contrary to what happen with output, external conditions played an important role in explaining the evolution of inflation (Figure 9). Fluctuations of this variable around its target are mostly explained by external shocks that moved the exchange rate. In particular, shocks to the relative price of imports

[25] This phenomena is related to the reduction of international prices associated with the increase of China exports.

[26] Spilimbergo (2002) provides evidence on the role of the Copper price on the short-term fluctuations of the Chilean economy for the period 1960-1998.

[27] Recently, the connection between developments in the Copper market and business cycle fluctuations seems to be broken down. Macroeconomic policy framework improvements have been pointed out as significant factor of this attenuation of the impact of Copper price shocks. See De Gregorio (2006), Larraín and Parro (2006), and Medina and Soto (2006).

and foreign interest rate movements have been very relevant to explain the observable path of inflation. Both variables affect inflation through their impact on the exchange rate. According to the model, the reduction in the observable foreign interest rate –the Libo rate– after 2001 exerted a significant deflationary pressure until 2004. Recently, the exchange appreciation caused by the Copper price boom has also helped maintaining inflation low.

Monetary policy shocks have been less relevant to explain inflation fluctuations. Only the contractionary monetary policy shock at the end of 1998 caused a short-lived downward movement of inflation. In contrast, productivity gains during the nineties exerted a more persistent downward pressure on inflation, but with a small effect on this variable.

Despite not having had important effects on output and inflation, monetary policy innovations –interest rate movements beyond what would be consistent with the estimated policy rule– are significant to explain the behavior of the interest rate over the period (Figure 10). However, not only policy shocks explain interest rate fluctuations. Technological shocks and domestic demand innovations are also relevant to account for the historical evolution of this variable. The increase in aggregate productivity during the second part of the 90s, plus the reduction in investment-specific cost and the domestic demand boom during this period also explain some of the increase in the interest rate until 1999. The reversion of the same structural shocks favored a loose in the monetary policy stance after 2000.

The evolution of the real exchange rate is mainly explained by innovations to the foreign premium, $\zeta_{\Phi,t}$ and fluctuations in the relative price of imports, $\zeta^*_{F,t}$ (Figure 11). Part of the real appreciation of the 90s is explained by the fall in the foreign premium during this period. This variable captures the behavior of capital inflows to Chile, as it reflects the relevant cost of international financing not measured by observed foreign interest rate. This foreign premium shows a downward trend during the nineties and a upward trend since 2000. The increase in the relative price of imports abroad in the 90s could be associated to a reduction in the relative productivity of tradable goods abroad compared to the domestic productivity. In other words, a rise in the relative price of imports aboard could be interpreted as a relative gain in domestic tradable productivity, and it implies a real exchange rate appreciation (i.e. a *Balassa-Samuelson* effect). Broad empirical literature for Chile show that in fact these productivity gains were important to explain the real appreciation of the Chilean peso during the nineties (see Valdés and Delano 1999; De Gregorio and Wolf, 1994). The reduction in the relative price of import after 2000 could reflect a decrease in the relative productivity of the domestic economy and explains part of the real depreciation of the currency observed since then on.

Other factors that explain the real exchange rate behavior are Copper-price and Libo-rate fluctuations. The Copper-price boom since mid-2004 caused an important downward pressure in the exchange rate. The decrease in the Libo rate since 2001, in turn, limited the real depreciation that would have occurred after 2000 as a consequence of the fall in relative productivity.

As in the case of the real exchange rate, the behavior of real wages over the sample period is mainly explained by fluctuations of the foreign premium, the relative price of import aboard, the commodity price and the observable foreign interest rate (Figure 12). The mechanisms through which these shocks affect real wages are equivalent to those behind the evolution of the real exchange rate. However, and in contrast to what happen with the real exchange rate, some domestic shocks are also relevant to explains the observed path of real wages. In particular, the increase in the domestic demand during the nineties plays an important role in explaining the rise in the real wages during that period. At the same time, the reduction in domestic demand after 2000 accounts for the downward trend observed in real wages.

Figures 13 and 14 show the historical decomposition of consumption and investment, respectively. The fit of the model for these two variables is less satisfactory than for the other variables, since the evolution of each of them is mainly explained by only one shock. In the case of consumption, domestic demand shock, $\zeta_{C,t}$, captures most of its observed path over the all sample period. In turn, the path followed by investment is mainly explained by the contribution of the investment-specific cost shock, $\zeta_{I,t}$. Other shocks also have an impact on these two variables, but their net contribution is small.

The last observable variable is exports. Its historical decomposition is shown in figure 15. According to the model, one important factor behind the historical evolution of exports were productivity developments. Productivity gains during the nineties are associated with increases of exports, while the reduction in productivity after 2000 lead to a decrease in this variable. Notice that shocks that appreciated the real exchange rate generated a contraction in the exports. For example, the decrease in the foreign premium –which we associated with capital inflows– during the nineties caused a real appreciation that made more expansive the production of *home* goods when measured in foreign currency. This change in relative prices depressed the exports of this type of goods. The increase in the foreign premium since 2000 has generated a real depreciation that has promoted exports. The recent real appreciation associated with the increase in the Copper price has also produced a reduction in exports, but its magnitude is small.

6 Conclusions

The paper presents the Model for Analysis and Simulations (MAS), a new dynamic stochastic general equilibrium (DSGE) model for the Chilean economy that is meant to characterize its main features. We present the main building blocks of the model and a jointly estimate some key parameters. Also, we provide a recount of the historical evolution of some macro variables through the lens of the estimated model.

The results of the estimation using a Bayesian methodology confirm the relevance of nominal and real rigidities to account for the Chilean data. According to our estimated parameters, wages are set optimally on average every eight quarters. The average length of the time span between optimal price settings for domestic goods sold in the domestic markets is several years. Prices of imported goods and domestic goods sold abroad are optimally reset on average every three quarters. The estimated degree of substitution between domestic and imported goods is moderate, with an elasticity close to one. Our estimates also show that habit persistent in consumption and adjustments cost in investment are relevant features of the Chilean economy. When looking at the complete posterior distributions we observe that most of the structural parameters are identified in the data.

We study the properties of the model by analyzing some impulse-responses to different shocks. A commodity price shock generates soft consumption and investment booms, and a GDP expansion. However, it also produce a real appreciation of the exchange rate that lowers inflation reduces employment.

Similar responses are obtained to a foreign output shock. However, this type of shock fosters employment. A monetary policy shock generates hump-shaped positive responses of GDP, consumption and investment, and a fall in inflation. However, the transmission mechanism implicit in the model implies faster responses in GDP and inflation when compared with the evidence in VARs model.

The quantitative analysis of the estimated model highlights the importance of external factors in explaining the evolution of the Chilean data. The historical decomposition of the model shows that copper price increases, foreign interest rate reductions, foreign output expansions and decreases in the foreign interest premium have generated important real exchange appreciations and decreases in inflation. However, the effects of these shocks on GDP seems to have had a minor role, at least when compared to other empirical studies. Structural shocks associated with relative changes in productivity are also a significant source of systematic real exchange rate movement. Finally, the large monetary shock of 1998 explains a important part of the reduction on GDP and inflation around that year. Nevertheless, this shock had no persistent effect on these variables after 1999.

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Appendix A: Steady state relationships

We normalize some relative prices to one at the steady state:

$$\frac{P_H}{P_C} = \frac{P_F}{P_C} = 1$$

The steady state level for the interest rate is defined as:

$$r = \frac{(1+g_y)^{1/\sigma_C}}{\beta} - 1$$

Net foreign asset position:

$$\frac{\mathcal{E}B^*}{P_Y Y}\left(\frac{1}{(1+i^*)\Theta(\frac{\mathcal{E}B^*}{P_Y Y})\zeta_\Theta} - \frac{1}{(1+g_y)(1+\pi^*)}\right) = \frac{P_X X}{P_Y Y} - \frac{P_M M}{P_Y Y} + \frac{Ren}{P_Y Y}$$

where Ren are the income from net foreign direct investment. Since part of the commodity production is owned by foreign investor we have:

$$\frac{Ren}{P_Y Y} = \frac{Ren_{NS}}{P_Y Y} - (1-\chi)\frac{\mathcal{E}P_S^* Y_S}{P_Y Y}$$

where Ren_{NS} is the income from net foreign direct investment excluding the commodity sector.

Investment Capital Ratio:

$$\frac{I}{K} = g_y + \delta$$

Real price of investment and Tobin's Q:

$$Pr_I = Qr$$

where $Pr_I = P_I/P_C$ and $Qr = Q/P_C$

Rental rate of Capital:

$$Zr = ((1+r) - (1-\delta))\, Pr_I$$

where $Zr = Z/P_C$

Capital-Labor ratio in the home goods sector:

$$\frac{K}{L} = \left(\frac{Wr}{Zr}\right)^{\theta_H} \frac{(1-\eta_H)}{\eta_H}$$

where $Wr = W/P_C$.

Production-Labor ratio in the home goods sector:

$$\frac{Y_H}{L} = \left(Wr + Zr\frac{K}{L}\right)^{\theta_H} \frac{\epsilon_H}{\epsilon_H - 1}$$

Imports:

$$\frac{P_M M}{P_Y Y} = (1-\gamma_C)\frac{P_C C}{P_Y Y} + (1-\gamma_I)\frac{P_I I}{P_Y Y}$$

Appendix B: Log-linearized model

Portfolio decisions are summarized in the following equations:

$$\widehat{c}_t = -\sigma_C \frac{1-h}{1+h} E_t\left[\widehat{i}_t - \widehat{\pi}_{C,t+1}\right] + \frac{1}{1+h} E_t\left[\widehat{c}_{t+1}\right] + \frac{h}{1+h}\widehat{c}_{t-1} + \frac{1-h}{1+h}\left[1-\rho_{\zeta_C}\right]\widehat{\zeta}_{C,t} \tag{1}$$

$$\widehat{i}_t = \widehat{i}^*_t + \widehat{\zeta}_{\Theta,t} + \varrho\widehat{\mathbf{b}}^*_t + E_t[\Delta\widehat{e}_{t+1}] \tag{2}$$

Labor supply:

$$\begin{aligned}\left[\kappa_L + (1+\beta)\right]\widehat{wr}_t = \kappa_L &\left(\sigma_L\widehat{l}_t + \frac{1}{1-h}\widehat{c}_t - \frac{h}{1-h}\widehat{c}_{t-1} + \widehat{\zeta}_{L,t}\right) \\ &+ \widehat{wr}_{t-1} + \beta E_t[\widehat{wr}_{t+1}] - (1+\beta\chi_L)\widehat{\pi}_{C,t} + \chi_L\widehat{\pi}_{C,t-1} + \beta E_t[\widehat{\pi}_{C,t+1}]\end{aligned}$$

where $\kappa_L = \frac{(1-\beta\phi_L)(1-\phi_L)}{\phi_L(1+\sigma_L\epsilon_L)}$

Consumption goods bundle:

$$\widehat{c}_{H,t} = \widehat{c}_t - \eta_C\widehat{pr}_{H_D,t} \tag{3}$$

$$\widehat{c}_{F,t} = \widehat{c}_t - \eta_C\widehat{pr}_{F,t} \tag{4}$$

$$0 = \gamma_C\widehat{pr}_{H,t} + (1-\gamma_C)\widehat{pr}_{F,t} \tag{5}$$

Capital accumulation:

$$\widehat{k}_{t+1} = \frac{1-\delta}{1+g_y}\widehat{k}_t + \left(1 - \frac{1-\delta}{1+g_y}\right)\left(\widehat{inv}_t + \widehat{\zeta}_{I,t}\right) \tag{6}$$

Investment goods bundle:

$$\widehat{inv}_{H,t} = \widehat{inv}_t - \eta_I\left(\widehat{pr}_{H,t} - \widehat{pr}_{I,t}\right) \tag{7}$$

$$\widehat{inv}_{F,t} = \widehat{inv}_t - \eta_I\left(\widehat{pr}_{F,t} - \widehat{pr}_{I,t}\right) \tag{8}$$

$$\widehat{pr}_{I,t} = \gamma_I\widehat{pr}_{H,t} + (1-\gamma_I)\widehat{pr}_{F,t} \tag{9}$$

De-trending and log-linearizing the equations above we will have the following supply and demand for investment goods:

$$\begin{aligned}\widehat{pr}_{I,t} \quad = \quad & \frac{Qr}{Pr_I}\left(\widehat{qr}_t + \widehat{\zeta}_{I,t}\right) - \frac{Qr}{Pr_I}\left(1 + \frac{1}{1+r}\right)\mu_S(1+g_y)^2\widehat{inv}_t + \\ & \frac{Qr}{Pr_I}\mu_S(1+g_y)^2\widehat{inv}_{t-1} + \frac{Qr}{Pr_I}\mu_S(1+g_y)^2\frac{1}{1+r}E_t[\widehat{inv}_{t+1}]\end{aligned}$$

$$\widehat{qr}_t = E_t[\pi_{C,t+1} - i_t] + \frac{1}{1+r}\frac{Zr}{Qr}E_t[\widehat{zr}_{t+1}] + \frac{1}{1+r}(1-\delta)E_t[\widehat{qr}_{t+1}]$$

First order condition cost minimization and marginal cost:

$$\frac{1}{\theta_H}\left(\widehat{k}_t - \widehat{l}_t\right) = \widehat{wr}_t - \widehat{zr}_t \tag{10}$$

$$\widehat{mcr}_{H,t} = \frac{Zrk}{MCr_H Y_H}(\widehat{zr}_t + \widehat{k}_t) + \frac{Wrl}{MCr_H Y_H}(\widehat{wr}_t + \widehat{l}_t) - \widehat{y}_{H,t} \tag{11}$$

De-trending and log-linearizing we have, we get the following Phillips curve for the domestic goods consumed at home:

$$\widehat{\pi}_{H,t} = \frac{\beta}{1+\beta\chi_{H_D}} E_t\left[\widehat{\pi}_{H,t+1}\right] + \frac{\chi_{H_D}}{1+\beta\chi_{H_D}}\pi_{H,t-1} + \frac{\kappa_{H_D}}{1+\beta\chi_{H_D}}\left[\widehat{mcr}_{H,t} - \widehat{pr}_{H,t}\right] \tag{12}$$

Similarly, we can write an expression for the inflation of the exported goods in this sector:

$$\widehat{\pi}^*_{H,t} = \frac{\beta}{1+\beta\chi_{H_F}} E_t\left[\widehat{\pi}^*_{H,t+1}\right] + \frac{\chi_{H_F}}{1+\beta\chi_{H_F}}\pi^*_{H,t-1} + \frac{\kappa_{H_F}}{1+\beta\chi_{H_F}}\left[\widehat{mcr}_{H,t} - \widehat{rer}_t - \widehat{pr}^*_{H,t}\right] \tag{13}$$

Phillips curve for the imported goods:

$$\widehat{\pi}_{F,t} = \frac{\beta}{1+\beta\chi_F} E_t\left[\widehat{\pi}_{F,t+1}\right] + \frac{\chi_F}{1+\beta\chi_F}\pi_{F,t-1} + \frac{\kappa_F}{1+\beta\chi_F}\left[\widehat{rer}_t + \widehat{\zeta}^*_{F,t} - \widehat{pr}_{F,t}\right] \tag{14}$$

where $\kappa_{H_D} = \frac{(1-\beta\phi_{H_D})(1-\phi_{H_D})}{\phi_{H_D}}$, $\kappa_{H_F} = \frac{(1-\beta\phi_{H_F})(1-\phi_{H_F})}{\phi_{H_F}}$ and $\kappa_F = \frac{(1-\beta\phi_F)(1-\phi_F)}{\phi_F}$

The monetary policy:

$$r_t = \varphi_i r_{t-1} + (1-\varphi_i)\varphi_\pi \widehat{\pi}_{C,t} + (1-\varphi_i)\varphi_y \widehat{y}_t + \zeta_{m,t} \tag{15}$$

The foreign demand for domestically produced goods is:

$$\widehat{y}^*_{H,t} = \widehat{y}^*_t - \eta^* \widehat{pr}_{H_F,t} \tag{16}$$

The law of one price for the commodity goods implies:

$$\widehat{pr}_{S,t} = \widehat{rer}_t + \widehat{pr}^*_{S,t} \tag{17}$$

Law of motion for relative prices:

$$\widehat{\pi}_{H,t} = \widehat{pr}_{H,t} - \widehat{pr}_{H,t-1} + \widehat{\pi}_{C,t} \tag{18}$$

$$\widehat{\pi}^*_{H,t} = \widehat{pr}^*_{H,t} - \widehat{pr}^*_{H,t-1} + \widehat{\pi}^*_t \tag{19}$$

$$\widehat{\pi}_{F,t} = \widehat{pr}_{F,t} - \widehat{pr}_{F,t-1} + \widehat{\pi}_{C,t} \tag{20}$$

$$\Delta\widehat{e}_t = \widehat{rer}_t - \widehat{rer}_{t-1} + \pi_{C,t} - \pi^*_t \tag{21}$$

Real interest rate

$$\widehat{r}_t = \widehat{i}_t - E_t\left[\pi_{C,t+1}\right] \tag{22}$$

The total demand for domestically produced goods is:

$$\frac{P_H Y_H}{P_Y Y}\widehat{y}_{H,t} = \gamma_C \frac{P_C C}{P_Y Y}\widehat{c}_{H,t} + \frac{P_H G}{P_Y Y}\widehat{g}_t + \gamma_I \frac{P_I I}{P_Y Y}\widehat{inv}_{H,t} + \frac{P_H Y^*_H}{P_Y Y}\widehat{y}^*_{H,t} \tag{23}$$

The total supply of domestically produced goods is:

$$\begin{aligned} \widehat{y}_{H,t} \quad &= \quad \widehat{a}_{H,t} + \eta_H^{1/\theta_H}\left(\frac{A_H L}{Y_H}\right)^{\frac{\theta_H - 1}{\theta_H}} \widehat{l}_t \\ &\quad + (1-\eta_H)^{1/\theta_H}\left(\frac{A_H K}{Y_H}\right)^{\frac{\theta_H - 1}{\theta_H}} \widehat{k}_t \end{aligned}$$

Real GDP:

$$\widehat{y}_t = \frac{P_C C}{P_Y Y}\widehat{c}_t + \frac{P_H G}{P_Y Y}\widehat{g}_t + \frac{P_I I}{P_Y Y}\widehat{inv}_t + \frac{P_X X}{P_Y Y}\widehat{x}_t - \frac{P_M M}{P_Y Y}\widehat{m}_t \tag{24}$$

Balance of payments:

$$\begin{aligned} \frac{(1-\varrho)\,\mathbf{B}^*}{(1+i^*)\Theta\left(\mathbf{B}^*\right)\zeta_\Theta}\widehat{\mathbf{b}}_t^* \quad = \quad & \frac{\mathbf{B}^*}{(1+i^*)\Theta\left(\mathbf{B}^*\right)\zeta_\Theta}\left(\widehat{i}_t^* + \widehat{\zeta}_{\Theta,t}\right) - (1-\chi)\frac{\mathcal{E}P_S^* Y_S}{P_Y Y}\left(\widehat{pr}_{S,t} + \widehat{y}_{S,t} - \widehat{pr}_{Y,t} - \widehat{y}_t\right) \\ & + \frac{\mathbf{B}^*}{(1+\pi^*)(1+g_y)}\left(\Delta\widehat{e}_t - \widehat{\pi}_{C,t} - \Delta\widehat{pr}_{Y,t} - \Delta\widehat{y}_t + \widehat{\mathbf{b}}_t^*\right) \\ & \frac{P_X X}{P_Y Y}\left(\widehat{pr}_{X,t} + \widehat{x}_t - \widehat{pr}_{Y,t} - \widehat{y}_t\right) - \frac{P_M M}{P_Y Y}\left(\widehat{pr}_{M,t} + \widehat{m}_t - \widehat{pr}_{Y,t} - \widehat{y}_t\right) \end{aligned} \tag{25}$$

where $\mathbf{B}^* = \mathcal{E}B^*/P_Y Y$

Real exports, imports and the corresponding price deflators:

$$\widehat{x}_t = \frac{\mathcal{E}P_S^* Y_S}{P_X X}\widehat{y}_{S,t} + \left(1 - \frac{\mathcal{E}P_S^* Y_S}{P_X X}\right)\widehat{c}_{H,t}^* \tag{26}$$

$$\widehat{pr}_{X,t} = \frac{\mathcal{E}P_S^* Y_S}{P_X X}\widehat{pr}_{S,t} + \left(1 - \frac{\mathcal{E}P_S^* Y_S}{P_X X}\right)\left(\widehat{pr}_{H_F,t} + \widehat{rer}_t\right) \tag{27}$$

$$\widehat{m}_t = (1-\gamma_C)\frac{P_C C}{P_M M}\widehat{c}_{F,t} + (1-\gamma_I)\frac{P_I I}{P_M M}\widehat{inv}_{F,t} \tag{28}$$

$$\widehat{pr}_{M,t} = \widehat{rer}_t + \widehat{\zeta}_{F,t}^* \tag{29}$$

Exogenous shocks:

$$\widehat{\lambda}_t = \rho_\lambda \widehat{\lambda}_t + \varepsilon_{\lambda,t},\ \varepsilon_{\lambda,t} \sim N(0, \sigma_\lambda^2)$$

with $\widehat{\lambda} = \widehat{a}_H$, $\widehat{y}_S$, $\widehat{y}^*$, $\widehat{i}^*$, π^*, $\widehat{\zeta}_m$, $\widehat{\zeta}_L$, $\widehat{\zeta}_C$, $\widehat{g}$, $\widehat{\zeta}_I$, $\widehat{\zeta}_F^*$, $\widehat{\zeta}_\Theta$, and $\widehat{pr}_S^*$.

Table 1: Prior Distributions

Name	mean/moda	st. Dev. /deg. F	shape	90% Interval
σ_L	1.00	1.00	Gamma	0.05 - 3.00
h	0.50	0.25	Beta	0.10 - 0.90
ϕ_L	0.75	0.10	Beta	0.57 - 0.90
χ_L	0.50	0.25	Beta	0.10 - 0.90
η_C	1.00	5.00	Inv. Gamma	0.66 - 3.05
η_I	1.00	5.00	Inv. Gamma	0.66 - 3.05
μ_S	2.00	3.00	Inv. Gamma	1.27 - 9.78
ϕ_{H_D}	0.75	0.10	Beta	0.57 - 0.90
χ_{H_D}	0.50	0.25	Beta	0.10 - 0.90
ϕ_{H_F}	0.75	0.10	Beta	0.57 - 0.90
χ_{H_F}	0.50	0.25	Beta	0.10 - 0.90
ϕ_F	0.75	0.10	Beta	0.57 - 0.90
χ_F	0.50	0.25	Beta	0.10 - 0.90
φ_r	0.75	0.15	Beta	0.47 - 0.95
$1+\varphi_\pi$	1.50	0.15	Gamma	1.26 - 1.75
φ_y	0.50	0.15	Gamma	0.28 - 0.77
η^*	1.00	4.00	Inv. Gamma	0.64 - 3.66
ϱ	0.01	4.00	Inv. Gamma	0.01 - 0.04
ρ_{a_H}	0.70	0.20	Beta	0.32 - 0.96
ρ_{y_S}	0.70	0.20	Beta	0.32 - 0.96
ρ_{y^*}	0.70	0.20	Beta	0.32 - 0.96
ρ_{i^*}	0.70	0.20	Beta	0.32 - 0.96
ρ_{π^*}	0.70	0.20	Beta	0.32 - 0.96
ρ_{ζ_L}	0.70	0.20	Beta	0.32 - 0.96
ρ_{ζ_C}	0.70	0.20	Beta	0.32 - 0.96
ρ_g	0.70	0.20	Beta	0.32 - 0.96
ρ_{ζ_I}	0.70	0.20	Beta	0.32 - 0.96
$\rho_{\zeta_F^*}$	0.70	0.20	Beta	0.32 - 0.96
ρ_{ζ_Θ}	0.70	0.20	Beta	0.32 - 0.96
σ_{a_H}	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_{y_S}	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_{y^*}	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_{i^*}	0.50	3.00	Inv. Gamma	0.32 - 2.45
σ_{π^*}	0.25	3.00	Inv. Gamma	0.16 - 1.22
σ_m	0.20	3.00	Inv. Gamma	0.13 - 0.98
σ_{ζ_L}	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_{ζ_C}	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_g	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_{ζ_I}	1.00	3.00	Inv. Gamma	0.64 - 4.89
$\sigma_{\zeta_F^*}$	1.00	3.00	Inv. Gamma	0.64 - 4.89
σ_{ζ_Θ}	0.25	3.00	Inv. Gamma	0.16 - 1.22

For inverse gamma distributions, mode and degrees of freedom are presented

Table 2: Posterior Distributions

Name	moda	mean	st. dev.
σ_L	0.00	0.00	0.00
h	0.72	0.74	0.04
ϕ_L	0.85	0.86	0.01
χ_L	0.38	0.33	0.06
η_C	0.99	1.05	0.12
η_I	1.00	1.07	0.20
μ_S	1.75	1.60	0.38
ϕ_{H_D}	0.98	0.98	0.00
χ_{H_D}	0.99	0.99	0.00
ϕ_{H_F}	0.65	0.66	0.08
χ_{H_F}	0.03	0.03	0.00
ϕ_F	0.68	0.69	0.04
χ_F	0.03	0.03	0.01
φ_r	0.60	0.60	0.06
$1+\varphi_\pi$	1.35	1.34	0.10
φ_y	0.09	0.09	0.02
η^*	0.50	0.55	0.11
ϱ	0.01	0.01	0.00
ρ_{a_H}	0.17	0.20	0.12
ρ_{y_S}	0.87	0.88	0.01
ρ_{y^*}	0.91	0.91	0.01
ρ_{i^*}	0.91	0.91	0.01
ρ_{π^*}	0.27	0.22	0.05
ρ_{ζ_L}	0.24	0.22	0.05
ρ_{ζ_C}	0.78	0.75	0.06
ρ_g	0.61	0.63	0.09
ρ_{ζ_I}	0.50	0.53	0.11
$\rho_{\zeta_F^*}$	0.99	0.99	0.00
ρ_{ζ_Θ}	0.98	0.99	0.01
σ_{a_H}	55.01	62.29	26.47
σ_{y_S}	2.50	2.53	0.22
σ_{y^*}	0.37	0.37	0.04
σ_{i^*}	0.15	0.15	0.02
σ_{π^*}	2.19	2.29	0.18
σ_m	0.33	0.35	0.04
σ_{ζ_L}	21.14	22.20	3.16
σ_{ζ_C}	4.62	5.08	0.72
σ_g	9.70	10.11	0.81
σ_{ζ_I}	6.37	5.84	1.30
$\sigma_{\zeta_F^*}$	5.40	5.46	0.75
σ_{ζ_Θ}	0.20	0.18	0.02

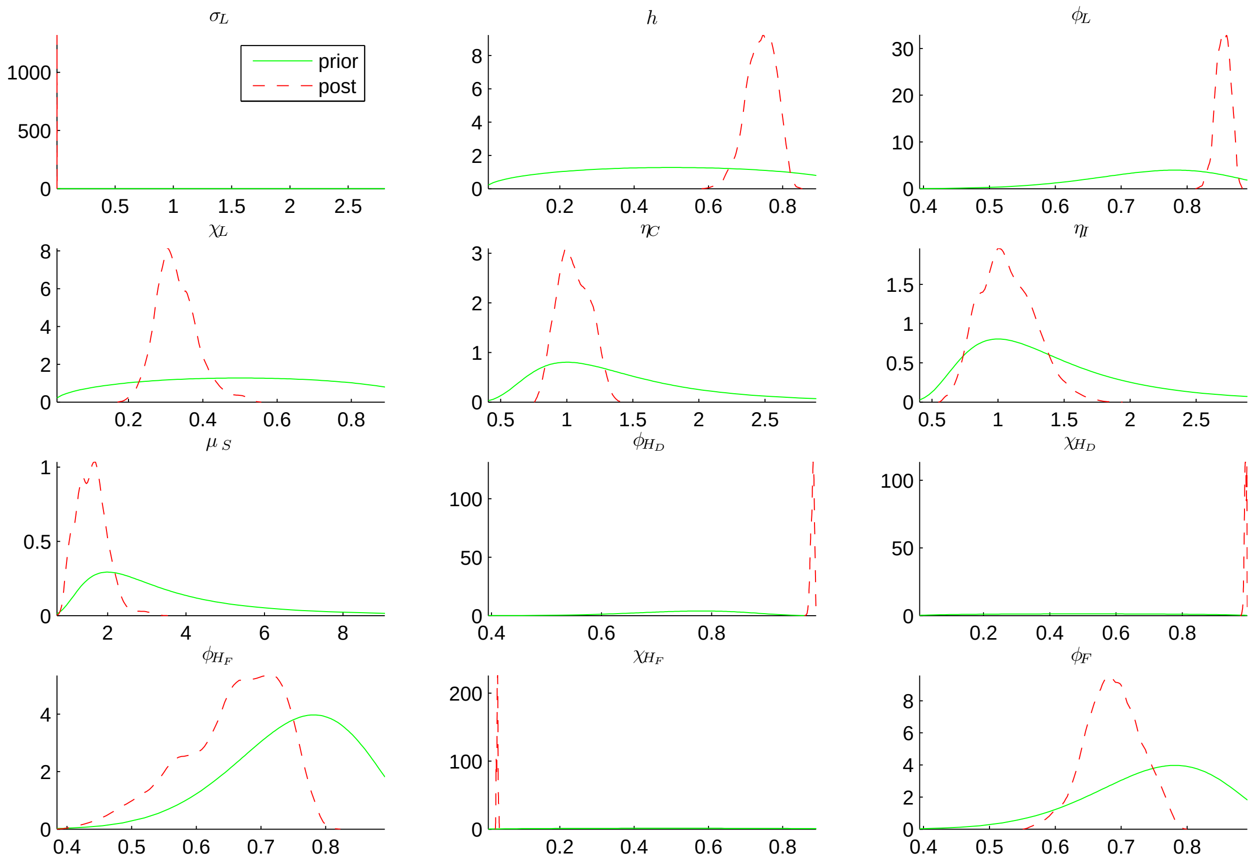

Figure 1: Posterior distributions I

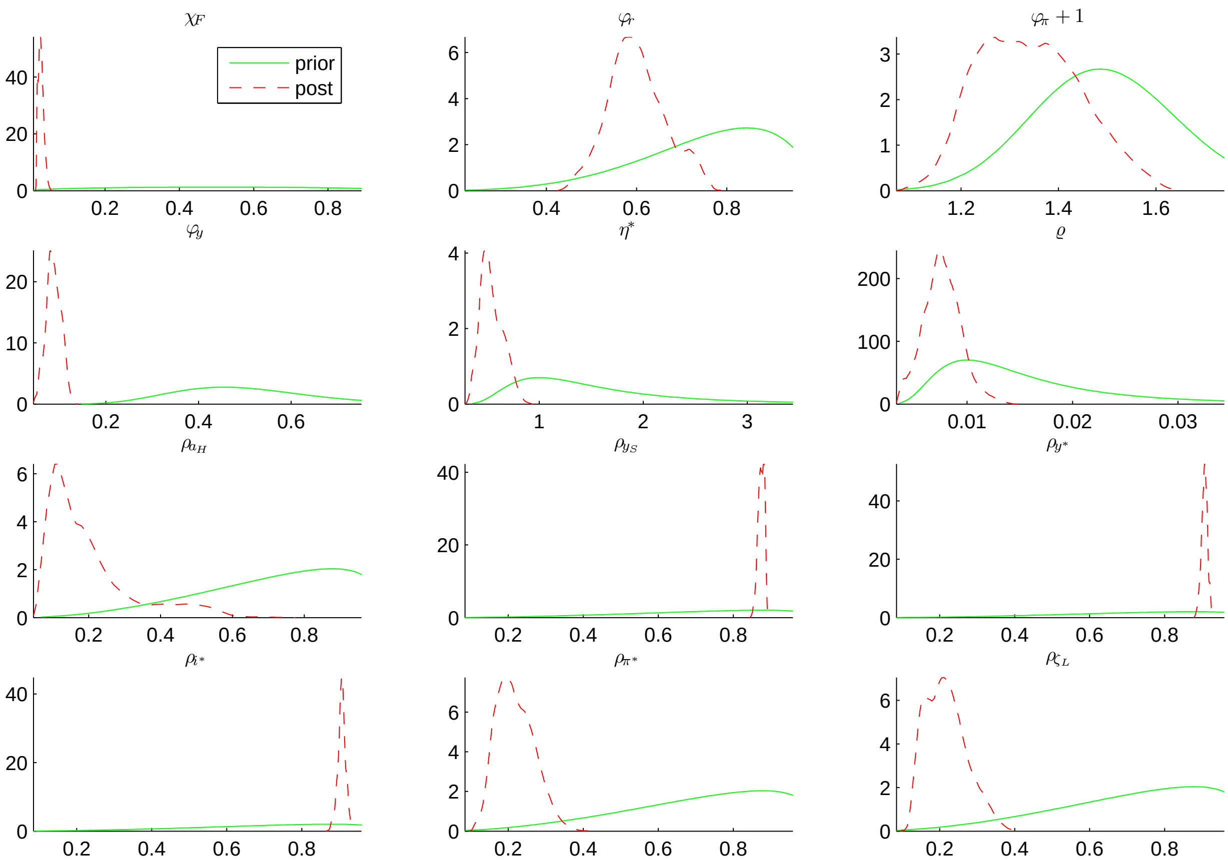

Figure 2: Posterior distributions II

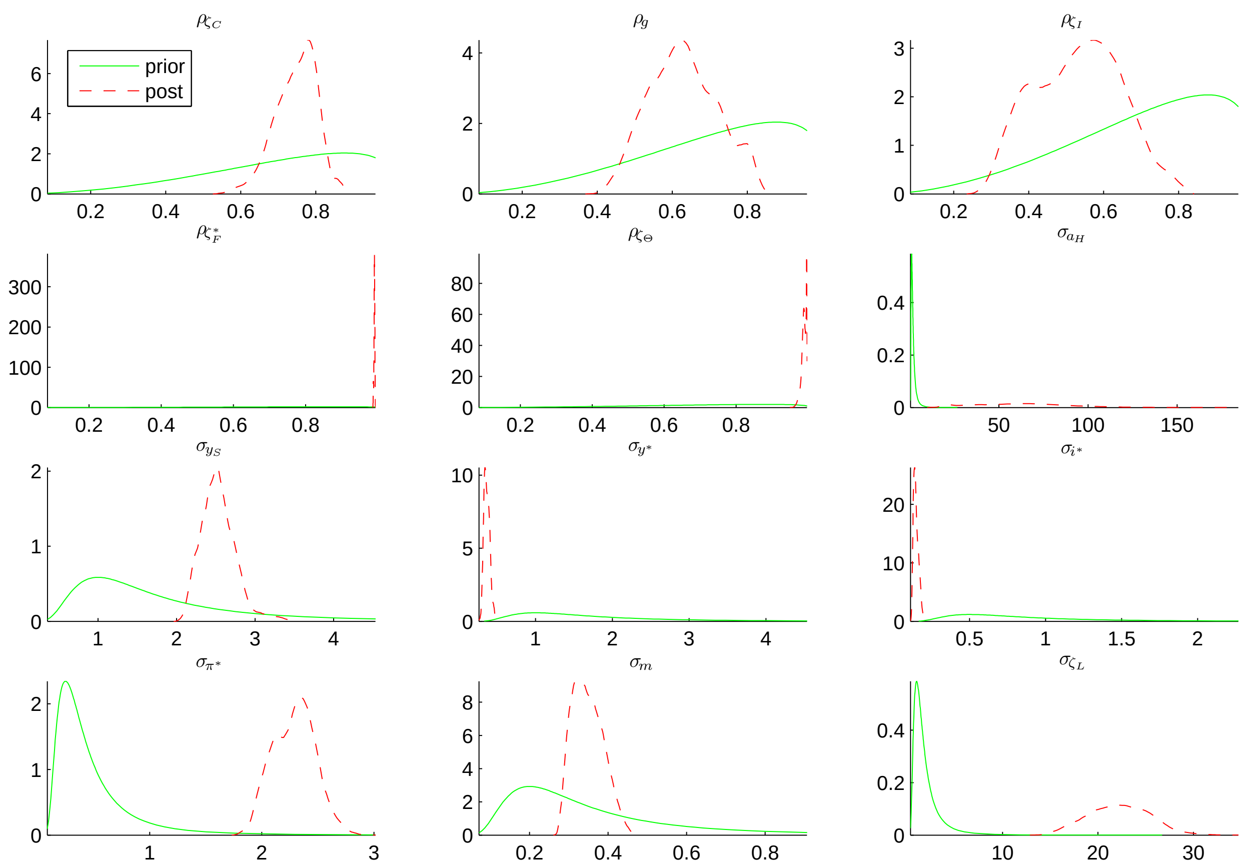

Figure 3: Posterior distributions III

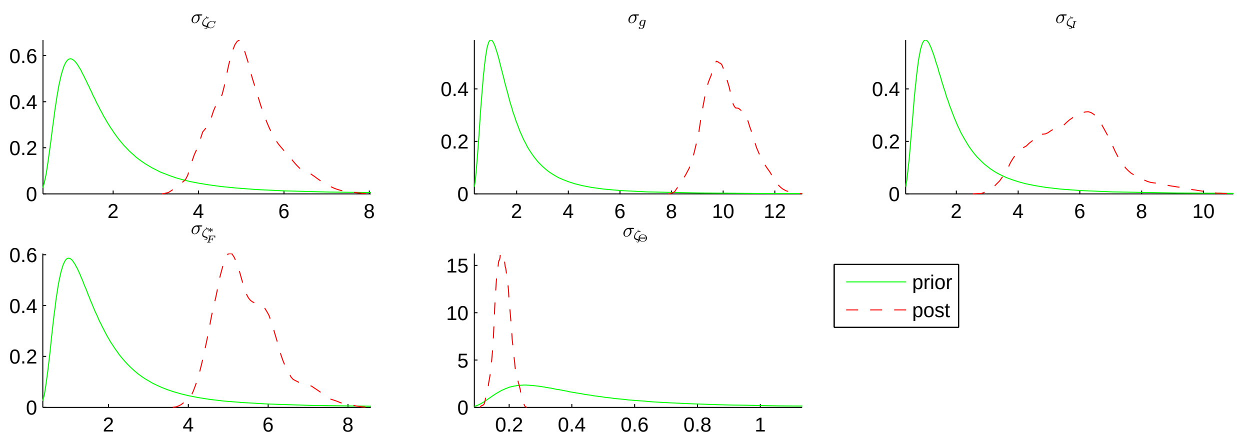

Figure 4: Posterior distributions IV

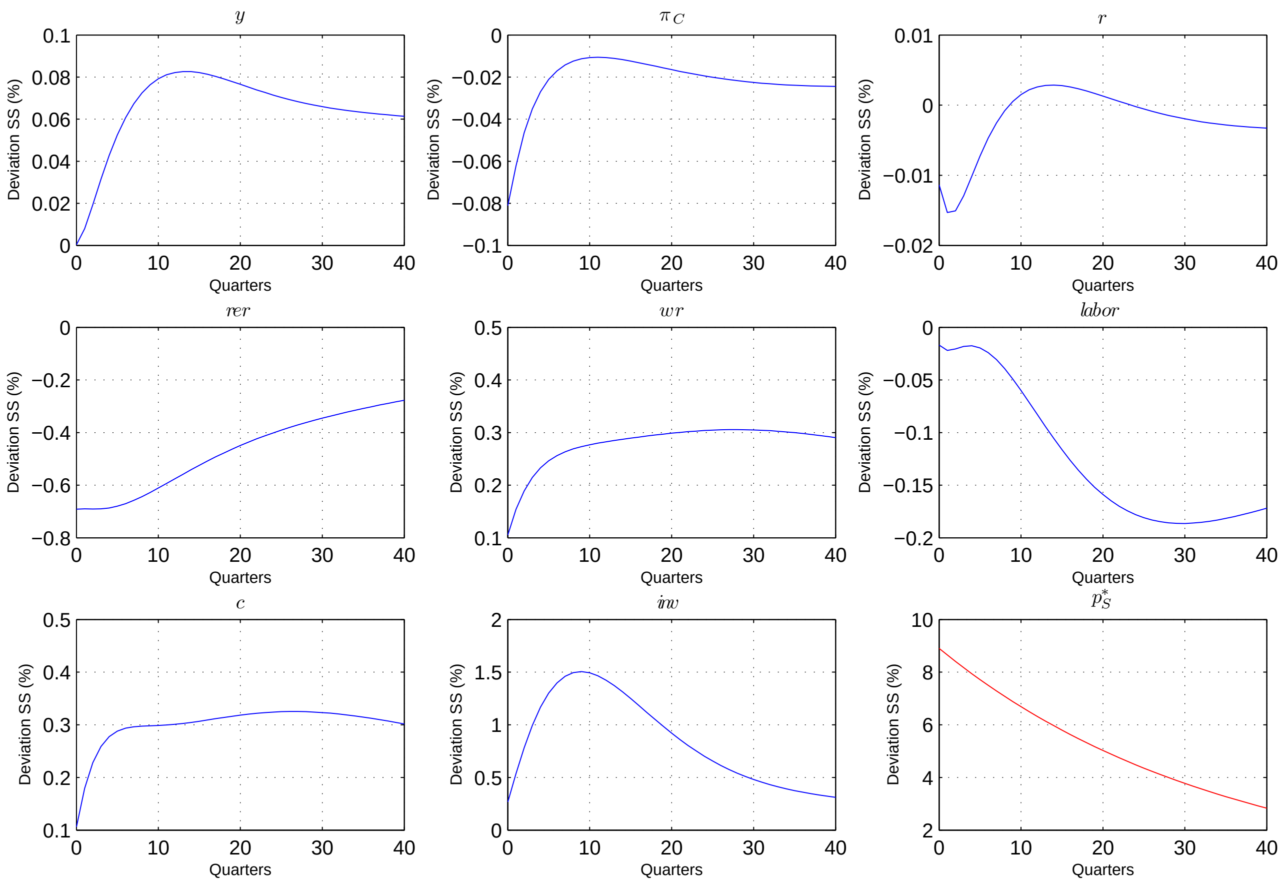

Figure 5: Responses to a commodity price shock

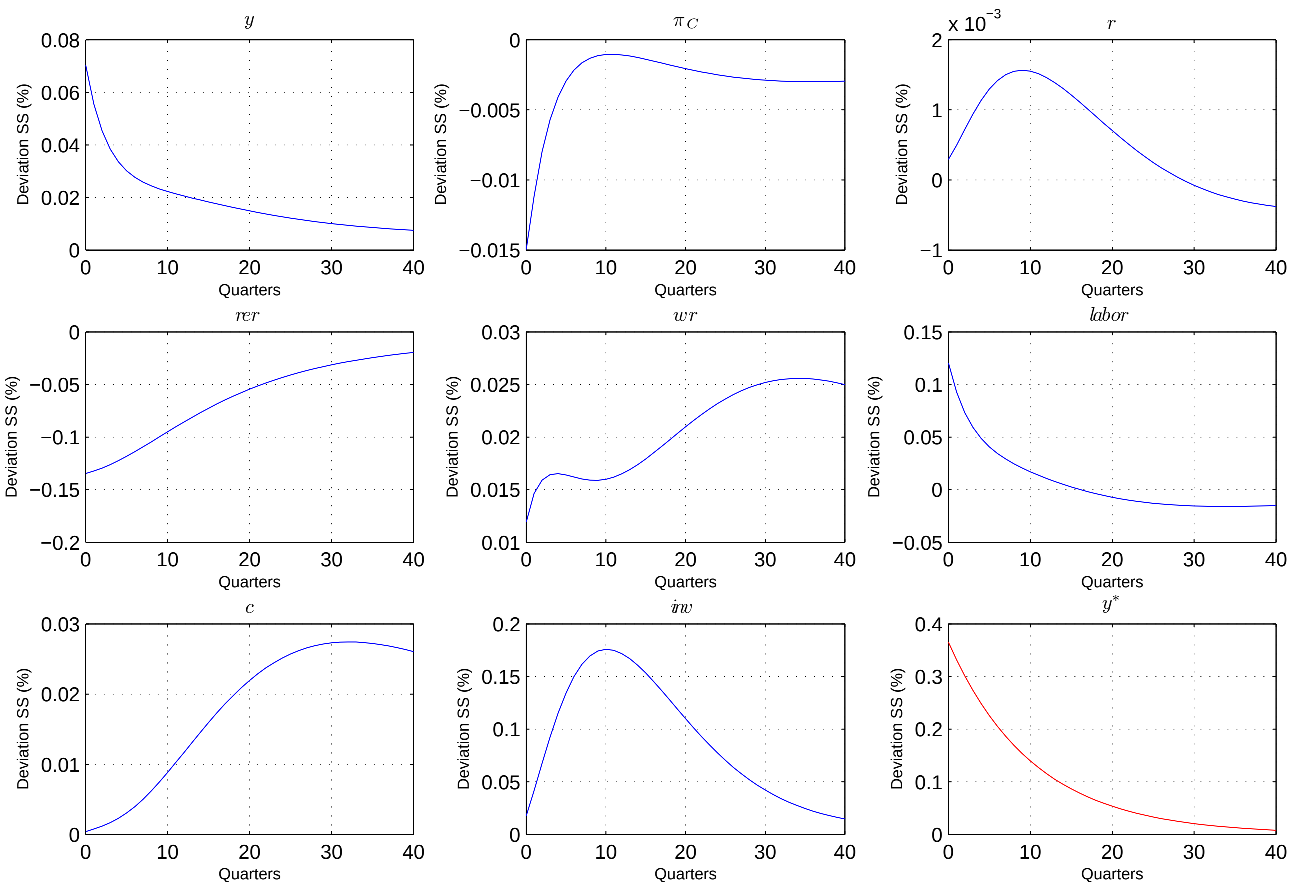

Figure 6: Responses to a foreign output shock

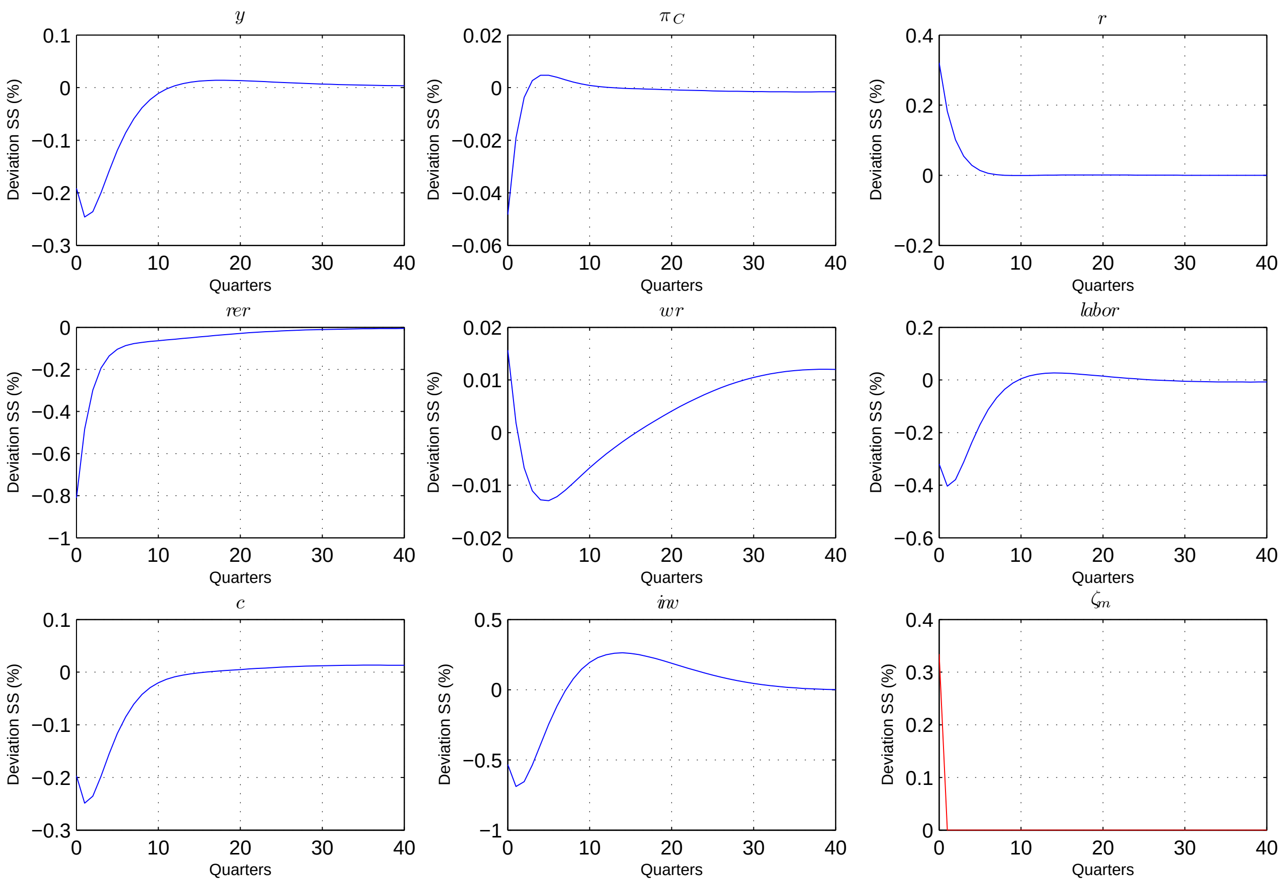

Figure 7: Responses to a monetary policy shock

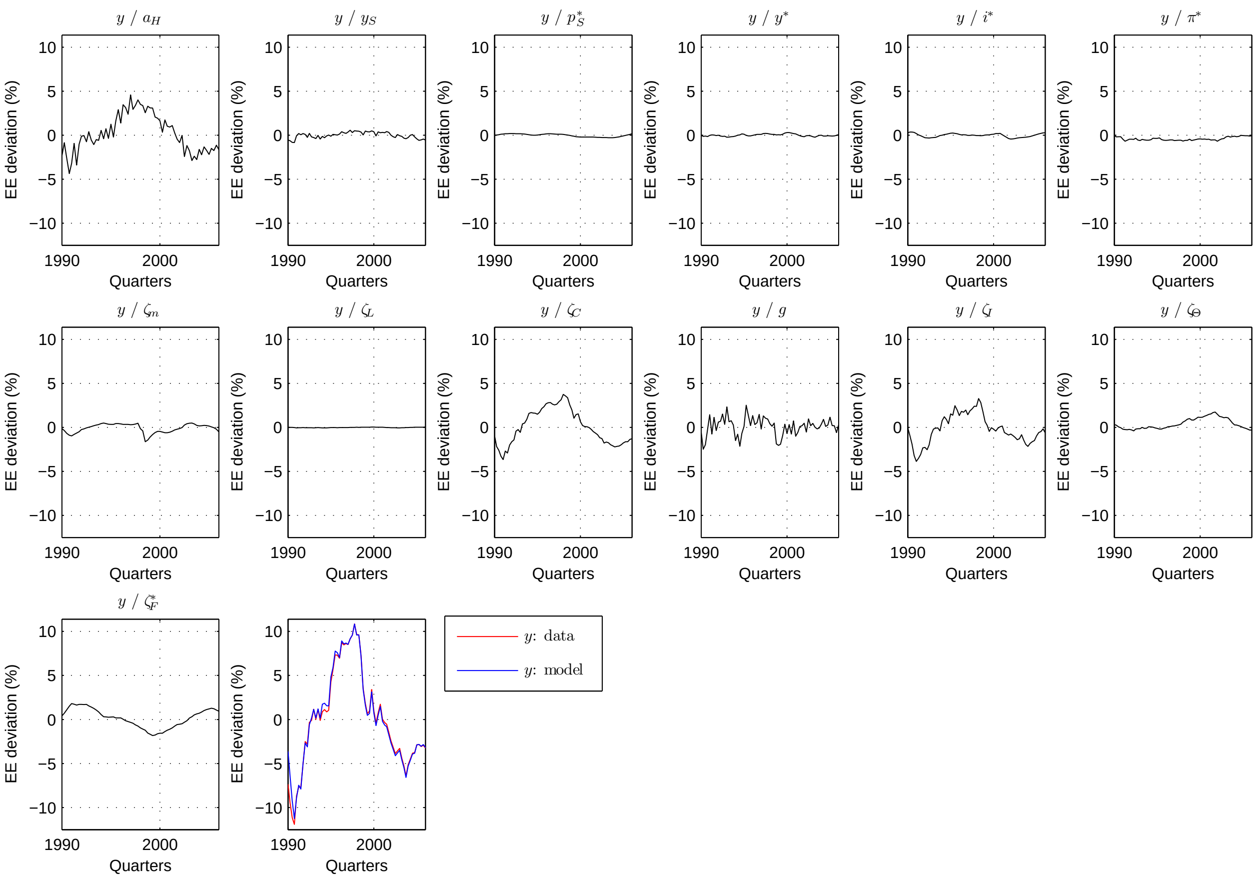

Figure 8: Historical Decomposition of GDP

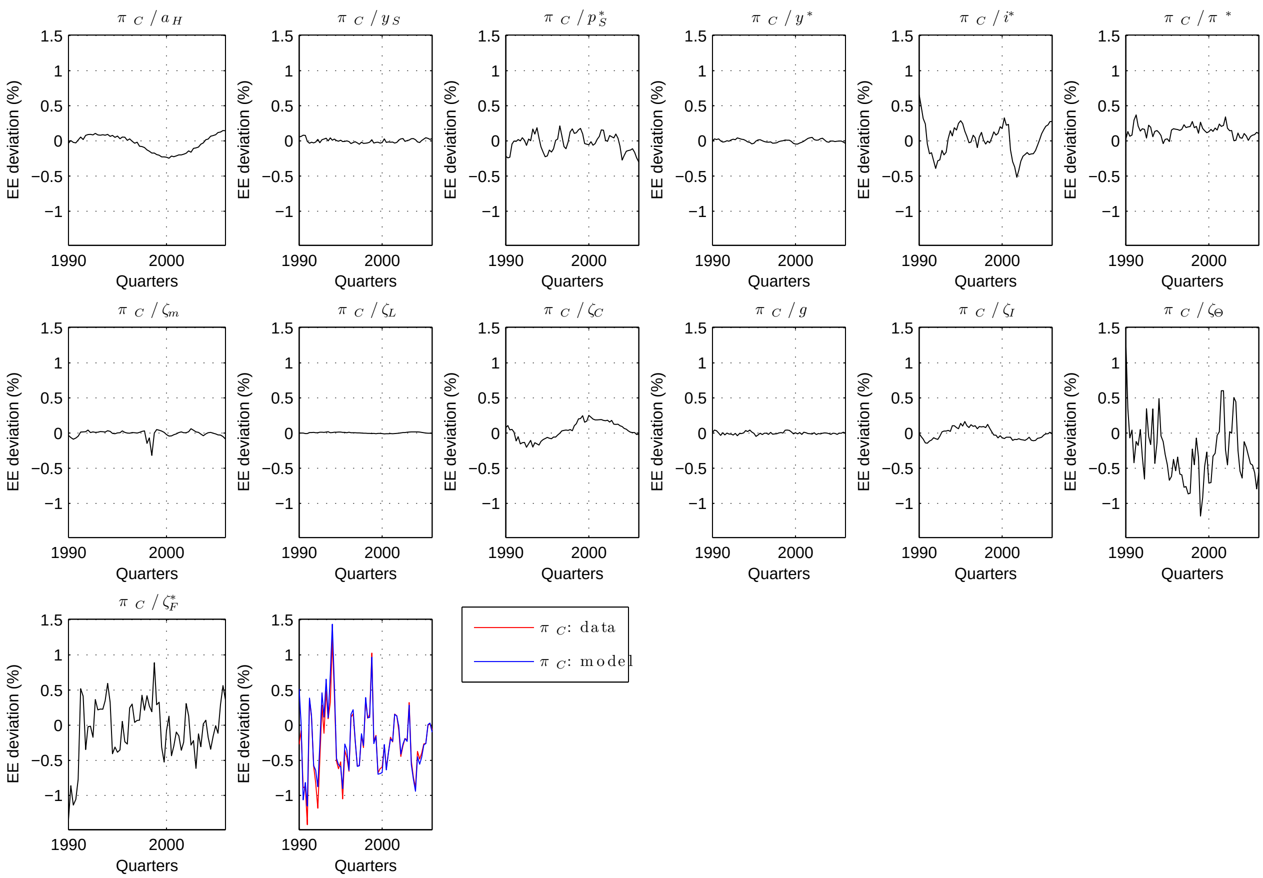

Figure 9: Historical Decomposition of π_C

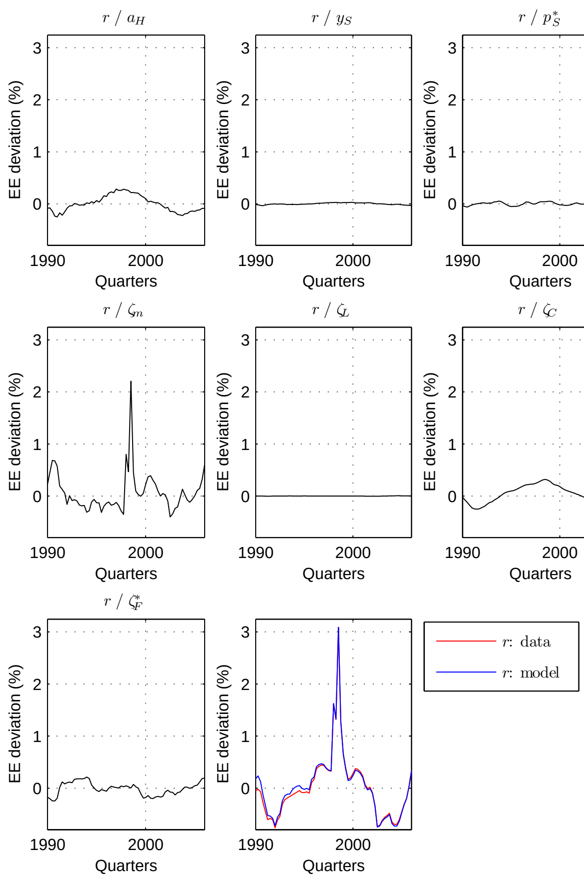

Figure 10: Historical Decomposition of real interest rate

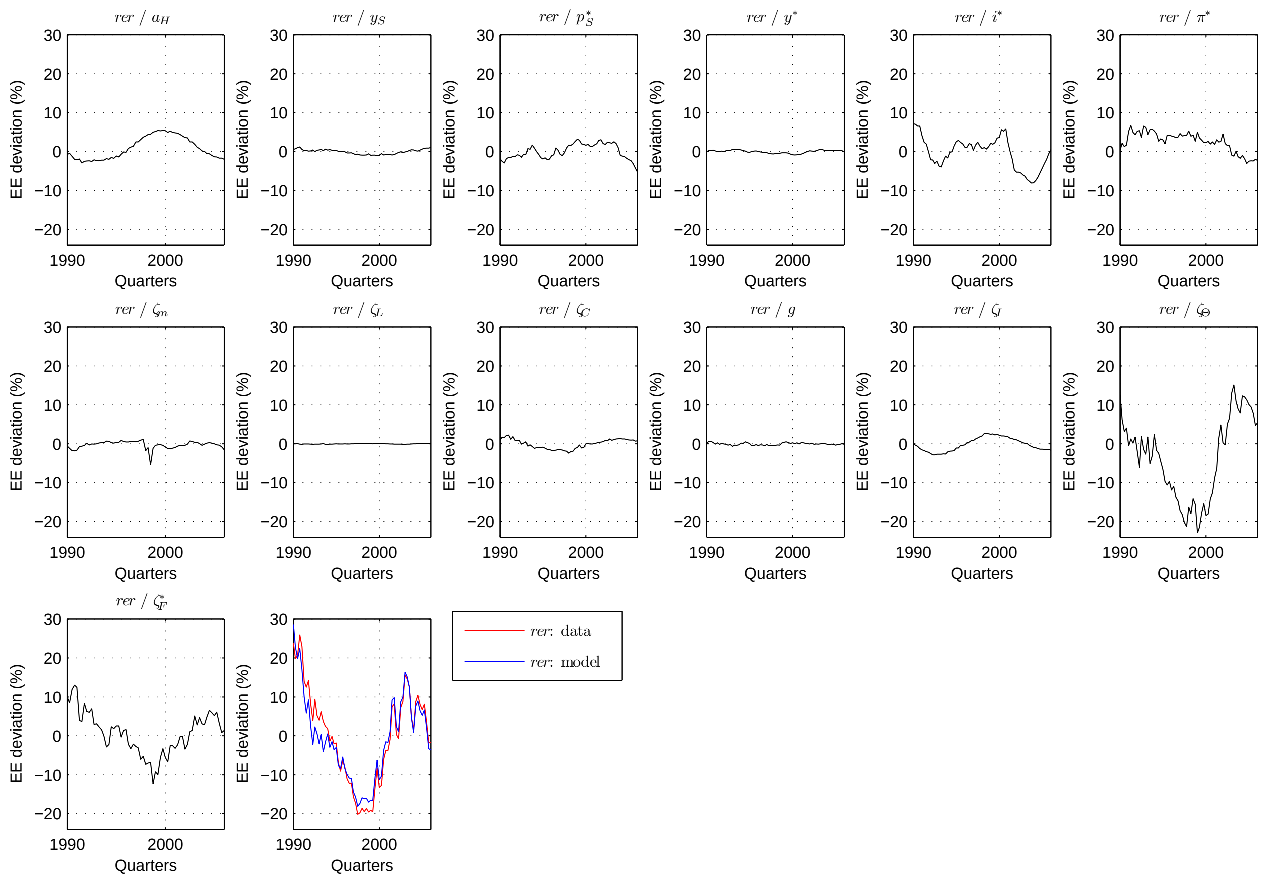

Figure 11: Historical Decomposition of real exchange rate

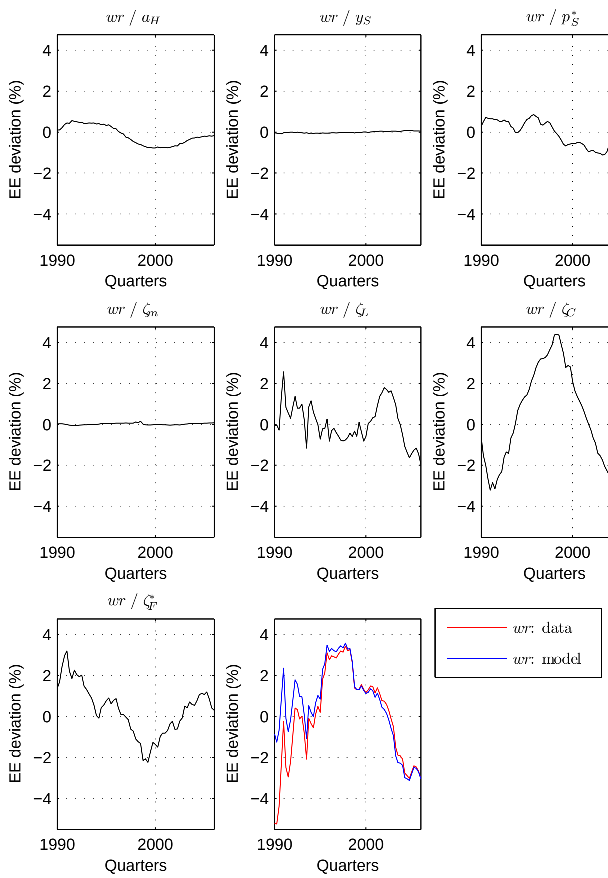

Figure 12: Historical Decomposition of real wages

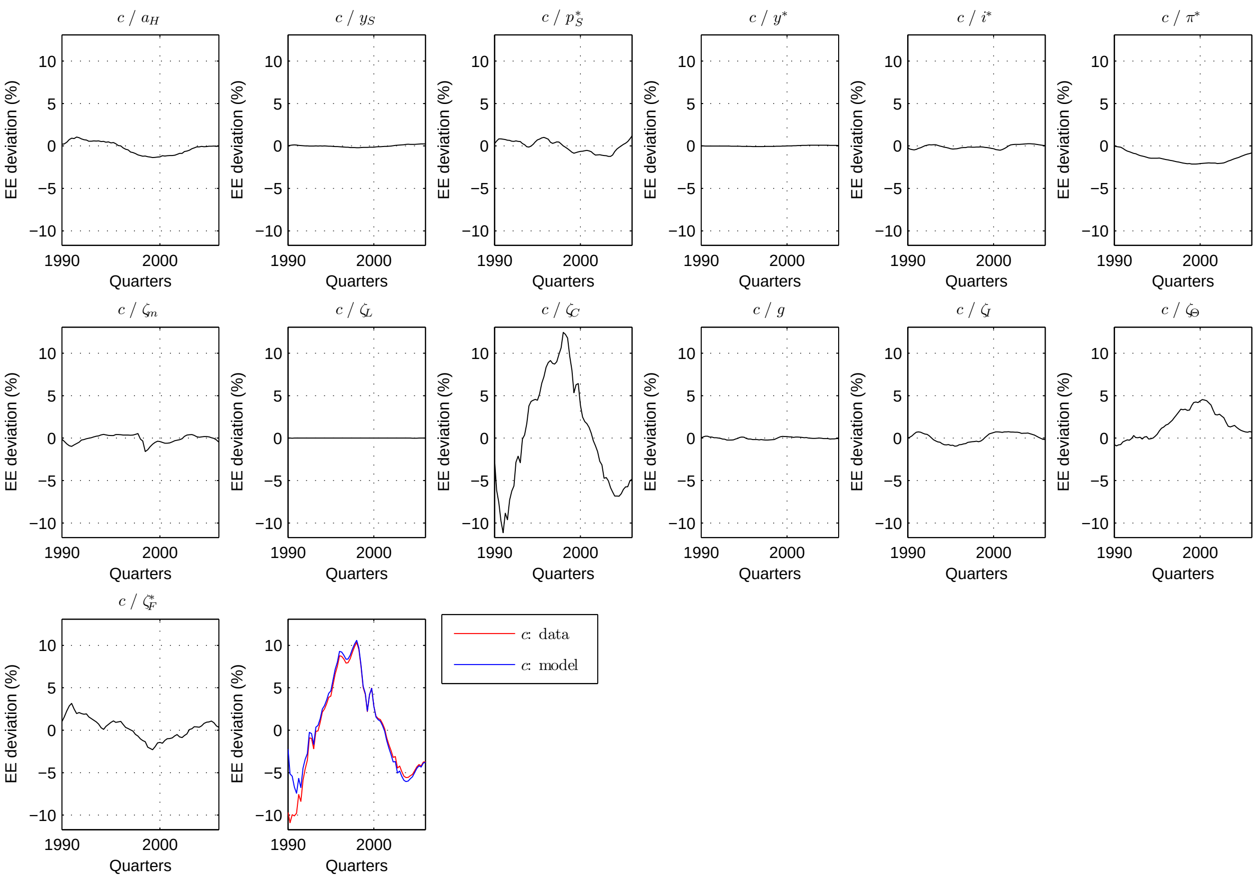

Figure 13: Historical Decomposition of Consumption

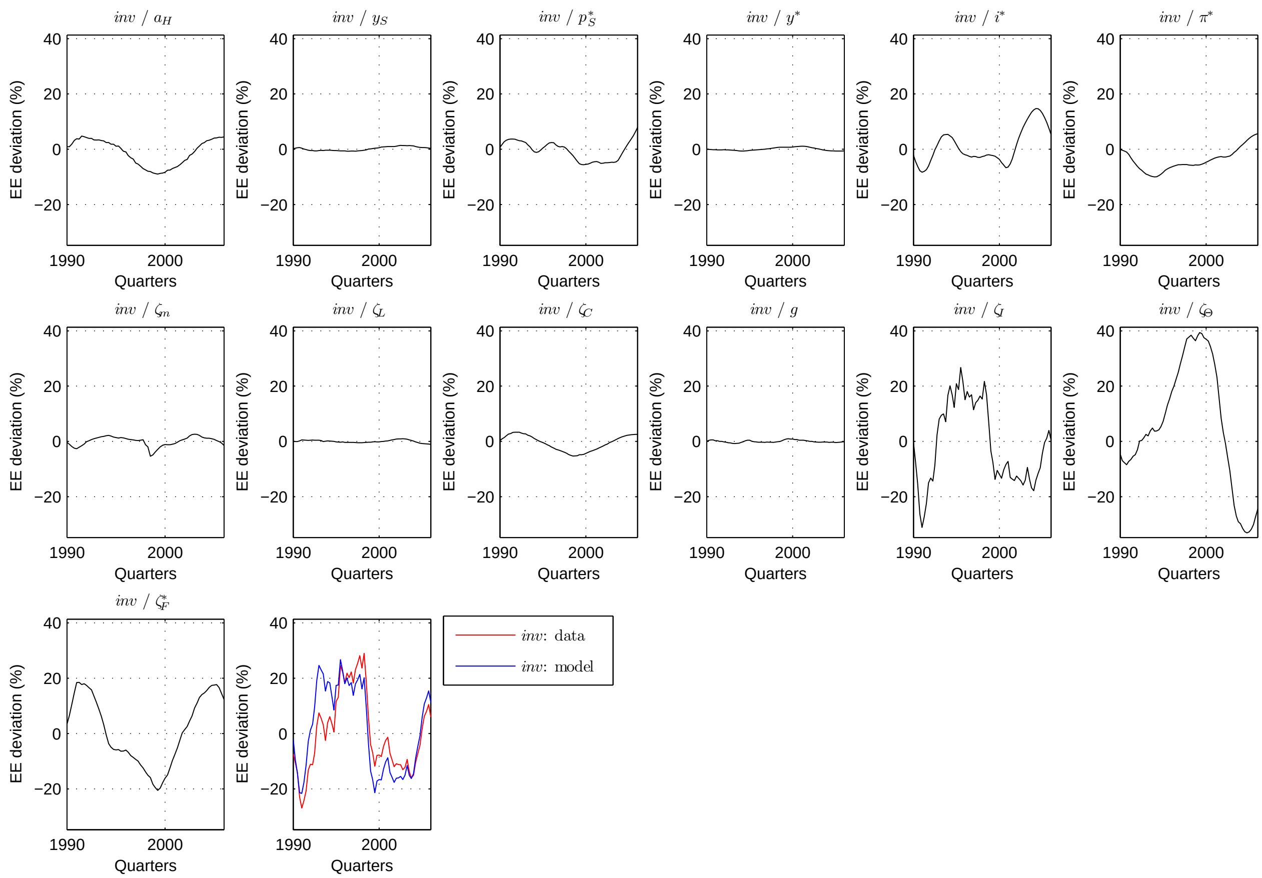

Figure 14: Historical Decomposition of Investment

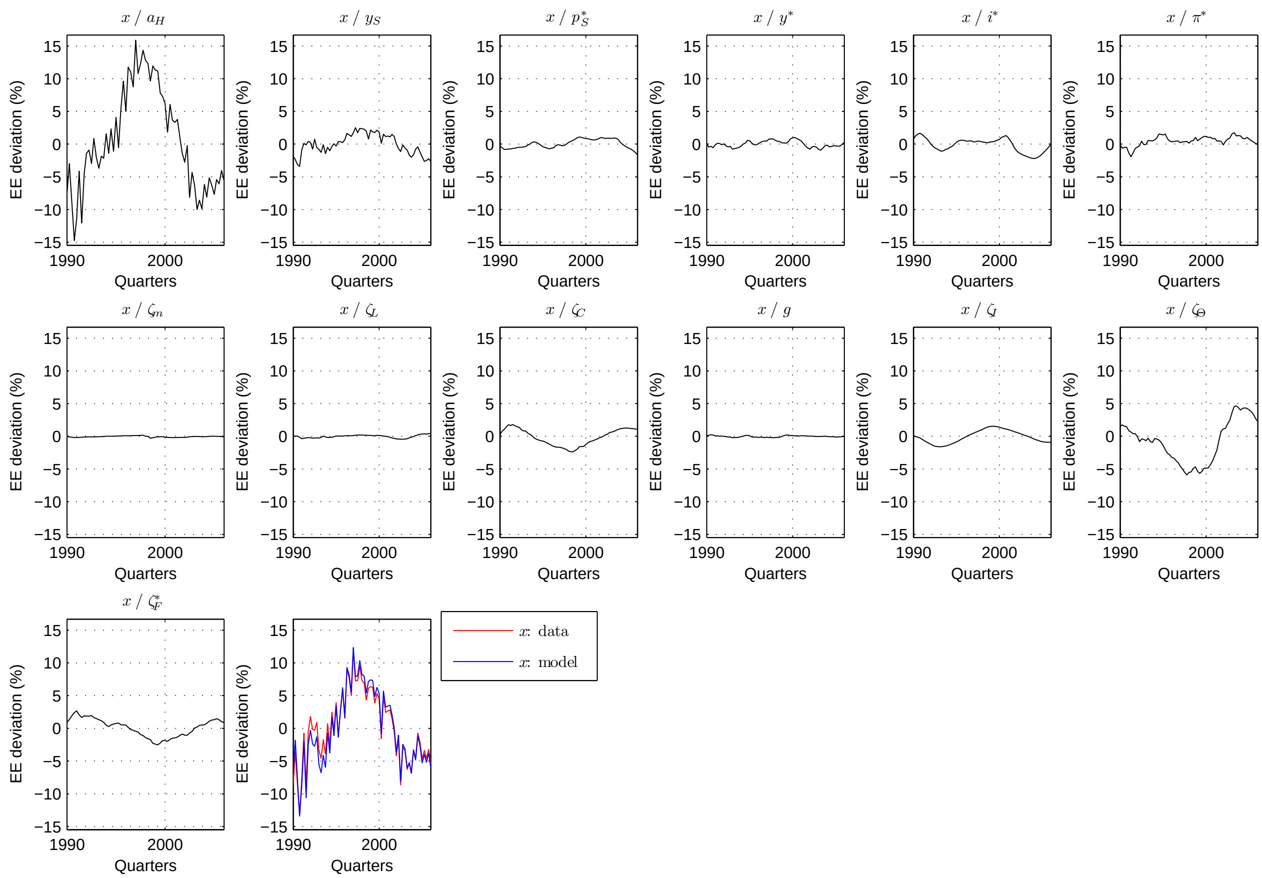

Figure 15: Historical Decomposition of Exports

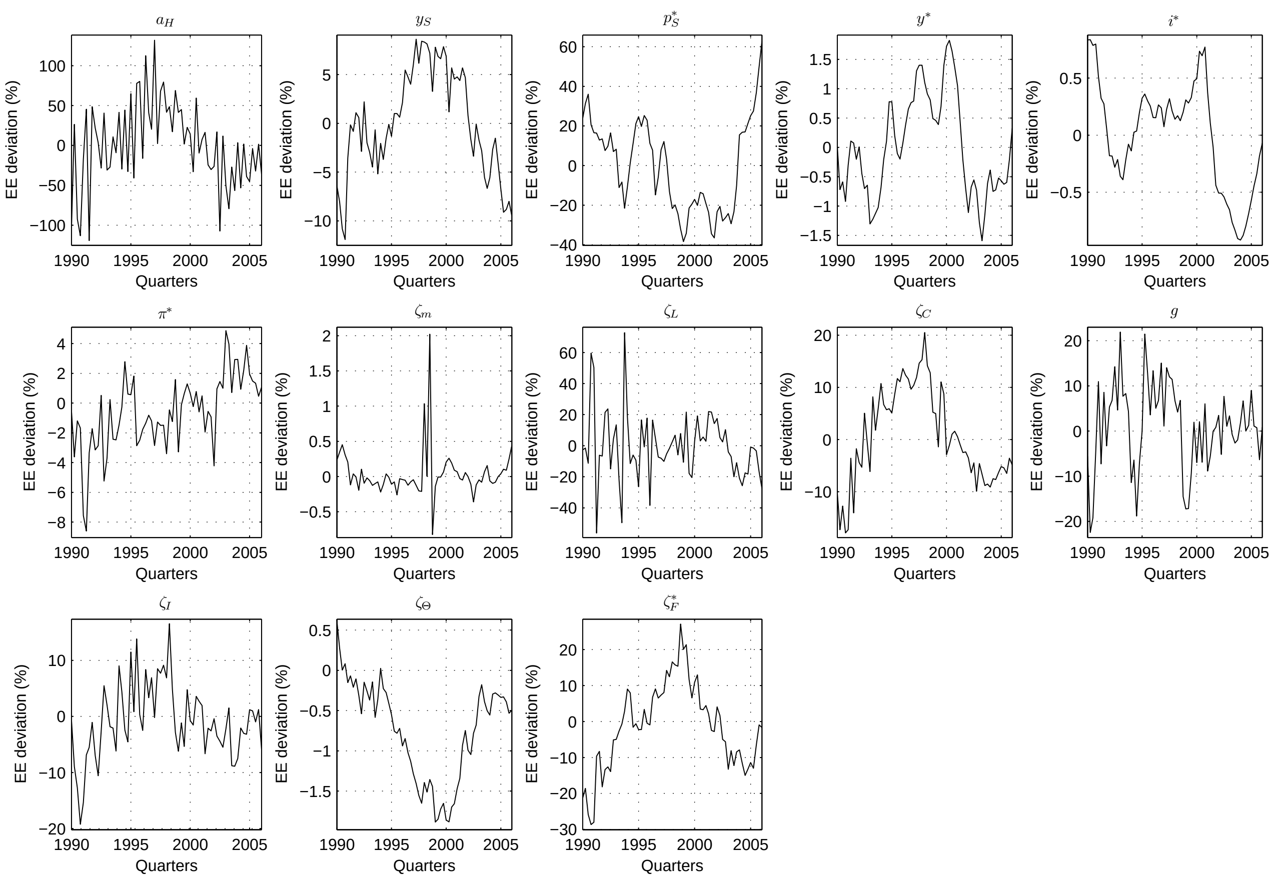

Figure 16: Observed and latent exogenous variables