DOCUMENTOS DE TRABAJO

Semi-Structural Forecasting Model

Francisco Arroyo Marioli
Francisco Bullano
Jorge Fornero
Roberto Zúñiga

N° 866 Enero 2020
BANCO CENTRAL DE CHILE

BANCO CENTRAL DE CHILE

CENTRAL BANK OF CHILE

Documentos de Trabajo del Banco Central de Chile
Working Papers of the Central Bank of Chile
Agustinas 1180, Santiago, Chile
Teléfono: (56-2) 3882475; Fax: (56-2) 3882231

Documento de Trabajo
N° 866

Working Paper
N° 866

Semi-Structural Forecasting Model*

Francisco Arroyo Marioli
Central Bank of Chile

Francisco Bullano
Central Bank of Chile

Jorge Fornero
Central Bank of Chile

Roberto Zúñiga
Central Bank of Chile

Abstract

The semi-structural gap forecasting (MSEP) model is the new gap model used by the Central Bank of Chile to forecast key macroeconomics variables. This document provides the technical details of this model including equations, estimated parameters and transmission mechanisms. The model has been improved relative to its initial version along several dimensions: (i) The parameters have been estimated with Bayesian methods; (ii) it separates core inflation into tradable and non-tradable inflation, linking each component to fundamental drivers; (iii) it explicitly specifies the empirical relationships between terms of trade and real exchange rate. We found that for a typical monetary policy shocks there are similar effects in comparison with the former MEP model.

Resumen

El modelo semi-estructural de proyecciones MSEP es el nuevo modelo de brechas utilizado por el Banco Central de Chile para proyectar las principales variables macroeconómicas chilenas. Este documento proporciona detalles de este modelo, incluidas ecuaciones, parámetros estimados y mecanismos de transmisión. El modelo se ha mejorado respecto a su versión inicial en varias dimensiones: (i) se utilizan métodos Bayesianos para estimar los parámetros; (ii) se separa la inflación subyacente en inflación transable y no transable, y determina su dinámica en función de variables endógenas fundamentales: (iii) se modela explícitamente la relacion empírica entre los términos de intercambio y el tipo de cambio real. Ante innovaciones de la política monetaria, encontramos efectos similares en comparación con el modelo MEP anterior.

*We would like to thank Elías Albagli, Miguel Fuentes, Andrés Fernandez, Matías Solorza, an anonymous referee, and seminar participants at the Central Bank of Chile for useful comments. The views expressed are those of the authors and do not necessarily represent official positions of the Central Bank of Chile or its Board members. Emails: farroyo@bcentral.cl; fbullano@bcentral.cl; jfornero@bcentral.cl; rzuniga@bcentral.cl.

1 INTRODUCTION

The Central Bank of Chile (CBoC) regularly uses two main models for medium-term forecasting: the XMAS (*Extended Model for Analysis and Simulation*, García et al. (2019)), a big-scale DSGE model, and the MSEP (for *Modelo Semi-Estructural del Proyección*), a semi-structural model. The first is an extension of the MAS (Medina and Soto (2007)) whereas the second is a stylized version of the MEP (2003).

The MSEP's primary function is to generate medium-term forecasts for activity, inflation, and the monetary policy rate (MPR). Additionally, the model allows us to assess the effects of different MPR paths on the macroeconomic scenario. The model also provides an inference of the shocks behind business cycle fluctuations. Finally, during the elaboration of the monetary policy (MP) report, the model's outputs serve as inputs for the CBoC's policy decisions.

In this paper we present a new model which will replace the former MEP. This new version presents up-to-date estimations of parameters using bayesian methods, incorporates further details in foreign variables, such as commodities' prices, to better describe relevant Chilean stylized facts, and defines more properly a set of equations for inflation dynamics. Besides, we make a forecast assessment relative to other benchmark empirical models. Finally, an analysis of the model's main propagation channels is also provided. For demand and monetary policy shocks, we also compare MSEP responses of key variables with those of other semi-structural models.

The MSEP is based on the basic structure of New-keynesian (NK) models. The simplest NK model contains three equations:[2]

- *IS curve*: it explains the reaction of consumption to interest rate changes and other shocks. The rationale is simple: in response to a higher interest rate, the agents save more on the margin, thus reducing their present consumption and increasing their future purchasing power. This behavior arises from inter-temporal consumption smoothing.

- *Phillips curve*: it explains inflation dynamics as a function of inflation expectations and the output or the unemployment gap. This relation assumes that production costs increase with economic activity, or, in other words, costs are higher when unemployment is low. Thus, higher costs imply higher prices. In turn, including inflation expectations is important because producers are forward-looking when setting their prices.

- *Central Bank's reaction function*: typically, the monetary authority's reaction function is represented by a simple rule with two aims: stabilizing inflation and the output gap. More specifically, if inflation rises, the Central Bank can stabilize prices by raising the nominal interest rate by an amount larger than the increase in inflation, thus raising the real interest rate (this is known the Taylor principle). In consequence, naturally, the activity slows down. On the other hand, the Central Bank can raise (lower) the interest rate if the activity level is above (below) potential output, in order to prevent rising (falling) inflation pressures.

The MSEP builds on NK models and extends it with the inclusion of relevant external variables to account for the propagation of external shocks properly. This is to reflect the fact that Chile is open to international trade and, by virtue of its small size, the literature assumes

[2]Standard textbooks (e.g. Galì (2015)) derive the NK model with three equations under restrictive assumptions, such as the closed economy and no capital accumulation. For more details see section 3.

that Chile is a price taker in global markets.[3] For example, Chile's activity is affected by the level and volatility of international prices.

Semi-structural models present two advantages over DSGE models. First, parsimony: a simpler model requires fewer assumptions, thus broadening the scope of the validity of the results. Second, versatility: operationally speaking, the model is easy to handle and to adapt to new requirements; that is, it is straightforward to add new modeling blocks.

The CBoC forecasting process combines a DSGE model and a semi-structural model, because their policy recommendations are complementary rather than exchangeable. Besides, both model's results help to build up economic narratives for supporting the analysis. Sometimes, each model sketches a different part of the whole picture. Furthermore, their forecasts can provide particular views, which are useful to formulate additional questions and devise sensitivity and risk scenarios. Finally, well established research in the literature suggests that forecast combinations have frequently been found in empirical studies to produce better forecasts on average than methods based on the ex ante best individual forecasting model, see Timmermann (2006).

We provide empirical results regarding unconditional and conditional variance decomposition, parameter estimations, impulse-response functions (IRF) analysis, and forecast performance of the MSEP. We find that this model outperforms standard time-series models. We also compare model's IRF results with those of similar models used by other Central Banks (CB). We also provide a historical analysis of Chile's main macroeconomic variables through the lens of the model and find that external variables contribute in a significant share to explain the output gap, inflation and real exchange rate cycles.

The remainder of this document is divided into eight sections. Section 2 describes the assumptions and the monetary policy transmission mechanisms in the MSEP. Section 3 presents the underlying structure of the model in detail; that is, which equations determine the dynamics of the economy. Section 4 describes the data set and the estimation/calibration strategy. Section 5 presents the main results of the model: a variance decomposition of forecast errors, IRFs, a forecasting performance evaluation, and a historical shock decomposition. Section 6 compares some of the MSEP properties with those of other CB's macroeconomic models. Section 7 sketches the forecasting process using the MSEP. Finally, Section 8 concludes.

2 ASSUMPTIONS AND TRANSMISSION OF THE MONETARY POLICY

The central assumptions of the model are the following:

- The economy is open and small. Thus, external shocks are exogenous to the local economy.[4]
- The model explains non-mining GDP (NMGDP) and assumes exogeneity of mining GDP; see Fuentes et al. (2018) for details.
- The exchange rate regime is free to float.
- The dynamics of inflation are explained by its sub-aggregates, where they are divided according to their fundamental drivers. We specify three Phillips curves among CPI

[3]Regarding copper production, although Chile has been the leading contributor in recent years, Fornero and Kirchner (2018) argue that the copper price is nonetheless exogenous for Chilean producers.

[4]For instance, the global cycle of commodity prices affect domestic variables, but not viceversa.

excluding Food and Energy: core tradables, core non-tradables and non-core. Food and Energy CPI are also specified within the model. The dynamics of these inflation components are consistent with nominal rigidities, which cause real variables to deviate from equilibrium levels in the short run.

The first assumption implies that we model all external variables as exogenous processes, independent of domestic variables. The second assumption means that the relevant output is NMGDP. We exclude mining GDP because it depends almost entirely on supply factors and is not responsive to the monetary policy stance. Furthermore, in the data, mining GDP does not correlate with core inflation. The third assumption relates to arbitrage between home and foreign interest rates, and the fourth has implications on the relevant variables in the Phillips curves.

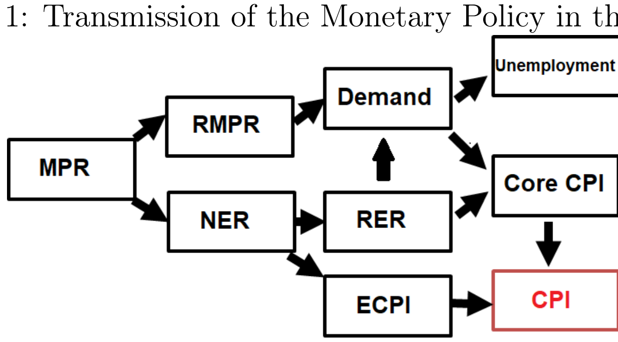
To provide an intuition of the rationale behind the model and its transmission mechanisms, in Figure 1, we present schematically the propagation of a monetary policy shock. We emphasize two channels: the demand channel and the exchange rate channel. According to the first, when the Central Bank raises the MPR, the real interest rate increases as well, due to nominal rigidities in the short run. This more restrictive monetary policy contracts aggregate demand.

The second channel involves the exchange rate's reaction. When the interest rate raises, the domestic currency appreciates via the arbitrage between rates prescribed by the uncovered interest parity condition. This reaction affects inflation both directly and indirectly. The direct effect is seen in the lower (higher) cost of imported inputs and products. The indirect effect comes from the adjustment of net exports. Additionally, the fall in aggregate demand induces downward pressures in the labor market, thus increasing the unemployment rate.

In summary, a weaker demand and the exchange rate appreciation generate downward pressures on inflation.

The model's mathematical structure, which we present in the following section, reflects each of these assumptions.

Figure 1: Transmission of the Monetary Policy in the MSEP



Notes: MPR: Monetary Policy Rate. RMPR: Real Monetary Policy Rate. NER: Nominal Exchange Rate. RER: Real Exchange Rate. ECPI: Energy CPI.

3 MODEL'S STRUCTURE

The main variables in the model are the output gap, core inflation, monetary policy rate, and real exchange rate (RER). Besides, the model includes other endogenous and exogenous variables. This section presents the equations that inter-relate all these variables, and describe the data we feed the model with.

3.1 MODEL'S EQUATIONS

3.1.1 Output Gap and Potential GDP

The output gap is defined as the difference between the log of NMGDP (Y) and the log of potential NMGDP ($\bar{Y}$):

The output gap

$$y_t = Y_t - \bar{Y}_t \tag{1}$$

Output is determined by the following equations:

Quarter on quarter (QoQ) variation of potential NMGDP

$$\Delta \bar{Y}_t = G_t + \xi_t^{\bar{Y}}, \qquad \xi_t^{\bar{Y}} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{\bar{Y}}}) \tag{2}$$

Potential NMGDP growth (Blagrave et al., 2015)

$$G_t = \theta_G G^{ss} + (1-\theta_G)G_{t-1} + \xi_t^G, \qquad \xi_t^G \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^G}) \tag{3}$$

IS curve

$$\begin{aligned} \Delta y_t = &- a_1(y_{t-1} + y_{t-2}) - a_2(y_{t-1} - y_{t-2}) - a_3(r_t - rn_t + r_{t-1} - rn_{t-1}) \\ &+ a_4(y_t^{em} + y_{t-1}^{em}) + a_5(y_t^{ad} + y_{t-1}^{ad}) + a_6 rer_{t-1} + a_7 tot_t + \nu_t^y. \end{aligned} \tag{4}$$

Demand shock ν^y

$$\nu_t^y = \rho^{\nu y}\nu_{t-1}^y + \xi_t^y, \qquad \xi_t^y \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^y}) \tag{5}$$

This specification follows closely Blagrave et al. (2015) and Blagrave and Santoro (2016), but with an important difference. We do not model the output gap as an AR(1) process, but rather as an error correction process as in Central Bank of Chile (2003). Equation (2) specifies the level of potential output in terms of its growth rate (G) and a shock to the level ($\xi^{\bar{Y}}$). In turn, potential growth follows an AR(1) process and converges to a long-run constant rate G^{ss}.

A semi-structural IS curve describes the change in the output gap, following an error correction setting, but including additional controls. The real interest rate (r), net of the neutral level (rn, see equations (6) and (24) below), has a negative impact on the output gap. The trading partners' output gaps, as a proxy for the external demand, have a positive effect. Finally, the shock ν^y follows an AR(1) with persistence $\rho^{\nu y}$, and the shocks $\xi^{\bar{Y}}$, ξ^G and ξ^y follow an iid process with zero mean and constant variance.

It is worth noticing that a closed output gap means that NMGDP is at its potential level. However, an output gap equal to zero does not imply that all the gaps in the economy are closed as well. Since we assume the economy is open, external shocks may by keeping the economy away from its equilibrium.

When forecasting, we feed the model with both the output gap and potential GDP as observable variables. So, the model does not infer a potential GDP in each forecasting exercise. We do so because, by protocol, the CBoC estimates potential GDP only once a year, using several methods and thorough analysis, and do not perform intermediate revisions. Thus, we avoid the problem of contaminating forecasts with difficult-to-explain potential GDP revisions driven by noisy data.[5]

The real neutral interest rate (rn) is determined by potential GDP growth according to equation (6). This definition follows Laubach and Williams (2016). We calibrate the parameter c_{rn_pot} using the long-term growth rate (G^{ss}) and the long-term real neutral interest rate (rn^{SS}), which we assume as given.

The Neutral Real Rate

$$rn_t = c_{rn\_pot}\mathbb{E}_t[G_{t+1}] + \xi_t^{rn}, \qquad c_{rn\_pot} = \frac{rn^{SS}}{G^{SS}}, \qquad \xi_t^{rn} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{rn}}) \tag{6}$$

3.1.2 Inflation

We measure total inflation using the CPI. However, we do not model the behavior of this index directly. Instead, we use a *divide-and-conquer* kind of strategy: we split the aggregate index into distinct components that behave similarly. Equations (7) to (19) reflect these divisions. First, we divide total CPI into food CPI, energy CPI, and CPIXFE (excludes food and energy). The CPIXFE comprises 72 percent of total CPI. Then, we separate the CPIXFE into two distinct components: core CPI (51 percent of total CPI) and non-core CPI (22 percent). Such separation follows the method of Carlomagno and Sansone (2019), who use econometric tools to isolate the most volatile components of consumer prices. Lastly, we divide core CPI into tradable (13 percent of total CPI) and non-tradable (38 percent) CPI. Tradable prices respond not only to the domestic business cycle, but also to exchange rates. On the other hand, non-tradable prices correlate more with domestic activity, past prices (via indexation), and inflation expectations.

For each CPIXFE's sub-component, we allow for two kinds of cost-push shocks: temporary and more persistent. Specifically, persistent shocks are the following ν^{NT}, ν^{T} and ν^{nCore} and one-period-lived shocks are ϵ_t^{NT}, ϵ_t^{T} and ϵ_t^{nCore}.

Equation (15) specifies that food inflation depends on its own lag and the output gap. Equation (17) shows that energy inflation depends on the MEPCO-smoothed price of oil[6] ($poil_t^{MEPCO}$, see equation (55)) and the QoQ nominal depreciation ($deus_t$). We use the nominal (instead of the real) depreciation because we assume that prices are rigid in the short-term. Finally, equation (19) reconstructs total inflation from its sub-components.

[5]For a detailed description of the estimation of potential GDP see Albagli et al. (2015); Fornero and Zúñiga (2017).

[6]The MEPCO is a device designed to smooth oil price variations, and implemented by the National Petroleum Enterprise.

CPI excluding Food and Energy[a]

$$\pi_t^{XFE} = \alpha_1 \pi_t^{Core} + (1-\alpha_1)\pi_t^{nCore}, \qquad \alpha_1, \in (0,1) \tag{7}$$

Core CPI[a]

$$\pi_t^{Core} = \alpha_2 \pi_t^{NT} + (1-\alpha_2)\pi^{T}, \qquad \alpha_2 \in (0,1) \tag{8}$$

Non-tradable Core CPI

$$\pi_t^{NT} = bnt_1 \mathbb{E}_t\left[\pi_{t+1}^{NT}\right] + bnt_2(\pi_{t-1}^{NT} - \epsilon_{t-1}^{NT}) + bnt_3 y_t + \epsilon_t^{NT} + \nu_t^{NT} \tag{9}$$

$$\nu_t^{NT} = \rho^{\nu NT}\nu_{t-1}^{NT} + \xi_t^{NT}, \qquad \xi_t^{NT} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{NT}}), \qquad \epsilon_t^{NT} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\epsilon^{NT}}) \tag{10}$$

Tradable Core CPI

$$\pi_t^{T} = bt_2(\pi_{t-1}^{T} - \epsilon_{t-1}^{T}) + bt_3 y_t + bt_4(deus_t + deus_{t-1}) + bt_5 rer_{t-1} + \epsilon_t^{T} + \nu_t^{T}, \tag{11}$$

$$\nu_t^{T} = \rho^{\nu T}\nu_{t-1}^{T} + \xi_t^{T}, \qquad \xi_t^{T} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi T}), \qquad \epsilon_t^{T} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\epsilon^{T}}) \tag{12}$$

Non-Core CPI

$$\pi_t^{nCore} = bv_1(\pi_{t-1}^{nCore} - \epsilon_{t-1}^{nCore}) + bv_2 deus_t + bv_3 rer_{t-1} + \epsilon_t^{nCore} + \nu_t^{nCore}, \tag{13}$$

$$\nu_t^{nCore} = \rho^{\nu nCore}\nu_{t-1}^{nCore} + \xi_t^{nCore}, \qquad \xi_t^{nCore} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{nCore}}), \qquad \epsilon_t^{nCore} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\epsilon^{nCore}}) \tag{14}$$

Food CPI

$$\pi_t^{F} = \rho^{F1}\pi_{t-1}^{F} + \rho^{F2} y_t + \xi_t^{F}, \tag{15}$$

$$\nu_t^{F} = \rho^{vF}\nu_{t-1}^{F} + \xi_t^{F}, \qquad \xi_t^{E} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{F}}) \tag{16}$$

Energy CPI

$$\pi_t^{E} = \alpha_3 poil_t^{MEPCO} + (1-\alpha_3)\nu_t^{E}, \tag{17}$$

$$\nu_t^{E} = \rho^{vE}\nu_{t-1}^{E} + \xi_t^{E}, \qquad \xi_t^{E} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{E}}) \tag{18}$$

[a] A measurement shock washes out differences between implicit weighted average and actual inflation.

Consumer Price Index (CPI)[a]

$$\pi_t^{CPI} = \alpha_4 \pi_t^{XFE} + \alpha_5 \pi^F + (1 - \alpha_4 - \alpha_5)\pi_t^E, \qquad \alpha_4, \alpha_5 \in (0,1) \tag{19}$$

The bilateral nominal depreciation of the peso against the dollar, *deus*, is not observed by the model, but deduced from the following identity:

Nominal depreciation

$$deus_t = rer_t - rer_{t-1} - \pi_t^* + \pi_t^{CPI}. \tag{20}$$

3.1.3 Monetary Policy Rule

The monetary policy reaction function follows a Taylor rule. This equation includes three terms. First, a persistence term to account for the Central Bank's reaction to changes in its macroeconomic outlook. Then, the expected inflation plays a significant role. Its associated coefficient satisfies the Taylor principle ($c_2 > 1$), implying that the Bank moves the nominal interest rate beyond the change in inflation, in order to accommodate the real interest rate, thus stabilizing prices. Finally, this rule also depends on the output gap. It is worth noticing that the Taylor rule does not operate on the interest rate directly but on its deviation from the neutral interest rate (*in*, equation (23)).

Taylor rule

$$i_t - in_t = c_1(i_{t-1} - in_{t-1}) + (1 - c_1)\left(c_2 \mathbb{E}_t\left[\pi_{t+1}^{XFE,annual}\right] + c_3 y_t\right) + \nu_t^i \tag{21}$$

$$\nu_t^i = \rho^{\nu i}\nu_{t-1}^i + \xi_t^i, \qquad \xi_t^i \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma_{\xi^i}^2) \tag{22}$$

The Fisher equation (24) establishes the relationship between real and nominal interest rates.

The neutral nominal rate

$$in_t = rn_t + Target \tag{23}$$

Fisher Equation

$$r_t - rn_t = i_t - in_t - 4\mathbb{E}_t \pi_{t+1}^{CPI}. \tag{24}$$

3.1.4 The Unconvered Interest Rate Parity (UIP)

The UIP allows us to deduce the expected bilateral depreciation in the short-run, $\mathbb{E}_t[deus_{t+1}]$, by equating the yield of domestic risk-free financial assets, i_t, and the yield of external assets,

i_t^* plus the sovereign risk premium, ρ_t^{embi}. On the other hand, empirical evidence shows that exchange rate expectations depend on fundamentals such as the terms of trade. Therefore, the spot exchange rate depends on the difference between domestic and international interest rates, risk premiums, and the terms of trade. This relation is expressed in equation (26):

ToT UIP modification

$$\mathbb{E}_t rer_{t+1} = \theta tot_t + \nu_t^{UIP}, \tag{25}$$

$$rer_t = \mathbb{E}_t rer_{t+1} - \frac{i_t - in_t}{4} + \frac{i_t^*}{4} + \frac{\rho_t^{embi}}{4}, \tag{26}$$

AR(1) structure for *UIP* shock

$$\nu_t^{UIP} = \rho^{\nu UIP} \nu_{t-1}^{UIP} + \xi_t^{UIP}, \qquad \xi_t^{UIP} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{UIP}}) \tag{27}$$

3.1.5 Unemployment rate

Although the unemployment rate does not affect other variables, it helps to identify the output gap via an Okun's Law. For this end, we include a labor market module in the same spirit as Blagrave et al. (2015). However, when forecasting, we feed the model with the output gap, so this channel is off.

Unemployment gap

$$u_t = U_t - \overline{U}_t, \tag{28}$$

$$u_t = \tau_2 u_{t-1} - \tau_1 y_t + \nu_t^u, \tag{29}$$

$$\nu_t^u = \rho^{\nu u} \nu_{t-1}^u + \xi_t^u, \qquad \xi_t^u \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^u}) \tag{30}$$

Natural rate of unemployment

$$\bar{U}_t = \tau_4 U^{ss} + (1 - \tau_4)\bar{U}_{t-1} + G\bar{U}_t + \xi_t^{\bar{U}}, \qquad \xi_t^{barU} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{\bar{U}}}) \tag{31}$$

$$G\overline{U}_t = (1 - \tau_3) G\overline{U}_{t-1} + \xi_t^{G\overline{U}}, \qquad \xi_t^{G\overline{U}} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi G\overline{U}}) \tag{32}$$

In equation (28), we define the unemployment gap, u, as the observed unemployment rate U minus the trend unemployment rate $\overline{U}$. In turn, equation (29) describes the dynamics of u, as a function of its own lag, the output gap (Okun's Law), and a perturbation term (equation (29)). Trend unemployment moves according to equations (31) and (32).

3.1.6 Exogenous variables

We assume that international variables are exogenous. In consequence, we model them as auto-regressive processes as shown in equations (33) to (44). These variables include: the output gaps of emerging and advanced trading partners, the oil price, the copper price, the terms of trade, the external interest rate, external inflation, and the risk premium. Terms of trade components are specified in equations (49) to (57) (Appendix B).

Emerging trading partners output gap

$$y_t^{em} = \rho^{em} y_{t-1}^{em} + \nu_t^{em}, \tag{33}$$

$$\nu_t^{em} = \rho^{\nu em} \nu_{t-1}^{em} + \xi_t^{em}, \qquad \xi_t^{em} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{em}}) \tag{34}$$

Advanced trading partners output gap

$$y_t^{ad} = \rho^{ad} y_{t-1}^{av} + \nu_t^{ad}, \tag{35}$$

$$\nu_t^{ad} = \rho^{\nu ad} \nu_{t-1}^{ad} + \xi_t^{ad}, \qquad \xi_t^{ad} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{ad}}) \tag{36}$$

Domestic oil price

$$poil_t^{mepco} = \alpha_{mepcomepco} poil_{t-1}^{mepco} + (1 - \alpha_{mepco})(deus_t + \pi_t^{ext} + poil_t + poil_{t-1}) + \xi_t^{mepco}, \tag{37}$$

$$\xi_t^{mepco} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{mepco}})$$

ToT (see Appendix B for further details)

$$tot_t = px_t - pm_t \tag{38}$$

Foreign interest rate

$$i_t^* = \rho^{i*} i_{t-1}^* + \nu_t^{i*}, \tag{39}$$

$$\nu_t^{i*} = \rho^{\nu i*} \nu_{t-1}^{i*} + \xi_t^{i*}, \qquad \xi_t^{i*} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{i*}}) \tag{40}$$

Foreign inflation

$$\pi_t^* = \rho^{\pi*} \pi_{t-1}^* + \nu_t^{\pi*}, \tag{41}$$

$$\nu_t^{\pi*} = \rho^{\nu\pi*} \nu_{t-1}^{\pi*} + \xi_t^{\pi*}, \qquad \xi_t^{\pi*} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{\pi*}}) \tag{42}$$

Risk premium

$$\rho_t^{embi} = \rho^{embi} \rho_{t-1}^{embi} + \nu_t^{embi}, \tag{43}$$

$$\nu_t^{embi} = \rho^{\nu\rho embi} \nu_t^{embi} + \xi_t^{embi}, \qquad \xi_t^{embi} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{embi}}) \tag{44}$$

4 DATA AND PARAMETERS ESTIMATION

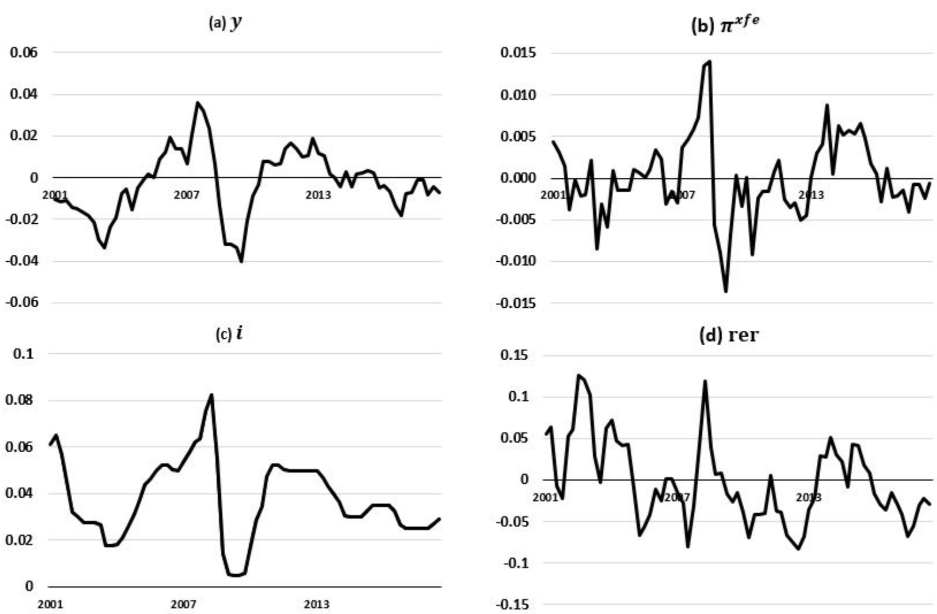
4.1 DATA

The model uses a quarterly sample, that ranges from 2001Q3 until 2019Q1[7]. This sample includes time series of activity, prices, interest rates, exchange rates and several external variables. In Table 1, we present a detailed description of these variables and their sources.

We specify the model in terms of gaps and assume that these converge to zero in the long-run. In other words, once the gaps are closed, in the absence of perturbations, the variable dynamics are those of the trend variables. The MSEP aims to explain the joint dynamics of these variables during the business cycle.

Table 1 shows the time series we use, while Box 1 presents how these series are transformed to be read by the model. These transformations are of two kinds: (i) *level gaps*, which we define as the percentual difference of a given variable with respect to a potential, trend, or equilibrium level (e.g. the output gap, the RER gap[8], etc.); and (ii) *velocity gaps*, which we define as the quarter on quarter percentual difference minus a trend value. For instance, the inflation velocity is measured with respect to the target inflation rate. Box 1 provides further details on these calculations.

Figure 2: Observables variables: Output Gap, CPIXFE, MPR y RER



Source: Authors' calculation based on official data, see Box 1.
Note: Data sample from 2001Q3 to 2019Q1.

Figure 2 shows some of the variables observed in the model. A simple inspection suggests that these variables reverse to the mean, which is consistent with the maintained assumption of stationarity.

[7]From 2001Q3 the CBoC has followed an inflation targeting framework, using the MPR as its policy instrument.

[8]For NMGDP, the trend is given by the level of potential GDP. For the RER, we suppose that the equilibrium RER is constant and equal to its historical average (consistent with the PPP hypothesis).

Table 1: Model Data Set

Abbreviation	Description	Source
$NMGDP$	Non-Mining GDP (*)	CBoC.
$NMGDP^{sa}$	Seasonally Adjusted Non-Mining GDP	CBoC.
$NMGDP^{pot}$	Potencial Non-Mining GDP	CBoC. (**)
CPI	Consumer Price Index (CPI)	NSO.
CPI^{sa}	Seasonally Adjusted CPI	CBoC. (***)
$CoreCPI$	Core CPI	Own calculations
$CoreCPI^{sa}$	Seasonally Adjusted Core CPI	CBoC. (***)
$CoreCPI_{NT}$	Non-Tradable Core CPI	Own calculations
$CoreCPI_{NT}^{sa}$	Seasonally Adjusted Non-Tradable Core CPI	BCCh. (***)
$CoreCPI_{T}$	Tradable Core CPI	Own calculations
$CoreCPI_{T}^{sa}$	Seasonally Adjusted Tradable Core CPI	CBoC. (***)
$NCoreCPI$	Non-Core CPI	Own calculations
$FCPI$	Food CPI	NSO.
$FCPI^{sa}$	Seasonally Adjusted Food CPI	CBoC. (***)
$ECPI$	Energy CPI	NSO
$ECPI^{sa}$	Seasonally Adjusted Energy CPI	CBoC. (***)
MPR	Monetary Policy Rate, annual basis	CBoC.
RER	Real Exchange Rate (Avg. 1986 = 100)	CBoC.
NER	Nominal Exchange Rate	CBoC.
ToT	Terms of Trade	CBoC.
ToT^{trend}	ToT trend	Own calculations
$ADGDP$	GDP of advanced trading partners	CBoC.
$ADGDP^{trend}$	GDP of advanced trading partners trend	Own calculations
$EMGDP$	GDP of emerging trading partners	CBoC.
$EMGDP^{trend}$	GDP of emerging trading partners trend	Own calculations
$EMBICH$	EMBI Chile	CBoC.
IUS	Libor 90 days, annual basis	CBoC.
FPI	Foreign Price Index	CBoC.
$PWTI$	WTI Price	CBoC.
$PWTI^{tend}$	WTI Price trend	Own calculations
PCU	Copper Price	CBoC.
PCU^{tend}	Copper Price trend	Own calculations
U	Unemployment Rate	NSO.
$NAIRU$	Non Accelerating Inflation Rate of Unemployment	CBoC.

Notes: Own calculations refers to data which is not officially provide by CBoC. NSO stands for National Statistics Office. (*) NMGDP excludes mining sector. (**) It's estimation follows Albagli et al. (2015) and Fornero and Zúñiga (2017) methodology. (***) Data is seasonally adjusted using the standard x12 procedure. Other observable variables: Target=3%, Equilibrium Real Exchange Rate, RER^{eq} and local risk premium, $EMBICH^{eq}$. The last two equal to their sample means.

Table 2: Stylized facts of observed variables used in the estimation

Variable	Mean $\mathbb{E}(X)$	Standard Dev. $\sqrt{\mathbb{V}ar(X)}$	Standard Dev. relative to Output Gap $\sqrt{\mathbb{V}ar(X)/\mathbb{V}ar(y)}$	First order autocor. $\mathbb{C}orr(X_t, X_{t-1})$	Output gap correlation $\mathbb{C}orr(X_t, y_t)$	Output gap(-1) correlation $\mathbb{C}orr(X_t, y_{t-1})$	RER correlation $\mathbb{C}orr(X_t, rer_t)$
y	-0.3	1.55	1.00	0.89	1.00	0.89	-0.39
y^{em}	0.0	2.71	1.75	0.87	0.55	0.39	-0.38
y^{ad}	-0.1	2.23	1.44	0.91	0.42	0.29	-0.09
π^{CPI}	0.0	0.66	0.43	0.54	0.54	0.46	0.04
π^{XFE}	0.0	0.47	0.31	0.57	0.46	0.49	0.25
π^{Core}	0.0	0.40	0.26	0.77	0.55	0.65	0.16
$\pi^{\pi^{NT}}$	0.0	0.35	0.23	0.75	0.68	0.75	-0.08
π^{T}	0.0	0.67	0.43	0.75	0.18	0.30	0.38
π^{nCore}	0.0	1.12	0.72	0.26	0.24	0.12	0.15
rer	-0.2	4.91	3.16	0.76	-0.39	-0.24	1.00
tot	0.3	13.44	8.67	0.86	0.21	-0.02	-0.44
pcu	1.45	29.26	18.88	0.88	0.44	0.21	-0.55

Source: Authors' calculations, based on official data, see Box 1.
Note: Data sample from 2001Q3 to 2019Q1.

Table 2 summarizes some stylized facts about the input variables of the model. The first column presents sample averages between 2001Q3 and 2019Q1.[9] The second column shows the standard deviation of each variable, and the third column shows these volatilities relative to the output gap volatility. The remaining columns show the correlation coefficients with the lagged variable, with the output gap and with the lagged output gap, respectively.

Some remarks are the following:

- The output gap of Chile's trading partners is more volatile than the domestic output gap, particularly when we focus on emerging economies. Additionally, the emerging partners' output gap correlates more with the domestic gap than the advanced partners do.
- Total CPI is more volatile than CPIXFE, due to the higher volatility of food and energy components.
- The measure of inflation called core CPI is constructed by excluding the most volatile components of the CPIXFE. Compared to other measures of inflation, the core CPI is less volatile, more persistent and correlates more with the output gap.
- The group the most volatile components of the CPIXFE defines a new index called non-core CPI. This volatile inflation has low persistence, correlates very little with the output gap, and is three times more volatile than the core CPI.
- We split the core CPI into tradable and non-tradable components. Tradable inflation correlates strongly with the exchange rate variation, whereas non-tradable inflation correlates more with the output gap.
- The terms of trade exhibit a negative correlation with the exchange rate. We model this empirical relationship in the MSEP.

[9]Some values might differ from zero for different reasons: (i) Some variables such as i and U are not detrended. (ii) Others, such as i^*, are detrended with long-term constants that might be different from the historical averages of the series.

Box 1: Observed Variables

We transform the variables in Table 1 to feed the model. We specify these transformations below. The model observes: the output gap (y), potential GDP ($\Delta\bar{Y}$), total inflation rate, inflation excluding food and energy (XFE), core inflation (tradable y non-tradable), non-core inflation rate, food and energy inflation (π^{CPI}, π^{XFE}, π^{Core}, π^{T}, π^{NT}, π^{nCore}, π^{F} and π^{E} respectively), monetary policy rate (i), real exchange rate (rer), terms of trade (tot), the output gap of advanced and emerging trading partners (y^{ad} and y^{em} respectively), Chile's EMBI (ρ^{embi}), external interest rate (i^{*}), oil price ($poil$), copper price (pcu), external inflation (π^{*}), and the unemployment rate (u_t). We get these variables through the following relationships:

$$\pi_t^{CPI} = \Delta \log\left(CPI_t^{sa}\right) - \bar{\pi}, \qquad \pi_t^{XFE} = \Delta \log\left(CPIXFE_t^{sa}\right) - \bar{\pi},$$

$$\pi_t^{Core} = \Delta \log\left(CoreCPI_t^{sa}\right) - \bar{\pi}, \qquad \pi_t^{nCore} = \Delta \log\left(NcoreCPI_t^{sa}\right) - \bar{\pi},$$

$$\pi_t^{NT} = \Delta \log\left(CoreCPI_{NT_t}^{sa}\right) - \bar{\pi}, \qquad \pi_t^{T} = \Delta \log\left(CoreCPI_{T_t}^{sa}\right) - \bar{\pi},$$

$$\pi_t^{F} = \Delta \log\left(FCPI_t^{sa}\right) - \bar{\pi}, \qquad \pi_t^{E} = \Delta \log\left(ECPI_t^{sa}\right) - \bar{\pi},$$

$$y_t = \log\left(\frac{NMGDP_t^{sa}}{NMGDP_t^{pot}}\right), \qquad \Delta\bar{Y}_t = \Delta \log\left(NMGDP_t^{pot}\right),$$

$$\Delta Y_t = \Delta \log\left(NMGDP_t\right), \qquad i_t = MPR_t,$$

$$rer_t = \log\left(\frac{RER_t}{RER^{eq}}\right), \qquad tot_t = \log\left(\frac{ToT_t}{ToT_t^{trend}}\right),$$

$$y_t^{em} = \log\left(\frac{EMGDP_t}{EMGDP_t^{trend}}\right), \qquad y_t^{ad} = \log\left(\frac{ADGDP_t}{ADGDP_t^{trend}}\right),$$

$$\rho_t^{embi} = \log\left(\frac{EMBI_t}{EMBI^{eq}}\right)/10000, \qquad pcu_t = \log\left(\frac{PCU_t}{PCU_t^{trend}}\right),$$

$$poil_t = \log\left(\frac{PWTI_t}{PWTI_t^{trend}}\right), \qquad \pi_t^{*} = \Delta \log\left(FPI_t\right) - \bar{\pi}^{*},$$

$$u_t = U_t - NAIRU_t, \qquad i_t^{*} = IUS_t - \bar{i}^{*},$$

where $NMGDP^{Pot}$ denotes potential GDP, estimated via multivariate filters; see Albagli et al. (2015); Fornero and Zúñiga (2017)). Also, we use Hamilton (2018)'s method to estimate the following trends: $EMGDP^{trend}$, $ADGDP^{trend}$, $PWTI^{trend}$, PCU^{trend} and ToT^{trend}. Finally, the constant trends RER^{eq}, $EMBI^{eq}$ and $\bar{\pi} = Target/4$ are defined in Table 1's notes.

4.2 PARAMETERS ESTIMATION

We use the following strategy for estimating the model's parameters: first, the set of parameters is divided between parameters associated with endogenous variables (IS curve's, Phillips curve's and Taylor rule's parameters) and parameters associated with exogenous variables or variance restrictions (i.e., autoregressive coefficients and relative standard deviations between potential GDP shocks, unemployment, etc.). We calibrated the parameters from the second group using different sources of information: (i) the stochastic processes describing the external interest rate and the MEPCO come from the XMAS model; (ii) the shares of the CPI correspond to the 2018 CPI basket from NSO; (iii) information about foreign trade (price deflators) provide by CBoC; (iv) signal to noise ratio of GDP and unemployment comes from the MVF used in Aldunate et al. (2019). Tables 11 and 12 in the appendix C show them. Second, the parameters associated with endogenous variables are jointly estimated using Bayesian methods. Priors distributions were informed both by univariate regressions using standardized economic techniques (OLS and GMM), as well as priors used in earlier estimations. Both Box 2 and 3 provide further detail when choosing priors means for the Taylor rule and the modified version of the UIP equation.

Bayesian estimation was performed using *Dynare* software. We performed 200,000 iterations of *Metropolis-Hasting* algorithm to recover key moments of the posterior distribution. The data set goes from 2001Q3 to 2019Q1.

Table 3 reports assumed priors distribution as well as the mode, mean and percentiles 5 and 95 of estimated parameter's *posterior* distribution. Results suggest that the Phillips Curve disaggregation delivers stronger relationships among its fundamentals. In particular, the output gap-inflation elasticity of non-tradable core inflation is higher than its tradable analog (0.07 vs. 0.02). Also, it stands out that when compared to the XMAS, the expectation channel results more limited.[10] Results also support the evidence that non-core inflation is not very persistent, since its AR(1) parameter is close to zero.

IS curve coefficients estimation indicate an important effect of both the monetary policy and the trading partners in the business cycle. In particular, its worth noticing the more significant effect of emerging over advanced trading partners. Finally, the estimation of the impact of the real exchange rate on the output gap is limited.

An important feature introduced to the model in comparison with its 2003 version, is the relationship between the RER and the ToT. Box 2 provides a description and how the standard UIP equation is modified in this new model. Theoretically, RER's expectations are based on the external fundamentals of the country. In the case of a small and open economy such as Chile, ToT are highly relevant. Consequently, we incorporate a channel that reflects this mechanism into the model, whose effects are captured by θ in the UIP equation. In this case, its estimation indicates that there is a significant negative relationship between ToT and RER. When ToT improves, for example, due to an increase in the copper price, it causes an appreciation of the RER through expectations of its future appreciation.

Finally, the posterior mode of the Taylor rule parameters is within the range observed in the literature. In fact, when comparing MSEP's monetary policy shock, the MPR dynamics are quite similar to those of the XMAS, see Central Bank of Chile (2020).

[10] In the XMAS, the parameter related to expected inflation is imposed to be equal to the discount factor, which value is close to 0.99.

Table 3: Estimated Parameters

Equation	Parameter	Priors			Posterior			
		Distribution	Mean	S.D.	Mode	Mean	p5	p95
(4)	a_1	B	0.15	0.04	0.14	0.14	0.10	0.19
	a_2	B	0.05	0.03	0.05	0.08	0.01	0.14
	a_3	B	0.07	0.02	0.05	0.05	0.03	0.08
	a_4	B	0.07	0.02	0.05	0.05	0.03	0.08
	a_5	B	0.06	0.02	0.04	0.05	0.02	0.07
	a_6	B	0.01	0.005	0.01	0.01	0.00	0.02
	a_7	B	0.04	0.02	0.01	0.01	0.00	0.02
(5)	$\rho^{\nu y}$	B	0.40	0.10	0.31	0.35	0.22	0.49
(9)	bnt_1	B	0.20	0.05	0.16	0.16	0.10	0.22
	bnt_2	B	0.50	0.15	0.49	0.45	0.33	0.58
	bnt_3	B	0.10	0.025	0.07	0.08	0.05	0.10
(11)	bt_2	B	0.70	0.075	0.64	0.63	0.55	0.72
	bt_3	B	0.02	0.005	0.02	0.02	0.01	0.03
	bt_4	B	0.05	0.01	0.04	0.04	0.03	0.05
	bt_5	B	0.02	0.005	0.02	0.02	0.01	0.02
(13)	bv_1	B	0.50	0.18	0.17	0.21	0.06	0.35
	bv_2	B	0.10	0.025	0.10	0.10	0.07	0.13
	bv_3	B	0.05	0.01	0.04	0.04	0.03	0.06
(10)	$\rho^{\nu NT}$	B	0.25	0.10	0.12	0.16	0.03	0.29
(14)	$\rho^{\nu nCore}$	B	0.25	0.10	0.23	0.29	0.04	0.51
(15)	ρ^{F1}	B	0.25	0.10	0.32	0.33	0.20	0.46
	ρ^{F2}	B	0.25	0.10	0.33	0.33	0.20	0.45
(21)	c_1	B	0.80	0.05	0.80	0.79	0.74	0.85
	c_2	N	1.70	0.10	1.63	1.63	1.46	1.79
	c_3	G	0.20	0.05	0.21	0.22	0.13	0.31
(25)	θ	B	0.35	0.07	0.23	0.23	0.16	0.30
(27)	ρ^{vUIP}	B	0.35	0.10	0.64	0.62	0.52	0.72
(43)	ρ^{embi}	B	0.70	0.10	0.79	0.78	0.70	0.87
(41)	ρ^{π^*}	B	0.25	0.18	0.26	0.25	0.15	0.37
(51)	ρ^{pcu}	B	0.50	0.10	0.77	0.77	0.70	0.84
(55)	ρ^{1poil}	B	0.63	0.15	0.81	0.81	0.72	0.90
(52)	$\rho^{px^{pnpcu}}$	B	0.50	0.10	0.57	0.56	0.45	0.68
(57)	$\rho^{pm^{pnoil}}$	B	0.50	0.10	0.42	0.43	0.30	0.55
(33)	ρ^{em}	B	0.85	0.10	0.87	0.86	0.78	0.94
(35)	ρ^{ad}	B	0.85	0.10	0.90	0.89	0.83	0.96

Note: The prior distribution are: beta distribution (B) on the open interval (0,1), inverse gamma distribution (IG) on $\mathbb{R}^+$, gamma distribution (G) on $\mathbb{R}_0^+$, normal distribution on $\mathbb{R}$.

Box 2: Terms of trade and real exchange rate

The standard equation for nominal exchange rate dynamics in the former MEP is described by the UIP condition:

$$NER_t = i_t^* - i_t + \rho_t + E[NER_{t+1}] \tag{45}$$

Changes in productivity and international prices (external fundamentals) affect spot nominal exchange rates (NER) through expectations. It is reasonable to assume agents have a fundamental NER, and believe that the NER will eventually converge to it. This fundamental NER can be approximated by the following equation:

$$X(A_x, P_x, RER^f) = M(A_M, P_M, RER^f) + rD, \tag{46}$$

where $X, M, A_x, P_x, A_M, P_M, r, D, RER^f$ correspond to exports, imports, exogenous export demand drift, export prices, exogenous import demand drift, import prices, interest rate, foreign net debt, and fundamental RER. This equation assumes that there is a level at which the RER stabilizes, that is consistent with a sustainable foreign net debt and trade balance. In this sense, changes in the terms of trade may affect the expectation of fundamental RER. These changes in expectations will be captured by the parameter θ.

$$E[NER_{t+1}] = -\theta tot_t + u_t \tag{47}$$

Then, the UIP equation can be rewritten as:

$$NER_t = i_t^* - i_t + \rho_t - \theta tot_t + u_t \tag{48}$$

The θ parameter must be interpreted as NER's reaction to permanent ToT shock, while the transitory component may operate through a non-specified channel, u_t.
We estimate θ using a small equation system that includes: (i) this modified version of UIP equation; (ii) a Taylor rule equation; and (iii) a Phillips Curve. A robust estimate of θ is around 0.35. This value is taken as a prior mean in the Bayesian estimation of the MSEP.

Box 3: Real time and ex-post output gap in Taylor's rule estimations

The monetary policy rules are intended to synthetically represent the behavior of the Central Bank's interest rate. The best-known case is that of the Taylor Rule, which relates the level of the MPR with measures of output gap and deviation from expected inflation to the inflation target.

Taylor's rule estimation for the MSEP model is useful since it is desirable that the model's interest rate evolves according to the systematic behavior of the MPR in history. However, its estimation is not free of difficulties, and it depends on the assumptions and data used. Thus, for example, Figueroa and García (2017) document significant differences in the coefficients of the rule when using real-time and *ex-post* output gap measures. Hence, we study the differences of using both real-time and ex-post output gap.

Estimates of the Taylor Rule using ordinary least squares (OLS) and generalized method of moments (GMM) are presented below. The specification we estimate is the following:

$$i_t - in_t = c_1(i_{t-1} - in_{t-1}) + (1 - c_1)\left(c_2\mathbb{E}_t\left[\pi_t^{expect}\right] + c_3 y_t\right]) + \epsilon_t,$$

where i is the MPR, in is the neutral rate of the MSEP which is derived from the potential GDP, π^{expct} are one-year total inflation expectations from the economic expectations survey, and y corresponds to the output gap, which can be a *real-time* (i.e., the level of output gap that was actually estimated in each period) or an *ex-post* (ie, the last output gap reviewed) measure. These estimates use quarterly data between 2005Q1 and 2019Q3. They also included a constant and a sub-prime post-crisis period dummy, when the Central Bank reached the zero lower bound and implemented the Term Liquidity Facilities (FLAP). The results are summarized in Table 4.

Table 4: Taylor's Rule Estimations

	real-time output gap		*ex-post output gap*	
	OLS	GMM	OLS	GMM
	(1)	(2)	(3)	(4)
c_1	0.68**	0.70**	0.58**	0.58**
	(0.04)	(0.09)	(0.04)	(0.07)
c_2	2.32**	1.99*	1.40**	1.69**
	(0.44)	(0.78)	(0.29)	(0.52)
c_3	0.23	0.36	0.71**	0.65**
	(0.21)	(0.32)	(0.12)	(0.16)
Obs.	59	59	59	59
R-squared	0.92	0.92	0.95	0.95
Adj. R-squared	0.91	0.91	0.94	0.94

The results show that the estimated coefficients using the *real-time* output gap are smaller than those estimated using *ex-post* data. This is similar to Figueroa and García (2017). We consider that in terms of actual policy-making it is more realistic to use real-time data. Hence, we proceeded to adjust our priors closer to those obtained when using real-time output gap.

We analyze three main results when making both a qualitative and a quantitative assessment of the model: the variance decomposition of forecast errors, the impulse-response functions of the main shocks determinating the dynamics of the endogenous variables and a recursive forecast exercise designed to assess predictive accuracy of the model.

5.1 *VARIANCE DECOMPOSITION OF FORECAST ERRORS*

5.1.1 *Unconditional Variance Decomposition*

Table 5 shows the unconditional variance decomposition of forecast errors of the main model's endogenous variables. This measure indicates the contribution of each shock (columns) to the total variance of the forecast error of each variable (rows).

Table 5: forecast error variance Decomposition (Percentage)

	Shock										
Variable	Demand	Cost	Monetary	UIP	F. fin.cond.	F.inflation	Foreign demand	ToT	F&E	Others	Total
y	53.0	1.8	3.8	0.20	0.1	0.4	36.0	4.4	0.2	0.2	100
u	2.6	0.1	0.2	0.0	0.0	0.0	2.1	0.2	0.0	94.7	100
π^{XFE}	5.9	54.4	2.0	8.4	1.5	9.3	4.5	1.9	0.2	11.8	100
π^{CPI}	10.3	16.3	1.7	5.5	0.8	3.3	8.0	18.8	27.2	8.2	100
π^{A}	17.8	0.7	1.4	0.1	0.0	0.2	13.3	1.6	64.9	0.1	100
π^{E}	0.0	0.0	0.2	2.8	0.3	0.2	0.0	55.0	41.5	0.0	100
π^{NT}	28.0	41.3	2.5	0.1	0.0	0.3	24.8	2.8	0.1	0.1	100
π^{T}	0.3	47.0	2.3	17.5	3.4	24.7	0.2	4.2	0.4	0.1	100
π^{NCore}	0.1	78.9	0.7	8.0	1.2	8.6	0.2	2.0	0.1	0.0	100
i	15.6	16.5	32.6	3.6	1.8	4.7	18.5	1.2	0.3	5.3	100
r	11.4	17.1	40.8	4.5	1.1	4.1	5.4	5.8	4.9	5.0	100
rer	4.2	4.8	5.2	49.6	11.5	2.3	6.8	15.2	0.1	0.4	100

Notes: Demand: ξ^{y}. Cost: ξ^{NT} ,ξ^{NTs}, ξ^{T}, ξ^{Ts}, ξ^{V} and ξ^{Vs} . Monetary: ξ^{i} and ξ^{rn} UIP: ξ^{UIP} and ξ^{UIPUS}. F. fin.cond.: ξ^{iext}, $\xi^{\rho embi}$. F. inflation:, $\xi^{\pi ext}$. Foreign demand: ξ^{em} and ξ^{av}. ToT: ξ^{pcu}, $\xi^{px^{pcu}}$, $\xi^{px^{pnpcu}}$, ξ^{poil}, $\xi^{pm^{oil}}$ and $\xi^{pm^{pnoil}}$. F&E: ξ^{A} and ξ^{E}. Others: $\xi^{\bar{Y}}$,ξ^{G},$\xi^{\bar{U}}$,$\xi^{G\bar{U}}$ and ξ^{u}.

For activity, it is observed that output gap unconditional forecast error variance is explained in more than 50 percent by ξ^{y} shock, which is interpreted as a demand shock. Then, foreign demand (emerging and advanced business partners) explains almost 36 percent. The rest of the shocks in the model have lower shares. In particular, monetary policy innovations explain in the order of 4 percent of the unconditional forecast error variance.

Regarding inflation, disaggregation between core and non-core components, and in the latter, between tradable and non-tradable, allows us to better identify the origins of fluctuations. In the case of non-tradable core inflation, domestic and foreign demand shocks explain 28 percent and 25 percent respectively, since the the output gap is a significant variable for its dynamics, while cost-push shocks explain about 41 percent. On the other hand, its tradable analogue is better explained by the exchange rate, through UIP shock (18 percent), foreign inflation shock (25 percent) and ToT shocks (4 percent).

At the same time, unconditional non-core inflation forecast error variance is mostly idiosyncratic (79 percent), unsurprisingly.

This means cost-push shocks explain roughly 50 percent of the unconditional core inflation forecast error variance, and that both the demand (domestic and foreign) and exchange rate channels explain about 10 and 17 percent, respectively.

When considering the total CPI, the unconditional forecast error variance is explained 27 percent by energy and food prices shocks and 16 percent by cost-push shocks. In addition, oil price shock (ToT) affects nearly 19 percent.

Regarding the nominal MPR, domestic demand (16 percent), cost-push (17 percent), monetary policy (34 percent) and foreign demand (19 percent) shocks explain most of its unconditional forecast error variance. Notice that foreign transitory shocks, such as UIP and oil price shocks, have relatively little impact.

Finally, as explained above, the RER is affected by its fundamentals in equilibrium. As a result of the specification used, more than 15 percent of its unconditional forecast error variance is explained by ToT shocks, especially copper price shocks.

5.1.2 Conditional Variance Decomposition

Now we examine how the forecast error variance is affected by shocks at specific horizons. Figures 3 to 6 show the share of the forecast error variance explained by different shocks, at horizons between 1 and 12, shown in the X-axis. We focus on three variables: the output gap, tradable and non-tradable inflation and the nominal interest rate.

Figure 3 presents the results for the output gap. At short horizons the demand shock contributes with more than 80 percent of the forecast error variance. At horizons longer than a year, foreign demand shocks become more important, explaining as much as 35 percent of the total variance. We see that monetary and terms of trade shocks play a minor role, while the rest of the shocks have negligible effects.

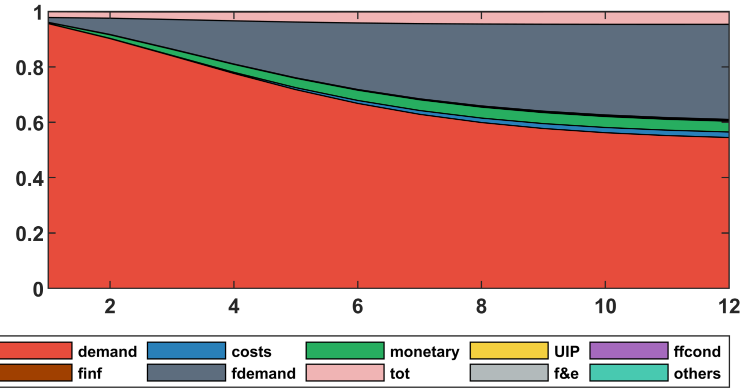
Figure 4 presents the results for the tradable inflation rate. Nearly a 90 percent of the variance is explained by three shocks: costs, UIP and foreign inflation. In the very-short-run, cost-push shocks contribute to nearly 80 percent, but at longer horizons this number goes down to 50 percent. As we discussed earlier, given Chile's openness to trade, foreign inflation shocks and exchange-rate-related shocks are an important source of inflation variation (about 40 percent in the medium and long run).

Figure 5 presents the results for the non-tradable core inflation rate. At short periods, cost-push shocks explain almost all of the forecast error variance, however, in the medium and long terms, demand shocks become more relevant. Interestingly, the effect of foreign demand shocks is not seen until a year ahead, once they have affected the domestic output gap.

Figure 6 presents the forecast error variance decomposition of the nominal interest rate. At short horizons, monetary shocks dominate explain the lion's share of the variance, with more than 80 percent. In the medium term, demand and cost-push shocks increase their shares, reaching shares of about 16 percent each one. The remaining two thirds are explained by monetary policy shocks (33 percent), and foreign inflation and demand shocks explain most of the remaining fraction (23 percent).

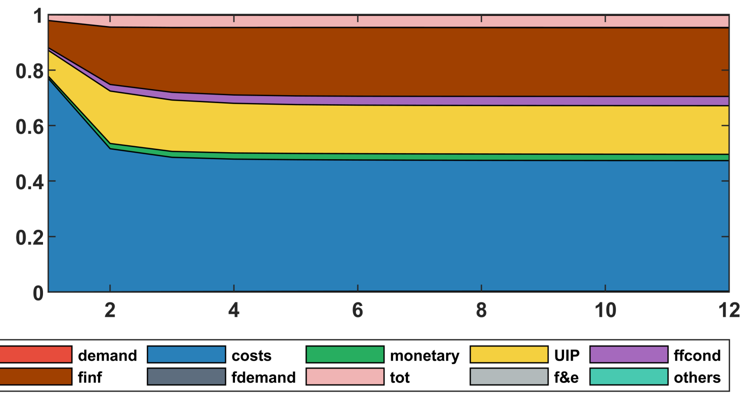
Finally, Figure 7 presents the forecast error variance decomposition of the RER. Apart from UIP shocks, which contribute the most, we observe an important fraction of the share explained by terms of trade shocks.

Figure 3: Forecast Error Variance Decomposition of the Output Gap



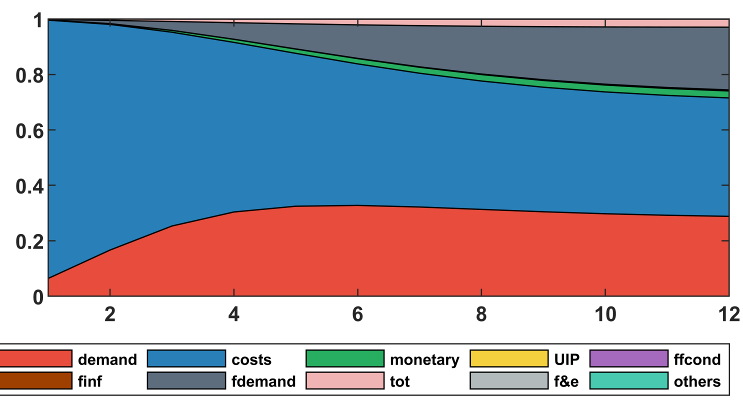
Notes: See Table 5's footnotes.

Figure 4: Forecast Error Variance Decomposition of Tradable Inflation



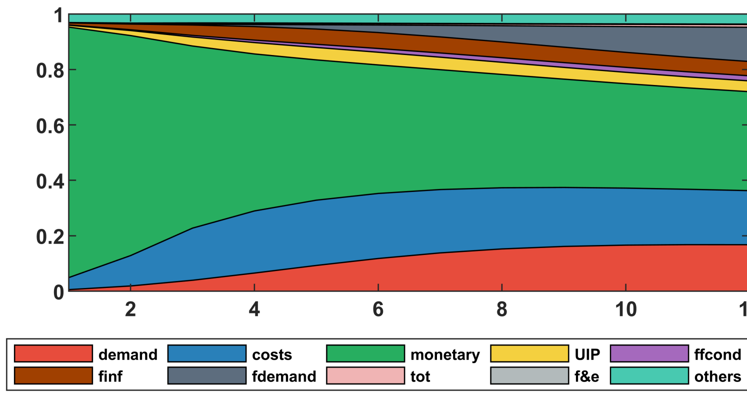
Notes: See Table 5's footnotes.

Figure 5: Forecast Error Variance Decomposition of Non-Tradable Inflation



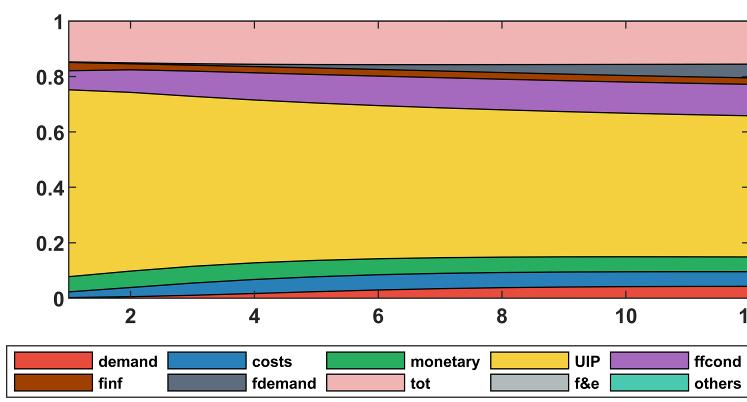
Notes: See Table 5's footnotes.

Figure 6: Forecast Error Variance Decomposition of the MPR



Notes: See Table 5's footnotes.

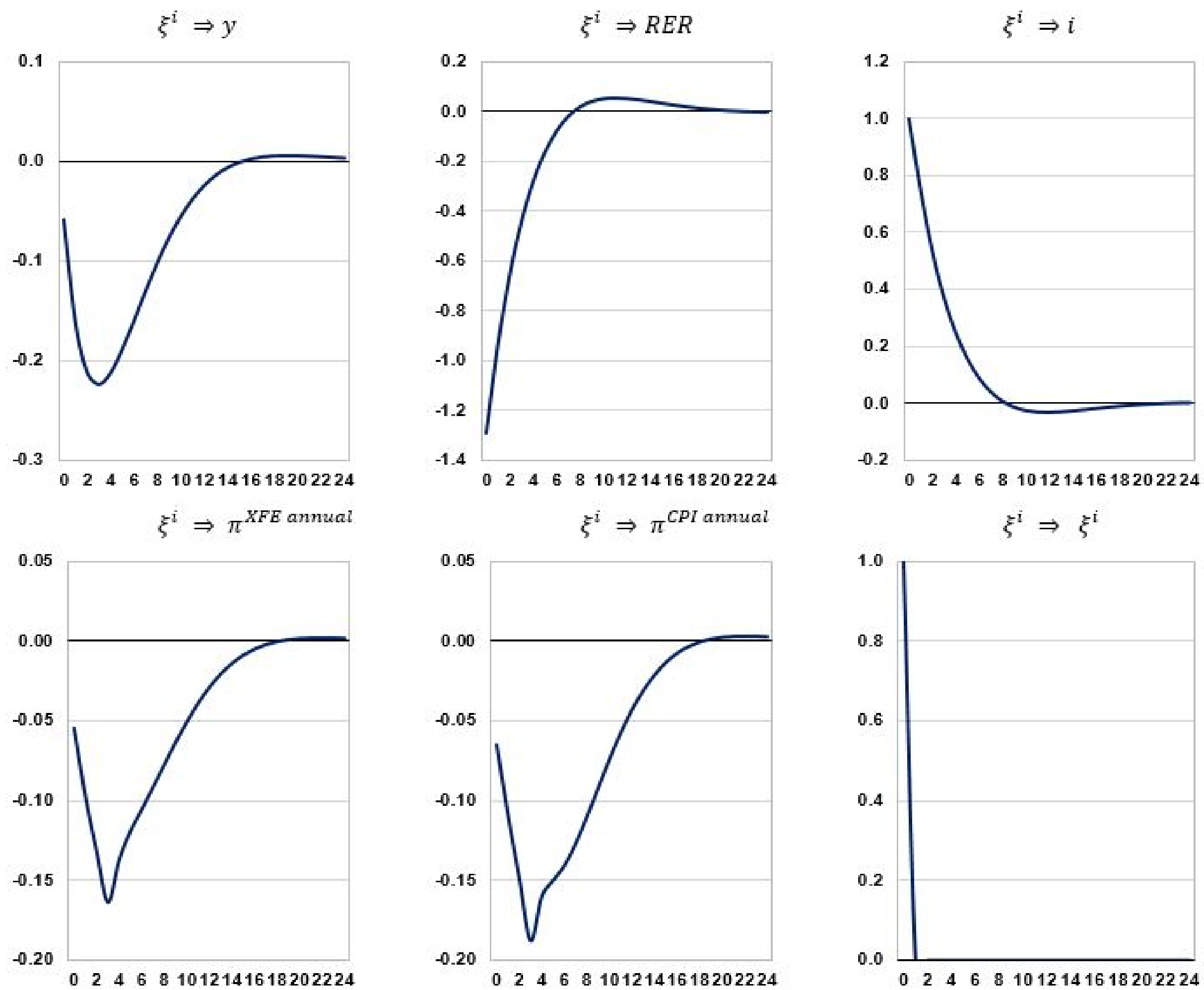
Figure 7: Forecast Error Variance Decomposition of the RER



Notes: See Table 5's footnotes.

For a qualitative assessment of MSEP, it is useful to look at the impulse-response functions. These show how endogenous variables respond to different shocks.[11] Figure 8 shows the response of the endogenous variables to a monetary policy shock that increases the MPR by 100 bp. First, a fall in the output gap is generated as well as an exchange rate appreciation due to domestic-foreign interest rate arbitrage. The combined effect of these last two variables translates into a fall in core inflation, which in cumulative terms, suffers a decrease of approximately 0.2 percent over a one-year period.

Figure 8: Monetary policy shock + 100 bp



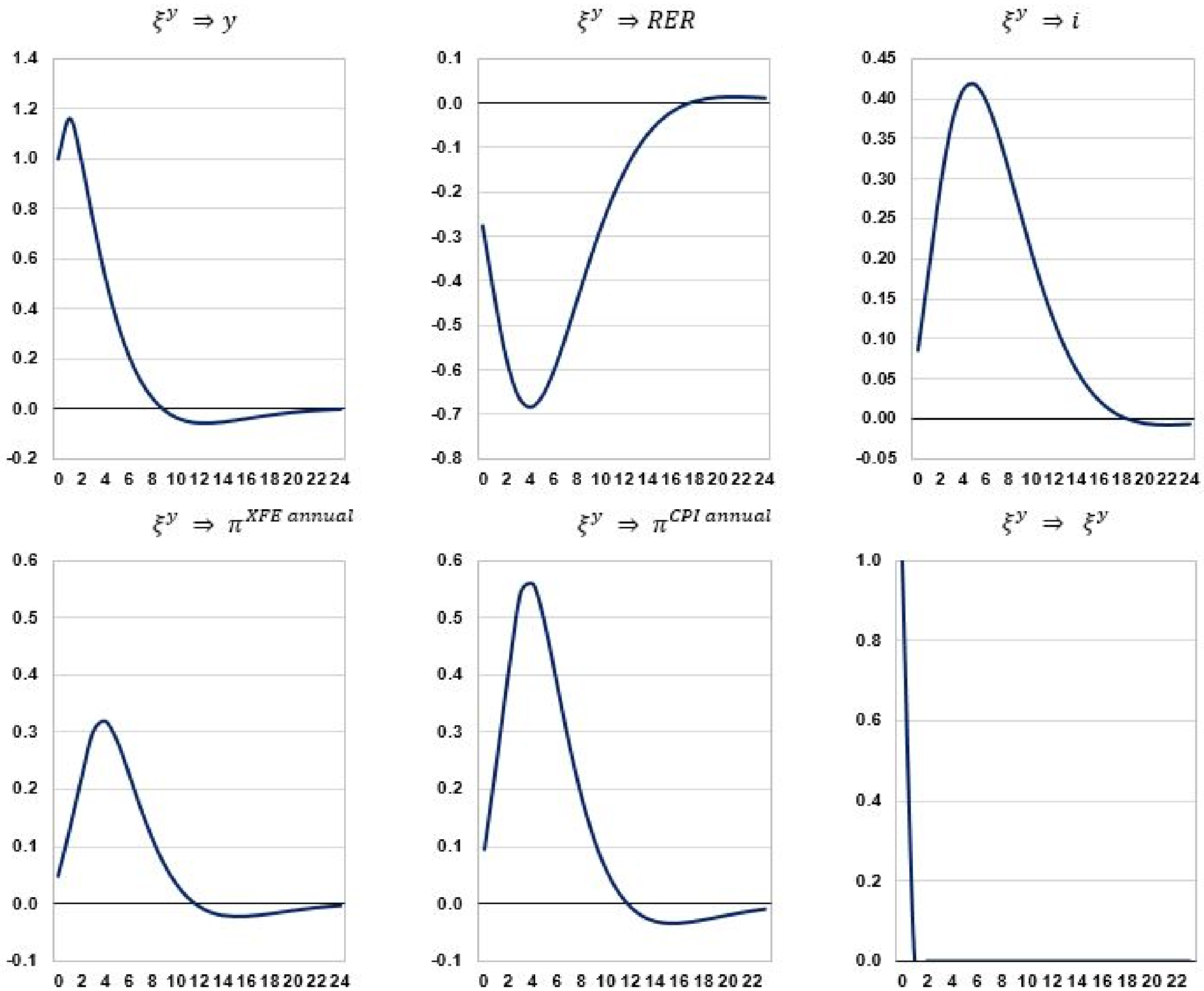
Note: IRFs use the posterior mode.

Figure 9 shows the model's dynamics when a domestic demand shock increases the output level by 1 percent with respect to potential output. In that case, the MPR increases in response to the new level of the output gap and the increase in inflation. The MPR increase translates into an appreciation of the real exchange rate that helps to stabilize the economy. Finally, as the initial shock dissipates, the economy returns to its equilibrium. Regarding

[11] For π^{XFE} and π^{CPI} it is plotted the sum of the QoQ variation to show an annualized measure of inflation.

XFE inflation, a shock of this magnitude generates an increase in annual inflation close to 0.3 percent in the fourth quarter (maximum effect). [12]

Figure 9: Domestic demand Shock +1 percent of NMGDP



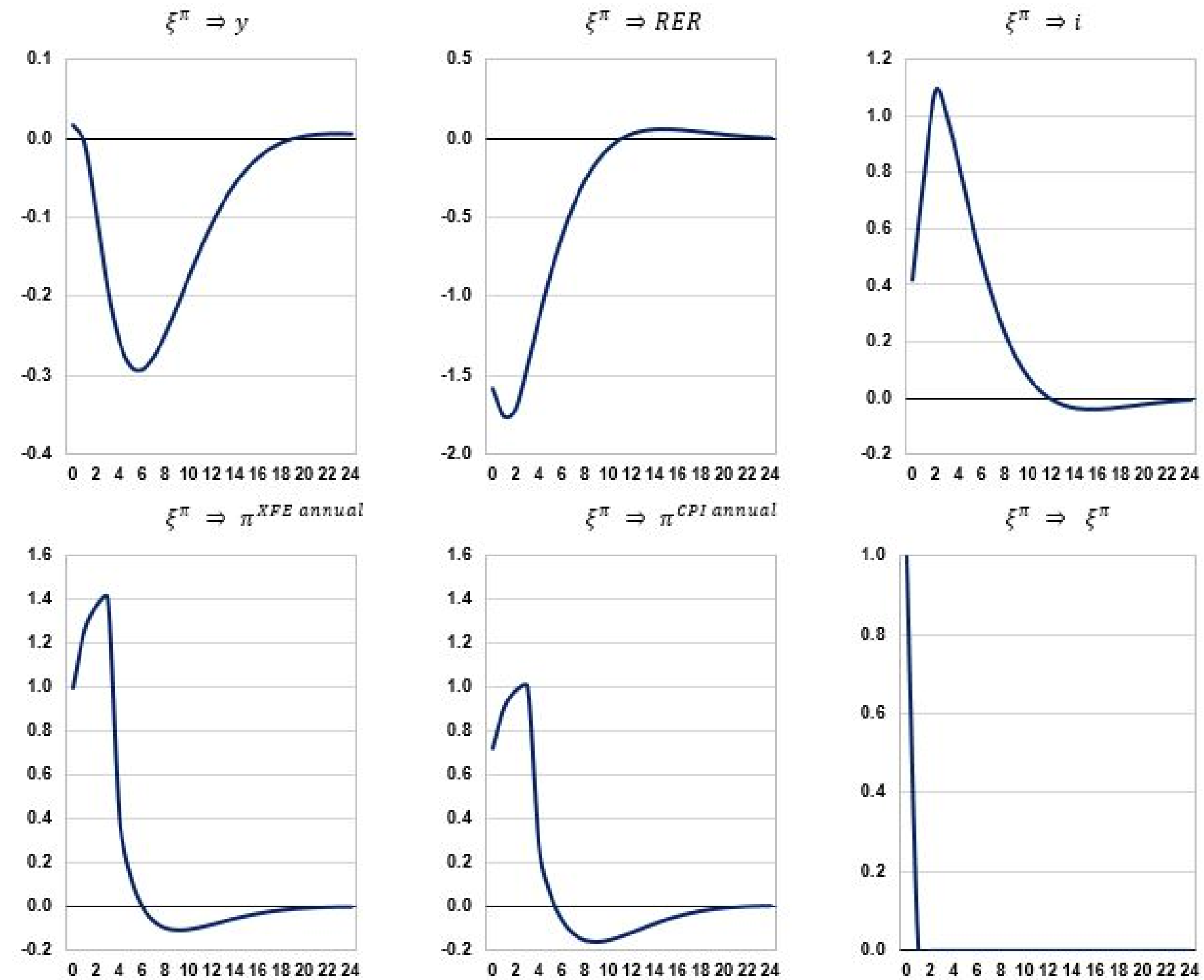
Note: IRFs use the posterior mode.

Figure 10 illustrates the model's dynamics when a cost-push shock of size 1*percent* hits the economy.[13] First, the output gap becomes positive due to a decrease in the real rate due to Taylor's rule persistence. However, once it becomes positive, the output gap decreases and, accompanied by an appreciation in the real exchange rate, inflation finally converges again to the equilibrium level.

[12] The larger effect on total CPI is due to the loading effect that the output gap has on food inflation.

[13] The calibration shown combines with equal weight transitory and more persistent shock. When the shock is purely transitory (more persistent), effects reduce (increase) in magnitude, but signs do not change. To simplify the analysis we weighted the effects of idiosyncratic cost push shocks from specific Phillips curves that comprise the CPIXFE aggregate.

Figure 10: Cost-push Shock +1 percent π^{XFE}

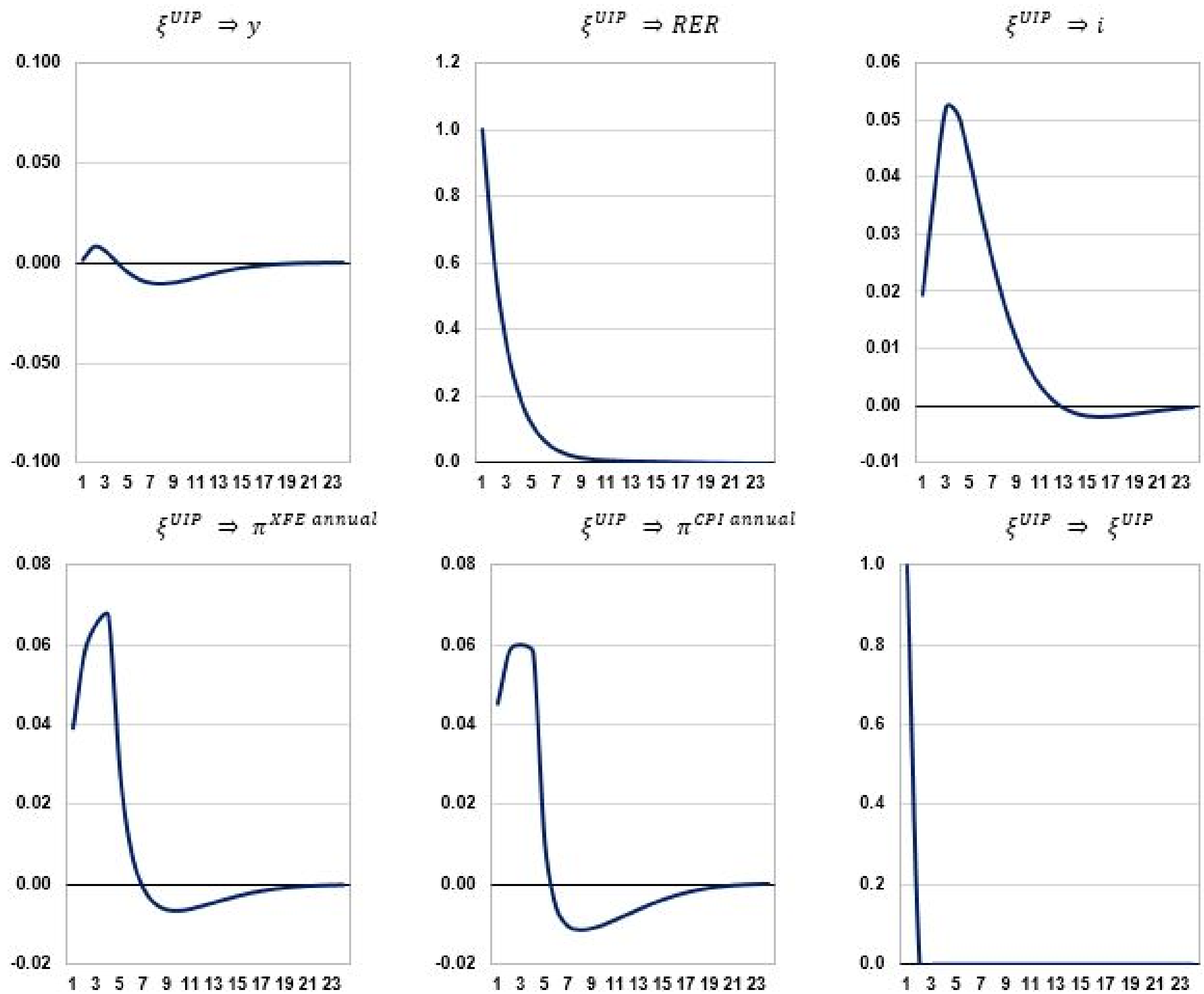


Note: IRFs use the posterior mode. IRFs reflect a weighted average of the three π^{XFE}'s Shocks.

Figure 11 shows the model's dynamics when a UIP shock calibrated for a 1 percent depreciation of the real exchange hits the economy. Exchange rate depreciation translates into an increase of both $CPIXFE$ and CPI. Notice that the inflationary effect manifests mostly in the first year. Given a shock of this magnitude, XFE inflation reaches 0.07 percent at the end of fist year.

The effects of this shock on both the output gap and monetary policy are limited.

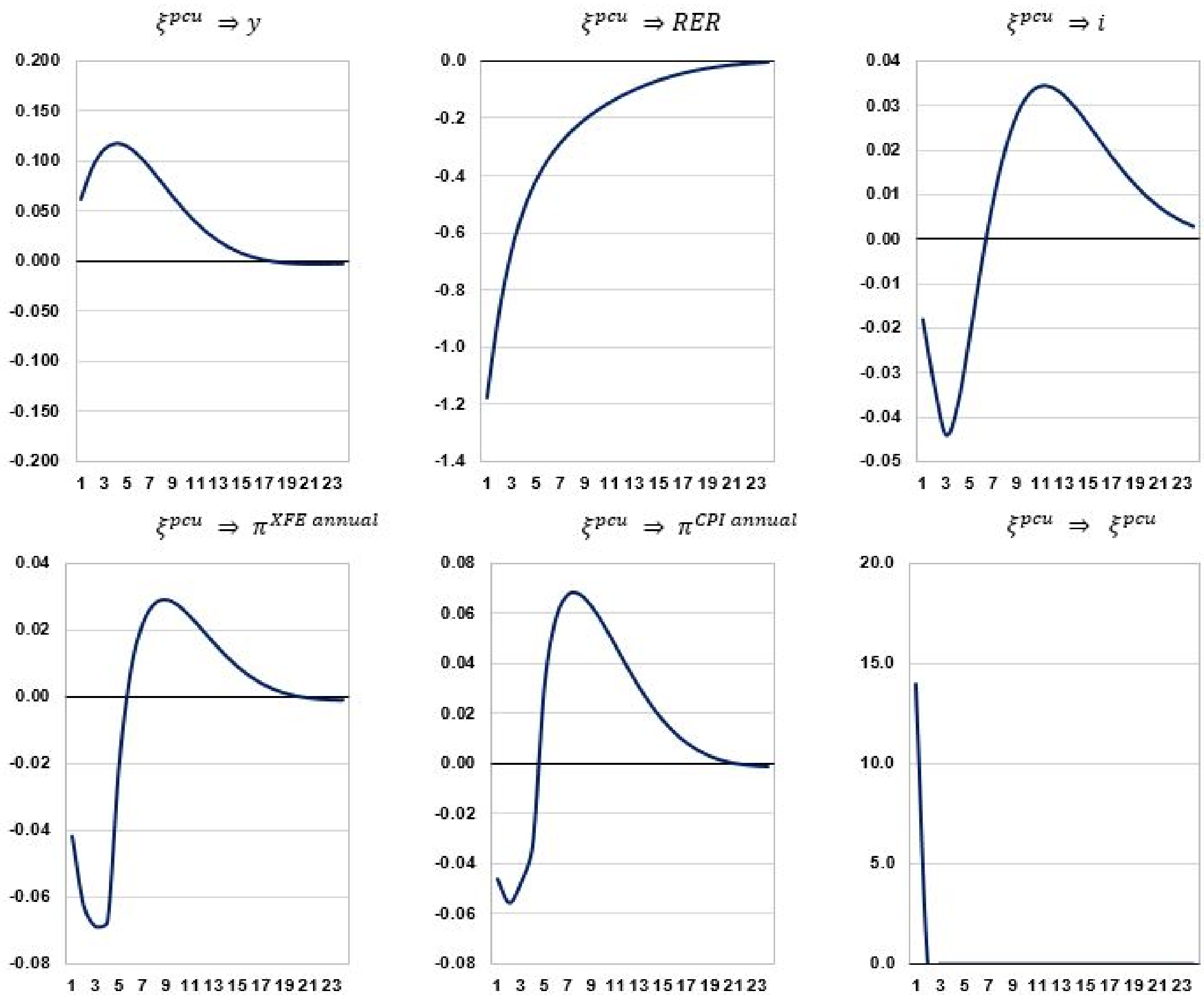
Figure 11: UIP Shock that rises + 1 percent the RER



Note: IRFs use posterior mode.

Figure 12 shows model's dynamics when a one standard deviation copper price shock hits the economy. Due to the modification of the UIP equation, the RER appreciates by roughly 1.2 percent on impact. At the same time, output gap increases by nearby 0.1 percent. Due to RER appreciation, inflation falls in the first year, but after the exchange rate effects disappear, inflationary pressures from the output gap dominates. However, it is worth noticing that both inflation and MRP effect are limited.

Figure 12: One standard deviation copper price Shock



Note: IRFs use posterior mode.

5.3 FORECAST ASSESSMENT

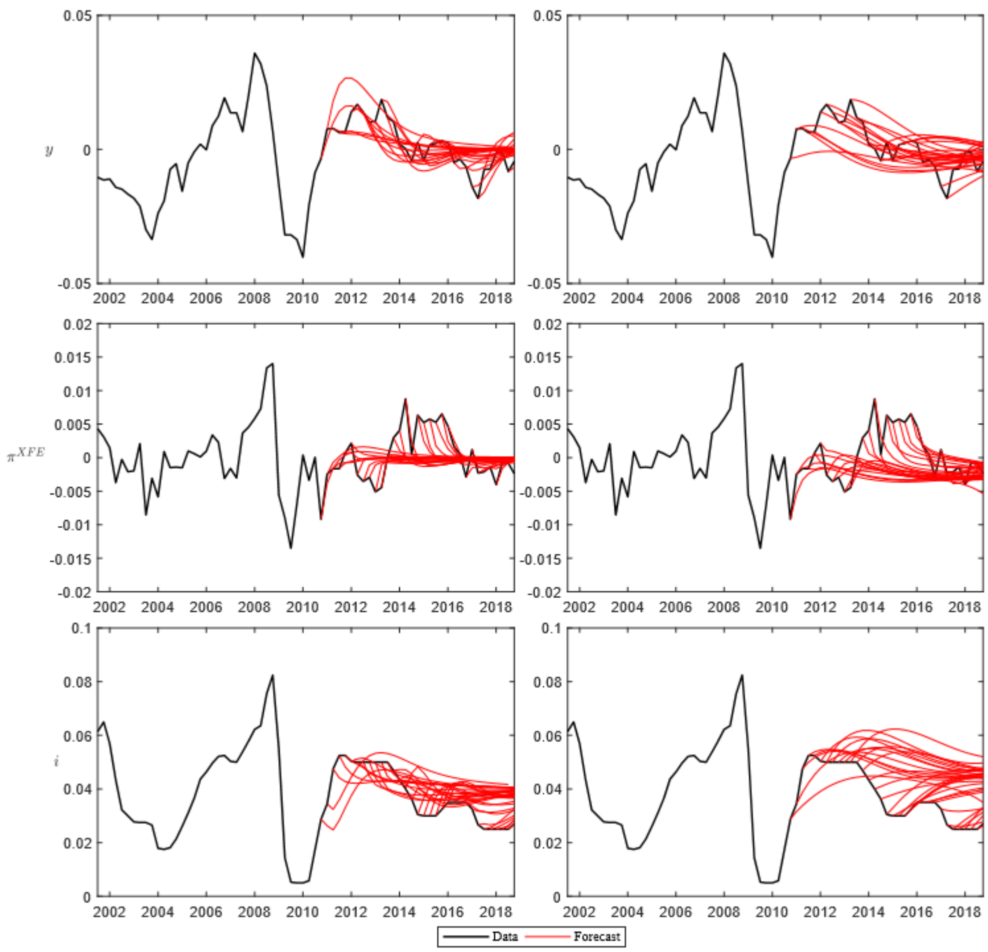
In this section we evaluate the MSEP's forecasting performance. To this end, we conducted a recursive forecast exercise, where the model's forecasts where compared with benchmark models. For each model, we generated a set of forecasts following the procedure below:

for T = *2011Q1* **to** *2019Q1* **do**
  Define the sample as $M^{(T)} = \{2001Q3, ..., T\}$
  Estimate the model using the sample $M^{(T)}$
  Use the estimated model and the sample $M^{(T)}$ to forecast each variable x for H periods, i.e. get $\tilde{x}^{(T)}_{T+1}, ..., \tilde{x}^{(T)}_{T+H}$
  Save forecast of each variable as $\tilde{x}^{(T)} := (\tilde{x}^{(T)}_{T+1}, ..., \tilde{x}^{(T)}_{T+H})$
end

Each model was estimated multiple times, adding one observation at a time. The first sample ranges from 2001Q3 to 2011Q1, and the last one from 2001Q3 to 2019Q1. In each iteration, $(1, 2, ..., H)$ quarterly forecast were made and stored by indexing them with the superscript (T). This exercise was carried out with three benchmark Bayesian VAR models. The first model (BVAR1) includes y, π^{XFE} and i; the second model (BVAR2) enlarges the previous model with the rer; and the third model (BVAR3) adds to the previous the set of external variables observed by the MSEP $(y^{em}, y^{ad}, i, poil, \pi^{*}, tot, \rho_{embi})$. All these models are specified with one lag for parsimony.

Figure 13 shows recursive forecast of the MSEP and BVAR1[14]. It can be appreciated that MSEP's forecast tends to reverse to the mean faster than the BVAR's forecasts.

Figure 13: Forecast MSEP vs BVAR1: y, π^{XFE} and MPR.



Notes: Left column for MSEP and right column for BVAR1. Black solid lines correspond to data. Red solid lines shows forecast based on recursive iterations.

We evaluated the forecasting performance of the four models using the root mean square error (RMSE), defined as:

$$\text{RMSE}(h) = \sqrt{\frac{1}{|M|} \sum_{T \in M} \left(\tilde{x}^{(T)}_{T+h} - x_{T+h} \right)^2}, \qquad h = 1, ..., H,$$

where $M = \{2011Q1, ..., 2019Q1\}$ and h corresponds to the forecast horizon being evaluated.

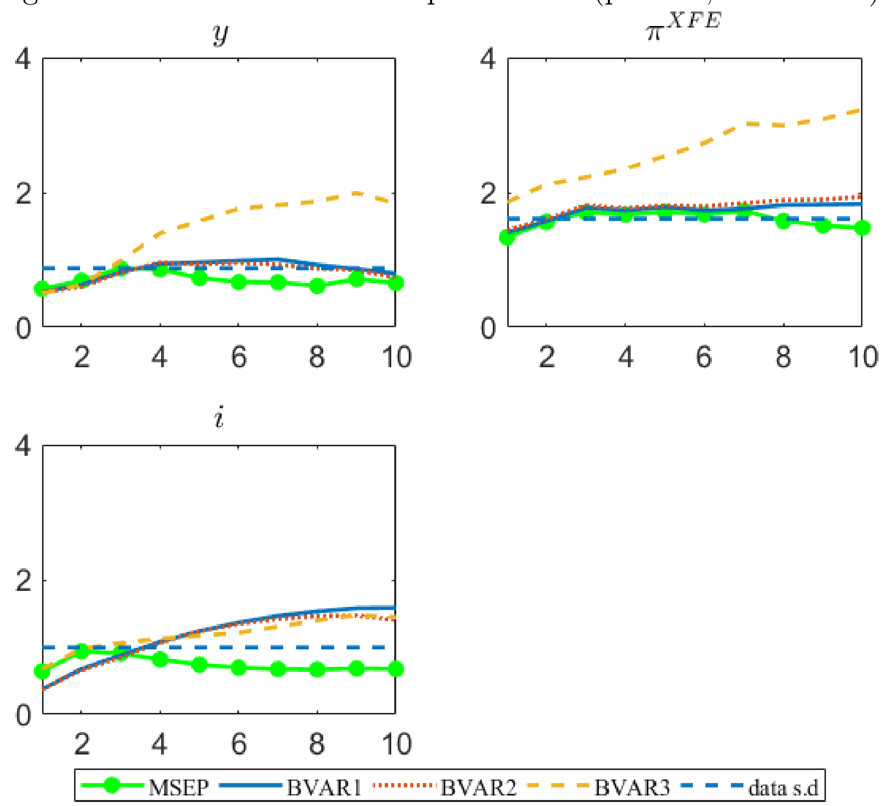
[14]The posterior mode is estimated in each iteration (Step 3).

Figure 14 shows the RMSE measured in annualized percentage points (vertical axis) for different forecast horizons (horizontal axis) for the variables y, π^{XFE} and i. First, for the output gap, we observe that in 1 to 3 quarters forecast horizons, there are no major differences among the models. However, from the fourth quarter, the MSEP has a lower forecast error than the BVAR models. The error is also lower than the standard deviation of the output gap over the evaluation period. Also, the model BVAR3 has a remarkably poorer performance than the other models. This result indicates that the inclusion of external variables, without restrictions, does not necessarily improve the models' forecasting capacity.

We find similar results for inflation (π^{XFE}), where the MSEP is not worse than the BVAR models on the short and medium terms, and slightly better on horizons longer than two years. Again, the model BVAR3 has a poorer performance than the rest.

Regarding the interest rate forecasts, BVAR models do slightly better on the first two quarters, while on the medium term the MSEP outperforms the other models by a large margin.

Figure 14: RMSE of out of sample forecast (percent, anualizado).



5.4 HISTORICAL SHOCKS DECOMPOSITION

The historical shocks decomposition is another relevant dimension for evaluating the MSEP. The decomposition reflects the contribution of shocks that the MSEP identifies to explain data. Thus, it allows to make an interpretation of historical data through the lens of the model. Figure 15 illustrates the output gap, XFE inflation, [15] the MPR, and RER shocks

[15]The sum of four QoQ variations is presented, which is an approximation to the YoY variation.

decomposition during the period 2001 -2019. It is possible to distinguish five cycles or events, which are summarized in Table 6 and are briefly discussed below.

First, in the 2004 − 2007 cycle, high growth rates observed during that period corresponded to a sustained increase in the output gap. In particular, it reached its maximum levels, mainly explained by a strong contribution from foreign demand and high copper prices (favorable ToT for Chile). On the other hand, a high level of inflation explained by foreign drivers, together with a positive output gap, resulting in a contractive MPR. It is worth noticing that favorable ToT explains substantial part of RER appreciation during this period.

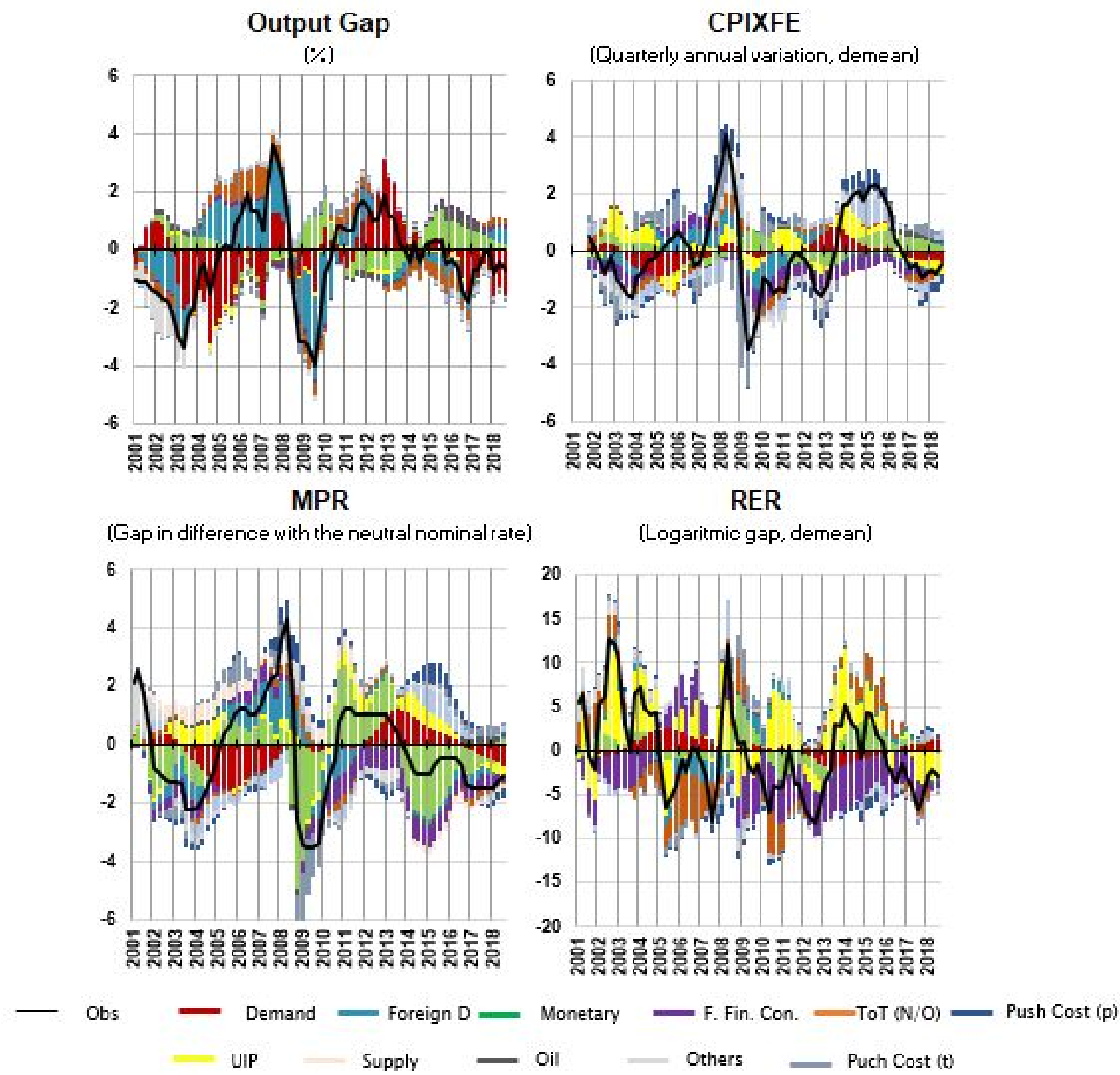
Second, we see the effects of the *Subprime* crisis that covers the 2008Q3-2010Q1 quarters. It is mainly characterized by a large negative foreign demand shock that moves the output gap from +4 to -4 percent in a short time. Domestic demand shocks are also significant, but the MSEP attributes the primary cause of this crisis to the foreign variables. As a result of these shocks, inflation also suffered an abrupt decline. The monetary authority reacted to these shocks by taking the MPR to its minimum. At the same time, local currency depreciation was mainly driven by both the reversal an abrupt fall in ToT and UIP shocks. The decomposition shows that the expansion of monetary policy contributed to sustain the output gap, not opening up further and inflation not being even lower.

The third episode is the post-crisis period, where the output gap recovered from -4 percent to +2 percent. Monetary policy and the foreign scenario contributed positively to this recovery, through international demand (emerging trading partners) and high copper prices. However, inflation remained low, with a appreciated RER mainly explained by low foreign international trade and high copper prices. At the same time, the MSEP also identifies a volatile cost-push shock. Finally, although inflation was below the target, monetary policy remains contractive since with a positive output gap, inflation should converge to the goal without a need for a monetary boost.

It is also possible to distinguish the effects of the *Taper tantrum* in 2013, after the announcements of normalization of the FED's monetary policy. The terms of trade contributed negatively, and demand gradually weakened during this period. Regarding inflation, there was a reversal of cost-push, ToT, and UIP shocks, which is consistent with the severe depreciation of the local currency. While inflation was above the target, monetary policy became expansive in response to the slowdown that closed the output gap. Without this monetary expansion, the output gap would have been even more negative, as indicated by the contribution of the monetary shock.

Finally, from the end of 2015 to the end of 2017, a persistent deceleration has been observed that reverts slightly towards 2019. During this period, monetary policy remained expansive in response to the persistent weakening of domestic demand. Inflation, on the other hand, slowed down due to: (i) the appreciation of the Chilean peso, which was mainly explained by a slight recovery of copper prices and UIP shocks; (ii) a weakened demand.

Figure 15: Historical shocks Decomposition: y, π^{XFE} , MPR and RER.



Note: Inflation correspond to the sum of four QoQ variations and it is reported demeaned. MPR is showed as deviation from the neutral rate *in*. For further details see Table's 5 note.

Table 6: Economics Events: last two decades

Quarters	Event	Output Gap	XFE Inflation	RER	Monetary Policy
2004Q1-2008Q2	Commodities Boom	Acceleration	Rise	Appreciation	Contractive
2008Q3-2010Q1	Subprime Crisis	Abrupt fall	Abrupt fall	Depreciation	Highly expansive
2010Q2-2013Q1	Recovery - ↑ *Copper price* - ↑ *China*	Fast recovery - *Expansive Monetary Policy* - *Favorable external conditions*	Low	Appreciation	Contractive
2013Q2-2015Q3	Taper tantrum - ↓ *Commodities prices* - ↓ *Emerging Economies, mostly LatAm*	Deceleration	High	Depreciation	Expansive
2015Q4-2017Q3	Deceleration - *More persistent than expected*	More negative - *Despite better foreign financial Con. and Expansive Monetary policy*	Low - *Weaker demand*	Appreciation	More Expansive

Analysis of historical events through the lens of the MSEP.

.

6 COMPARISON WITH OTHER MODELS

Monetary authorities have widely used gap models, such as the MSEP, as their primary projection models. However, in recent years central banks around the world have begun the transition from gap to DSGE models. The CBoC is not an exception to this trend and has developed a DSGE model, adapted to the Chilean economy (MAS models and its successor XMAS). In this transition, the Central Bank has chosen to complement both gap and DSGE models for macroeconomic interpretation and forecast.

A model comparison between the MSEP and its peers used in other central Banks is shown. Although an exhaustive analysis is beyond the scope of this paper, since we consider some of the models presented here may have been phased out, they are still useful as comparative references.

In particular, we are interested in measuring three aspects we believe are significant within the model. First, the implicit relationship between the output gap and inflation of these models. Second and third, the implications of what we believe are the two most important model's shocks: monetary and demand shocks.

6.1 THE OUTPUT GAP AND INFLATION RELATIONSHIP

The main direct inflationary channel in gap models lies in the output gap level. The relationship between the output gap and inflation is represented by each inflation sub-aggregate Phillips curve. In particular, we are interested in the output gap's coefficient as an inflation determinant.

In the case of the MSEP Model, since the CPIXFE has three subcategories, there are consequently three specifications. They capture the expected theoretical mechanisms, although they have flexibility in some restrictions for a better data adjustment. By calculating the output gap-inflation elasticity for each subcategory and considering its share in the CPIXFE, an CPIXFE-final output gap elasticity can be obtained. The estimated elasticity is 0.042, which translates to approximately 0.17 in annualized terms. This means that a decrease of one point in the output gap, decreases directly SAE inflation by 0.17.[16]

[16]It is important to clarify that it is the immediate effect, but not the total, since model variables are endogenous, which means movements of the output gap may have an impact on other variables, such as

When reviewing models used in other countries, we find this estimate similar to other Central Banks' estimations, which values range between 0.13 and 0.80 per year. This comparison is presented in Table 7. However, it is worth mentioning at least two aspects. First, the output gap is an unobservable variable; therefore the estimation methodology has direct implications on the estimation of this coefficient.[17]

Second, it should also be considered that inflation metrics are affected by the output gap, and its exact measurement may vary across countries.

Table 7: Output gap - inflation elasticities in other semi-structural models.

Country	**Reference**	**Model's Name**	**Price Index (ToY)**	**Output gap elasticity(*)**
Brazil	Souza-Sobrinho and Minella (2009); p. 17	Semi-structural model	CPI	0.80
Netherlands	Berben et al. (2018); p. 74	Delfi	CPIXE	0.32
England	Murray (2012);p. 53	SMUKE	GDP Deflator	0.13
Sweden(**)	Bardsen et al. (2012); p. 30	MOSES	CPI	0.64
Perú	Winkelried (2013); p. 70	MPT	CPIXFE	0.80
Colombia	González et al. (2013); p. 286	Semi-structural model	CPI	0.13
Spain(**)	Hurtado et al. (2014) ; p. 25	MTBE	CPIXFE	0.26
Australia	Stone et al. (2005); p. 27	SMAE update 2005	CPIXFE	0.36
Chile		MSEP	CPIXFE	0.17
			Range	**[0.13-0.80]**

Note: (*) Based on YoY inflation. (**) GDP growth instead of the output gap enters in the equations.

6.2 DYNAMICS OF A MONETARY AND A DEMAND SHOCK

It is interesting to compare inflation and GDP reactions to a monetary policy shock. Table 8 summarizes the effects of a monetary shock on inflation and GDP for models used in each country. In the case of the MSEP, a shock of 100 basis points causes total inflation to fall by 0.19 percent in one year, and GDP to fall by 0.22 percent.

Evidence indicates that the monetary policy shock effect in the MSEP lies between observed values for other countries. In cases such as Spain and England, the impact on inflation is limited. At the same time, for Sweden and Peru, the effects are similar in magnitude, but with different timing (more persistent effects, towards the second year after shock). The strongest effect is found in Brazil's model, where the index reduction is about 0.6 percent.

Table 9 shows the case of a demand shock that increases GDP by 1 percent. The MSEP's one-year term effect on inflation is higher than those of England and Australia models. However, the two-years term effect shows greater persistence. As in monetary policy shocks, the most significant inflationary effect is found in Brazil's model.

7 FORECASTING PROCESS

This section briefly explains the forecasting process.[18] Notice that effective data along with judgement yield short-run forecasts (six-month ahead), which are used as input for the MSEP.

exchange rate, which affect inflation.

[17]For example in the case of MSEP, the IS curve and the dynamics of the growth of potential GDP, together with relative variance restriction between potential and output gap shocks allows to identify it. However, if we used the HP Filter, for example, it would be different.

[18]The CBoC's Staff regularly use the XMAS and the MSEP models to obtain average projections, which are enriched with informed judgment from the Board as well as additional information not included in the models.

Table 8: Effects of + 100 bp Monetary Policy Shock

Country	**End of First Year**			**End of Second Year**		
	CPI YoY	Output Gap	GDP Growth	CPI YoY	Output Gap	GDP Growth
Chile	-0.19	-0.22	-0.22	-0.13	-0.13	0.09
Brazil	-0.6	-0.18	-	-0.5	-0.02	-
United States	-0.04	-	-0.5	-	-	-
Japan	-0.07	-	-0.2	-	-	-
Italy	-0.14	-	-0.3	-	-	-
England	0	-0.3	-	-0.05	-0.25	-
Sweden	-0.13	-	-0.125	-0.18	-	0
Perú	-0.08	-0.12	-	-0.13	-0.04	-
Spain	-0.02		-0.10	-0.06		-0.21

Source: IRFs taken from published papers. See appendix D.

Table 9: Effects of a Demand Shock of size +1 percent of GDP

Country	**End of First Year**			**End of Second Year**		
	CPI YoY	Output Gap	GDP Growth	CPI YoY	Output Gap	GDP Growth
Chile	0.55	0.75	0.75	0.27	0.11	-0.63
Brazil	1.2	0	-	0.8	0	-
England	0.2	1	-	0.5	0.6	-
Australia	0.25	0.5	-	0.3	0.25	-

Source: IRFs taken from published papers. See appendix D.

It is widely known that when nowcasts and short-term forecasts are fed into structural models, overall projections become more accurate (see, Del Negro and Schorfheide (2013)). Besides, equilibrium or trend values of a subset of variables such as *rer*, *tot*, *pmoil*, *embich*, y^{ad}, and y^{em} are occasionally revised and potential GDP is estimated once a year (The most recent estimation is documented by Aldunate et al. (2019)). Finally, external medium-term forecasts of the foreign baseline scenario, mining GDP and food and energy inflation are used for conditioning the main forecast. These forecasts are provided by CBoC's specialized forecasters.

8 CONCLUSIONS

This document has presented a detailed description of the MSEP model's structure and its transmission mechanisms. In addition, results show the usefulness of the MSEP for the CBoC's monetary policy analysis under its two-year inflation target scheme. This new model will be able to generate medium-term forecasts as input for CBoC's monetary policy. At the same time, the new mechanisms incorporated allow us to better capture the relationship between the external sector and domestic variables. Particularly, the model correctly interprets the relationship between copper prices (the main Chilean export) and the real exchange rate.

In this paper, we explain how this model is specified, estimated, and tested. We provide empirical results regarding unconditional variance decomposition, parameter estimations, IRF analysis, and forecast performance. Among the results, the forecast assessment of the model stands out. The MSEP provides output gap, inflation, and interest rates forecast comparable to or better than those of BVAR type time series models. These forecasts are also consistent from an economic perspective. Furthermore, the MSEP offers the possibility to study the effect of different MPR trajectories using its impulse-response functions. According to the results, monetary policy in the MSEP has an inflation and output gap effect within the ranges of similar models for other countries. The MSEP's historical shock decomposition is also useful since it allows us to interpret data through the lens of the model. This permits to identify main events that are responsible for Chile's economic dynamics and helps to elaborate on events affecting the economy.

As future work, we are interested in extending the MSEP in view of incorporating absent or simplified channels in the current version. On one hand, better modeling of the labor market and labor force would allow us to understand the effects of recent Chilean migration flow better. On the other hand, modeling aggregate demand components such as consumption and investment would allow for better inference of demand shocks. Finally, the model would benefit from a financial mechanism, which would allow a better understanding of the scope and effectiveness of monetary policy when facing big financial stressful periods.

REFERENCES

Albagli, E., Gatty, A., Kirchner, M., Luttini, E., Naudon, A., Tranamil, R., Fornero, J., and Yany, A. (2015). Producto Potencial Relevante para la Inflación. *Mimeo, Central Bank of Chile.*

Aldunate, R., Bullano, F., Canales, M., Contreras, G., Fernandez, A., Fornero, J., García, M., García, B., Peña, J., Tapia, M., and Zúñiga, R. (2019). Estimación de Parámetros Estructurales de la Economía Chilena.

Bardsen, G., den Reijer, A., Jonasson, P., and Nymoen, R. (2012). MOSES: Model of Swedish economic studies. *Economic Modelling*, 29(6):2566 – 2582.

Berben, R.-P., Kearney, I., and Vermeulen, R. (2018). DELFI 2.0, DNB's Macroeconomic Policy Model of the Netherlands. DNB Occasional Studies 1605, Netherlands Central Bank, Research Department.

Blagrave, P., García-Saltos, M. R., Laxton, M. D., and Zhang, F. (2015). *A simple multivariate filter for estimating potential output.* Number 15-79. International Monetary Fund.

Blagrave, P. and Santoro, M. (2016). *Estimating Potential Output in Chile: A Multivariate Filter for Mining and Non-Mining Sectors.* International Monetary Fund.

Busetti, F. (2019). Remarks on "The FRB/US Model" and "The Quarterly Japanese Economic Model". Banca d'Italia.

Carlomagno, G. and Sansone, A. (2019). Marco Metodológico para el Análisis de la Inflación Subyacente. *Mimeo, Central Bank of Chile.*

Central Bank of Chile (2003). Modelos Macroeconómicos y Proyecciones del Banco Central de Chile.

Central Bank of Chile (2020). Recuadro III.4, "Uso de Modelos Macroeconómicos en el Banco Central de Chile". *Modelos Macroeconómicos en el Banco Central de Chile*, pages –.

Del Negro, M. and Schorfheide, F. (2013). Chapter 2 - DSGE Model-Based Forecasting. In Elliott, G. and Timmermann, A., editors, *Handbook of Economic Forecasting*, volume 2 of *Handbook of Economic Forecasting*, pages 57 – 140. Elsevier.

Figueroa, C. and García, P. (2017). Desafíos de la Política Monetaria Sistemática. Economic Policy Papers Central Bank of Chile 64, Central Bank of Chile.

Fornero, J. and Kirchner, M. (2018). Learning about Commodity Cycles and Saving-Investment Dynamics in a Commodity-Exporting Economy. *International Journal of Central Banking*, 14(2):205–262.

Fornero, J. and Zúñiga, R. (2017). PIB Potencial y Brechas de Capacidad. *Mimeo, Central Bank of Chile.*

Fuentes, M., Fornero, J., and Rubio, H. (2018). PIB minero y no minero. *Notas de Investigación Journal Economía Chilena (The Chilean Economy)*, 21(3):94–109.

Galì, J. (2015). *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications*. Princeton University Press.

García, B., Guarda, S., Kirchner, M., and Tranamil, R. (2019). XMAS: An extended model for analysis and simulations. *Central Bank of Chile Working Papers*, 833.

González, A., Ocampo, S., Pérez, J., and Rodríguez, D. (2013). Brecha del producto y medidas de la tasa de interés neutral para Colombia. *Monetaria*, 35(2):251–310.

Hamilton, J. D. (2018). Why you should never use the Hodrick-Prescott filter. *Review of Economics and Statistics*, 100(5):831–843.

Hurtado, S., Manzano, P., Ortega, E., and Urtasun, A. (2014). Update and re-estimation of the Quarterly Model of Banco de España (MTBE). *Banco de España Occasional Paper*, (1403).

Laubach, T. and Williams, J. C. (2016). Measuring the natural rate of interest redux. *Business Economics*, 51(2):57–67.

Medina, J. P. and Soto, C. (2007). The Chilean business cycles through the lens of a stochastic general equilibrium model. *Central Bank of Chile Working Papers*, 457.

Murray, J. (2012). A small model of the UK economy. *Office for Budget Responsibility, WP*, (4).

Souza-Sobrinho, N. F. and Minella, A. (2009). Monetary Channels in Brazil through de Lens of a Semi-Structural Model. In *31º Meeting of the Brazilian Econometric Society*.

Stone, A., Wheatley, T., and Wilkinson, L. (2005). A Small Model of the Australian Macroeconomy: An Update. RBA Research Discussion Papers rdp2005-11, Reserve Bank of Australia.

Timmermann, A. (2006). Forecast combinations. *Handbook of Economic Forecasting*, 1:135–196.

Winkelried, D. (2013). Modelo de proyección trimestral del BCRP: Actualización y novedades. *Revista de Estudios Económicos*, 26:9–60.

A STYLIZED FACTS OF VARIABLES USED IN THE ESTIMATION

Table 10: Stylized facts of variables used in the estimation

Variable	Mean $\mathbb{E}(X)$	standard dev. $\sqrt{\mathbb{V}ar(X)}$	Standard dev. relative to Output gap $\sqrt{\mathbb{V}ar(X)/\mathbb{V}ar(y)}$	First order autocor. $\mathbb{C}orr(X_t, X_{t-1})$	Output gap correlation $\mathbb{C}orr(X_t, y_t)$	Output gap(-1) correlation $\mathbb{C}orr(X_t, y_{t-1})$
ΔY_t	1.01	0.9	0.60	0.4	0.16	-0.31
y	-0.30	1.55	1.00	0.89	1.00	0.89
y^{em}	-0.01	2.71	1.75	0.87	0.55	0.39
y^{ad}	-0.14	2.23	1.44	0.91	0.42	0.29
π^{CPI}	0.00	0.66	0.43	0.54	0.54	0.46
π^{XFE}	0.00	0.47	0.31	0.57	0.46	0.49
π^{Core}	0.00	0.40	0.26	0.77	0.55	0.65
π^{NT}	0.00	0.35	0.23	0.75	0.68	0.75
π^{T}	0.00	0.67	0.43	0.75	0.18	0.30
π^{nCore}	0.00	1.12	0.72	0.26	0.24	0.12
π^{A}	-0.01	1.41	0.91	0.55	0.57	0.55
π^{E}	-0.06	3.37	2.17	0.10	0.08	-0.08
i	3.78	1.63	1.05	0.89	0.73	0.84
rer	-0.16	4.91	3.16	0.76	-0.39	-0.24
tot	0.33	13.44	8.67	0.86	0.21	-0.02
ρ^{embi}	0.00	0.55	0.35	0.82	0.01	0.24
i^{*}	-1.27	1.62	1.04	0.97	0.31	0.28
$poil$	1.15	26.27	16.95	0.84	0.48	0.37
pcu	1.45	29.26	18.88	0.88	0.44	0.21
π^{*}	0.01	2.76	1.78	0.41	-0.02	-0.17
U	7.74	1.36	0.88	0.96	-0.60	-0.58
Δpx	0.22	6.10	3.93	0.24	-0.42	-0.50
Δpx^{pcu}	0.67	13.68	8.82	0.28	-0.44	-0.51
Δpx^{pnpcu}	-0.02	3.43	2.21	-0.33	-0.07	-0.12
Δpm	0.07	3.52	2.27	-0.19	0.05	0.03
Δpm^{oil}	0.16	11.77	7.59	0.13	0.00	-0.15
pm^{pnoil}	0.03	3.65	2.35	0.35	-0.22	-0.10

Source: Authors' elaboration based on official data, see Box 1.
Note: Sample from 2001Q3 to 2019Q1.

Export Prices [a]

$$px_t = \rho_c px_t^{pcu} + (1-\rho_c) px_t^{pnpcu} \tag{49}$$

$$px^{pcu} = pcu + \xi_t^{px^{pcu}}, \qquad \xi_t^{px^{pcu}} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{px^{pcu}}}) \tag{50}$$

$$pcu = \rho^{pcu} pcu_{t-1} + \xi_t^{pcu}, \qquad \xi_t^{pcu} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{pcu}}) \tag{51}$$

$$px_t^{pnpcu} = \rho^{px^{pnpcu}} px_{t-1}^{pnpcu} + \xi_t^{px^{pnpcu}}, \qquad \xi_t^{px^{pnpcu}} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{px^{pnpcu}}}) \tag{52}$$

Import Prices [a]

$$pm = \rho_o pm_t^{oil} + (1-\rho_o) pm_t^{pnoil} \tag{53}$$

$$pm^{oil} = oil + \xi_t^{pm^{oil}}, \qquad \xi_t^{pm^{oil}} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{pm^{oil}}}) \tag{54}$$

$$poil_t = \rho^{1poil} poil_{t-1} + \rho^{2poil} poil_{t-2} + \nu_t^{poil}, \tag{55}$$

$$\nu_t^{poil} = \rho^{\nu poil} \nu_{t-1}^{poil} + \xi_t^{poil}, \qquad \xi_t^{poil} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{poil}}) \tag{56}$$

$$pm^{pnoil} = \rho^{pm^{pnoil}} pm_{t-1}^{pnoil} + \xi_t^{pm^{pnoil}}, \qquad \xi_t^{pm^{pnoil}} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2_{\xi^{pm^{pnoil}}}) \tag{57}$$

[a] A measurement shock washes out differences between implicit and actual export and import prices.

C MSEP PARAMETERS

Table 11: Calibrated model's parameters

Description	Equation	Parameter	Calibration
CPI basket shares	(7)	$\alpha 1$	0.70
	(8)	$\alpha 2$	0.74
	(17)	$\alpha 3$	0.70
	(19)	$\alpha 4$	0.73
	(19)	$\alpha 5$	0.19
MEPCO	(37)	α_{mepco}	0.70
	(37)	$_{mepco}$	0.43
CPI target	(23)	Target	0.03
ToT shares	(49)	ρ_c	0.40
	(53)	ρ_o	0.10
Foreign	(39)	ρ^{i*}	0.88
	(55)	ρ^{2poil}	0.00
Unemployment	(31)	$\tau 4$	0.10
	(32)	$\tau 3$	0.10
	(29)	$\tau 2$	0.50
	(29)	$\tau 1$	0.03
Shock persistences	(22)	$\rho^{\nu i}$	0.00
	(12)	$\rho^{\nu T}$	0.00
	(16)	$\rho^{\nu F}$	0.00
	(18)	$\rho^{\nu E}$	0.00
	(40)	$\rho^{\nu i*}$	0.00
	(42)	$\rho^{\nu \pi^*}$	0.00
	(44)	$\rho^{\nu embi}$	0.00
	(30)	$\rho^{\nu u}$	0.00
	(56)	$\rho^{\nu poil}$	0.00
	(34)	$\rho^{\nu em}$	0.00
	(36)	$\rho^{\nu ad}$	0.00
Others	(6)	rn^{SS}	0.01
	(6)	G^{SS}	0.033
	(3)	θ_G	0.07

Table 12: Calibrated and estimated standard deviation

Equation	Parameter	Prior distribution			Posterior			
		Distribution	Mean	S.D.	Mode	Mean	p5	p95
(5)	σ_{ξ^y}	IG	0.007	∞	0.006	0.006	0.005	0.007
(22)	σ_{ξ^i}	IG	0.007	∞	0.007	0.007	0.006	0.008
(27)	$\sigma_{\xi^{UIP}}$	IG	0.007	∞	0.012	0.013	0.009	0.017
(10)	$\sigma_{\xi^{NT}}$	IG	0.007	∞	0.002	0.002	0.001	0.002
(10)	$\sigma_{\epsilon^{NT}}$	IG	0.007	∞	0.002	0.002	0.001	0.002
(12)	σ_{ξ^T}	IG	0.007	∞	0.003	0.003	0.002	0.004
(12)	σ_{ϵ^T}	IG	0.007	∞	0.002	0.002	0.002	0.003
(14)	$\sigma_{\xi^{nCore}}$	IG	0.007	∞	0.009	0.008	0.006	0.011
(14)	$\sigma_{\epsilon^{nCore}}$	IG	0.007	∞	0.004	0.005	0.002	0.008
(31)	$\sigma_{\xi^{\bar{U}}}$	IG	0.007	∞	0.003	0.005	0.002	0.009
(16)	σ_{ξ^F}	IG	0.007	∞	0.011	0.011	0.009	0.012
(18)	σ_{ξ^E}	IG	0.007	∞	0.003	0.012	0.002	0.036
(34)	$\sigma_{\xi^{em}}$	IG	0.007	∞	0.013	0.014	0.012	0.016
(36)	$\sigma_{\xi^{ad}}$	IG	0.007	∞	0.009	0.009	0.008	0.010
(40)	$\sigma_{\xi^{i*}}$	IG	0.007	∞	0.004	0.004	0.004	0.005
(44)	$\sigma_{\xi^{embi}}$	IG	0.007	∞	0.003	0.003	0.003	0.004
(42)	$\sigma_{\xi^{\pi*}}$	IG	0.007	∞	0.032	0.033	0.028	0.037
(51)	$\sigma_{\xi^{pcu}}$	IG	0.007	∞	0.141	0.144	0.124	0.164
(56)	$\sigma_{\xi^{poil}}$	IG	0.007	∞	0.138	0.140	0.121	0.159
(50)	$\sigma_{\xi^{px^{pcu}}}$	IG	0.007	∞	0.080	0.081	0.070	0.093
(52)	$\sigma_{\xi^{px^{pnpcu}}}$	IG	0.007	∞	0.030	0.031	0.027	0.035
(54)	$\sigma_{\xi^{pm^{oil}}}$	IG	0.007	∞	0.082	0.084	0.072	0.096
(57)	$\sigma_{\xi^{pm^{pnpoil}}}$	IG	0.007	∞	0.034	0.034	0.029	0.039
(37)	$\sigma_{\xi^{mepco}}$	IG	0.007	∞	0.037	0.036	0.030	0.043

Equation	Parameter	Calibration
(2)	$\sigma_{\xi^{\overline{Y}}}$	0.001
(3)	σ_{ξ^G}	0.001
(32)	$\sigma_{\xi^{G\overline{U}}}$	0.001
(29)	σ_{ξ^u}	0.003
(6)	$\sigma_{\xi^{rn}}$	0.001

Note: The prior distribution is inverse gamma distribution (IG) on $\mathbb{R}^+$.

Table 13: Monetary policy shocks in other semi-structural models

Country	**Source**
Brazil	Souza-Sobrinho and Minella (2009); Figure 4.
United State, Japan and Italy	Busetti, F. (2019); p. 4
England	Murray (2012); p. 41.
Sweden	Bardsen et al. (2012); p. 18.
Perú	Winkelried (2013); p. 31.
Spain	Hurtado et al. (2014) ; p. 18.

Table 14: Demand shocks in other semi-structural models

Country	**Source**
Brazil	Souza-Sobrinho and Minella (2009); Figure 3.
Ingland	Murray (2012); p. 40.
Autralia	Stone et al. (2005) ; p. 40.

Documentos de Trabajo **Banco Central de Chile**	**Working Papers** **Central Bank of Chile**
NÚMEROS ANTERIORES	PAST ISSUES
La serie de Documentos de Trabajo en versión PDF puede obtenerse gratis en la dirección electrónica: www.bcentral.cl/esp/estpub/estudios/dtbc. Existe la posibilidad de solicitar una copia impresa con un costo de Ch$500 si es dentro de Chile y US$12 si es fuera de Chile. Las solicitudes se pueden hacer por fax: +56 2 26702231 o a través del correo electrónico: bcch@bcentral.cl.	Working Papers in PDF format can be downloaded free of charge from: www.bcentral.cl/eng/stdpub/studies/workingpaper. Printed versions can be ordered individually for US$12 per copy (for order inside Chile the charge is Ch$500.) Orders can be placed by fax: +56 2 26702231 or by email: bcch@bcentral.cl.

DTBC – 865
Semi-Structural Forecasting Model
Francisco Arroyo Marioli, Francisco Bullano, Jorge Fornero, Roberto Zúñiga

DTBC – 864
Price Rigidity and the Granular Origins of Aggregate Fluctuations
Ernesto Pasten, Raphael Schoenle, Michael Weber

DTBC – 863
Welfare Effects of Fiscal Procyclicality: Public Insurance with Heterogeneous Agents
Alvaro Aguirre

DTBC – 862
Análisis de Sentimiento Basado en el Informe de Percepciones de Negocios del Banco Central de Chile
María del Pilar Cruz, Hugo Peralta, Bruno Ávila

DTBC – 861
Unequal Political Business Cycles: Inequality, Policy Uncertainty and the Macroeconomy
Alvaro Aguirre

DTBC – 860
Proyección de Inflación en Chile con Métodos de Machine Learning
Felipe Leal, Carlos Molina, Eduardo Zilberman

DTBC – 859
A note on currency-hedging
Rodrigo Alfaro, Natan Goldberger

DTBC – 858
Multimarket Contact in Banking Competition in The United States
David Coble

DTBC – 857
Immigration in Emerging Countries: A Macroeconomic Perspective
Agustín Arias, Juan Guerra-Salas

DTBC – 856
Saving Rates in Latin America: A Neoclassical Perspective
Andrés Fernández, Ayşe Imrohoroğlu, Cesar Tamayo

DTBC – 855
Returns to Work Experience in Chile
Rosario Aldunate

DTBC – 854
Hindsight vs. Real time measurement of the output gap: Implications for the Phillips curve in the Chilean Case
Camila Figueroa, Jorge Fornero, Pablo García

DTBC – 853
Prudential Policies and Bailouts - A Delicate Interaction
Ernesto Pasten

DTBC – 852
Capital Controls and Firm Performance
Eugenia Andreasen, Sofia Bauducco, Evangelina Dardati

DTBC – 851
S&P 500 under Dynamic Gordon Model
Rodrigo Alfaro, Andrés Sagner

BANCO CENTRAL
DE CHILE