Oil Shocks and Monetary Policy in an Estimated DSGE Model for a Small Open Economy*

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December, 2005

Abstract

This paper analyzes the effects of oil-price shocks from a general equilibrium standpoint. We develop a dynamic stochastic general equilibrium (DSGE) model, estimated by Bayesian methods for the Chilean economy. The model explicitly includes oil in the consumption basket and also in the technology used by domestic firms. With the estimated model we simulate how monetary policy and other variables would respond to an oil-price shock under the policy rule that best describes the behavior of the Central Bank of Chile (CBC). We also simulate the counterfactual responses in a flexible prices and wages equilibrium, and under alternative monetary frameworks. We show that a 13% increase in the real price of oil leads to a fall in output of about 0.5% and an increase in inflation of about 0.4%. The contractionary effect of the oil shock is mainly due to the endogenous tightening of the monetary policy.

JEL: E52, E58, E61
Keywords: Oil Shock, DSGE, Bayesian estimation.

*Paper presented at the First Monetary Policy Research Workshop in Latin America and the Caribbean on Monetary Policy "Response to Supply and Asset Price Shocks," organized by the Central Bank of Chile and the Centre of Central Banking Studies (CCBS) of The Bank of England, Santiago, Chile, November 17-18, 2005. We thank comments by Charly Evans and the assistance of Marcelo Ochoa and Christopher Neilson. The views expressed in this paper are our own and do not necessarily reflect those of the Central Bank of Chile. E-mail: jpmedina@bcentral.cl; csoto@bcentral.cl.

1 Introduction

Oil prices have risen dramatically over the last few years. While by the end of 2001 the price of WTI oil was about US$19 per barrel, in September 2005 it reached US$65. Changes in oil prices have a direct impact on the price level of the economy, they affect intra/inter-temporal consumption decisions, and also influence the cost structure of firms –and through this channel have a second-round effect on domestic prices. Moreover, wage and price indexation may propagate the effects of oil-price shocks on inflation and output. In this context, what is the impact of an oil-price shock on output? How is this effect related to the endogenous policy response of monetary policy?

To shed some light on these questions, we present an estimated dynamic stochastic general equilibrium (DSGE) model for the Chilean economy. The model is framed in the New Keynesian tradition, where firms are assumed to adjust prices infrequently and wages are set in a staggered fashion. Oil is used as an input in production and also part of the consumption basket of households. We allow for a flexible elasticity of substitution between oil and other types of consumption goods in the consumption bundle, and also in the technology used by domestic firms. Key structural parameters of the model are jointly estimated following a Bayesian approach as in Smets and Wouters (2003), Schorfheide (2000), DeJong, Ingram, and Whiteman (2000), and Fernandez-Villaverde and Rubio-Ramirez (2004).

In our theoretical framework, an oil-price shock generates an income effect that affects consumption and labor decisions. It also affects the marginal costs faced by domestic firms and, through this channel, their pricing decisions. Monetary policy –modelled as a Taylor rule– endogenously reacts to the movements in inflation and output caused by the oil-price shock. The presence of oil in the total consumer price index (CPI) opens the question of whether monetary policy should react to fluctuations in total CPI inflation (including fuels) or just core inflation.

Using the estimated model we simulate how the monetary policy instrument and other variables would respond to an oil-price shock under the policy rule that best describes the behavior of the Central Bank of Chile (CBC) over the last fifteen years. This rule is a Taylor-type policy reaction function, whereby the central bank adjusts the (real) interest rate in response to deviations of core inflation from a target.[1] We then compute the counterfactual responses of several variables to the shock under flexible prices and wages –which corresponds to a second-best outcome–, as well as alternative monetary frameworks. In one case, we let the monetary policy undo wage rigidities by replicating the flexible wages

[1] At the beginning of the 1990s the Central Bank of Chile began implementing its monetary policy by announcing yearly targets for inflation. In 2001 it moved to a full-fledged inflation targeting regime with a permanent range for inflation around 3%.

equilibrium. In another case, we consider a policy that is aimed at fully stabilizing consumer price inflation (CPI inflation). We also compute the endogenous response of the monetary policy under a flexible CPI inflation targeting regime.

Several studies have investigated the effect of oil-price shocks on output for the U.S., and the role played by the monetary policy. In general, these studies have used VAR models to decompose the direct effects of an oil-price shock on output and other variables, from those generated by the endogenous monetary policy response (Hamilton, 1983; Bernanke, Gertler and Watson, 1997; Hamilton and Herrera, 2004). However, lack of structural interpretation of the reduced-form coefficients of these types of model makes it very hard to disentangle the contribution of monetary policy, and to evaluate alternative monetary policy regimes.

Using a DSGE model that explicitly includes oil allows us to better understand the mechanisms through which oil-price shocks affect inflation, output and the endogenous response of monetary policy. Moreover, this methodological approach allows us to make policy analysis overcoming the Lucas Critique.[2]

Using a similar approach, Leduc and Sill (2001) find that the systematic component of monetary policy accounts for up to two thirds of the fall in output as a consequence of the oil shock. Our model differs from theirs in two important dimensions. First, our model introduces an additional channel through which an oil-price increase may depress the income of households. Namely, the presence of oil in the consumption basket which exacerbates the negative impact of oil-price increases on aggregate demand. Second, rather than being calibrated, the structural parameters in our model have been jointly estimated with the available data for Chile.[3]

Our main results are the following. First, an oil-price shock has a contractionary effect on output. A 13% increase in the real price of oil (one standard deviation) leads to a fall in output of about 0.5% and an increase in inflation of about 0.4%. Second, the contractionary effect of the oil shock is due mainly to the endogenous tightening of the monetary policy. Third, a policy that counteracts wages rigidities delivers an aggregate real allocation – i.e. aggregate employment and GDP– that is closer to the second-best outcome than the allocation obtained under a policy rule that targets core inflation deviation from target. However, the cost of this policy is an inflation response to the shock that is three times

[2] Rotemberg and Woodford (1996) also utilize a micro-founded general equilibrium model to analyze the effects of oil-price shocks on output. More recently, Hunt (2005) develops a version of GEM –the new DSGE model of the IMF– to analyze whether oil-price shock could account for the stagflation of the 1970s in the U.S.

[3] Another difference with the Leduc and Sill model is the way oil enters in the production technology. They assume that oil consumption by firms is a function of the capital utilization rate. In our case, oil is just another production input whose demand depends on its relative price.

larger than under the latter policy. Fourth, a policy rule that targets CPI inflation delivers an outcome that is very close to the one obtained under core inflation targeting. However, if the central bank tries to fully stabilize inflation there will be a considerably decrease in output.

The rest of the paper is organized as follows: section 2 presents the basic structure of the model. Section 3 discusses the estimation methodology utilized. Section 4 discusses the results obtained and compares them with other estimated models that utilize a similar methodology. Section 5 presents some impulse-response functions to an oil-price shock. Section 6 concludes.

2 The Model

In this section we describe a dynamic stochastic general equilibrium (DSGE) model with nominal and real rigidities. The model is a micro-founded model closely related to the New Open Economy models. It is a simplified version of the model developed by Medina and Soto (2005) for the Chilean economy.

The domestic economy is open and it is small for the rest of the world. The latter assumption implies that international prices, the foreign interest rate and foreign demand are not affected by domestic agents' decisions. Prices and wages are sticky. They are optimally adjusted infrequently, and they are partially indexed to past inflation. The introduction of wage rigidities together with price rigidities is very important in our model not only because it increases the realisms of the model but because it implies a stronger trade-off between inflation and output fluctuations (see Erceg *et al.*, 2000, and Blanchard and Galí, 2005).[4]

Domestic households consume domestically-produced goods (Home goods), imported differentiated goods (Foreign goods), and fuel (oil). All three different types of goods are imperfect substitutes in the consumption basket. We assume that consumption exhibits habit formation. Home goods are partly sold domestically and partly exported abroad. There is also a commodity good whose endowment is exogenously determined that is exported and not consumed domestically. The exogenous endowment of this good is subjected to stochastic shocks.

Households supply a differentiated labor service and receive the corresponding wage compensations. Each household has a monopolistic power over the type of labor service it provides. Furthermore, households are the owners of firms producing Home goods, and

[4] Blanchard and Galí emphasize that price rigidities alone does not imply a conflict between output gap and inflation stabilization –what they call the *divine coincidence*. They show that adding wage rigidities breaks down this *divine coincidence*.

therefore, they receive the income corresponding to the monopolistic rents generated by these firms.

Domestic firms produce differentiated varieties of Home goods. For simplicity, we assume that labor and Oil are the only variable inputs used for production. These firms have monopolistic power over the variety of goods they produce. We assume that productivity is subjected to stochastic shocks and grows at a rate g_y in steady state.

Monetary policy is modelled as a Taylor-type rule that incorporates interest rate inertia. In particular, the interest rate reacts to inflation, GDP growth and its own lagged value. Finally, we also assume that in the steady state, the inflation rate is exogenously determined by the monetary authority (the inflation target).

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:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[log\left(C_t(j) - h(1+g_y)C_t\right) + \frac{a}{\mu}\left(\frac{\mathcal{M}_t(j)}{P_t}\right)^{\mu} - \frac{\zeta_t}{1+\sigma_L} l_t(j)^{1+\sigma_L} \right], \tag{1}$$

where $l_t(j)$ is labor effort, $C_t(j)$ is total consumption, and $\mathcal{M}_t(j)$ stands for total nominal balances held at the beginning of period t. Parameter σ_L is the inverse elasticity of labor supply with respect to real wages. ζ_t is a preference shock that shifts the labor supply. Preferences display habit formation in consumption governed by parameter h. The consumption bundle of household j is given by

$$C_t(j) = \left[\delta^{\frac{1}{\eta}} \left(O_{C,t}(j)\right)^{\frac{\eta-1}{\eta}} + (1-\delta)^{\frac{1}{\eta}} \left(Z_t(j)\right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $O_{C,t}$ represents fuel (Oil) consumption, and Z_t is a bundle of non-fuel consumption (core consumption). The composition of this core consumption bundle is given by

$$Z_t(j) = \left[\gamma^{\frac{1}{\theta}} \left(C_{F,t}(j)\right)^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} \left(C_{H,t}(j)\right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{3}$$

where C_H represents a bundle of domestically produced goods (Home goods), and C_F corresponds to a bundle of imported goods (Foreign goods).

Parameter η is the elasticity of substitution between Oil and core consumption, and parameter θ is the intratemporal elasticity of substitution between Home and Foreign goods. For any level of consumption, each household purchases a composite of Home and Foreign goods and Oil in order to minimize the total cost of its consumption basket. Hence, each household minimizes $P_{O,t}O_{C,t}(j) + P_{Z,t}Z_t(j)$, subject to (2), where $P_{O,t}$ and $P_{Z,t}$ are the price of Oil and the core consumption deflator, respectively. The demand for Oil and core consumption are given by

$$Z_t(j) = (1-\delta)\left(\frac{P_{Z,t}}{P_t}\right)^{-\eta} C_t(j), \quad O_{C,t}(j) = \delta\left(\frac{P_{O,t}}{P_t}\right)^{-\eta} C_t(j). \tag{4}$$

Analogously, each household determines the optimal composition of core consumption by minimizing the cost of the core consumption basket, $P_{H,t}C_{H,t}(j) + P_{F,t}C_{F,t}(j)$, subject to (3). The demand functions for Home goods and Foreign goods are given by,

$$C_{H,t}(j) = (1-\gamma)\left(\frac{P_{H,t}}{P_{Z,t}}\right)^{-\theta} Z_t(j), \quad C_{F,t}(j) = \gamma\left(\frac{P_{F,t}}{P_{Z,t}}\right)^{-\theta} Z_t(j). \tag{5}$$

The consumption-based price index (CPI), P_t, and the core consumption price index, which excludes the price of Oil, are given by

$$P_t = \left[\delta P_{O,t}^{1-\eta} + (1-\delta)P_{Z,t}^{1-\eta}\right]^{\frac{1}{1-\eta}} \quad \text{and} \quad P_{Z,t} = \left[\gamma P_{H,t}^{1-\theta} + (1-\gamma)P_{F,t}^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{6}$$

Domestic households have access to three different types of assets: money $\mathcal{M}_t(j)$, one-period non-contingent foreign bonds $B_t^*(j)$, and one-period domestic contingent bonds $D_{t+1}(j)$ which pay out one unit of domestic currency in a particular state. There are no adjustment costs in the portfolio composition. However, each time a domestic household borrows from abroad it must pay a premium over the international price of external bonds. This premium is introduced in the model to obtain a well defined steady state for the economy.[5]

$$\begin{aligned} E_t[Q_{t,t+1}D_{t+1}(j)] + \frac{\mathcal{E}_t B_t^*(j)}{(1+i_t^*)\,\Theta\left(\frac{\mathcal{E}_t B_t^*}{P_{X,t}X_t}\right)} + \mathcal{M}_t(j) = \\ D_t(j) + \mathcal{E}_t B_{t-1}^*(j) + \mathcal{M}_{t-1}(j) + W_t(j)l_t(j) + \Pi_t(j) + T_t(j) - P_tC_t(j), \end{aligned} \tag{7}$$

where i_t^* is the return on the international bond in the international market, $\Pi_t(j)$ are profits received from domestic firms, $\mathcal{E}_t$ is the nominal exchange rate, $W_t(j)$ is the nominal wage set by household j, $T_t(j)$ are per capita lump sum net transfers from the government. The term $\left[\Theta\left(\frac{\mathcal{E}_t B_t^*}{P_{X,t}X_t}\right)\right]$ corresponds to the premium domestic households have to pay each time they borrow from abroad, where $B_t^* = \int_0^1 B_t^*(j)dj$ is the aggregate net foreign asset position of the economy and $P_{X,t}X_t$ is the nominal value of exports.[6] Variable $Q_{t,t+1}$ is the

[5] See Schmitt-Grohé and Uribe (2003) for different ways to get steady state independent of initial conditions for small open economy models.

[6] Since the economy is growing in steady state, the net asset position is also growing in the long run. Therefore, in order to have a stationary risk premium it is necessary that this premium be a function of the ratio of the net asset position to some variable that grows at the same rate in steady state. We choose export since that could represent a form of international collateral (see Caballero and Krishnamurthy, 2001).

period t price of domestic contingent bonds normalized by the probability of 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.

Since the premium depends on the aggregate net foreign asset position of the economy, households take $\Theta(\cdot)$ as given when deciding their optimal portfolios. In other words, households do not internalize the effect on the premium of changes in their own foreign asset position. In steady state $\Theta(.)$ is parameterized so that:

$$\Theta\left(\frac{\mathcal{E}B^*}{P_X X}\right) = \overline{\Theta}, \qquad \text{and} \qquad \frac{\Theta'\left(\frac{\mathcal{E}B^*}{P_X X}\right)}{\Theta\left(\frac{\mathcal{E}B^*}{P_X X}\right)} \frac{\mathcal{E}B^*}{P_X X} = \varrho.$$

Here B^* corresponds to the steady state net foreign asset position, while $P_X X$ is the steady state value of exports. When the country as a whole is a net debtor, ϱ corresponds to the elasticity of the upward slopping supply of international funds.

2.1.1 Consumption and saving decisions

Households choose consumption and the composition of their portfolios by maximizing (1) subject to (7). Since we are assuming the existence of a complete set of contingent claims, consumption is equalized across households. Therefore, in what follows we omit index j from consumption.

Aggregating the first order conditions on different contingent claims over all possible states we obtain the following Euler equation:

$$E_t\left[\beta\left(1+i_t\right)\frac{P_t}{P_{t+1}}\left(\frac{C_t - h(1+g_y)C_{t-1}}{C_{t+1} - h(1+g_y)C_t}\right)\right] = 1, \tag{8}$$

where in equilibrium it must be true that $1+i_t = 1/E_t[Q_{t,t+1}]$.

The first-order condition with respect to foreign bond holdings implies the following expression:

$$E_t\left[\beta\left(1+i_t^*\right)\Theta\frac{\mathcal{E}_{t+1}P_t}{\mathcal{E}_t P_{t+1}}\left(\frac{C_t - h(1+g_y)C_{t-1}}{C_{t+1} - h(1+g_y)C_t}\right)\right] = 1. \tag{9}$$

Combining the two expressions above we obtain an expression for the uncovered interest parity condition (UIP).

2.1.2 Labor supply decisions and wage setting

Each household j is a monopolistic supplier of a differentiated labor service. There is a set of perfectly competitive labor service assemblers that hire labor from each household and combine it into an aggregate labor service unit, l_t, that is then used by the intermediate goods producer. The labor service unit is defined as:

$$l_t = \left(\int_0^1 l_t(j)^{\frac{\epsilon_L - 1}{\epsilon_L}} dj \right)^{\frac{\epsilon_L}{\epsilon_L - 1}}. \tag{10}$$

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

$$l_t(j) = \left(\frac{W_t\,(j)}{W_t} \right)^{-\epsilon_L} l_t, \tag{11}$$

where $W_t\,(j)$ is the wage rate set by household j and W_t is an aggregate wage index defined as

$$W_t = \left(\int_0^1 W_t(j)^{1-\epsilon_L} dj \right)^{\frac{1}{1-\epsilon_L}}. \tag{12}$$

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 constant probability $(1 - \phi_L)$ of being able to re-optimize its nominal wage. We assume there is an updating rule for all those households that cannot re-optimize their wages. In particular, if a household cannot re-optimize during i periods between t and $t + i$, then its wage at time $t + i$ is given by

$$W_{t+i}(j) = \Gamma^i_{W,t} W_t(j), \tag{13}$$

where $\Gamma^i_{W,t}$ describes an adjustment rule for wages, that is defined as:

$$\Gamma^i_{W,t} = \prod_{j=1}^{i} (1 + \pi_{t+j-1})^{\xi_L} (1 + \overline{\pi}_{t+j})^{1-\xi_L} (1 + g_y)\,.$$

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 and the inflation target set by the authority, $\overline{\pi}_t$. The term $(1 + g_y)$ is included in the expression above in order to avoid large real wage dispersion along the steady state growth path. Once a household has decided on a wage, it must supply any quantity of labor service that is demanded at that wage.

A particular household j that is able to re-optimize its wages at t solves the following problem:

$$\max_{W_t(j)} E_t \left\{ \sum_{i=0}^{\infty} \phi^i_L \Lambda_{t,t+i} \left(\frac{W_t(j)\Gamma^i_{W,t}}{P_{t+i}} - \zeta_t \left(l_{t+i}(j)\right)^{\sigma_L} \left(C_{t+i} - h(1+g_y)C_{t+i-1}\right) \right) l_{t+i}\,(j) \right\},$$

subject to the labor demand (11) and the updating rule for the nominal wage (13). The variable $\Lambda_{t,t+i}$ is the relevant discount factor between periods t and $t+i$, and is given by $\Lambda_{t,t+i} = \beta^i \frac{C_t-(1+g_y)hC_{t-1}}{C_{t+i}-(1+g_y)hC_{t+i-1}}$.

2.2 Domestic production

Production in the Home goods sector is characterized by firms that act as a monopoly in the production of a single variety. Each firm maximizes profits by choosing the price of its variety subject to the corresponding demand and the available technology,

$$Y_{H,t}(z_H) = A_{H,t}\left[(1-\alpha)^{\frac{1}{\omega}}(L_{H,t}(z_H))^{1-\frac{1}{\omega}} + \alpha^{\frac{1}{\omega}}(O_{H,t}(z_H))^{1-\frac{1}{\omega}}\right]^{\frac{\omega}{\omega-1}}, \tag{14}$$

where $Y_{H,t}(z_H)$ represents the quantity of a particular variety z_H, $L_{H,t}(z_H)$ is the labor input utilized, and $O_{H,t}(z_H)$ is Oil used in production of that variety.

Variable $A_{H,t}$ represents a productivity shock in the Home goods sector that is common to all firms. Parameter ω defines the elasticity of substitution between Labor and Oil in production. The value of this parameter is key to determine the effects of oil-price shocks in output and also their effects on the marginal cost and core inflation.

2.2.1 Demand for inputs and marginal cost

Firms determine the optimal mix of inputs by minimizing total costs of production, subject to the constraint imposed by the technology. From the first-order condition we obtain the following relation:

$$\frac{1-\alpha}{\alpha}\frac{O_{H,t}(z_H)}{L_{H,t}(z_H)} = \left(\frac{W_t}{P_{O,t}}\right)^{\omega}.$$

From this cost minimization problem and from (14) we also obtain an expression for the nominal marginal cost,

$$MC_{H,t} = A_{H,t}^{-1}\left[(1-\alpha)W_t^{1-\omega} + \alpha P_{O,t}^{1-\omega}\right]^{\frac{1}{1-\omega}}.$$

Notice that the nominal marginal cost depends only on the prices of inputs and the technology level, which is common for all firms. Therefore, the marginal cost is independent from the scale of production of a particular firm.

2.2.2 Price setting

Following Calvo (1983) we assume that only a fraction ϕ_H of the producers can reset their prices each period. We assume that a firm that does not receive the signal to adjust optimally its price follows a simple "passive" rule to update the price. In particular, if the firm does not adjust its price between t and $t+i$, then the price it charges in $t+i$ is given by $\Gamma^i_{H,t} P_{H,t}(z_H)$, where $\Gamma^i_{H,t}$ is a function that defines the updating rule. If the firm receives a signal to optimally adjust its price it will choose $P^{op}_{H,t}(z_H)$ to maximize

$$\sum_{i=0}^{\infty} \phi^i_H E_t \left\{ \Lambda_{t,t+i} \frac{\Gamma^i_{H,t} P^{op}_{H,t}(z_H) - MC_{H,t+i}}{P_{t+i}} Y_{H,t+i}(z_H) \right\}, \tag{15}$$

subject to the demand for variety z_H given by

$$C_{H,t}(z_H) = \left(\frac{P_{H,t}(z_H)}{P_{H,t}} \right)^{-\epsilon_H} \left(C_{H,t} + C^*_{H,t} \right), \tag{16}$$

where ϵ_H is the price elasticity of the demand for variety z_H.[7] This parameter also defines the flexible price equilibrium markup charged by firms producing Home goods.

The "passive" adjustment rule for those firms that do not receive a signal between t and $t+i$ is given by

$$\Gamma^i_{H,t} = \prod_{j=1}^{i} (1 + \pi_{H,t+j-1})^{\xi_H} (1 + \overline{\pi}_{t+j})^{1-\xi_H}, \tag{17}$$

where $1 + \pi_{H,t} = (P_{H,t}/P_{H,t-1})$, and where $\overline{\pi}_{t+j}$ corresponds to the inflation target set by the authority. Notice that relative price changes may have a feedback impact through this adjustment rule. Firms that do not optimally adjust take into consideration the inflation target that is set in terms of consumer goods inflation. The parameter ξ_H captures the degree of "indexation" in the economy. The larger this parameter, the larger the weight of past inflation in defining new prices.

Given the price charged by a firm producing variety z_H, its profits are given by:

$$\Pi_t(z_H) = P_{H,t}(z_H) Y_{H,t}(z_H) - W_t L_{H,t}(z_H) - P_{O,t} O_{H,t}(z_H).$$

2.3 Foreign sector

We assume the economy exports two types of goods: Home goods and an exportable commodity $Y_{S,t}$ whose endowment is determined exogenously. For simplicity, we assume that this commodity is not consumed domestically. The exogenous process for $Y_{S,t}$ is given by[8]

$$\frac{Y_{S,t}}{(1+g_y)^t Y_S} = \left(\frac{Y_{S,t-1}}{(1+g_y)^{t-1} Y_S} \right)^{\rho_S} \exp(\varepsilon_{S,t}). \tag{18}$$

[7] This demand for a particular variety z_H comes from the assumption that the Home consumption good is a composite of a continuum of varieties z_H defined as $C_{H,t} = \left(\int (C_{H,t}(z_H))^{1-\frac{1}{\epsilon_H}} dz_H \right)^{\frac{\epsilon_H}{\epsilon_H - 1}}$.

[8] In Chile, a significant fraction of total exports is made up of commodities based on natural resources. These commodities are produced somehow independently of the domestic economic conditions (e.g., interest rate, real wages) and therefore, they can be considered as exogenous in the short run.

The foreign demand for Home goods is given by the following expression,

$$C_{H,t}^{*} = \gamma^{*} \left(\frac{P_{H,t}^{*}}{P_{F,t}^{*}} \right)^{-\eta^{*}} C_{t}^{*}, \tag{19}$$

where γ^* corresponds to the share of domestic intermediate goods in the consumption basket of foreign agents and η^* is the price elasticity of demand. We assume that domestic firms cannot price discriminate across markets. Therefore, the law of one price holds for Home goods sold abroad, $P_{H,t}^{*} = P_{H,t}/\mathcal{E}_t$.

The real exchange rate is defined as the relative price of the foreign consumption basket, $P_{F,t}^{*}$, relative to the price of the domestic consumption basket,

$$RER_t \equiv \frac{\mathcal{E}_t P_{F,t}^{*}}{P_t}. \tag{20}$$

Notice that we are assuming that the price of Foreign goods is the relevant international price to be used when constructing the real exchange rate. In other words, we are implicitly assuming that the consumption bundle abroad does not include Oil and that the share of Home goods in this bundle, γ^*, is negligible.

The domestic real price of oil is given by the following expression

$$\frac{P_{O,t}}{P_t} = RER_t \frac{P_{O,t}^{*}}{P_{F,t}^{*}} \psi_t \tag{21}$$

where $P_{O,t}^{*}$ is the foreign currency price of Oil abroad. Variable ψ_t in equation (21) corresponds to deviations from the law of one price in the oil price. Empirical evidence shows that the pass-through from the international oil price to its price in domestic currency is not complete in the short run.[9] Both $P_{O,t}^{*}/P_{F,t}^{*}$ and ψ_t are assumed to follow a log-linear autoregressive process of order one.

2.4 Aggregate equilibrium

For simplicity we assume that there is no public spending. Therefore, the government budget constraint is simply given by

$$\int \frac{\mathcal{M}_{t+1}(j) - \mathcal{M}_t(j)}{P_t} dj - \int T_t(j)\, dj = 0. \tag{22}$$

The equilibrium in both the Home goods sector and the labor market implies:

$$Y_{H,t} = C_{H,t} + C_{H,t}^{*} \qquad l_t = L_{H,t}. \tag{23}$$

[9] In the case of Chile these deviations from the law of one price could be explained by the operation of the Oil Stabilization Fund ("FEP").

Combining these equilibrium conditions, the budget constraint of the government and the aggregate budget constraint of households, we obtain an expression for the aggregate accumulation of international bonds

$$\frac{\mathcal{E}_t B_t^*}{(1+i_t^*)\,\Theta\left(\frac{\mathcal{E}_t B_t^*}{P_{X,t} Y_{X,t}}\right) P_t} = \frac{\mathcal{E}_t B_{t-1}^*}{P_t} + \frac{P_{X,t}}{P_t} X_t - \frac{P_{M,t}}{P_t} M_t. \tag{24}$$

The total value of exports and the total value of imports are given by

$$\frac{P_{X,t}}{P_t} X_t = \frac{P_{H,t}}{P_t} C_{H,t}^* + \frac{P_{S,t}}{P_t} Y_{S,t} \quad \text{and} \quad \frac{P_{M,t}}{P_t} M_t = RER_t C_{F,t} + \frac{\mathcal{E}_t P_{O,t}^*}{P_t} O_t, \tag{25}$$

respectively, where $O_t = O_{N,t} + O_{C,t}$ stands for total oil imports.

Let $P_{Y,t}$ denote the implicit output deflator. Then, total GDP –at current prices– satisfies the following relation:

$$\frac{P_{Y,t}}{P_t} Y_t = C_t + \frac{P_{X,t}}{P_t} X_t - \frac{P_{M,t}}{P_t} M_t. \tag{26}$$

2.5 Monetary policy rules

The monetary policy is characterized as a simple feedback rule for the *real* interest rate. Under the baseline specification of the model, we assume that the central bank responds to deviations of CPI inflation from target and to deviation of output growth from trend,

$$\frac{1+r_t}{1+r} = \frac{1+r_{t-1}}{1+r}^{\rho_i} \left(\frac{Y_t}{Y_{t-1}} \frac{1}{1+g_y}\right)^{(1-\rho_i)\varpi_x} \left(\frac{1+\pi_t}{1+\overline{\pi}_t}\right)^{(1-\rho_i)\varpi_\pi} \exp\left(\nu_t\right) \tag{27}$$

where $\overline{\pi}_t$ is the inflation target set for period t and $r_t = (1+i_t)/E_t\left(P_{t+1}/P_t\right) - 1$ is the net real interest rate. Variable ν_t is a monetary policy shock that corresponds to a deviation from the policy rule.

We define a rule in terms of the real interest rate to be consistent with the common practice of the CBC during most part of the sample period utilized to estimate the model.[10]

We also consider an alternative specification for the policy rule where we assume that the central bank responds to deviations of core rather than CPI inflation from target, where core inflation is defined as $\pi_{Z,t} = \frac{P_{Z,t}}{P_{Z,t-1}} - 1$.

[10] From 1985 to July 2001 the CBC utilized an index interest rate as its policy instrument. This indexed interest rate corresponds roughly to an ex-ante real interest rate (Fuentes *et al.*, 2003).

3 Model Estimation

3.1 Empirical methodology

The model is estimated by using a Bayesian approach (see DeJong, Ingram, and Whiteman, 2000; Lubik and Schorfheide, 2005).[11]

The Bayesian approach is a system-based methodology that fits the DSGE model to a vector of time series. The estimation is based on the likelihood function generated by the solution of the log-linear version of the model. Prior distributions are used to incorporate additional information into the parameters' estimation.

Appendix A presents the log-linearized version of the model developed in the previous section. Equations (A1) through (A32) form a linear rational expectation system that can be written in canonical form as

$$\Omega_0\left(\vartheta\right)\mathbf{z}_t = \Omega_1\left(\vartheta\right)\mathbf{z}_{t-1} + \Omega_2\left(\vartheta\right)\boldsymbol{\varepsilon}_t + \Omega_3\left(\vartheta\right)\boldsymbol{\xi}_t$$

where $\mathbf{z}_t = \{\widehat{c}_t,\ \widehat{c}_{F,t},\ \widehat{c}_{H,t},\ \widehat{i}_t,\ \widehat{r}_t,\ \widehat{\pi}_t,\ \widehat{\pi}_{Z,t},\ \Delta\widehat{e}_t,\ \widehat{b}_t^*,\ \widehat{rer}_t,\ \widehat{pr}_{H,t},\ \widehat{pr}_{O,t},\ \widehat{\pi}_{H,t},\ \widehat{wr}_t,\ \widehat{mrs}_t,\ \widehat{l}_t,\ \widehat{o}_t,$ $\widehat{o}_{C,t},\ \widehat{o}_{H,t},\ \widehat{y}_t,\ \widehat{y}_{H,t},\ \widehat{x}_t,\ \widehat{m}_t,\ \widehat{a}_{H,t},\ \widehat{\zeta}_t,\ \widehat{c}_t^*,\ \widehat{pr}_{O,t}^*,\ \widehat{\psi}_t,\ \widehat{i}_t^*,\ \widehat{\pi}_t^*,\ \widehat{y}_{S,t},\ \nu_t\}$ is a vector containing the model's variables expressed as log-deviations from their steady-state values, $\boldsymbol{\varepsilon}_t = \{\varepsilon_{a,t},\ \varepsilon_{i^*,t},$ $\varepsilon_{c^*,t},\ \varepsilon_{\pi^*,t},\ \varepsilon_{\zeta,t},\ \varepsilon_{\psi,t},\ \varepsilon_{o,t},\ \varepsilon_{S,t},\ \varepsilon_{\widehat{\nu},t}\}$ is a vector containing white noise innovations to the structural shocks of the model, and $\boldsymbol{\xi}_t$ is a vector containing rational expectation forecast errors. Matrices Ω_i are non-linear functions of the structural parameters contained in vector ϑ. The solution to this system can be expressed as follows

$$\mathbf{z}_t = \Omega_z\left(\vartheta\right)\mathbf{z}_{t-1} + \Omega_\varepsilon\left(\vartheta\right)\boldsymbol{\varepsilon}_t \tag{28}$$

where Ω_z and Ω_ε are functions 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:

$$\mathbf{y}_t = H\mathbf{z}_t \tag{29}$$

where H is a matrix that selects elements from $\mathbf{z}_t$. In our case we assume that the vector of observable variables is given by $\mathbf{y}_t = \{\widehat{y}_t,\ \widehat{\pi}_{Z,t},\ \widehat{r}_t,\ \Delta\widehat{e}_t,\ \widehat{rer}_t,\ \widehat{wr}_t,\ \widehat{l}_t,\ \widehat{o}_t,\ \widehat{pr}_{O,t}^*\}$. The rest of the variables are assumed to be non-observable.

Equations (28) and (29) 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

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

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 $\mathbf{p}(\vartheta)$ be a prior density on the structural parameters. We can 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

$$\mathbf{p}\left(\vartheta \mid \mathcal{Y}^T\right) = \frac{L(\vartheta \mid \mathcal{Y}^T)\mathbf{p}(\vartheta)}{\int L(\vartheta \mid \mathcal{Y}^T)\mathbf{p}(\vartheta)\, d\vartheta} \tag{30}$$

An approximated solution for the posterior distribution is computed by using the Metropolis-Hastings algorithm (see Appendix B).

One of the advantages of the Bayesian approach is that it can cope with potential model misspecification and possible lack of identification of the parameters of interest. For example, if in a misspecified model the likelihood function peaks at a value that is at odds with the prior information of any given parameter, the posterior probability will be low. Therefore, the prior density allows to weight information about different parameters according to its reliability. On the other hand, lack of identification may lead to a likelihood function that is flat for some parameter values. Hence, based on the likelihood function alone, it may not be possible to identify some parameters of interest. In this case, a proper prior can introduce curvature into the objective function, the posterior distribution, making it possible to identify the values of different parameters (Lubik and Shorfheide, 2005).

The parameter vector to be estimated is $\vartheta = (\sigma_L,\, h,\, \theta,\, \eta,\, \eta^*,\, \varrho,\, \phi_H,\, \phi_L,\, \xi_H,\, \xi_L,\, \rho_i,\, \varpi_\pi,\, \varpi_y,\, \rho_a,\, \rho_\zeta,\, \rho_{c^*},\, \rho_\psi,\, \rho_{i^*},\, \rho_{\pi^*},\, \rho_s,\, \sigma_a,\, \sigma_\zeta,\, \sigma_{c^*},\, \sigma_\psi,\, \sigma_{i^*},\, \sigma_{\pi^*},\, \sigma_s,\, \sigma_\nu)$. Parameters ρ_o and σ_o are estimated outside the model using data on oil prices. Parameter ρ_ν is assumed to be zero. All other parameters of the model are 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%.[12] The long-run annual inflation rate is set at 3%, which is consistent with the midpoint target value for CPI inflation defined by the CBC in 1999. The subjective discount factor, β, is set at 0.99 (annual basis) in order to get an annual nominal interest rate of 7.5% in the steady state.

The share of imported goods in the consumption basket, γ, is set at 40%, while the share of Home goods in total GDP, $\frac{C_H + C_H^*}{Y}$, is set at 80%.[13] The net export to GDP ratio, $\frac{X-M}{Y}$, equals 0.5% in steady state, which is consistent with its average value in the sample period analyzed. The remaining shares can be obtained by using these values and the steady state relationships (see Appendix A). We do not have information on price and wage markups.

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

[13] Natural Resources accounts for 20% of total GDP. In our case that correspond to output of good S.

Therefore, we use values consistent with those utilized by other studies. In particular, we set $\epsilon_L = \epsilon_H = 9$.[14]

We take the steady-state share of oil in the consumption basket, $\frac{O_C}{C}$, to be 0.04. This figure is consistent with the share of fuels in the representative consumption basket utilized to compute the CPI. To compute the steady-state share of oil in the production of Home goods $\frac{O_H}{Y_H}$ we utilize the figures for the total oil imports ratio to GDP, $\frac{O_C+O_H}{Y}$, which is around 0.05, and then subtract the share of fuel consumption by households. Finally, the estimation of the autoregressive process for the real price of oil implies that $\rho_o = 0.88$ and $\sigma_o = 13.4\%$.

3.2 Data

To estimate the model we use Chilean quarterly data for the period from 1990Q1 to 2005Q1. We choose the following seven observable variables: real GDP, short-run real interest rate, a measure of core inflation computed by the Central Bank of Chile ("IPCX1"), the real exchange rate, nominal exchange rate devaluation, real wages and labor input. We also utilize series on oil imports and the real price of oil (international price of WTI oil deflated by an index of relevant external prices for the Chilean economy).

In order to work with stationary series we demean all variables. In the case of real wages and GDP we de-trend and demean the series using a linear trend. Labor input is constructed as the fraction of total employment over the working-age population. 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 latter 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 of Chile.

3.3 Prior distributions

Priors' density functions reflect our beliefs about parameter values. Setting a relatively high standard deviation for a density function implies that our prior for the corresponding parameter is more diffuse. In general, we choose priors based on evidence from previous studies for Chile. When the evidence is weak or nonexistent, we impose more diffuse priors.

[14] Christiano *et al.* (2005) use $\epsilon_L = 21$ and $\epsilon_H = 6$ for a closed economy model calibrated for US. Adolfson *et al.* (2005a) use the same values for an open economy model calibrated for the 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.

Table 1 depicts the prior distribution for each parameter contained in ϑ, its mean and the 90% probability interval. For the inverse elasticity of labor supply, σ_L, we assume an inverse gamma distribution with mode 1.0 and three degrees of freedom. This implies that the elasticity of labor supply, σ_L^{-1}, can take values between 0.2 and 1.6 in the 90% confidence interval. This is a wide range. It reflects our uncertainty with respect to this coefficient. The habit formation coefficient, h, has a beta distribution with mean 0.5 and a standard deviation of 0.25. As a result, the 90% confidence interval for this coefficient is between 0.1 and 0.9. This range is much wider than the one considered by Adolfson *et al.* (2005a) for the same coefficient in the euro area, reflecting again our uncertainty on the value for this parameter.

The probabilities that prices and wages are not reset optimally every quarter, ϕ_H and ϕ_L, respectively, are assumed to follow a beta distribution with mean 0.75 and a standard deviation of 0.05. These are similar priors to the ones considered by Adolfson *et al.* (2005a) for the euro area and by Rabanal and Rubio-Ramírez (2005) for the US. The elasticity of substitution between foreign and domestic goods, θ, follows an inverse gamma distribution with mode 1.0 and three degrees of freedom. The same prior is assumed for η^*. In this case, this elasticity can vary between 0.64 and 4.89. This wide range is in line with the one suggested by Adolfson *et al.* (2005a). The elasticity of the international supply of funds, ϱ, is assumed to follow an inverse gamma distribution with mode 0.1 and four degrees of freedom.

As in Rabanal and Rubio-Ramírez (2005), we do not impose non-negativity restrictions on the policy rule coefficients. In particular, we assume normal distributions for ϖ_π and ϖ_y. For ϖ_π we set a mean of 0.75 with a standard deviation of 0.15. For ϖ_y, we set a mean of 0.5 and a standard deviation of 0.15. As a result, the prior 90% probability interval for this coefficient goes from 0.25 to 0.75. Finally, for the interest rate smoothing coefficient, ρ_i, we assume a beta distribution with mean 0.75 and a standard deviation of 0.2. These priors are in line with the estimated policy-rule coefficients in previous studies for Chile.[15]

Following other studies, we assume a low degree of substitution of Oil in the consumption basket and also in the production function.[16] In particular, our priors are such that η and ω have inverse gamma distributions with mode 0.2 and four degrees of freedom. These distributions imply that a 90% interval for these elasticities is between 0.13 and 0.73.

The autoregressive parameters of the stochastic shocks, ρ_ζ, ρ_{i^*}, ρ_{π^*}, ρ_S, ρ_{c^*}, ρ_ψ, ρ_a have beta distributions. This means that their value should lie in the (0,1) interval range. We

[15] See Schmidt-Hebbel and Tapia (2002) and Caputo (2005).

[16] See e.g. Backus and Crucini (2000) and Frondel and Schmidt (2002) for a review of the estimates of the elasticity of energy or Oil with other inputs.

do not impose tight priors on these distributions, so shocks can be either persistent or non-persistent. In particular, for all parameters we set the prior mean at 0.7 and the standard deviation at 0.25. In this way the 90% probability interval considers values that go from 0.21 to 0.99. The variances of the shocks are assumed to be distributed as an inverse gamma distribution with two degrees of freedom. The shape of this distribution implies a rather diffuse prior, i.e., we do not have strong prior information on those coefficients. In any case, the means of the distributions are set based on previous single equation estimations and on trials with weak priors. In particular, σ_a, σ_{c^*}, σ_S, σ_ψ and σ_ζ have a prior mode of 1.0, which implies values for these parameters between 0.63 and 8.44. For σ_{i^*} the mode is set at 0.5 implying values that go from 0.31 to 4.22, whereas for σ_{π^*} and σ_m the mode is set at 0.25 and 0.20, respectively.

4 Results

Once priors have been specified, we estimate the model by first computing the posterior mode, and then constructing the posterior distribution with the Metropolis-Hastings algorithm. In table 2, we present the posterior mean of each parameter and its standard deviation under two alternative specifications for the monetary policy rule. One specification considers a rule that reacts to current CPI inflation. The other specification has a rule that targets core inflation. In order to compare these two different models, we also report the value of the log marginal likelihood.[17]

For the first model specification, the elasticity of labor supply, σ_L^{-1}, is estimated at 0.78, which is smaller than the values estimated for the US by Rabanal and Rubio-Ramírez (2005). On the other hand, the estimated habit formation coefficient, h, is 0.32. This is coherent with an autoregressive coefficient for consumption –$h/(1+h)$– of nearly 0.24, which is smaller than the one found for Europe by Adolfson *et al.* (2005a) and Caputo *et al.* (2005) for the Chilean economy. This could be explained by the explicit inclusion of Oil in the consumption basket. Since we estimate an elasticity of substitution between Oil and core consumption of less than one, the persistence of oil shocks by itself will also generate more persistence in aggregate consumption, without having to rely on habit formation.

The estimated elasticity of substitution between Home and Foreign goods in the consumption basket of domestic households, θ, is 0.6. In turn, the estimated value for demand elasticity of Home goods abroad, η^*, is 1.1. These values are somehow below the corres-

[17] As pointed out by Fernández-Villaverde and Rubio-Ramírez (2004) and Rabanal and Rubio-Ramírez (2005), the marginal likelihood can be used to compare models. An advantage of using the marginal likelihood is that it penalizes over-parametrization.

ponding ones estimated for the euro area by Adolfson *et al.* (2005a).

The estimated Calvo probabilities of not resetting optimally prices and wages, ϕ_H and ϕ_L, are 0.17 and 0.82, respectively. These figures imply that prices are set optimally more frequently than wages. In particular, prices are reset optimally every 1.2 quarters whereas wages are re-optimized, on average, every 5 to 6 quarters. The result for ϕ_H is in sharp contrast with the evidence for developed economies. Adolfson *et al.* (2005) estimations for the euro area find values for ϕ_H and ϕ_L of 0.895 and 0.710 respectively. These values imply average duration between re-optimization of prices and wages of 9.5 and 3.5 quarters, respectively. On the other hand, Rabanal and Rubio-Ramírez (2005) find that for the US, the average duration between re-optimization of prices and wages is 6.2 and 2.4 quarters. In a partial equilibrium estimation for Chile, Céspedes *et al.* (2005) find more prices stickiness than we do. In particular, they find that prices are re-optimized every 3 to 8 quarters. However, in their estimations they do not consider the cross-equation restrictions imposed by a full information approach as in this paper. Consistently with our results, Caputo *et al.* (2005) estimate that re-optimization of prices and wages in Chile take places every 1.3 and 7 quarters, respectively.[18]

Our results show a high degree of wage indexation. In particular, the coefficient ξ_L is estimated to be 0.91. In contrast, we do not find significative evidence of price indexation ($\xi_H = 0.26$). This latter result implies a reduced-form coefficient on lagged inflation in the Home goods Phillips curve, $\frac{\xi_H}{1+\beta\xi_H}$, close to 0.2. Our estimated values for ξ_L and ξ_H are consistent with the ones found by Levin *et al.* (2005) for the US economy. In particular, they estimate that the indexation of wages is about 0.8 whereas the corresponding parameter for prices is below 0.2. For Chile, Céspedes *et al.* (2005) find a much larger value for ξ_H. However, they do not consider wage indexation. Therefore, it seems that once wage indexation is introduced, price inflation inertia by itself tends to be less important to fit the aggregate data.

The results for the policy rule coefficients, ρ_i, ϖ_π and ϖ_y tend to confirm the findings of previous research. First there is a degree of interest rate smoothing. However, the posterior mean of ρ_i is slightly smaller than previous estimates for Chile. Second, the response of the interest rate to inflation deviation from target is relatively more important than the response to output growth deviation from trend. In particular, ϖ_π is estimated to be 0.85, whereas ϖ_y is 0.12.

The estimated value of the elasticity of substitution between oil and core consumption, η, is higher that the one between labor and oil in production, ω. In particular, η is estimated

[18] It is important to mention that Caputo *et al.* (2005) use the same methodology as in this paper and a similar data set.

to be around 0.66, whereas ω is 0.51. These values lie in the upper range of the support of the corresponding prior distributions.

If we compare this estimation with the one presented by Caputo *et al.* (2005) for a model of Chilean economy that excludes the effects of Oil, we see that the estimated rigidities are smaller when Oil is included. The persistence of the oil price shock ($\rho_o = 0.88$) introduces inertia through its effect on core consumption and marginal costs. Hence, the estimated magnitude of rigidities has to be smaller in order to explain the dynamics of the aggregate data.

The estimated posterior mean of several structural parameters does not change significantly when the model includes a monetary policy rule that targets core inflation. Exceptions are the coefficients in the monetary policy rule. Although the coefficient that captures the reaction of the interest rate to core inflation is similar to the one found in the previous case, the rule features less persistency and almost no reaction to GDP growth. The posterior mean of the elasticity of substitution of oil in the consumption basket under this specification is smaller than the one in the production function. Nevertheless, the estimated values of both parameters are quite similar to the previous case.

The apparent similarity between both specification disappears when one looks at the log marginal likelihood (last row in table 2). This statistic highlights that a model with a monetary rule that targets core inflation makes a better account of the Chilean data *vis-à-vis* a model with a policy rule that targets CPI inflation. This result does not imply that monetary policy in Chile has not reacted to oil-price shocks. What it does show is that monetary policy has not responded to the direct inflationary consequences of oil-price shocks on CPI inflation. Rather, monetary policy has reacted to the increases in costs associated to these shocks and, consequently, to their effects on core inflation. In other words, monetary policy has been more concerned with the "second-round" effects of oil-price shocks.

5 Effects of an Oil-Price Shock

In this section we discuss the effects of an oil shock –an increase in the real price of oil– on different domestic variables. We present some impulse-response functions generated under the preferred model and we compare the outcome with the one that would have been obtained under different policy rules, and under flexible wages and prices. As discussed in the previous section, the model that better fits the Chilean data over the last fifteen years is a model where the monetary policy targets core rather than CPI inflation. Therefore, the baseline policy rule for the impulse-response analysis corresponds to that rule. To compute the impulse-response functions we use the posterior mean of the structural parameters presented in table 2.

Figure 1 shows the responses of the main aggregate variables to an unanticipated increase of the real price of oil of 13% (one standard deviation) under the estimated baseline policy rule. Given that a fraction of households' expenditure is devoted to oil consumption –and since the economy is a net oil importer– the rise in the oil price implies a negative income effect that contracts domestic consumption. As a consequence, the demand for all three types of goods in the consumption basket falls. There is also a substitution effect that tends to increase the demand for both Home and Foreign goods. However, since the degree of substitution between oil and the other types of goods is low, this effect does not counteract the negative income effect on the demand for Home goods. Moreover, the shock also pushes up the cost of firms producing these types of goods, and their prices relative to the prices of Foreign goods increases. Therefore, there is an additional expenditure-switching mechanism that lowers even further the demand for Home goods.

The negative income effect of the shock and the consequent contraction in consumption induces an expansion in labor supply. However, there is also a contraction in labor demand by firms producing Home goods. Those firms tend to hire more labor to substitute for the more expensive oil. However, the elasticity of substitution between those two inputs is low. Moreover, the decrease in the demand for Home goods dominates this substitution effect and the resulting labor demand falls. Thus, total employment falls by approximately 0.8% during the first year after the shock. Total GDP, in turn, falls by a slightly smaller amount. Real wages fall by 0.4% on impact and then slowly converge to their steady-state level.

The path of core inflation is moderately stabilized by the monetary policy. core inflation drops slightly on impact (due to a nominal appreciation of the exchange rate) and then increases up to 0.2% above its target level in the second quarter after the shock. This deviation above target of core inflation disappears slowly over time. Total inflation deviates almost 0.5% above the target initially which is mainly explained by the direct incidence of the oil price in the CPI. However, the subsequent deviations are related to deviations of core inflation from target. The observed real appreciation of 1% is consistent with the sharp increase in the CPI after the shock. The real interest rate increases significantly (50 basis points) in the second quarter after the oil price shock, and slowly returns to its neutral level.

Since the monetary policy reacts by increasing the real interest rate, it is not clear if the contractive consequence of the oil price shock are due the shock itself or just the consequence of the endogenous response of the policy. To shed some light on the degree of stabilization that monetary policy can achieve, we analyze how the economy would have responded after the same oil price shock under alternative monetary regimes.

As a first benchmark case, figure 2 shows the effects of an increase in the oil price under flexible prices and wages. Given that the only two nominal rigidities in our model are those of prices and wages, this flexible wages and prices case corresponds to the second best equilibrium outcome.[19] In this case, there is a slightly increase in GDP in response to the shock, which is explained by the increase in employment. When wages are flexible, the negative effect of the oil price shock on households' income leads to an expansion in labor supply that generates a significative reduction in real wages. This contrasts with the baseline case, when the two nominal rigidities are present, where the fall in the real wage is lower and also less persistent. This fall in the real wages induces a stronger substitution effect in production, that results in a small expansion of employment.

It is important to notice that in our model this second-best outcome is not feasible under both price and wage rigidities. In other words, it is not possible for monetary policy alone to replicate the allocation that would be obtained under flexible wages and prices (see Erceg, Henderson and Levin 2000; Blanchard and Galí, 2005). Moreover, given that wages are sticky, and given the presence of wage indexation, if the monetary policy tries to replicate the flexible price (not flexible wages) allocation, the system becomes undetermined.

For that reason, as a second benchmark case we compare the responses to the oil price shock when the monetary policy follows a contingent rule that undoes the nominal wage rigidity. Figure 3 depicts the impulse-response functions under this alternative rule. Like in the case with flexible wages and prices, the negative response of real wages implies a less severe contraction in labor demand which reduces the contractionary effect of the oil price shock on output. In presence of wages rigidities, this fall in the real wage is achieved by means of an unanticipated increase in total inflation. Therefore, this alternative policy rule conveys a lower monetary contraction than under the baseline case. However, this policy also generates a response of both CPI and core inflation that is three times larger than under the baseline policy rule. In other words, this policy achieves a significative stabilization of output –which is much closer to the second best outcome–, but at the cost of more and more persistent deviation of inflation from target. Moreover, when the credibility of the central bank in controlling the inflation depends on its observed deviation from target, this policy may lead to a lose in the reputation of the monetary authority.

Figure 4 shows the responses under a rule that targets CPI inflation. For this case, we use the same coefficients of the rule under the preferred model, but we replace core inflation by CPI inflation in the specification. This policy is more contractionary after the oil price shock, generating in the short run a higher contraction in GDP. In contrast, CPI inflation

[19] The first best outcome is a allocation that also undoes the distortions generated by the monopoly power of workers and firms.

deviates by less form its targets, but core inflation becomes more volatile. Since inflation jumps up by less under this policy, real wages fall also by less than in the preferred model. As a consequence, employment and GDP fall more under this policy. In summary, the relative success of reducing the increase in CPI nflation in the short run contrasts with a more significative deviation of core inflation, GDP and employment with respect its steady state values. The negative consequence of stabilizing CPI inflation can be seen more clearly in the case of policy that follows a strict CPI inflation targeting. The responses of the aggregate variables after the same oil price shock under this monetary arrangement are shown in figure 5. In this case, monetary policy is much more contractionary. Employment falls more than 1% whereas the higher increase in interest rate implies a bigger appreciation. The full stabilization of inflation is achieved through a fall in core inflation on impact, which is a direct consequence of the nominal exchange rate appreciation.

6 Conclusions

In this paper we present an estimated dynamic stochastic general equilibrium (DSGE) model for the Chilean economy. The model is framed in the New Keynesian tradition, where firms are assumed to adjust prices infrequently and wages are set in a staggered fashion. Oil is used as an input in production and it is also part of the consumption basket of households. We allow for a flexible elasticity of substitution between oil and other types of consumption goods in the consumption bundle, and also in the technology utilized by domestic firms. Key structural parameters of the model are jointly estimated following a Bayesian approach as in Smets and Wouters (2003), Schorfheide (2000), DeJong, Ingram, and Whiteman (2000), and Fernandez-Villaverde and Rubio-Ramirez (2004).

Using the estimated model we simulate how the monetary policy would respond to an oil shock under the policy rule that best describes the behavior of the Central Bank of Chile (CBC) over the last fifteen years. This rule is a Taylor type policy reaction function for the real interest, where the central bank responds to deviation of core inflation from target. We then compute the counter-factual policy response under alternative monetary frameworks. In one case, we let the monetary policy to undo wages rigidities by replicating the flexible wages equilibrium. In another case, we consider a policy that is aimed at fully stabilize consumer price inflation (CPI inflation). We also compute the endogenous response of the monetary policy under a flexible CPI inflation targeting regime.

Our main results are the following. First, an oil price shock has a contractionary effect on output. A 13% increase in the real price of oil leads to a fall in output of about 0.5% and an increase in inflation of about 0.4%. Second, the contractionary effect of the oil shock is due mainly to the endogenous tightening of the monetary policy. Third, a policy that counteracts wages rigidities delivers an aggregate real allocation that is closer to the second-best outcome than the allocation obtained under a policy rule that targets core inflation deviation from target. However, the cost of this policy is an inflation response to the oil shock that is three times larger than under the last policy. Fourth, a policy rule that targets CPI inflation delivers an outcome that is very close to the one obtained under core inflation targeting. However, if the central bank tries to fully stabilize inflation there would be a considerably decrease in output.

Appendix

A Log-linearized model

The model is log-linearized using Taylor expansions around the steady state. In order to simplify the model we normalize the steady state level of productivity to $A_H = \frac{\epsilon_H}{\epsilon_H - 1}$. We also normalize the steady state labor disutility parameter ζ so that the real wage is one. Under these two normalizations and properly choosing the foreign currency price level of imported goods all relative prices are one.

Let a variable in lowercase with a hat represent the log deviation with respect to the steady state. In what follows a "real" price, denoted by $\widehat{pr}_{J,t}$, is the corresponding nominal price of good J relative to the price of the consumption bundle $\widehat{pr}_{J,t} = \widehat{p}_{J,t} - \widehat{p}_t$. Analogously, the real wage corresponds to the nominal wage relative to the CPI, $\widehat{wr}_t = \widehat{w}_t - \widehat{p}_t$.

A.1 Aggregate Demand

We detrend and log-linearize expressions (4) and (5) to obtain the following expressions for domestic consumption of Home and Foreign goods, and oil consumption

$$\widehat{c}_{H,t} = (1-\gamma)(\theta-\eta)\,\widehat{rer}_t - (\theta(1-\gamma)+\gamma\eta)\,\widehat{pr}_{H,t} + \widehat{c}_t \tag{A1}$$

$$\widehat{c}_{F,t} = -(\theta\gamma+\eta(1-\gamma))\,\widehat{rer}_t + \gamma(\theta-\eta)\,\widehat{pr}_{H,t} + \widehat{c}_t \tag{A2}$$

$$\widehat{o}_{C,t} = -\eta\widehat{pr}_{O,t} + \widehat{c}_t \tag{A3}$$

where $\widehat{rer}_t = \widehat{e}_t + \widehat{p}^*_{F,t} - \widehat{p}_t$ is the log-deviation of the real exchange rate from its steady-state level. We are assuming that the law of one price holds for the imported good, meaning that $\widehat{p}_{F,t} = \widehat{e}_t + \widehat{p}^*_{F,t}$, where $\widehat{p}^*_{F,t}$ is imported good price in foreign currency.

The optimal conditions can be combined to obtain log-linear expressions for the Euler equation and for the uncovered interest parity condition:

$$\widehat{c}_t = \frac{1}{1+h}E_t\widehat{c}_{t+1} + \frac{h}{1+h}\widehat{c}_{t-1} - \frac{1-h}{1+h}(\widehat{i}_t - E_t\widehat{\pi}_{t+1}) \tag{A4}$$

$$\widehat{i}_t = \widehat{i}^*_t + E_t\Delta\widehat{e}_{t+1} + \varrho\widehat{b}^*_t \tag{A5}$$

where $\widehat{b}^*_t = \ln\left(\frac{\mathcal{E}_t B^*_t}{P_{X,t}X_t} / \frac{\mathcal{E}B^*}{P_X X}\right)$. The foreign interest rate $\widehat{i}^*_t$ captures not only the relevant interest rate in the international market but also any exogenous fluctuation in the risk premium not captured by $\varrho\widehat{b}^*_t$. The process for this variable is given by

$$\widehat{i}^*_t = \rho_{i^*}\widehat{i}^*_{t-1} + \varepsilon_{i^*,t} \tag{A6}$$

A.2 Aggregate Supply and Inflation

From the optimal price setting and the passive resetting price equation (17) we obtain the following expression for the inflation of Home goods:

$$\begin{aligned}\widehat{\pi}_{H,t} \quad = \quad & \frac{(1-\phi_H)(1-\beta\phi_H)}{\phi_H(1+\beta\xi_H)}\left((1-\alpha)\,\widehat{wr}_t + \alpha\widehat{pr}_{O,t} - \widehat{a}_{H,t} - \widehat{pr}_{H,t}\right) + \\ & \frac{\beta}{1+\beta\xi_H}E_t\widehat{\pi}_{H,t+1} + \frac{\xi_H}{1+\beta\xi_H}\widehat{\pi}_{H,t-1} \end{aligned} \tag{A7}$$

The first order condition for cost minimization problem of firms producing Home goods determines the following relation between the quantity demanded of both inputs, labor and oil, and their relative prices:

$$\widehat{o}_{H,t} - \widehat{l}_t = \omega\left(\widehat{wr}_t - \widehat{pr}_{O,t}\right) \tag{A8}$$

From the production function we obtain the following log-linearized version output in the Home goods sector:

$$\widehat{y}_{H,t} = \widehat{a}_{H,t} + (1-\alpha)\,\widehat{l}_t + \alpha\widehat{o}_{H,t}\ , \tag{A9}$$

where the technology in the Home goods sectors evolves according to

$$\widehat{a}_{H,t} = \rho_a\widehat{a}_{H,t-1} + \varepsilon_{a,t}\ . \tag{A10}$$

Combining the optimal choice of wages with the updating rule and the definition of the aggregate real wages we can obtain the following log-linear expression:

$$\begin{aligned}&\frac{1+\nu_L\phi_L+\sigma_L\epsilon_L(\phi_L+\nu_L)}{1+\sigma_L\epsilon_L}\widehat{wr}_t - \phi_L\widehat{wr}_{t-1} - \nu_L E_t\widehat{wr}_{t+1} = \\ &\frac{(1-\nu_L)(1-\phi_L)}{1+\sigma_L\epsilon_L}\widehat{mrs}_t - (\phi_L+\nu_L\xi_L)\,\widehat{\pi}_t + \phi_L\xi_L\widehat{\pi}_{t-1} + \nu_L E_t\widehat{\pi}_{t+1} + \widehat{\zeta}_t\end{aligned} \tag{A11}$$

and where $\nu_L = \beta\phi_L$. Variable $\widehat{\zeta}_t = \frac{(1-\nu_L)(1-\phi_L)}{1+\sigma_L\epsilon_L}\ln\left(\frac{\zeta_t}{\zeta}\right)$ is a preference shock —a shock to the labor disutility parameter. We assume that this variable is stochastic and it follows

$$\widehat{\zeta}_t = \rho_\zeta\widehat{\zeta}_{t-1} + \varepsilon_{\zeta,t} \tag{A12}$$

with $E_{t-1}\left(\varepsilon_{\zeta,t}\right) = 0$ and $E_{t-1}\left(\varepsilon^2_{\zeta,t}\right) = \sigma^2_\zeta$.

The marginal rate of substitution between labor and consumption, $\widehat{mrs}_t$, is given by

$$\widehat{mrs}_t = \sigma_L\widehat{l}_t + \frac{1}{1-h}\widehat{c}_t - \frac{h}{1-h}\widehat{c}_{t-1} \tag{A13}$$

A.3 Relative prices

The real price of Home goods and the domestic currency real price of oil evolve according to the following equations:

$$\widehat{pr}_{H,t} = \widehat{pr}_{H,t-1} + \widehat{\pi}_{H,t} - \widehat{\pi}_t \tag{A14}$$

$$\widehat{pr}_{O,t} = \widehat{rer}_t + \widehat{pr}^*_{O,t} + \widehat{\psi}_t \tag{A15}$$

The real price of oil abroad –the relative price of oil abroad with respect to the foreign price index– evolves according to the following expression:

$$\widehat{pr}^*_{O,t} = \rho_o \widehat{pr}^*_{O,t-1} + \varepsilon_{o,t} \tag{A16}$$

with $E_{t-1}(\varepsilon_{o,t}) = 0$ and $E_{t-1}\left(\varepsilon^2_{o,t}\right) = \sigma^2_o$

We assume that the variable that captures deviation of the law of one price for oil, $\widehat{\psi}_t$, follows an AR(1) process:

$$\widehat{\psi}_t = \rho_\psi \widehat{\psi}_{t-1} + \varepsilon_{\psi,t} \tag{A17}$$

Let $\widehat{\pi}^*_t = \widehat{p}^*_{F,t} - \widehat{p}^*_{F,t-1}$ be foreign inflation expressed in foreign currency. From the definition of the real exchange rate we obtain the following expression for the evolution of this variable:

$$\widehat{rer}_t = \widehat{rer}_{t-1} + \Delta\widehat{e}_t + \widehat{\pi}^*_t - \widehat{\pi}_t \tag{A18}$$

Foreign inflation evolves according to the following exogenous process:

$$\widehat{\pi}^*_t = \rho_{\pi^*} \widehat{\pi}^*_{t-1} + \varepsilon_{\pi^*,t} \tag{A19}$$

with $E_{t-1}(\varepsilon_{\pi^*,t}) = 0$ and $E_{t-1}\left(\varepsilon^2_{\pi^*,t}\right) = \sigma^2_{\pi^*}$.

Finally, from the definition of the CPI and the core consumption price level we have the following relation among the real price of oil, the real price of Home goods and the real exchange rate:

$$0 = \delta\widehat{pr}_{O,t} + (1-\delta)\gamma\widehat{pr}_{H,t} + (1-\delta)(1-\gamma)\widehat{rer}_t \tag{A20}$$

A.4 Aggregate Equilibrium

Using the log-linear expression of equations (A21) and (19) we can express the market clear condition for the Home goods sector as:

$$\widehat{y}_{H,t} = \frac{C_H}{Y_H}\widehat{c}_{H,t} + \frac{Y_H - C_H}{Y_H}\widehat{c}^*_t - \eta^*\frac{Y_H - C_H}{Y_H}\left(\widehat{pr}_{H,t} - \widehat{rer}_t\right) \tag{A21}$$

The ratio $\frac{C_H}{Y_H}$ corresponds to the steady state fraction of Home goods that is consumed by domestic households. From the definition of total GDP we get the following expression for the log-linearized total output

$$\widehat{y}_t = \frac{C}{Y}\widehat{c}_t + \frac{X}{Y}\widehat{x}_t - \frac{M}{Y}\widehat{m}_t \tag{A22}$$

where $\frac{C}{Y}$ is the consumption ratio to GDP in steady state, $\frac{X}{Y}$ is total exports to GDP ratio and $\frac{M}{Y}$ is the total imports to GDP ratio.

The detrended and log-linearized expression for exports can be expressed as:

$$\widehat{x}_t = -\eta^* \frac{C_H^*}{X}\left(\widehat{pr}_{H,t} - \widehat{rer}_t\right) + \frac{C_H^*}{X}\widehat{c}_t^* + \frac{Y_S}{X}\widehat{y}_{S,t} \tag{A23}$$

The evolution of commodity exports, $\widehat{y}_{S,t}$ and total foreign consumption, $\widehat{c}_t^*$, are assumed to be determined by the following exogenous processes:

$$\widehat{y}_{S,t} = \rho_S \widehat{y}_{S,t-1} + \varepsilon_{S,t} \tag{A24}$$

$$\widehat{c}_t^* = \rho_{c^*}\widehat{c}_{t-1}^* + \varepsilon_{c^*,t} \tag{A25}$$

The real price index of exports is –exports deflator relative to the consumer price index– is given by, $\widehat{pr}_{X,t} = \frac{C_H^*}{X}\widehat{pr}_{H,t}$, where we are assuming that the real price of commodity exports is constant, which implies that $\widehat{pr}_{S,t} = 0$.

The detrended and log-linearized expression for imports and its real price are given by:

$$\widehat{m}_t = \frac{C_F}{M}\widehat{c}_{F,t} + \frac{M - C_F}{M}\widehat{o}_t \tag{A26}$$

where total oil imports are given by:

$$\widehat{o}_t = \frac{O_C}{O}\widehat{o}_{C,t} + \frac{O_H}{O}\widehat{o}_{H,t} \tag{A27}$$

The real price index of imports –imports deflator relative to the consumer price index– is given by $\widehat{pr}_{M,t} = \frac{C_F}{M}\widehat{rer}_t + \frac{O}{M}\widehat{pr}_{O,t}^*$.

The net foreign asset position of the domestic economy evolves according to the following expression:

$$\begin{aligned}(1-\varrho)\,\beta\widehat{b}_t^* \quad &= \quad \beta i_t^* + \chi\widehat{b}_{t-1}^* + \chi\widehat{x}_{t-1} + \frac{C_H^*}{X}\chi\widehat{pr}_{H,t-1} + \chi\left(\Delta\widehat{s}_t - \pi_t\right) \\ &\quad + \left(\frac{P_X X}{\mathcal{E}B} - \beta\right)\widehat{x}_t + \left(\frac{P_X X}{\mathcal{E}B} - \beta\right)\frac{C_H^*}{X}\widehat{pr}_{H,t} \\ &\quad - \frac{P_X X}{\mathcal{E}B}\frac{M}{X}\widehat{m}_t - \frac{P_X X}{\mathcal{E}B}\frac{C_F}{X}\widehat{rer}_t - \frac{P_X X}{\mathcal{E}B}\frac{O}{X}\widehat{pr}_{O,t}^*\end{aligned} \tag{A28}$$

where $\chi = \frac{1}{(1+\pi^*)(1+g_y)}$.

A.5 Policy Rule

The linearized version of the baseline policy rule can be expressed as:

$$\widehat{r}_t = \rho\widehat{r}_{t-1} + (1-\rho)\,\varpi_\pi\widehat{\pi}_t + (1-\rho)\,\varpi_y\,(\widehat{y}_t - \widehat{y}_{t-1}) + \widehat{\nu}_t \tag{A29}$$

where $\widehat{r}_t$ corresponds to deviation of the real interest rate from its steady state value, defined as:

$$\widehat{r}_t = \widehat{i}_t - E_t\widehat{\pi}_{t+1} \tag{A30}$$

As we mentioned, we also consider an alternative rule where instead of CPI inflation the central bank targets core inflation, $\widehat{\pi}_{Z,t}$, which can be expressed as:

$$\widehat{\pi}_{Z,t} = \widehat{\pi}_t - \frac{\delta}{1-\delta}\Delta\widehat{pr}_{O,t} \tag{A31}$$

Finally, we assume that the monetary shock is given by

$$\widehat{\nu}_t = \rho_\nu\widehat{\nu}_{t-1} + \varepsilon_{\nu,t} \tag{A32}$$

B Bayesian Algorithm

In order to derive the posterior distribution of the coefficients, we proceed in two steps. First, we find the posterior mode, which is the most likely point in the posterior distribution, and computed the Hessian at the mode. In doing so, we use a standard optimization routine.[20] In this case the likelihood function is computed by first solving the model and then using the Kalman filter. Second, we implement the Metropolis-Hastings algorithm to generate draws from the posterior. The algorithm generates a sequence of draws that is path dependent and it works as follows:

1. Start with an initial value of the parameters, say ϑ^0. Then, compute the product of the likelihood and the prior at this point: $L(\vartheta^0/\mathcal{Y}^T)\mathbf{p}(\vartheta^0)$.

2. From ϑ^0, generate a random draw ϑ^1 such that $\vartheta^1 = \vartheta^0 + \upsilon^1$, where υ^1 follows a multivariate normal distribution whose variance-covariance matrix is proportional to the inverse Hessian of the likelihood function evaluated at the posterior mode. Then, for ϑ^1 compute $L(\vartheta^1/\mathcal{Y}^T)\mathbf{p}(\vartheta^1)$.

3. The new draw ϑ^1 is accepted with probability R and is rejected with $(1-R)$, where $R = \min\left\{1, \frac{L(\vartheta^1/\mathcal{Y}^T)\mathbf{p}(\vartheta^1)}{L(\vartheta^0/\mathcal{Y}^T)\mathbf{p}(\vartheta^0)}\right\}$.

   If the draw is accepted, generate another draw $\vartheta^2 = \vartheta^1 + \upsilon^2$ as in step 2. On the contrary, if the draw is rejected, we go back to the initial value, ϑ^0, and generate another draw. The idea of this algorithm is that, regardless of the starting value, more draws will be accepted from the regions of the parameter space where the posterior density is high. At the same time, areas of the posterior support with low density are less represented, but will eventually be visited. In practice we implement this algorithm with 5,000 draws.

B.1 Model Comparison

In order to compare alternative model specifications, we make use of the marginal likelihood function. This is the probability that the model assigns to having observed the data. It is defined as the integral of the likelihood function across the parameter space using the prior as the weighting function:

$$\mathbf{p}\left(\mathcal{Y}^T \mid \mathbb{M}_i\right) = \int L\left(\vartheta \mid \mathcal{Y}^T, \mathbb{M}_i\right) \mathbf{p}\left(\vartheta \mid \mathbb{M}_i\right) d\vartheta$$

[20] The `csminwel` command in Matlab.

where $\mathbf{p}\left(\mathcal{Y}^T \mid \mathbb{M}_i\right)$ is the probability of having observed the data under model specification $\mathbb{M}_i$, whereas $L\left(\vartheta \mid \mathcal{Y}^T, \mathbb{M}_i\right)$ and $\mathbf{p}\left(\vartheta \mid \mathbb{M}_i\right)$ are, respectively, the likelihood function and the prior distribution under model specification $\mathbb{M}_i$. A natural way of assessing which model is more plausible, is to construct the ratio of the marginal likelihood functions under alternative model specifications. This ratio is known as the Bayes factor and takes the form:

$$\mathbf{B}_{i,j} = \frac{\mathbf{p}\left(\mathcal{Y}^T \mid \mathbb{M}_i\right)}{\mathbf{p}\left(\mathcal{Y}^T \mid \mathbb{M}_j\right)}$$

where $\mathbf{B}_{i,j}$ is the Bayes factor of model i over model j. As is clear, if $\mathbf{B}_{i,j} > 1$, model i is more plausible than model j and viceversa. Since we are unable to obtain the marginal likelihood function in a closed-form we estimate it as in Geweke (1998) and Rabanal and Rubio-Ramírez (2005). In particular, we integrate over the draws used to construct the posterior distribution.

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Table 1: Prior Densities

Param.	Description	Density	mean/moda	sd/df	90% interval	
σ_L	Inv. labor elasticity	Inverse Gamma	1.00	3.00	0.64	4.89
h	Habit coefficient	Beta	0.50	0.25	0.10	0.90
ϕ_H	Price rigidity	Beta	0.75	0.05	0.66	0.83
ϕ_L	Wage rigidity	Beta	0.75	0.05	0.66	0.83
θ	H/F elast. substit.	Inverse Gamma	1.00	3.00	0.64	4.89
η^*	Elast. frgn demand	Inverse Gamma	1.00	3.00	0.64	4.89
ϱ	Elast. risk. premium	Inverse Gamma	0.10	4.00	0.06	0.37
ξ_L	Weight past inflation	Beta	0.50	0.25	0.10	0.90
ξ_H	Weight past inflation	Beta	0.50	0.25	0.10	0.90
η	core/oil elast. subst.	Inverse Gamma	0.20	4.00	0.13	0.73
ω	Labor/oil elasticity	Inverse Gamma	0.20	4.00	0.13	0.73
ρ_i	AR policy rule	Beta	0.75	0.20	0.35	0.99
ϖ_π	Inf. weight pol. rule	Normal	0.75	0.15	0.50	1.00
ϖ_x	Out. weight pol. rule	Normal	0.50	0.15	0.25	0.75
ρ_a	AR product. shock	Beta	0.70	0.25	0.21	0.99
ρ_S	AR exports shock	Beta	0.70	0.25	0.21	0.99
ρ_{c^*}	AR frgn. cons. shock	Beta	0.70	0.25	0.21	0.99
ρ_{i^*}	AR frgn int. shock	Beta	0.70	0.25	0.21	0.99
ρ_{π^*}	AR frgn. inflat shock	Beta	0.70	0.25	0.21	0.99
ρ_ζ	AR utility shock	Beta	0.70	0.25	0.21	0.99
ρ_ψ	AR oil lop shock	Beta	0.70	0.25	0.21	0.99
σ_a	s.d. product. shock	Inverse Gamma	1.00	2.00	0.63	8.44
σ_S	s.d. exports shock	Inverse Gamma	1.00	2.00	0.63	8.44
σ_{c^*}	s.d. frgn. cons. shock	Inverse Gamma	1.00	2.00	0.63	8.44
σ_{i^*}	s.d. frgn int. shock	Inverse Gamma	0.50	2.00	0.32	4.22
σ_{π^*}	s.d. frgn. inflat shock	Inverse Gamma	0.25	2.00	0.16	2.11
σ_ν	s.d. monetary shock	Inverse Gamma	0.20	2.00	0.13	1.69
σ_ζ	s.d. utility shock	Inverse Gamma	1.00	2.00	0.63	8.44
σ_ψ	s.d. oil lop shock	Inverse Gamma	1.00	2.00	0.63	8.44

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

Table 2: Posterior distributions

Param.	Description	Monetary Policy reacts to CPI Inflation		Monetary Policy reacts to core Inflation	
		mean	st. Dev.	mean	st. Dev.
σ_L	Inv. labor elasticity	0.781	0.141	0.959	0.102
h	Habit coefficient	0.324	0.104	0.254	0.040
ϕ_H	Price rigidity	0.166	0.013	0.159	0.026
ϕ_L	Wage rigidity	0.819	0.019	0.804	0.005
θ	H/F elast. substit.	0.616	0.183	0.612	0.143
η^*	Elast. frgn demand	1.140	0.174	1.052	0.178
ϱ	Elast. risk. premium	0.012	0.004	0.010	0.001
ξ_L	Weight past inflation	0.908	0.079	0.920	0.028
ξ_H	Weight past inflation	0.257	0.143	0.276	0.081
η	core/oil elast. subst.	0.656	0.006	0.568	0.010
ω	Labor/oil elasticity	0.507	0.045	0.660	0.095
ρ_i	AR policy rule	0.331	0.256	0.247	0.112
$\varpi_p i$	Inf. weight pol. rule	0.850	0.032	0.835	0.028
ϖ_x	Out. weight pol. rule	0.120	0.263	-0.004	0.147
ρ_a	AR product. shock	0.936	0.017	0.931	0.032
ρ_S	AR exports shock	0.917	0.013	0.915	0.015
ρ_{c^*}	AR frgn. cons. shock	0.887	0.021	0.865	0.013
ρ_{i^*}	AR frgn int. shock	0.991	0.027	1.000	0.000
ρ_{π^*}	AR frgn. inflat shock	0.140	0.114	0.074	0.032
ρ_ζ	AR utility shock	0.521	0.198	0.480	0.143
ρ_ψ	AR oil lop shock	0.968	0.017	0.971	0.007
σ_a	s.d. product. shock	3.019	0.224	3.146	0.103
σ_S	s.d. exports shock	5.341	0.118	5.201	0.037
σ_{c^*}	s.d. frgn. cons. shock	4.659	0.055	4.872	0.029
σ_{i^*}	s.d. frgn int. shock	0.474	0.189	0.355	0.074
σ_{π^*}	s.d. frgn. inflat shock	1.167	0.019	1.361	0.073
σ_ν	s.d. monetary shock	0.627	0.140	0.612	0.061
σ_ζ	s.d. utility shock	3.115	1.302	3.924	0.928
σ_ψ	s.d. oil lop shock	5.376	0.153	5.301	0.002
Log marginal likelihood		-3049.3		-3021.9	

Figure 1: Baseline policy rule

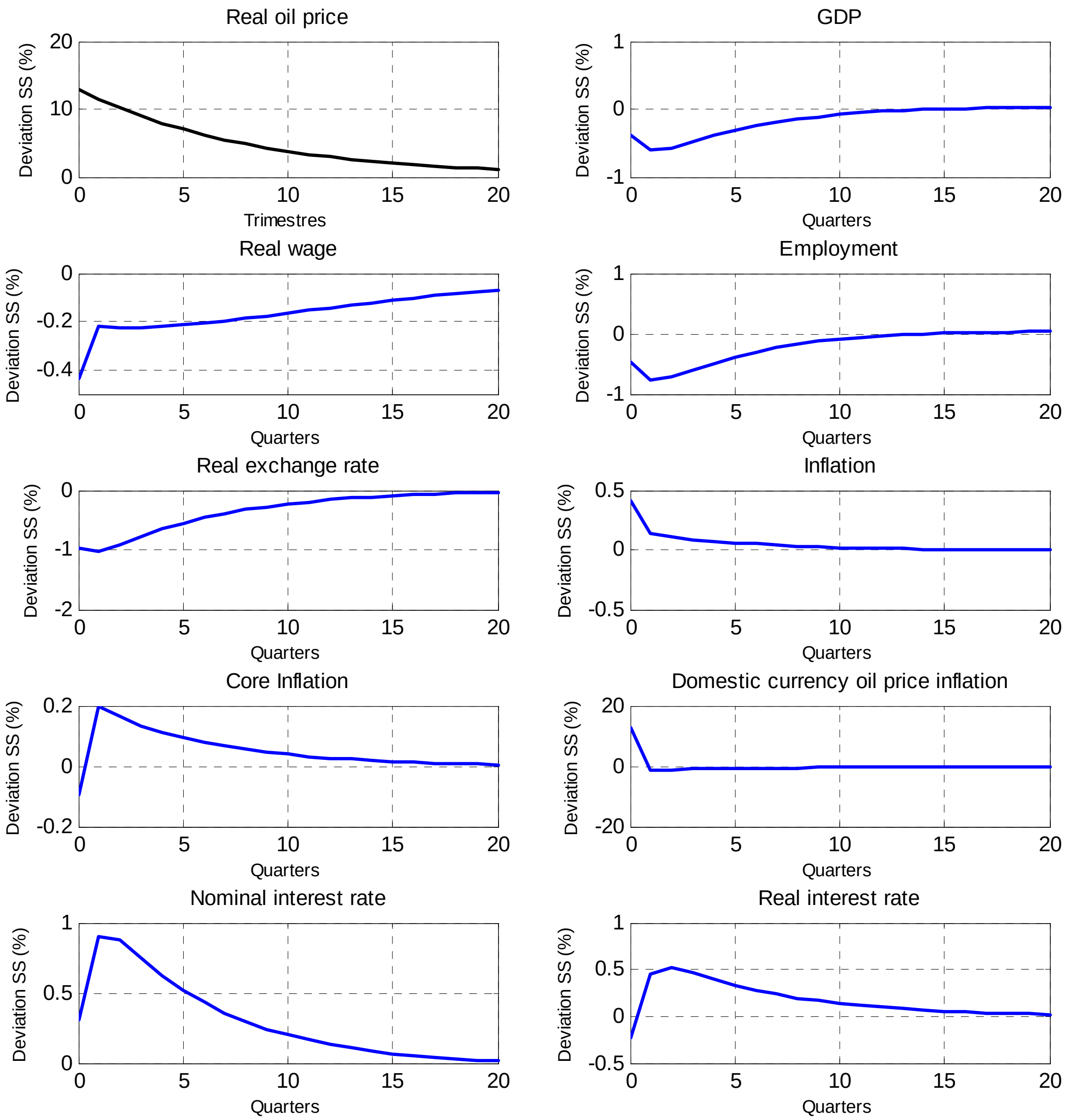

Figure 2: Flex. prices and wages

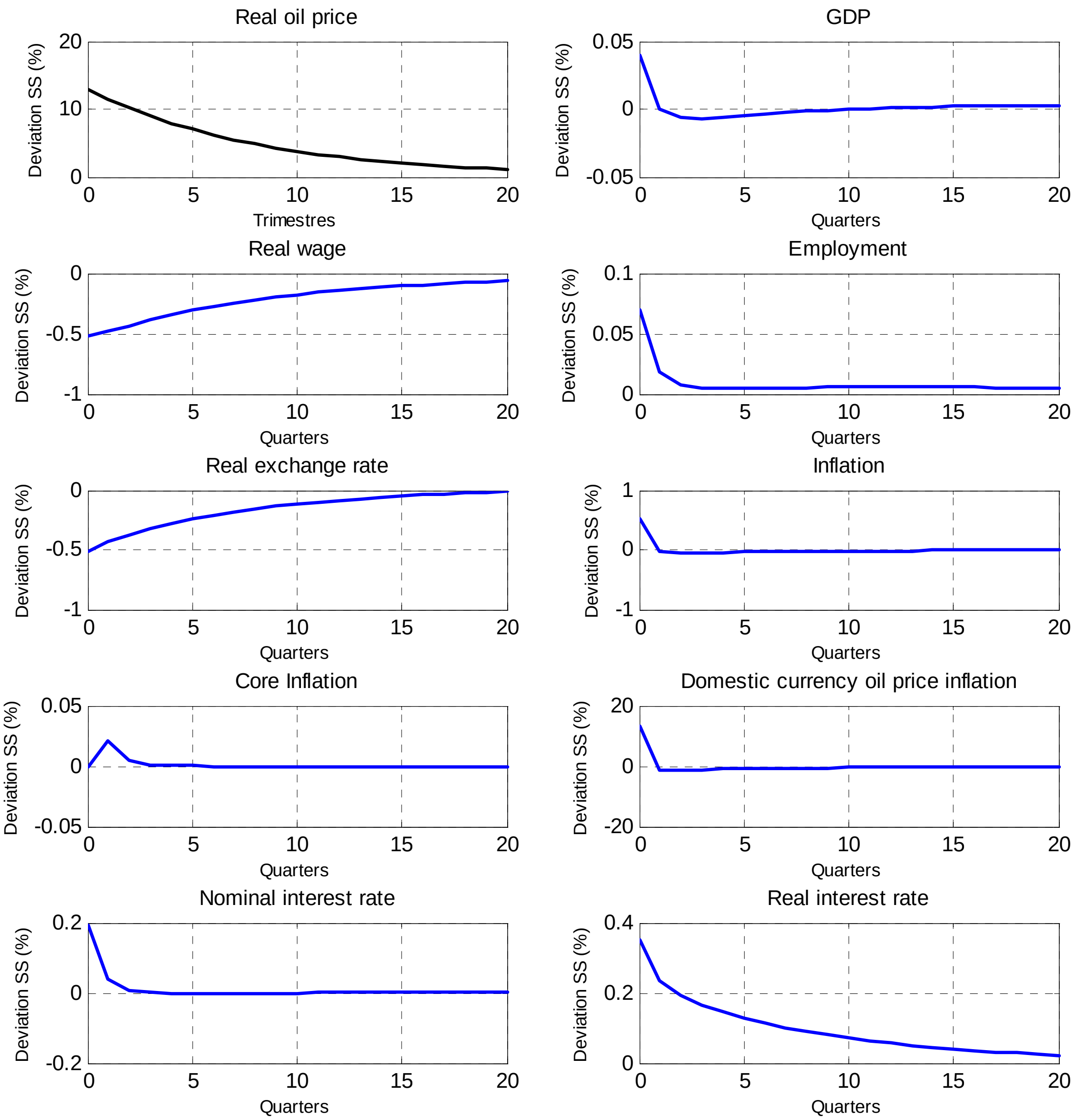

Figure 3: Policy that undoes wages rigidity

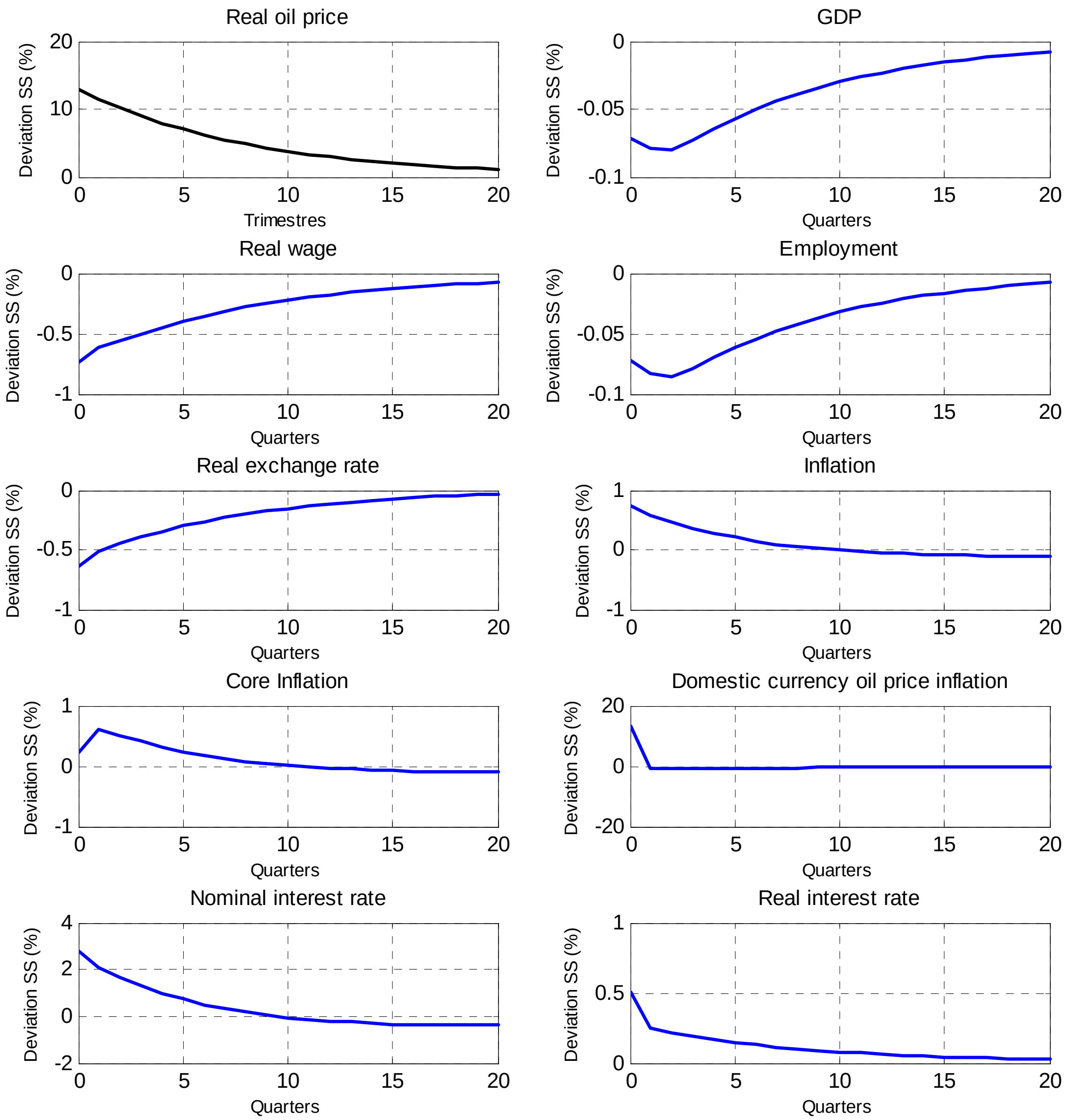

Figure 4: CPI targeting

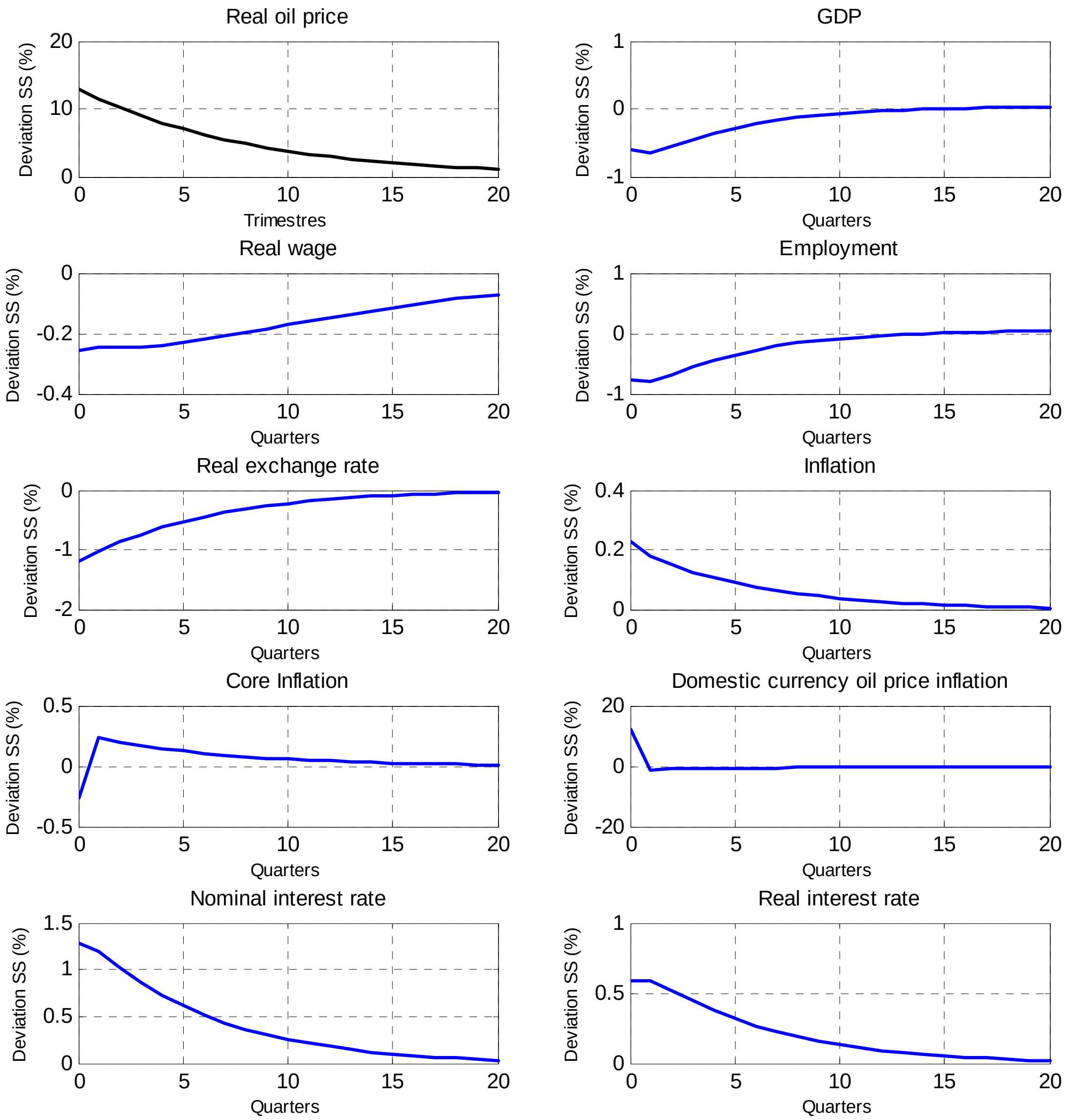

Figure 5: Policy that stabilizes CPI inflation