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Estimating Shadow Policy Rates in a Small Open Economy and the Role of Foreign Factors*

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Abstract

Shadow monetary policy rates (SMPRs) are useful to evaluate the policy stance when interest rates are at their lower bounds and unconventional policies are implemented. We present a methodology to estimate an SMPR for the case of a small open economy based on a dynamic factor model, which allows to consider the impact of foreign monetary conditions on domestic ones. An application to Chile shows that under large negative shocks, unconventional policies drove the domestic SMPR to negative levels. Also, the SMPR is mainly driven by domestic (foreign) factors in the short (long) run, lending support to the classic trilemma.

Resumen

Las tasas de política monetaria sombra (TPMS) son útiles para evaluar la postura de la política cuando las tasas de interés están en sus límites inferiores y se implementan políticas no convencionales. Presentamos una metodología para estimar una TPMS para el caso de una pequeña economía abierta basada en un modelo de factores dinámicos, que permite considerar el impacto de las condiciones monetarias extranjeras sobre las domésticas. Una aplicación a Chile muestra que bajo grandes shocks negativos, las políticas no convencionales llevan a estimar una TPMS doméstica en niveles negativos. Además, la TPMS se explica principalmente por factores domésticos (extranjeros) a corto (largo) plazo, apoyando el trilema clásico.

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1 Introduction

The international financial crisis of 2008-09 and recently the global economic crisis generated by the Covid-19 pandemic have led to unprecedented macroeconomic policy responses. Regarding monetary policy, short-term interest rates have reached their effective (or technical) lower bounds in many countries, further complemented in most cases by unconventional measures aimed at providing additional liquidity to financial markets. In this paper we address the question of how to gauge the monetary policy stance for this type of situation, focusing on the case of a small open economy that is affected at the same time by changes in domestic and external monetary and financial conditions.

How to correctly measure the monetary stimulus when the monetary policy rate (MPR) is at its effective lower bound and unconventional policies are deployed? The literature has frequently used the concept of "shadow" interest rate, defined as the short-term interest rate that would prevail in the market if there were no lower bound on nominal rates (Black, 1995). The shadow rate is not directly observable but can be estimated through different methodologies. Its main advantage is that it represents a coherent and concise measure of the monetary policy stance both in normal times and during periods when policy rates reach their lower bounds. Previous studies provide applications of this concept in the context of the quantitative easing policies deployed first by the Bank of Japan to mitigate persistent deflation during the 2000s, and then in the U.S. and Europe to face the international financial crisis and its aftermath (see, e.g., Krippner, 2013; Wu and Xia, 2016).

Recently, the central banks of many economies, including several emerging ones, have cut their benchmark rates and adopted unconventional policies to deal with the economic effects of the Covid-19 pandemic, in a highly synchronized fashion. In this context, this paper aims to estimate a shadow monetary policy rate (SMPR) that allows to gauge the overall monetary stance for the case of a small open economy. To do this, we extend the methodology of Lombardi and Zhu (2018), who estimate a SMPR for the U.S. based on a broad set of monetary indicators including interest rates, monetary aggregates, and Fed balance sheet items, using a dynamic factor model with missing observations.[1] Our extension allows a feedback from monetary and financial conditions in the rest of the world to the domestic economy, but it rules out any feedback in the opposite direction, which is a reasonable premise for an open economy that represents a small share of the world economy. This is achieved by imposing a block exogeneity assumption through zero restrictions on the effects of the domestic onto the foreign block. In turn, this allows to identify the contribution of external and domestic factors separately to explain the local SMPR. Such restrictions have been extensively used to incorporate the small open economy dimension in structural vector autoregression (SVAR) models (e.g., Hamilton, 1994; Cushman and Zha, 1997; Zha, 1999; Dungey and Pagan, 2000; Canova, 2005; Mackowiakl, 2007; Neri and Nobili, 2010; Bhuiyan, 2012; Willems, 2013; Fornero et al., 2015; MacDonald and Popiel, 2020), factor-augmented VARs (e.g., Mumtaz and Surico, 2009; Dahlhaus et al., 2018), and dynamic factor models (e.g., Charnavoki and Dolado, 2014; Hartigan and Morley, 2020).

We apply our methodology to the case of Chile, a small and open economy with a central bank that conducts its monetary policy under an inflation targeting regime with a freely floating exchange rate. Chile's business cycle at the time of writing of this paper is contractionary due to the impact of the Covid-19 pandemic. In response, the Central Bank of Chile (CBC) has adopted a wide range of expansionary policy measures. The MPR reached its effective lower bound at the end of March 2020, and since that month, different unconventional instruments were deployed to provide liquidity, including financial asset purchase programs and other measures aimed at supporting credit provision with incentives towards small firms (see CBC, 2020b, and Garcia, 2021). Similar unconventional policies were adopted by central banks in other economies, including many emerging and frontier economies (see Fratto et al., 2021). Previously, during the international financial crisis, the CBC also implemented unconventional measures with the MPR at its lower bound (see Céspedes et al., 2013). Therefore, we believe that our application and results provide a useful case study to illustrate

[1] The methodology is based on the algorithm developed by Bańbura and Modugno (2014).

the estimation of the monetary policy stance in the context of small open economies. Our methodology can be easily adapted and applied to other economies, especially given the global nature of the Covid-19 shock and the similarities in monetary policy responses across countries.

Regarding our main results, in a first step we find that the evolution of the estimated SMPR is coherent with the timing and scope of the monetary policy actions taken by the CBC. In particular, the shadow rate is negative for several months between 2009 and 2010 and after March 2020, both periods with a highly expansionary policy stance. Counterfactual exercises excluding quantitative indicators such as monetary aggregates and CBC balance sheet items support the view that these indicators provide information on monetary expansiveness, as the resulting SMPR is less negative in these cases. That is, the SMPR would be estimated with an upward bias if quantitative measures related to unconventional policies were disregarded. Also, the estimated SMPR is robust to different variations in the model specification and similar to the rates predicted by simple Taylor rules for Chile, especially in periods when the effective lower bound is binding. This highlights the usefulness of the SMPR as a robust and concise measure to reflect the conduct of monetary policy in practice.

In a second step, we use the estimated model to explain the variability of the SMPR in terms of foreign and domestic factors, using forecast error variance decompositions. We find that, in the short run, shocks to domestic factors explain most of the share of the variance of the forecast errors of the SMPR. As the time horizon increases, the contribution of domestic factors to the variability of the SPMR declines monotonically and in the long run foreign factors play a dominant role. This result is also robust to changes in the model specification. We return to its interpretation below.

Our paper contributes to a growing literature that recognizes the need for a robust analytical framework to measure the monetary policy stance when policy rates reach their lower bounds and traditional monetary policy is complemented with unconventional measures. Among the first contributions, Gorovoi and Linestky

(2004) and Ueno et al. (2006) estimate the SMPR for Japan during the period 2001-06, when the Bank of Japan's reference rate reached its lower bound.[2] The works of Kim and Singleton (2012), Krippner (2013) and Bauer and Rudebusch (2016) estimate SMPRs consistent with the behavior of the term structure of interest rates using numerical methods. Several studies use the SMPR to quantify the monetary policy stance (see, e.g., Bullard, 2012; Krippner, 2013). Wu and Xia (2016) provide a methodology to measure the macroeconomic effect of monetary policy in normal times and when the reference rate reaches its lower bound. The authors develop an analytical solution of a term structure model to infer the shadow rate and demonstrate that it exhibits dynamic correlations with other macroeconomic variables similar to those displayed by the Federal Funds Rate (FFR) in normal times.[3] Several studies have used the Wu & Xia shadow rate or similar measures in empirical macroeconomic models to analyze the effects of unconventional monetary policy.[4] A recent paper by Johannsen and Mertens (2021) develops a flexible time-series approach that considers the effective lower bound restriction to identify monetary policy shocks. Their strategy exploits the fact that shadow rates must be consistent with expected interest rates and out-of-sample forecasts of other variables. They find that monetary policy shocks measured as shadow rate surprises were effective at stimulating economic activity during the global financial crisis, consistent with the notion that shadow rates capture the effects of unconventional policies. On the other hand, Krippner (2020) shows that the Wu & Xia measure can be sensitive to minor choices in the estimation, and suggests to explore alternative methodologies.

Recently, Lombardi and Zhu (2018) adapted the algorithm developed by Bańbura and Modugno (2014) to estimate an SMPR for the U.S. using a dynamic factor model with missing observations and a broader set

[2]Additional empirical studies for the U.S., the euro area, and Japan can be found in Basu and Bundick (2012), Nikolsko-Rzhevskyy et al. (2014), Aizenman et al. (2016), Bauer and Rudebusch (2016), and Nordström (2020).

[3]These estimates are obtained for the U.S., the euro area and England and are available in public and private databases. It is common to find references to shadow rates in speeches and technical notes of Fed officials, see for instance Altig (2014), Hakkio and Kahn (2014), and Yellen (2016), among others, as well as in academic works and specialized press.

[4]In a recent study, MacDonald and Popiel (2020) use the Wu & Xia estimate of the U.S. shadow rate in a Bayesian SVAR model with block exogeneity restrictions, and they adopt the method of Wu & Xia to estimate a Canadian shadow rate. Thus, their approach is different from ours, since we endogenously calculate the shadow rate in our dynamic factor model, as in Lombardi and Zhu (2018). Mouabbi and Sahuc (2019) introduce three alternative shadow rates in a structural model and extract their common factor. The latter measure is used as the relevant interest rate in a medium-scale DSGE model. The results provide evidence of positive and significant effects of unconventional measures on output and prices in the euro area.

of indicators than previous studies. In particular, the authors use data that comprise the entire term structure of interest rates, traditional monetary aggregates, Fed balance sheet variables capturing its size, and also indicators that measure the relative maturity of assets and liabilities held in the central bank's portfolio. The estimated SMPR is considered plausible by Lombardi and Zhu (2018) since its evolution coincides with the implementation of unconventional policy programs. Furthermore, their evidence shows that the quantitative information contained in the accounts of the Fed's balance sheet helps to identify the SMPR more precisely, especially when asset purchase programs are carried out that cause changes in financial asset prices and the term structure of interest rates through changes in the size and composition of the Fed's balance sheet.

Our work is also related to the strand of the international finance literature that analyzes whether and how the conduct of monetary policy can be affected or conditioned by global financial conditions. Obstfeld and Taylor (2004) analyze international capital mobility since 1870 and suggest that these flows should be understood within the framework of a policy trilemma in the sense of Mundell-Fleming. The latter establishes that, if the mobility of capital is unrestricted, it is possible to implement an independent monetary policy by letting the exchange rate float freely. More recently, Rey (2015, 2016) has argued that local monetary policies are conditioned by a global financial cycle independently of the exchange rate regime. The factors behind the global financial cycle are associated with monetary conditions in central countries (mainly the U.S.) and changes in risk aversion and uncertainty (see Bekaert et al., 2013; Miranda-Agrippino and Rey, 2015; Bruno and Shin, 2015).[5] According to this argument, an autonomous monetary policy is only possible if the capital account of the balance of payments is managed. Chile is an interesting case of study because it has an open capital account and a freely floating exchange rate. Thus, we use our methodology to examine these hypotheses. Our finding that the domestic SMPR - being a synthetic measure of local monetary conditions or effective monetary stimulus - is determined mainly by domestic factors in the short

[5]This argument emphasizes the importance of monetary shocks in central countries that generate changes in the leverage of global banks (changes in credit flows and the size of the international financial system), which impact financial conditions in other countries.

term, tends to support the classic trilemma and the possibility of conducting an independent monetary policy without the need for capital controls.

The rest of the paper is organized as follows. Section 2 provides some relevant background information on the monetary policy of the CBC, Section 3 describes the dynamic factor model with small open economy restrictions, its estimation and the data used, Section 4 presents the results, including the estimated SMPR and its main drivers, Section 5 presents several robustness exercises, and Section 6 concludes.

2 Background

A vast literature reviews lessons of unconventional monetary policies implemented in response to the international financial crisis (see, e.g., Rajan, 2013; Woodford, 2012; Wu, 2014). The evidence supports the view that these measures temporarily reduced long-term interest rates, flattening the yield curve, and through their effects on expectations help to reverse the loss of confidence of agents in the financial system, raise inflation expectations and support the recovery of economic activity.[6]

Recently, the Fed, the European Central Bank, the Bank of Canada and the Bank of England, among others, have deployed unconventional monetary measures reacting to the significant decrease in global activity as a result of the Covid-19 pandemic (IMF, 2020). Similar policies were adopted by central banks in other economies, including emerging and frontier countries (Fratto et al., 2021). Chile has not been the exception.

[Figure 1: Interest rate structure, U.S. and Chile]

Figure 1 shows the evolution of average monthly U.S. and domestic interest rates. The vertical lines indicate

[6]Unconventional measures provide liquidity into the market through financial asset purchase programs. Hence, expansive measures reduce the interest rates of bonds and other related financial assets, especially for longer maturities. Naturally, the programs increased the size of the central banks' balance sheets–affecting their composition and maturity –and the different monetary aggregates.

dates when the MPRs reached their effective lower bounds, being 0.5% for Chile (CBC, 2020a) and 0.25% in the case of U.S.[7] In 2008 the Fed aggressively cut the FFR to its lower bound and provided a significant amount of liquidity into financial markets through a quantitative easing program, QE1; followed by others known as QE2 and QE3. In Chile, the effective lower bound was also binding a few months later, once inflation expectations fell in a context where inflation recorded values above the CBC's target until the end of 2008.

Recently, the policy rates of the U.S. and Chile again reached their effective lower bounds in response to the Covid-19 pandemic. While in 2009 long-term interest rates did not drop as much, in the current episode interest rates of both short and long maturity bonds fell considerably, reflecting the operation of the monetary policy transmission mechanism consistent with the implementation of conventional and unconventional measures. Therefore, when the reference rates reached their lower bounds and unconventional policies were implemented, the MPR fell short of providing useful information regarding the overall monetary stance; hence, the need for alternative measures that consider the monetary stimulus in a broader sense, such as shadow rates.

[Figure 2: Fed and CBC assets (% of GDP)]

Figure 2 shows the evolution of the assets on the Fed and CBC balance sheets as a percentage of the previous year's nominal GDP. In periods when the FFR reached its lower bound, the Fed's assets and balance sheet expanded considerably as a result of the implementation of quantitative easing programs. The case of Chile differs in 2009 because the CBC used transitory lending facilities of lower magnitude and scope. In contrast, recent unconventional measures have significantly increased the size of the CBC's balance sheet since

[7] The literature has considered different thresholds to assess the robustness of estimated shadow rates for the U.S. (Krippner, 2015). Frequently the threshold of 0.25% is used, which corresponds to the interest paid on banks' reserves; see Woodford (2012), Wu and Xia (2016), and Lombardi and Zhu (2018).

March 2020. These include, among others, the purchase of financial assets, including private bank bonds, repurchase of central bank debt, and provision of liquidity and financing through a Conditional Financing Facility for Increased Loans (FCIC program).

Figure 3 shows in detail the evolution, size and composition of the CBC's balance sheet since 2007. The recent increase in the size of the balance sheet stands out, which is largely explained by the FCIC program and other exceptional measures that have been adopted to deal with the economic and financial impact of the health crisis, allowing agents to ease their liquidity constraints.[8]

[Figure 3: CBC balance sheet]

3 Methodology, Estimation Strategy and Data

3.1 Dynamic factor model with small open economy restrictions

We extend the methodology of Lombardi and Zhu (2018) who estimate a shadow rate for the U.S. Let $y_t = y_1, \ldots, y_T, t = 1, \ldots, T$, denote a sequence of vectors with n stationary observed variables, standardized with zero mean and unit variance. It is assumed that y_t admits a dynamic representation in terms of r unobserved common factors. Let $f_t = \{f_1, \ldots, f_T\}$ be a sequence of column vectors (of dimension r) of factors, for each t. Analogously, e_t groups idiosyncratic terms: $e_t = [e_{1,t}, \ldots, e_{n,t}]'$. Then, the model's measurement equation can be written as follows:

$$y_t = \Lambda f_t + e_t, \qquad e_t \sim N(0, R), \tag{1}$$

[8] Albagli et al. (2020) study the effects of the FCIC program. The evidence provided shows that the program has allowed banks to maintain credit lines to firms. Thus, in 2020 a year-on-year (counter-cyclical) growth of commercial credit is observed (CBC, 2020c).

where Λ is a matrix of $n \times r$ factor loadings and the idiosyncratic innovations e_t correspond to normal independent errors with zero mean and diagonal variance-covariance matrix R.

Next, it is assumed that the joint dynamics of the latent factors follow a VAR of order p:

$$f_t = \sum_{i=1}^{p} A_i f_{t-i} + u_t, \qquad u_t \sim N(0, Q), \tag{2}$$

where A denotes a matrix of $r \times r$ autoregressive coefficients and Q is the variance-covariance matrix of the shocks to the common factors, which can be correlated. The idiosyncratic shocks are assumed to be uncorrelated and, furthermore, $E[e_t u'_{t-s}] = 0$, for $s \in \{1, 2, \ldots\}$.

In order to study the case of a small open economy like Chile, our application extends the analytical framework of Lombardi and Zhu (2018) to accommodate the corresponding restrictions. In particular, we assume block exogeneity (zero) restrictions on Λ and A, as follows:

$$\Lambda = \begin{bmatrix} \Lambda_{11} & 0 \\ \Lambda_{21} & \Lambda_{22} \end{bmatrix}, \qquad A = \begin{bmatrix} A_{11} & 0 \\ A_{21} & A_{22} \end{bmatrix}, \tag{3}$$

where Λ_{11} (A_{11}) is a matrix of dimension $n_e \times r_e$ ($r_e \times r_e$), Λ_{21} (A_{21}) is a matrix of dimension $n_d \times r_e$ ($r_d \times r_e$), and Λ_{22} (A_{22}) is a matrix of dimension $n_d \times r_d$ ($r_d \times r_d$) with $n_e + n_d = n$ and $r_e + r_d = r$. The vectors of observed variables and unobserved factors are partitioned accordingly, into external and domestic blocks:

$$y_t = \begin{bmatrix} y_t^e \\ y_t^d \end{bmatrix}, \qquad f_t = \begin{bmatrix} f_t^e \\ f_t^d \end{bmatrix}, \tag{4}$$

where the super-indices *"e"* and *"d"* indicate the external and the domestic block, respectively. Equations (1) to (4) specify the dynamic factor model that we will use to estimate the SMPR for Chile. The imposition of block exogeneity restrictions in (3) reflects the small open economy assumption according to which foreign factors can affect the variables and factors of the domestic block, while any feedback in the opposite direction is discarded.

3.2 Estimation of the model with the EM algorithm

The methodology of dynamic factor models is particularly attractive and robust as it allows some of the n observed variables to contain missing data. Once the unobserved factors and parameters have been estimated, the missing data can be recovered from (1). This may include the SMPR when the MPR is restricted by its effective lower bound.

The methodology for estimating the unknown parameters of the state-space representation (1)-(4) uses standard optimization techniques, conditional on having complete data. In this case, the evaluation of the likelihood function is carried out using the Kalman filter (see Engle and Watson, 1981; Doz et al., 2011). However, it is not possible to evaluate the likelihood function in the presence of missing data. To deal with that case, Bańbura and Modugno (2014) modify the general expectation maximization (EM) algorithm (Dempster et al., 1977) to estimate parameters in the presence of arbitrary patterns of missing data, in addition to adapting it to include restrictions on the model parameters, as in Bork (2009) and Bork et al. (2009). This allows to incorporate small open economy restrictions for our application.

The EM algorithm consists of two steps that are iterated until convergence: an expectation step (E-step) and a maximization step (M-step).[9] In an initialization stage, the researcher replaces the missing data from y_t with values that follow certain rules.[10] y_t^0 is constructed and the matrices of the system are estimated using principal components, then the Kalman filter is applied and an initial estimate of the unobserved factors is

[9]The EM algorithm (Dempster et al., 1977) is a method for maximizing the likelihood function with incomplete or latent data. This algorithm was adapted to estimate linear dynamic models with unobserved components by Shumway and Stoffer (1982) and small dynamic factor models by Watson and Engle (1983). This was extended to large dynamic factor models by Doz et al. (2011) based on the previous work of Giannone et al. (2005, 2008).

[10]The evidence suggests that the specific procedure or rule to complete missing values does not significantly affect the results (for a discussion of advocated rules, see Bańbura and Modugno, 2014).

obtained.

In the E-step, the initial values of the missing data are replaced by their expected values, which are obtained from evaluating (1) using the parameters and factors estimated in the previous iteration. This allows to evaluate and maximize the likelihood function conditional on the available information y_t^j and the set of parameters $\theta(j)$, which can be written as:

$$L(\theta, \theta(j)) = E_{\theta(j)} \left[l(Y, F; \theta | y_t^j) \right]$$

In the M-step, the conditional likelihood function is optimized to obtain a new estimate, $\theta(j+1)$:

$$\theta(j+1) = \arg\max_{\theta} L(\theta, \theta(j)),$$

subject to linear constraints on a subset of $\eta_\theta \geq 0$ elements of θ of the form[11]

$$H_\theta \operatorname{vec}(\theta) = k_\theta.$$

This process is iterated until convergence, yielding a vector of estimated parameters θ^*.[12] Conditional on θ^*, the Kalman filter yields the moments of the latent factors, especially their expected value with which the matrix of final smoothed observations can be obtained by applying (1):

$$y_t = E_{\theta^*} \left[y_t | y_{1:T} \right] = \Lambda^* f_t^*,$$

where the entries of this matrix corresponding to the originally missing data are replaced by expected values

[11] k_θ is an $\eta_\theta \times 1$ vector that collects the restrictions and H_θ is an $\eta_\theta \times length(\theta)$ matrix. In our application, the restrictions on Λ and A given in (3) may be written in the form $H_\Lambda \operatorname{vec}(\Lambda) = k_\Lambda$ and $H_A \operatorname{vec}(A) = k_A$, where k_Λ in an $\eta_\Lambda \times 1$ vector and, k_A is an $\eta_A \times 1$ vector, H_Λ is an $\eta_\Lambda \times nr$ and H_A is an $\eta_A \times r^2$ matrix.

[12] We use as a convergence criterion that the relative change in the likelihood function of the observed data, $\left[l_Y(\theta(j+1)) - l_Y(\theta(j)) \right] / |l_Y(\theta(j))|$, be less than 10^{-6}.

conditional on the estimated parameters and factors.[13] In our application, allowing for missing data on interest rates is intended to capture the fact that the MPR cannot fall below the effective lower bound. In the next section we discuss how we treat interest rates as missing observations.

3.3 Estimation of the SMPR using missing observations

The application of our methodology allows to estimate the local SMPR consistent with the historical correlations of the observed variables and enables us to answer the following question: what would be the policy rate consistent with the overall domestic and foreign monetary stimulus in the absence of the effective lower bound?

Our strategy follows Lombardi and Zhu (2018) and consists of estimating the SMPR by feeding the dynamic factor model with missing observations of interest rates when the lower bound restriction becomes binding. As discussed in Section 2, this occurred during two episodes, both in the U.S. and in Chile. Starting with the external data block, for the episode of the international financial crisis the same decisions are made as in Lombardi and Zhu (2018) and we follow their criteria when we extend the sample to 2020. Lombardi & Zhu assume missing observations for the FFR, three- and six-month interest rates from December 2008 to December 2015, and from November 2009 to October 2015 for one- and two-year interest rates. For the recent Covid-19 episode we assume missing observations for all these rates since April 2020, which is when the FFR dropped to its minimum range (0-0.25%).

Using analogous criteria, the domestic block considers missing observations for the three- and six-month rates between August 2009 and May 2010, while long rates are left as observable since they do not fall enough to be considered minimum levels. For the recent Covid-19 episode, missing observations are imputed for the MPR, three- and six-month rates, and one-, two- and three-year rates, from April 2020 onwards.[14]

[13] Online appendix A contains details about the EM algorithm.

[14] To be precise, the technical lower bound was reached at the end of March, however, the average for the month was around 1.4%. For this reason, we will treat as a technical minimum those months that, when considered as a whole, average 0.5% for the MPR.

3.4 Key parameters to be determined in the model's specification

Among the parameters of the model specification that the researcher decides, two are particularly relevant: (i) the number of external and domestic factors and (ii) the number of lags in the factor VAR from (2). Regarding the number of factors to estimate in (1), we apply the criterion developed in Alessi et al. (2010), hereafter abbreviated as ABC criterion.[15] This methodology results in the selection of 4 factors for the external block and 5 factors for the domestic block. With this specification, the baseline model is able to explain 87 and 94% of the variance in the data, respectively (see online appendix C for details). The choice of lags in the factor VAR is based on standard information criteria - AIC, SIC, HQC. All of them suggest choosing one lag, i.e., $p = 1$.

The robustness section explores the sensitivity of the main results to changes in the number of factors, lags in the VAR and alternative choices in the selection of observed time series.

3.5 Data

We use monthly data for Chile and the U.S. from September 2002 to October 2020. The choice of this sample period is based on the common availability of data from both countries, the limiting factor being the beginning of the sample of domestic variables. In addition, the beginning of this period coincides with the consolidation of the Chilean inflation targeting regime with the nominal short-term interest rate as the main instrument of monetary policy.[16]

The organization of domestic and U.S. data follows the structure of block one to four defined in Lombardi and Zhu (2018). In the case of external variables, block one includes information on the interest rates

[15] When evaluating the number of factors using criteria suggested by Bai and Ng (2002), we found that the choice of factors was highly dependent on the maximum number of factors allowed, similar to the findings of Forni et al. (2009) and Alessi et al. (2010). For this reason, we use the criterion developed by Alessi et al. (2010), called the ABC criterion, which is robust to different values for the maximum number of factors to be tested.

[16] The CBC had changed its main instrument of monetary policy from an inflation-indexed MPR to a nominal one in August 2001. This nominalization led to the consolidation of a market for nominal instruments. The extension of data on interest rates for financial assets with different maturities only began in September 2002. For the case of the U.S., Lombardi and Zhu (2018) used data starting in the 1970s.

of bonds of different maturities that cover the term structure, block two includes a selection of traditional monetary aggregates, and blocks three and four consider assets and liabilities from the Fed's balance sheet. The selection of domestic variables is guided by an analogous structure, but it should be noted that a few variables are not perfectly comparable with those of the U.S. Also, while extending the sample of Lombardi and Zhu (2018) we noticed that one U.S. variable has been discontinued. Online appendix B provides details of variable definitions and data sources.[17]

4 Results

4.1 Dynamics of the estimated SMPR

This section presents the results obtained with the baseline dynamic factor model with block exogeneity restrictions. Figure 4 compares the evolution of the local MPR with the estimated shadow rate. It stands out immediately that both rates are practically the same when the effective lower bound is not binding. In contrast, when the MPR reaches the lower bound of 0.5% and unconventional policy measures are implemented, the SMPR is estimated to be significantly negative.

At the end of the sample considered, October 2020, the estimated SMPR is approximately -2.7%, with a confidence interval between [-4.5%; -0.5%]. This estimate is below the previous minimum of about -1.5% registered in January 2010. In a previous section, Figure 3 showed that the size of the most recent unconventional stimulus is significantly larger than the one implemented in 2009 in terms of the effect on the CBC's balance sheet, and it is also expected to be more persistent.[18] Beyond the size of the package of measures, we will now delve into the two episodes in which the SMPR is negative: (i) between August 2009 and May

[17]The CBC's Organic Constitutional Law includes a prohibition to purchase Treasury bonds. It was modified in July 2020 to allow purchasing such bonds in the secondary market for financial stability considerations. Nonetheless, the CBC cannot purchase such bonds for monetary policy reasons only. Therefore, our dataset incorporates other types of interest rates, including MPR swap rates and interest rates on bonds issued by the CBC. In addition, domestic variables that are not available are the ratios of long-term bonds to total bonds. Lombardi and Zhu (2018) point out that with these variables they can study portfolio changes that tend to lengthen average maturity (long section of the yield curve). No comparable data for Chile are available.

[18]The term of the FCIC announced in March 2020 is up to four years. The program is currently being developed in its third phase (announced in January 2021).

2010, and (ii) between July and October 2020.

[Figure 4: Effective MPR and estimated SMPR]

We first consider the 2009-10 episode. For a discussion of the unconventional measures implemented in the U.S., see Meaning and Zhu (2011, 2012), Woodford (2012), Wu and Xia (2016), and Lombardi and Zhu (2018). The policies significantly increased the size of the Fed's balance sheet.[19] In Chile, unconventional policy measures were implemented with a few months of delay due to the high inflation in 2008. The MPR fell aggressively at the beginning of 2009, reaching its lower bound in May of that year. In addition, a Term Liquidity Facility (FLAP) was implemented between July 2009 and May 2010.[20] These considerations are relevant because Figure 4 shows that the local SMPR adjusted to negative levels with some lag relative to the Fed's response. The estimated SMPR remained negative for 10 months from August 2009 onwards, coinciding with the period of the FLAP. The latter result contrasts with the case of the U.S. where the SMPR reached negative values in December 2008 and remained negative for almost six years (see Lombardi and Zhu, 2018).[21]

Second, in the recent Covid-19 episode the Fed reacted lowering the FFR and delivering a significant unconventional monetary stimulus.[22] In the case of Chile, Section 2 described the program of special measures implemented by the CBC in this context, highlighting the large magnitude of the program and the novel

[19]The first Large Scale Asset Purchase Program (LSAP1) was announced in November 2008. It focused on assets backed by mortgage contracts. It was subsequently reinforced with the purchase of long-term treasury assets in March 2009. Besides, in November 2010 a second program (LSAP2) was launched, followed by the announcement of the Maturity Extension Program (MEP) in September 2011 and by a third Asset Purchase Program (LSAP3) announced on September 13, 2012 (see https://www.federalreserve.gov/monetarypolicy/timeline-balance-sheet-policies.htm).

[20]The program was denominated "Facilidad de Liquidez a Plazo" in Spanish, FLAP. Banks participated in the FLAP program for an amount close to USD 6.5 billion. In addition to the FLAP, the number of eligible collaterals in operations with the CBC was increased and repo and swap programs were implemented to provide liquidity in pesos and dollars to the financial system (see Céspedes et al., 2013).

[21]Part of the transitory character of the monetary stimulus is explained by the improvement in the terms of trade and the growth of Chile's main trading partners, especially East Asia towards the fourth quarter of 2009.

[22]See Cheung (2020) for more details.

unconventional instruments involved.[23] The results indicate a significantly negative SMPR level during this episode and, also, a larger monetary impulse than in the previous episode of 2009-10. This finding seems consistent with the greater scope and magnitude of the monetary policy actions implemented during the recent episode compared to the previous one. However, since market interest rate adjustments were not immediate, our estimate of the shadow rate exhibits a slight lag with respect to the overnight rate.[24] The bigger width of the SMPR confidence bands in the margin reflects the higher uncertainty due to the 'out of the ordinary' singularity of the Covid-19 shock that is still ongoing.[25]

4.2 Interpretation of the factors

In this section we analyze the intensity of the association between the estimated common factors and the observed variables. Figure 5 illustrates on the vertical axis the 'pass-through' coefficients obtained from the factor loadings matrix, while the horizontal axis represents the observed external and domestic variables. Note that the coefficients are directly comparable because the observed variables are standardized and stationary.

[Figure 5: Factor loadings matrix coefficients]

A first general consideration is that U.S. variables correlate with external factors only, consistent with the

[23]The program includes purchases of bank assets for up to USD 8 billion and the opening of a Conditional Financing Facility for Increased Loans (FCIC) for USD 40 billion. The FCIC was split into two versions in 2020, the first announced on March 16 for an amount of USD 24 billion and the second in June for an additional USD 16 billion. Additionally, a liquidity credit line (LCL) was activated under favorable conditions and a series of repo and swap programs were deployed to provide liquidity in pesos and foreign currency to the financial system, together with the expansion of eligible collaterals in operations with the Central Bank (see https://www.bcentral.cl/en/exceptional-measures).

[24]The recent episode required a quick reaction by the CBC. In effect, whereas the MPR averaged 1.4% in March 2020, at the beginning of the month it was 1.75%, and it was cut to 1% in the extraordinary monetary policy meeting on March 16 and reduced again to 0.5% at the end of March.

[25]In online appendix D, we illustrate the variability of the estimated shadow rate around turning points of monetary policy rates by means of a simple recursive estimation exercise. This exercise shows that as new data comes in during the global financial crisis episode, the methodology tends to revise more the SMPR than in normal times, lending support to the view that around turning points confidence bands could be wider. In general, most econometric models are subject to larger estimation uncertainty around turning points.

block exogeneity restrictions reflecting the small open economy assumption (i.e., any feedback from local to foreign variables is discarded). The first external factor (F1), which explains proportionally more of the variance in the U.S. data, is associated negatively with the term structure of interest rates and positively with monetary aggregates and with variables that relate to the Fed's balance sheet. In addition, the signs seem plausible: everything else equal, the larger (smaller) the size of the balance sheet, the lower (higher) are interest rates, and the higher (lower) are asset prices.

Regarding the coefficients of domestic variables, in relative terms, the foreign factors (F1 to F4) show a relatively smaller association compared to the domestic factors. It is important to remember that Chile's monetary policy framework is based on inflation targeting with a floating exchange rate and free movement of capital. In this context, the shock-absorbing role of the exchange rate could explain the lower relative importance that external factors exerted on domestic monetary conditions in the short term. This result would also support the classic trilemma in the sense of Mundell-Fleming. We will analyze this hypothesis in more detail below.

Among the domestic factors, the first (F5) is the most relevant component and mainly associated with the term structure of interest rates. The second domestic factor (F6) shows a negative association with short rates and positive association for longer rates, consistent with changes in portfolio composition and with substitution effects between different maturities of financial assets. The third and fourth domestic factors (F7 and F8) are analogous in their interpretation to the previous one, but with smaller coefficients and changed signs. Finally, it is interesting to note that the fifth domestic factor (F9) is strongly linked to the internal credit stimulus, which is related to the implementation of the FCIC and other special credit support programs in the context of the Covid-19 pandemic.

An alternative way to approach the relationship of the SMPR with the factors is through the analysis of partial correlations. We find a significant and large correlation of 0.86 between the first domestic factor (F5) and the

SMPR, confirming the findings discussed above. In summary, the evidence indicates that the methodology is effectively and reasonably synthesizing the information contained in the 39 observed time series into 9 factors.

4.3 The role of foreign versus domestic factors for the SMPR

In this section we present the contributions to the variance of the forecast errors of the SMPR by the domestic and foreign factors, based on identifying assumptions to infer structural shocks. In the literature on factor-augmented VARs or dynamic factor models, different methodologies are used to identify the shocks that affect the factors (see, e.g., Stock and Watson, 2005). Following the standard practice of orthogonalizing the variance-covariance matrix of the residuals in the factor VAR using the Cholesky decomposition, we obtain an ordering of the factors from the most exogenous (external factors) to the most endogenous (domestic factors).[26]

Figure 6 shows the forecast error variance decomposition (FEVD) of the SMPR at different horizons, distinguishing between the contribution of external and domestic factors.[27] In the short run, for horizons below six months, the contribution of shocks to domestic factors is more important, explaining up to 75% of the SMPR forecast error two months ahead. We interpret that this result is explained by the high contemporaneous correlation between domestic factors and the (S)MPR (see Figure 5). However, the contribution of domestic shocks decreases in importance as the horizon expands, reaching around 40% in twelve months, 20% in two years and converging to zero in the long run. In contrast, shocks to external factors increase their relative contribution as the time horizon increases. In particular, they represent approximately 60% in twelve months and almost 80% in two years.

[26]The ordering of the factors within each block is determined in the initialization step through the principal component methodology, where the factors are ordered according to the percentage of the variance explained in each block. Therefore, the ordering of the variables does not affect the results discussed.

[27]In a basic SVAR the sum of both proportions should be equal to one. However, in our dynamic factor model there are idiosyncratic shocks in the measurement equation that explain part of the variance.

[Figure 6: Forecast Error Variance Decomposition for the SMPR]

The relative low importance of external factors in the short run suggests a relative autonomy of monetary policy in Chile from that of the rest of the world. The monetary policy framework of the CBC consists of an inflation targeting scheme in a context of free capital mobility and a floating exchange rate (CBC, 2020). The role of the latter is to absorb external shocks and facilitate the independent conduct of monetary policy over the business cycle, allowing the (S)MPR to be at a level consistent with domestic price stability, conditional on domestic and external fundamentals. In the long run, it should converge to an equilibrium level consistent with the domestic inflation target and interest rate parity.[28] In our model, external fundamentals are captured by movements in U.S. monetary variables and the FFR through their relationship with the estimated foreign factors, while domestic fundamentals are captured by changes in domestic factors not attributed to foreign shocks.

The result that the variability of the SMPR in Chile is mainly driven by shocks to domestic factors in the short run seems consistent with the classic trilemma, rather than the dilemma suggested by Rey (2015, 2016).

4.4 Use of the SMPR in practice

In this section we analyze the level of the SMPR in relation to other benchmark rates, following Wu and Xia (2016) and Lombardi and Zhu (2018). A widely used benchmark is the policy rate predicted by simple Taylor rules. We therefore estimate Taylor rules for Chile, using expected inflation and the non-mining output gap as arguments. These arguments are justified by the facts that Chile is an economy that produces primary goods and the CBC bases its monetary policy decisions on inflation projections. In addition, simple Taylor rules are part of the macroeconomic projection models of the CBC (see Garcia et al., 2019, and Marioli et al.,

[28] In a small open economy, under free movement of capital, the risk-free real domestic interest rate should converge to the foreign real rate in the long run.

2020).[29] These simple rules give support to the view that in certain crises episodes where there is a lack of demand, the required monetary policy rate should be below the effective lower bound.

[Figure 7: Policy rate predicted by estimated Taylor rule and SMPR]

Figure 7 shows the policy rate predicted by one of the estimated Taylor rules. Given the estimated parameters, the estimated rule predicts negative rates during the international financial crisis and the Covid-19 pandemic, in line with our estimates of the SMPR. Also, the the estimated SMPR is very similar to that predicted by the rule, both in normal periods and when unconventional measures are deployed. This suggests that, in practice the SMPR is a useful reference for policymakers to guide and gauge in real time the unconventional stimulus, when the MPR is at its effective lower bound.

5 Robustness and Sensitivity

In this section we study the robustness of the SMPR estimates obtained from our baseline model. The related empirical literature documents variability of the results due to changes in the number of factors, see for example Christensen and Rudebusch (2015), changes in the reference limit for the effective lower bound and also the sample size, see for example Krippner (2015). In addition, we explore the sensitivity of the results to changes in the information set (observed variables). In particular, we conduct a counterfactual exercise where we remove monetary aggregates and items of the CBC's balance sheet from the set of observed variables. Intuitively, the resulting SMPR should be less negative than the baseline estimate. This is confirmed below.

[29] Alternatively, the standard arguments and parameters for effective inflation and total GDP growth or the GDP-based output gap could be used, as in Wu and Xia (2016) and Lombardi and Zhu (2018). However, we decided to estimate the parameters of a specific rule for Chile because, contrary to the case of the U.S., there is no consensus to assume standard reaction function parameters.

5.1 Changes in model specification

The baseline model explains 87 and 94% of the variance in the foreign and domestic blocks, respectively. We estimate three alternative specifications with different numbers of factors, keeping the number of lags invariable at $p = 1$. Alternative specifications are chosen to target certain percentages of explained variances; in particular, we aim to explain 70, 80 and 90% of the variance in each block.

Figure 8 presents the SMPR that results from the three alternatives specifications, and the baseline specification is added with its 95% confidence bands. By varying the number of factors, the estimates slightly differ in the levels, but stay within the confidence bands, showing high correlation with the results obtained from the baseline specification. The quantitative differences are small and similar in size to the findings reported by Lombardi and Zhu (2018).

[Figure 8: Robustness to the number of factors]

Figure 9 shows the estimated SMPR from specifications varying the number of lags of the factor VAR, using $p = 2$ and 3.[30] In general terms, a quantitative difference is observed in the level of the SMPR, however, the differences are again relatively small for most of the specifications. During the 2009 crisis, all of the alternative models deliver results very similar to the baseline model, while in the most recent period the differences are somewhat larger. In both episodes, the results from the alternative specifications are contained within the confidence bands from the baseline model.

[Figure 9: Robustness of SMPR to the number of lags in the factor VAR]

[30] Augmenting the lag order further is not recommended with the sample at hand, given the dimension of the VAR. Lombardi and Zhu (2018) find no relevant differences in results using lag $p = 6$.

We also explore the robustness of the FEVD to changes in the number of factors. As in the previous exercises, three alternative specifications target 70, 80 and 90% of the variance in each block. Figure 10 shows the different FEVDs obtained with the alternative specifications and the baseline model. Despite some quantitative differences, the results are qualitatively alike to those from the baseline model. In particular, in the short run the biggest contribution to the variance of the forecast errors comes from shocks to domestic factors. Also, its importance decreases over time, whereas shocks to external factors gain relative importance. Therefore, this exercise confirms the findings from the baseline model regarding the role of shocks to foreign and domestic factors in explaining the variability of the SMPR.

[Figure 10: Robustness of FEVD to changes in specification]

5.2 Changes in observed variables

Finally, we analyze the sensitivity of the estimated SMPR to changes in the selection of observed variables, using a subset of the available data and factors (6 factors, 4 foreign and 2 domestic ones, and $p = 1$ in the factor VAR). Figure 11 compares the SMPR from the baseline model with the alternative estimates arising from a sample that excludes the domestic monetary aggregates and CBC balance sheet items. This exercise delivers a less expansionary estimate of the SMPR during 2020, by approximately 230 basis points on average in September-October 2020, a difference that is marginally statistically significant at the conventional 95 percent confidence level. These results confirm the relevance of incorporating quantities that reflect the liquidity injected by unconventional measures for estimating more precisely the monetary policy stance (i.e., a more negative shadow rate).

[Figure 11: Robustness to the inclusion of variables]

6 Conclusions

In this paper we presented a methodology based on a dynamic factor model to estimate a SMPR for a small open economy, defined as the unobservable policy rate that is consistent with the monetary stimulus provided by the monetary authority in a broad sense, including through unconventional measures. The SMPR represents a consistent and concise measure of the monetary policy stance both in normal times and in periods when the MPR reaches its effective lower bound.

The main innovation of our methodology is to account for the fact that small open economies are affected not only by domestic monetary policy but also by monetary conditions in the rest of the world. This is achieved by imposing block exogeneity restrictions in the model that allow for a feedback from the rest of the world to the domestic economy but not vice versa. Thereby, our methodology also allows to identify the contribution of foreign and domestic factors to the dynamics of local variables, including the SMPR. We apply our methodology to the case of Chile using a broad set of indicators for Chile and the U.S., including the term structure of interest rates, monetary aggregates, and the evolution of the balance sheets of the Fed and the CBC.

We obtain two main results. First, the methodology used allows to estimate a local SMPR that exhibits dynamics consistent with the monetary policy actions implemented by the CBC, in particular, the inferred rate is negative for several months during 2009-10 and in 2020. Second, the variance decomposition of the SMPR shows that in the short run shocks to domestic factors explain most of the variance of its forecast errors. In contrast, at longer horizons, shocks to foreign factors explain the largest proportion of the variance of the SMPR. These two results are robust to changes in the specification of the model. These findings are consistent with the classic trilemma in the sense of Mundell-Fleming, and in particular, the possibility of conducting an autonomous monetary policy under a floating exchange rate and an open capital account.

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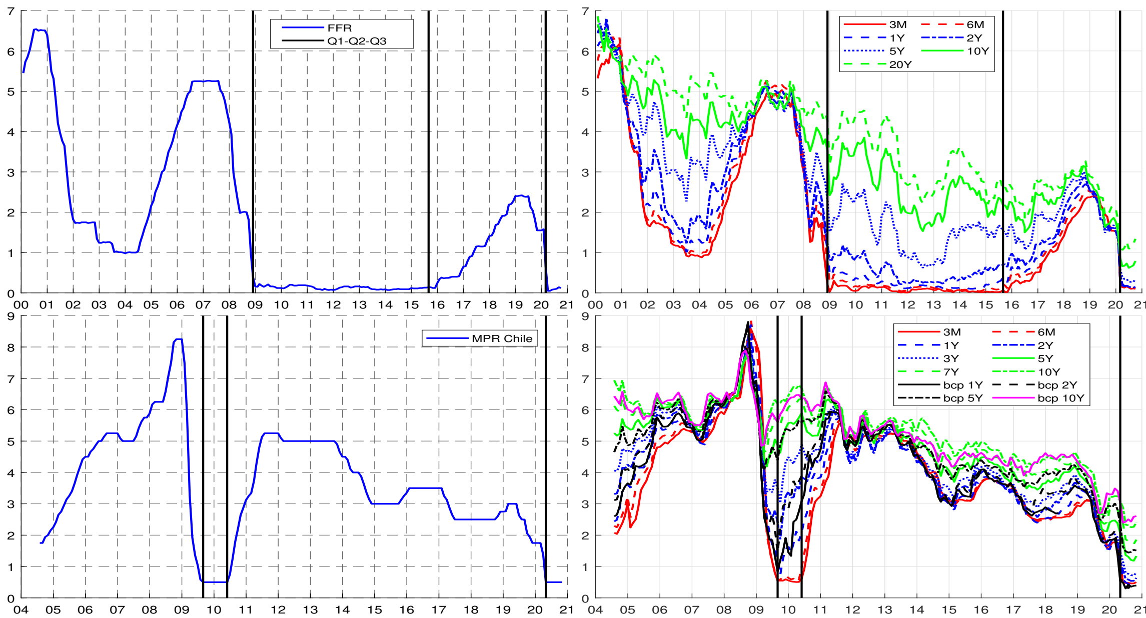
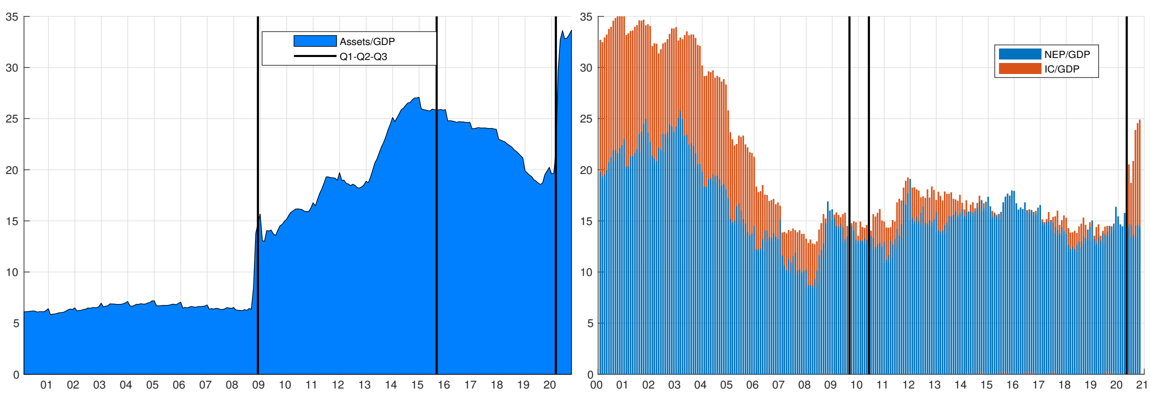
A Figures and Tables

Figure 1: Interest rate structure, U.S. and Chile



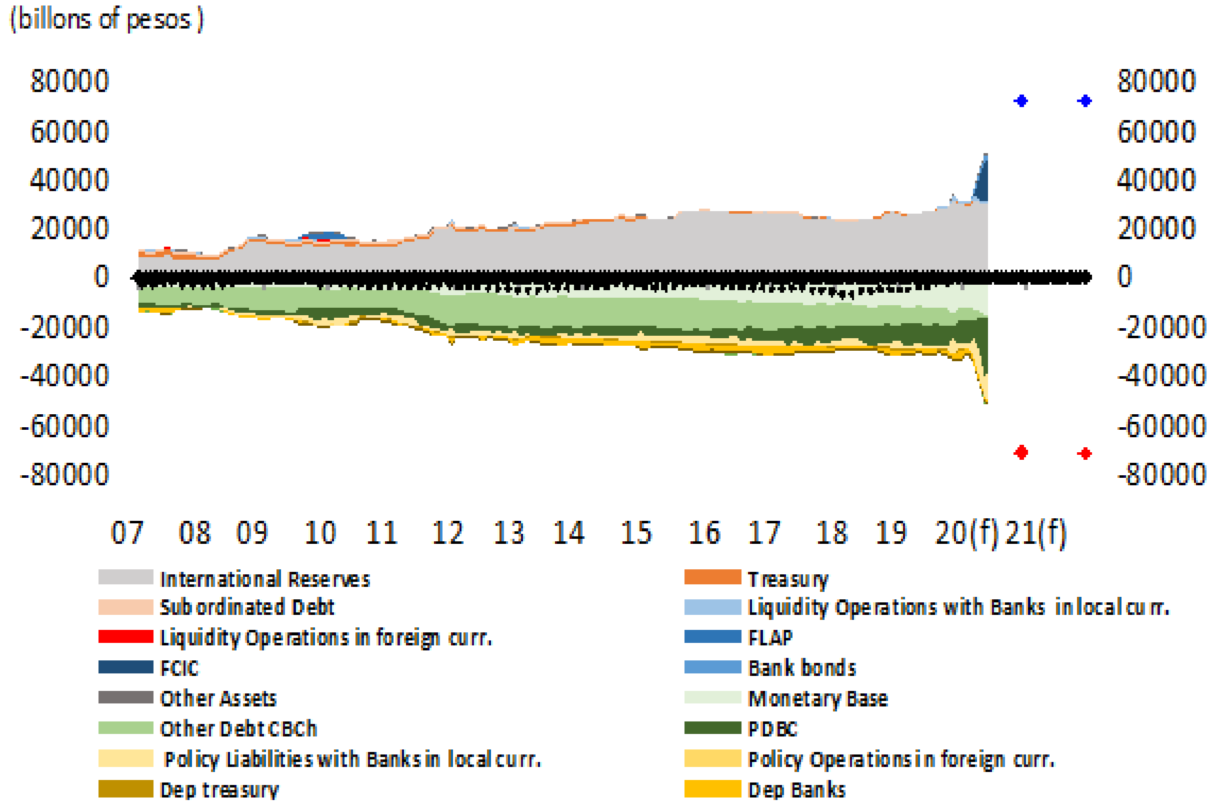
Notes: Vertical lines indicate periods in which the benchmark rates were at their effective lower bounds. Data source: CBC and Federal Reserve Bank of St. Louis (FRED).

Figure 2: Fed and CBC assets (% of GDP)



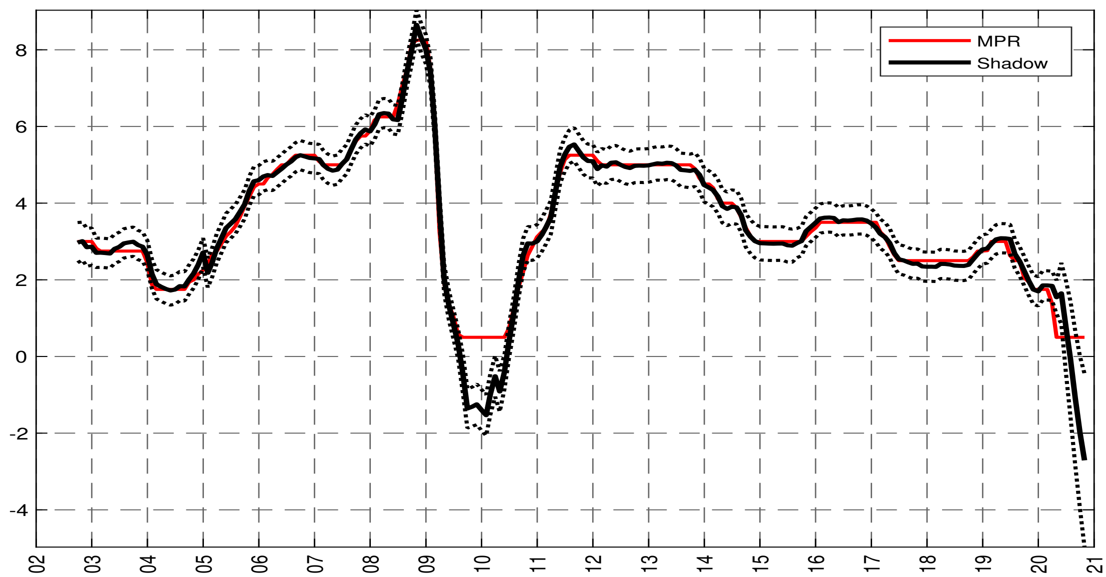
Notes: Assets are expressed as percentages of the previous year's nominal GDP. Vertical lines indicate periods in which the benchmark rates were at their effective lower bounds. Abbreviations: Net External Position (NEP), Internal Credit (IC). Data source: CBC and FRED.

Figure 3: CBC balance sheet



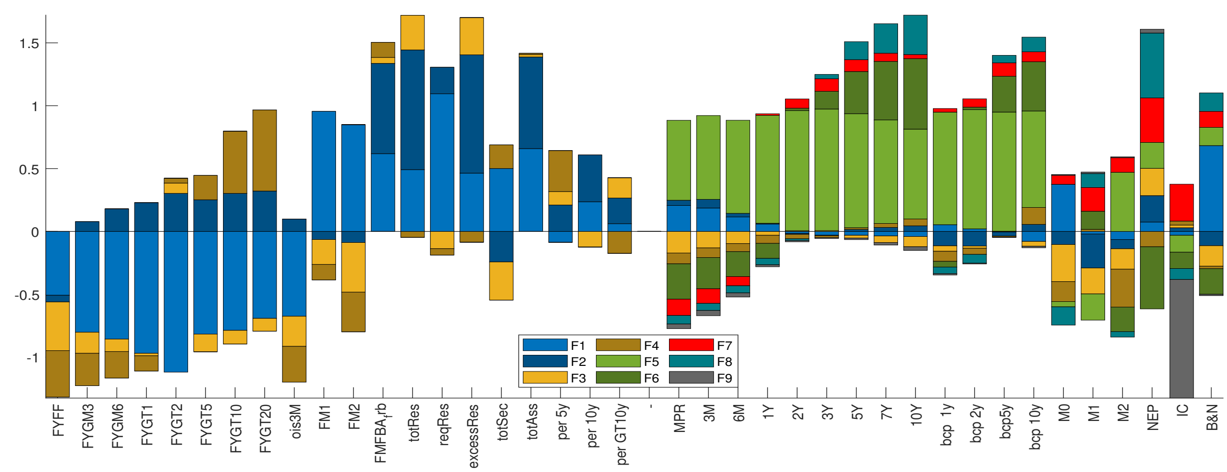
Notes: (*) Effective monthly data up to June 2020. Diamonds correspond to projections for assets, liabilities and equity in 2020 and 2021. (f) Forecast. Source: Central Bank of Chile.

Figure 4: Effective MPR and estimated SMPR



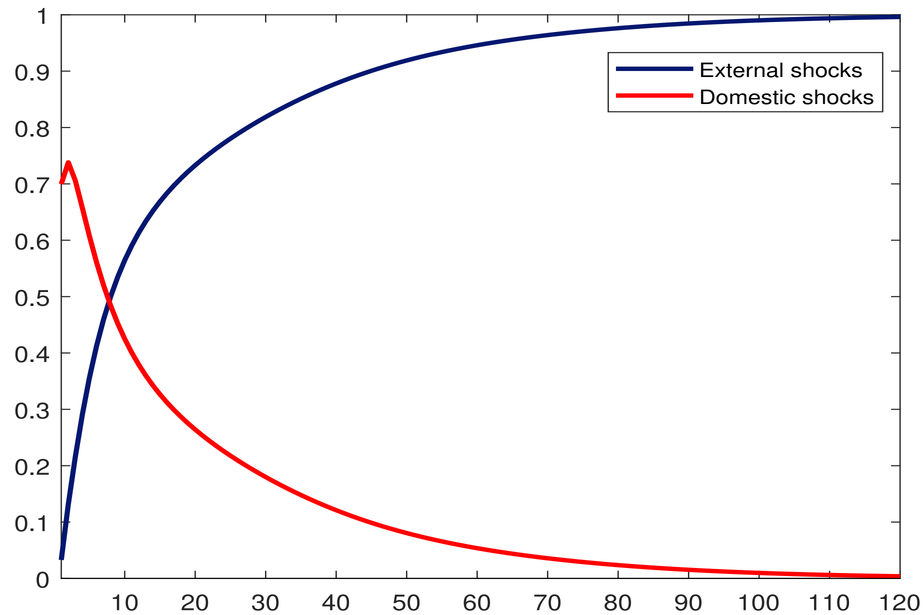
Notes: The thick black line depicts the estimated SMPR, and the dotted lines are the corresponding 95% confidence intervals. The thin red line depicts the effective MPR.

Figure 5: Factor loadings matrix coefficients



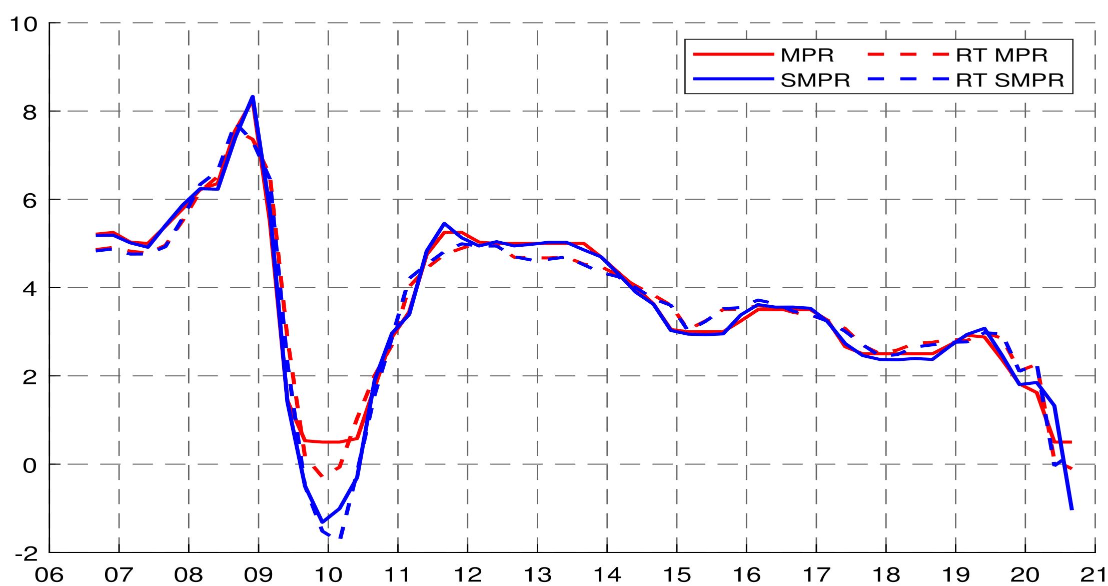
Notes: F1-F4 are the foreign factors and F5-F9 the domestic factors. For details on the variable definitions, see online appendix B .

Figure 6: Forecast Error Variance Decomposition for the SMPR



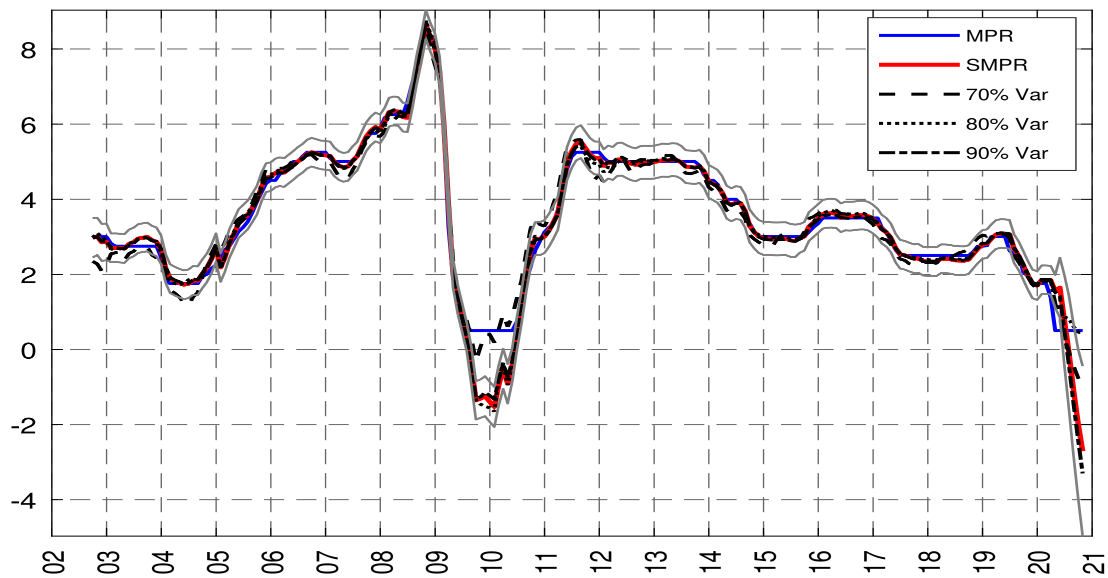
Notes: The figure reports the contributions, in percent, to the variance of the SMPR's forecast error at different forecast horizons (in months). The shocks affect external factors (EF) and domestic factors (DF). The contributions of the shocks to the factors plus the contribution of idiosyncratic shocks sums to 100%. To obtain the contribution of external and domestic factors, the contributions of the shocks to each of the external and domestic factors are aggregated.

Figure 7: Policy rate predicted by estimated Taylor rule and SMPR



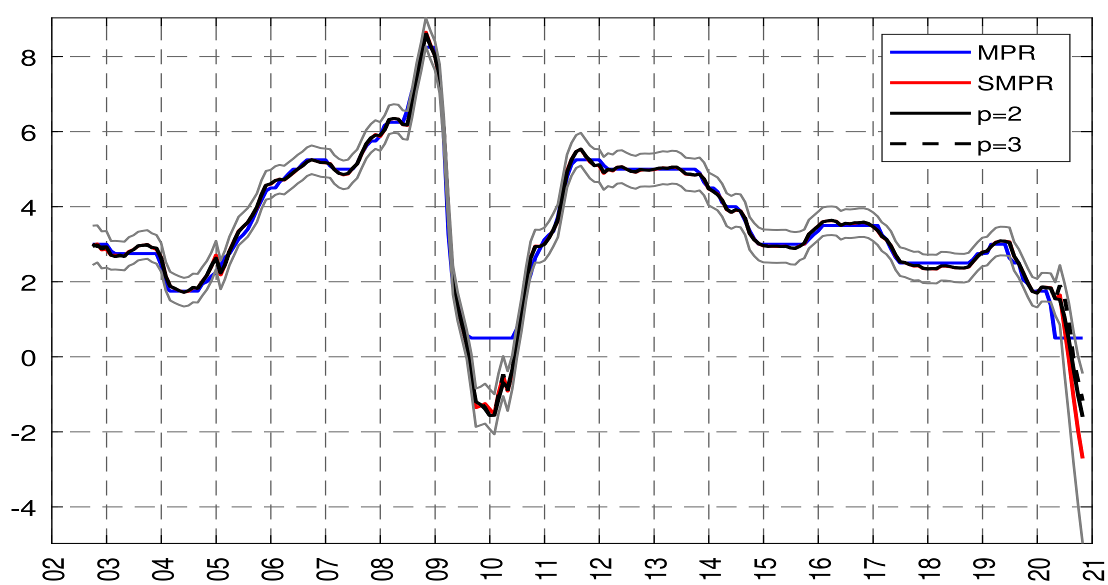
Notes: Predicted rates come from estimated Taylor rules (TR). To estimate the TR we use the non-mining output-gap, which is only available in quarterly frequency. The solid black (yellow) line depicts the quarterly average of the effective (shadow) MPR. The dotted green and blue lines are predicted rates from TR estimated using the MPR and the SMPR, respectively. Results obtained with alternative specifications and estimation techniques are provided in online appendix E.

Figure 8: Robustness to the number of factors



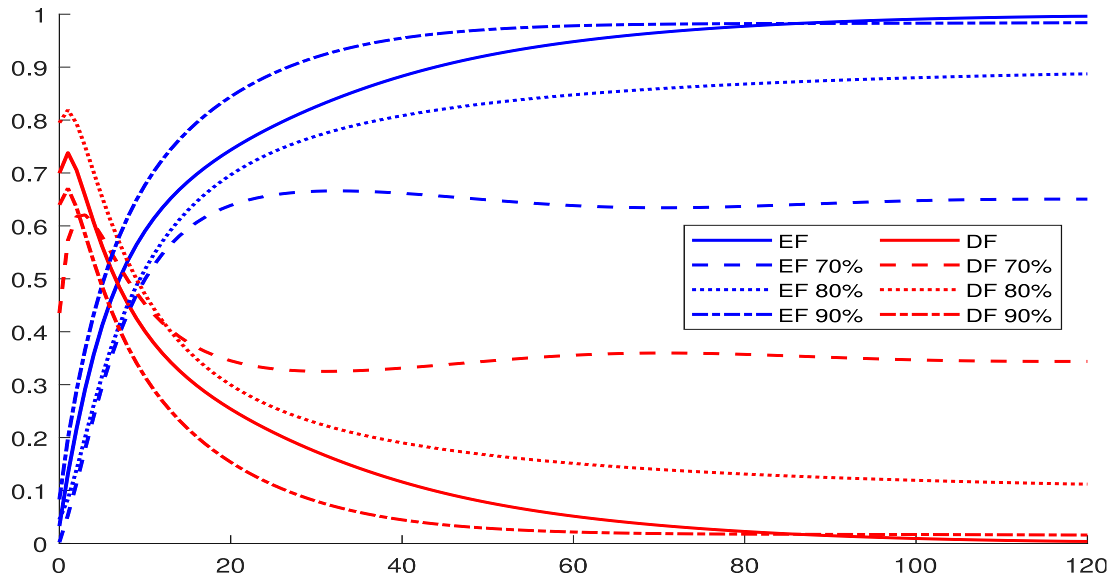
Notes: The baseline specification has 4 external factors, 5 domestic factors, and p = 1. The thin gray lines indicate the 95% confidence intervals of the SMPR (thick red line). The dashed, dotted and dash-dotted lines indicate alternative specifications that capture approximately 70, 80, and 90% of the variance in each block and have 2 external factors and 2 domestic ones, 3 external factors and 2 domestic ones, and 5 external factors and 4 domestic ones, respectively.

Figure 9: Robustness of SMPR to the number of lags in the factor VAR



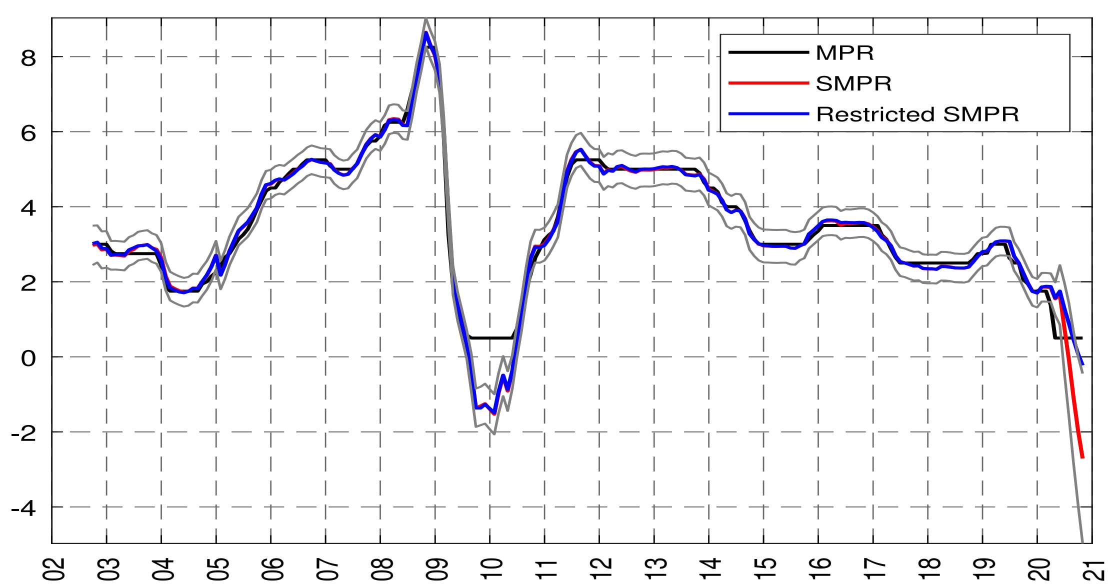
Notes: The baseline model considers $p = 1$ based on the AIC, SIC, and HQC information criteria. The thin gray lines indicate the 95% confidence intervals of the SMPR (thick red line).

Figure 10: Robustness of FEVD to changes in specification



Notes: The figure provides the contributions to the variance of the SMPR forecast error at different horizons (see note to Figure 6). The shocks affect external factors (EF) and domestic factors (DF). Robustness is studied with alternative specifications that capture approximately 70, 80, and 90% of the variance in each block and have 2 external factors and 2 domestic ones, 3 external factors and 2 domestic ones, and 5 external factors and 4 domestic ones, respectively.

Figure 11: Robustness to the inclusion of variables



Notes: The baseline model considers $p = 1$ based on the AIC, SIC, and HQC information criteria. The thin gray lines indicate the 95% confidence intervals of the SMPR (thick red line).

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