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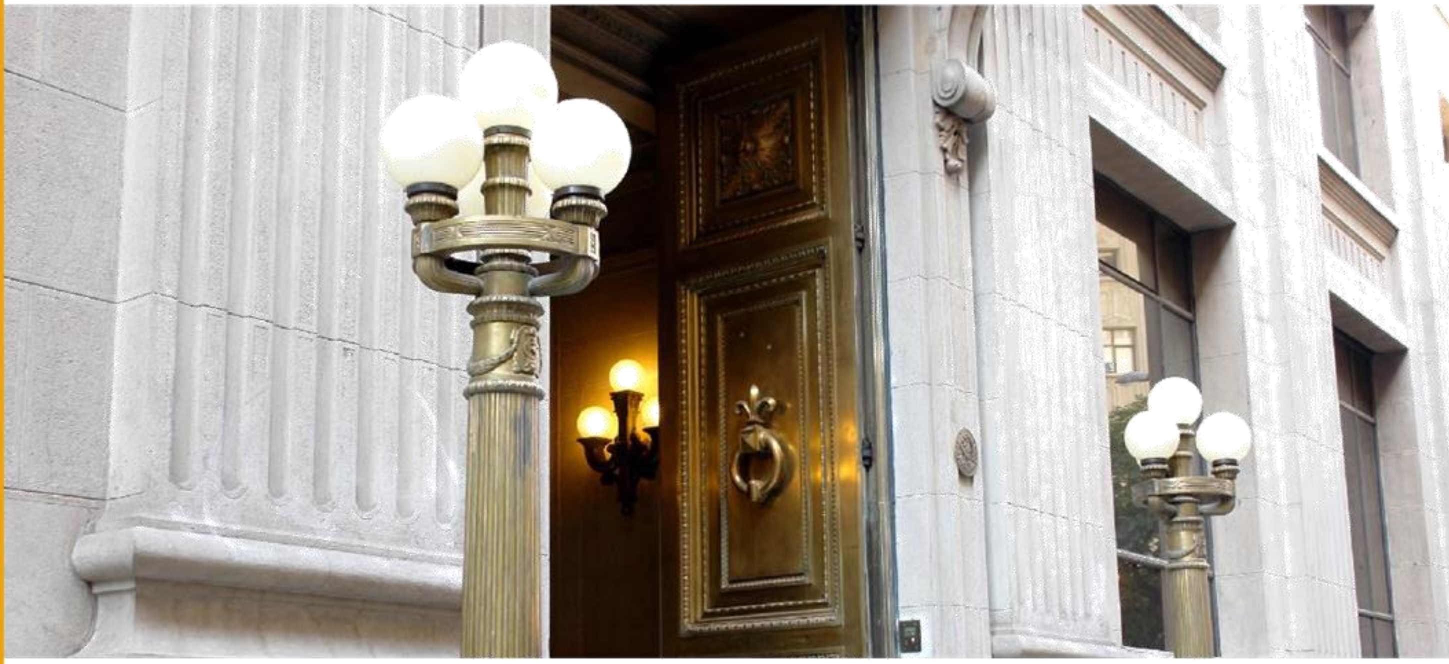

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A semi-structural model with banking sector for stress testing scenario design*

J. Sebastián Becerra†- José Carreño‡- Juan Francisco Martínez §

Abstract

In this paper, we estimate a semi-structural New-Keynesian model for the Chilean economy. Our contribution consists of including a *financial block*, with an explicit description of the lending interest rate, credit volume, credit risk, and interest rate spreads. Firstly, we find the presence of a financial accelerator, that amplifies shocks. We find a significant relevance of financial sector feedback to the real economy. The incorporation of financial elements in a simple and flexible way allows the developed macro-financial model to be useful for various purposes. In this work, we carry out exercises in which extreme scenarios are simulated and are suitable for stress testing purposes.

Resumen

En este trabajo, estimamos un modelo Neo-keynesiano semi-estructural para la economía chilena. Nuestra contribución consiste en incluir un *bloque financiero*, con una descripción explícita para la tasa de interés de colocación, el volumen de crédito, el riesgo de crédito y los diferenciales de la tasa de interés. En primer lugar, encontramos la presencia de un acelerador financiero, que amplifica los shocks. Comprobamos la importancia de la retroalimentación del sector financiero a la economía real. La incorporación de elementos financieros de forma sencilla y flexible permite que el modelo macrofinanciero desarrollado sea útil para diversos fines. En este trabajo, se realizan ejercicios en los que se simulan escenarios extremos que son apropiados para la realización de pruebas de tensión.

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1 Introduction

The objective of this paper is to provide a useful and flexible tool for the elaboration of stress test scenarios for the Chilean economy. These scenarios are relevant to support policy analysis and the decision-making process. Our contribution aims at extending the standard semi-structural New-Keynesian model by nesting a set of equations for the main financial variables. These equations emphasize the relationship and feedback effect from the real sector to the financial sector and vice versa. Specifically, we start from the simplest version of the semi-structural New-Keynesian model, in line with the approach used by the Central Bank of Chile (MSEP, Arroyo-Marioli et al. (2020)), and incorporate a block of interrelated equations for interest rate, credit volume, credit risk, and interest rate spreads. Following Macroeconomic Assessment-Group (2010a), we assume that the channel through which the financial block influences the real sector is the interest rate spreads over the output gap.

The difficulty in developing stress test scenarios (recessions and/or recoveries) and designing policy experiments in semi-structural models without financial variables is well known in at least two dimensions (Becerra et al., 2017; Del Negro et al., 2015; Ehrenbergerová and Malovaná, 2019; Piazzesi, 2014; Tovar, 2008): First, these models do not capture strong movements because, over the analysis horizon, variables converge relatively quickly to their equilibrium levels and second, financial shocks are introduced indirectly without considering feedback effects between the real and financial sector. For example, Becerra et al. (2017) design stress test scenarios using the Monetary Policy Report (IPoM) as a baseline. In that case, they propose a drop on economic activity of 6.6pp along with a long-run convergence around 3pp, however, it is not possible to quantify feedback effects. In our extended model, we can decompose this fall and determine that 4.5pp corresponds to the real sector (75%) and 1.65pp (25%) to financial feedback. Thus, this extended model introduces some aspects of the Chilean financial cycle that would help to strengthen the response of the economic cycle to specific shocks. It is important to note that this extended model is intended to be a complementary tool for the design of stress test scenarios and should not be used as a forecasting model.

The extended model is estimated using Bayesian techniques described by An and Schorfheide

(2007). We use data from the first quarter of 2001 to the fourth quarter of 2019. The estimation period also includes the structural break caused by the international financial crisis and the policy measures taken. To test its performance, we compute impulse-response functions and find that the reaction of aggregate demand to different shocks (real and financial) is higher than that of the standard model because the transmission of shocks is strengthened in the financial sector through the interest rate spreads. These results are consistent with the literature (Adrian and Liang, 2018; Caldara and Herbst, 2019; Samano, 2011).

The remainder of the article is organized as follows. Section 2 presents the model descriptions and the literature, section 3 describes the data used, section 4 shows the model estimation, section 5 shows the results, section 6 shows the variance decomposition, section 7 shows the stress test scenarios, and the section 8 offers the conclusions.

2 Model

An increasing body of literature stresses the importance of macro-financial linkages in monetary policy analysis. Vlcek and Roger (2012) created a large list of Central Banks that have financial frictions or financial intermediation models. As in Bernanke et al. (1999) and Iacoviello (2005), the majority of these models only include endogenous financial frictions. These models, in general, focus on understanding the factors influencing credit demand and tend to spread and amplify the transmission of shocks via an accelerator mechanism, with no involvement for financial intermediaries. Another set of macroeconomic models, however, highlights the importance of credit supply factors, banking system structure, and the composition of the bank balance sheet in macroeconomic and financial shocks transmission (Curdia and Woodford, 2010; Gertler and Karadi, 2011). Despite these efforts, no recognized framework for studying the link between financial friction and macroeconomic activity, as well as its implications for monetary and macroprudential policy, has been developed. Nonetheless, that model would be useful for guiding policy decisions. Hence, the contribution of this work, that incorporates a financial block in an otherwise standard semi-structural New-Keynesian model for a small open economy.

We employ a model that takes into consideration the interplay of a standard macroeconomic configuration with a few important financial factors. As the foundation for the macroeconomic block, we use a basic Neo-Keynesian DSGE model for a small and open economy (Laxton et al., 2006a). Although this sort of model has been effective in directing central banks in determining interest rates, it does not include financial factors that the authority may be interested in. A financial block is included to provide a basic framework in which financial variables are important to the monetary authority. As a result, the basic model is expanded to take into consideration the interaction of the key macroeconomic variables with the financial sector. This approach is largely used in literature over the last few years (Ehrenbergerová and Malovaná, 2019; Nuguer et al., 2016; Samano, 2011).[1]

For the macroeconomic block, there are four equations, and for the financial block, there are three equations. We model an IS curve, a Phillips curve, a real exchange rate equation (UIP condition), and a Taylor rule in the macroeconomic block. It's worth noting that, as stated by Aguirre and Blanco (2015), the equations (1) and (2) may be derived as log-linear approximations of the first-order conditions by consumers and firms based on an optimization problem with monopolistic competition and sticky prices.

In the financial block, we model a spread (difference between the lending and monetary policy rates), lending rates, credit, and credit risk. All these variables capture the role of the financial sector. The financial block feeds the macroeconomic block through the *IS* curve. At the same time, the macroeconomic block feeds back into the financial block through output and interest rates, generating an acceleration effect. As it is common in these types of specifications, lowercase variables represent gaps (deviations in logarithms) of their respective steady states. Finally, to capture the risk in the financial sector, we use the relationships found by Aguirre and Blanco (2015); Ehrenbergerová and Malovaná (2019); Samano (2011).

2.a Macroeconomic block

In this section, we discuss the elements that make up the system of equations that we will estimate in the next section. As previously described, it is made up of a standard macro module, which

[1] A similar idea is proposed by Alfaro and Sagner (2011), Becerra et al. (2017) the elaboration of stress test scenarios. However, their approach is based on VAR-type econometric models and not models with macroeconomic structure.

extends the IS-LM analysis to incorporate elements of international economics and financial feedbacks.

We would like to point out the differences with the macroeconomic block presented by Arroyo-Marioli et al. (2020). In that work, the authors model the non-mining output gap following an error correction setting and explicitly incorporating terms of trade as its determinants. In addition, for inflation, they propose specific equations for food, energy, tradable, and non-tradable. This stronger structure in the macro component, especially in the case of inflation modelling, adds more richness to the monetary policy analysis, but reduces some flexibility in the model and partially reduces the relevance of the macro-financial feedback. In contrast, our macroeconomic block is simpler to emphasize the impact of the financial channel on the total output gap. This impact goes through the interest rate spread, a mechanism that is in line with the work done by Macroeconomic-Assessment-Group (2010). The first equation of this block is the IS curve.

$$\hat{y}_t = \alpha_1 E_t[\hat{y}_{t+1}] + (1-\alpha_1)\hat{y}_{t-1} - \alpha_2 \hat{rr}_t + \alpha_3 \hat{q}_t + \alpha_4 E_t[\hat{y}^*_{t+1}] - \alpha_5 SPR_t + \varepsilon_t^{\hat{y}_t}, \tag{1}$$

where $\hat{y}_t$ is the output gap[2]; rr_t is the real interest rate gap[3]; $\hat{q}_t$ is the real exchange rate gap; y^*_t is the foreign output gap; SPR_t is the interest rate spread. Equation (1) states that the output gap depends on its expected value and its lag, where the relative impact is given by α_1. The forward-looking term is due to the process of intertemporal optimization of households and the lagged term arises as a result of consumption habits or because of the capital stock adjustments that are expensive for firms (see, for example, Christiano et al., 2005; Clarida et al., 2002; Smets and Wouters, 2003). The aggregate demand is also influenced by changes in real interest rates. The presence of the real exchange rate in equation (1) represents the transmission channel of external shocks to the local economy. For more details and motivation see Gali and Monacelli (2005); McCallum and Nelson (2000); Obstfeld and Rogoff (2000); Svensson (2000). In addition, the IS curve contains the spread between the lending interest rate (the rate charged for taking a loan) and the short-term interest rate, as in Samano (2011). This last variable is not present in the traditional Keynesian

[2] The output gap is defined as $\hat{y}_t = Y_t - \bar{Y}_t$ where $\Delta\bar{Y}_t = \theta_1 \Delta\bar{Y}_{t-1} + (1-\theta_1)\Delta\bar{Y}^{ss} + \xi_t^{\bar{Y}}$. Thus, the output gap is defined as the difference between the log of GDP (Y) and the log of the trend GDP ($\bar{Y}$). The trend converges to a long-run constant $\Delta\bar{Y}^{ss}$

[3] The real interest rate gap is defined as $\hat{rr}_t = rr_t - \bar{rr}_t$ where $\Delta\bar{rr}_t = \theta_3 \Delta\bar{rr}_{t-1} + (1-\theta_3)\Delta\bar{rr}^{ss} + \xi_t^{\bar{rr}}$. The trend converges to a long-run constant $\Delta\bar{rr}^{ss}$.

models, and it arises to capture the impact of financial conditions on aggregate demand. Thus, the spread will be the variable that drives the effects of the feedback effects between the financial sector and the rest of the economy.

The equation (2) describes a Hybrid Neokeynesian Phillips Curve (CPNK) where inflation depends on its expected value, its lag, and the output gap.

$$\pi_t^{core} = \beta_1 E_t(\pi_{t+1}^{core}) + (1-\beta_1)\pi_{t-1}^{core} + \beta_2 \hat{y}_t + \beta_3 \Delta q_t + \varepsilon_t^{\pi^{core}} \tag{2}$$

The CPNK arises as a result of a price adjustment mechanism - Calvo type - with partial indexation to the last period inflation. Since firms cannot re-optimize their prices in any period, they adjust prices according to the inflation of the last period and the inflation target. The exchange rate in the CPNK explains the imported inflation component. The inclusion of the real exchange rate in both equations (1) and (2) is analytically derived by Gali and Monacelli (2005).

$$q_t = \gamma_1 E_t(q_{t+1}) + (1-\gamma_1) q_{t-1} - \left(\frac{1}{4}\right)(rr_t - rr_t^* - \rho_t^{embi}) + \varepsilon_t^q \tag{3}$$

The equation (3) represents the interest rate parity. This expression describes the dynamics of the exchange rate where r^* is the real external interest rate and ρ is the risk premium. The real exchange rate q_t is defined in such a way that an increase of this is considered a depreciation, in percentage points we have, $q_t = 100log(\frac{P_t^F e}{P_t})$, where P_t^F is the external price level, P_t is the domestic price level and e is the exchange rate nominal expressed in local currency units per foreign currency units. A coefficient of one is assumed for the interest rate differential (Laxton et al., 2006b). The interest rate and risk premium measures are divided by 4 because they are expressed in annual terms. Finally, the dynamics of the real exchange rate depend on its expected value and its lag.

To close the macroeconomic block there is a Taylor rule that describes the behavior of the Central Bank. This version uses a version of Taylor's rule that emphasizes the forward-looking perspective to adjust the interest rate. From the equation (4), we see that monetary authority responds to the expected value a period ahead of the output gap and annual inflation, $E_t(y_{t+1}, \pi_{t+1}^{core,A})$ [4], with some

[4] The formula is $\pi_t^{core,A} = \frac{\pi_t^{core} + \pi_{t-1}^{core} + \pi_{t-2}^{core} + \pi_{t-3}^{core}}{4}$.

degree of inertia that is captured by the lag in the interest rate , where i_t is the nominal interest rate.

$$i_t = \phi_1 i_{t-1} + (1-\phi_1)[i_t^n + \phi_2(E_t(\pi_{t+4}) - \bar{\pi}] + \phi_3 E_t(\hat{y}_t) + \varepsilon_t^i \tag{4}$$

Where i_t^n is the real neutral interest rate defined as

$$i_t^n = \bar{r}r_t + E_t[\pi_{t+1}]. \tag{5}$$

Note that we do not use the Fisher equation or the neutral nominal rate.

2.b Financial Block[5]

We analyze a financial sector in which banks are responsible for the intermediation of resources between borrowers and lenders. This intermediation comes at a cost, which is represented by the equation (6). The equation (6) indicates that the disparity between the rate charged for loans and the monetary policy rate.

$$SPR_t = i_t^{Loan} - i_t. \tag{6}$$

According to Curdia and Woodford (2010), given the frictions in loan demand, it is conceivable to charge borrowers an extra premium on their interest rate. In a similar vein, Gerali et al. (2010) demonstrate that banks dedicate resources to balance sheet management and/or to pay the expenses associated with regulatory requirements. We also assume in this paper that banks have some market power because of monopolistic competition, which allows them to charge a margin on the policy rate when granting credit.

Equation (7) describes the dynamics of the lending rate.

$$i_t^{Loan} = \eta_1 i_t + \eta_2 LLP_t + \eta_3 CAR_t + \varepsilon_t^{i^{Loan}} \tag{7}$$

[5]This financial block is also introduced in a semi-structural model, elaborated by Arroyo-Marioli et al. (2021). It should be noted that the present work was developed before the publication of the aforementioned paper and served as a reference for its model configuration. The latter appropriately cites the present research.

The lending rate is affected by the monetary policy rate (MPR) with an impact equal to (η_1) that captures the transfer of the policy rate to the credits. It is also affected by credit risk (η_2). That is, if the banking sector experiences complications to recover the payment of its credits, the rate at which the new credits will be made will be higher to compensate for losses. On the other hand, if the regulation becomes more severe - greater capital requirement on risk-weighted assets (CAR) - the banks will increase the interest rate at which they grant loans (η_3) [6].

The equation (8) shows the demand for credit expressed in terms of gaps[7]. Credit depends on its own dynamics (θ_1), has a positive relationship with the output gap (θ_2) and a negative with the spread (θ_3).

$$\hat{cr}_t = \theta_1 \hat{cr}_{t-1} + \theta_2 \hat{y}_{t-1} - \theta_3 SPR_t + \varepsilon_t^{\hat{cr}} \tag{8}$$

We can capture the accumulation of risks in the financial sector through the evolution of the credit gap, which will be positively related to the economic activity (θ_2, that is, credit booms generally begin after periods of rapid economic growth) and negatively related to the spread (θ_3). This last relationship accounts for the link between financial conditions and credit booms.

$$LLP_t = \vartheta_1 LLP_{t-1} - \vartheta_2 \hat{y}_t + \vartheta_3 \hat{cr}_{t-1} + \varepsilon_t^{LLP} \tag{9}$$

Equation (9) is a measure of credit risk for banks. We assume that it depends on economic activity and credit. The intuition behind this specification is that periods of expansion in economic activity are accompanied by reductions in loan-loss-provision levels (ϑ_2), as debtors can meet the payment of their obligations. On the other hand, an accelerated expansion of credit, which would be captured by a positive credit gap could result in vulnerabilities for banks, as there is a possibility that the new loans are of lower quality as a result of a relaxation in standards for grant credit during credit booms. This translates into higher provisions (ϑ_3).

[6] Banks will seek to obtain a higher return their obligation to maintain a higher level of capital, in other words, will keep the return on capital constant.

[7] This is defined as $\hat{cr}_t = CR_t - \bar{CR}_t$ with $\Delta\bar{CR}_t = \theta_2 \Delta\bar{CR}_{t-1} + (1-\theta_2)\Delta\bar{CR}^{ss} + \xi_t^{\bar{CR}}$. The equations make clear that changes on credit growth as deviation of its trend and shocks to the level $(\xi_t^{\bar{CR}})$. In turn, credit trends converges to a long-run constant rate $\Delta\bar{CR}^{ss}$.

The rule for the evolution of the bank capital index is described by auto-regressive processes given by

$$CAR_t = \rho_1 CAR_{t-1} + \varepsilon_t^{CAR}. \tag{10}$$

Finally, we assume that internationals variables are exogenous. We model them as auto-regressive processes as shown in equations (11) to (13). These variables include the external output gaps, the external interest rate the risk premium. At last, all shocks in the model are *AR(1)* (equation 14).

$$\hat{y}_t^* = \rho^{\hat{y}^*} \hat{y}_{t-1}^* + \varepsilon_t^{\hat{y}_t^*} \tag{11}$$

$$rr_t^* = \rho^{rr^*} rr_{t-1}^* + \varepsilon_t^{rr_t^*} \tag{12}$$

$$\rho_t^{embi} = \rho_{t-1}^{embi} + \varepsilon_t^{\rho^{embi}} \tag{13}$$

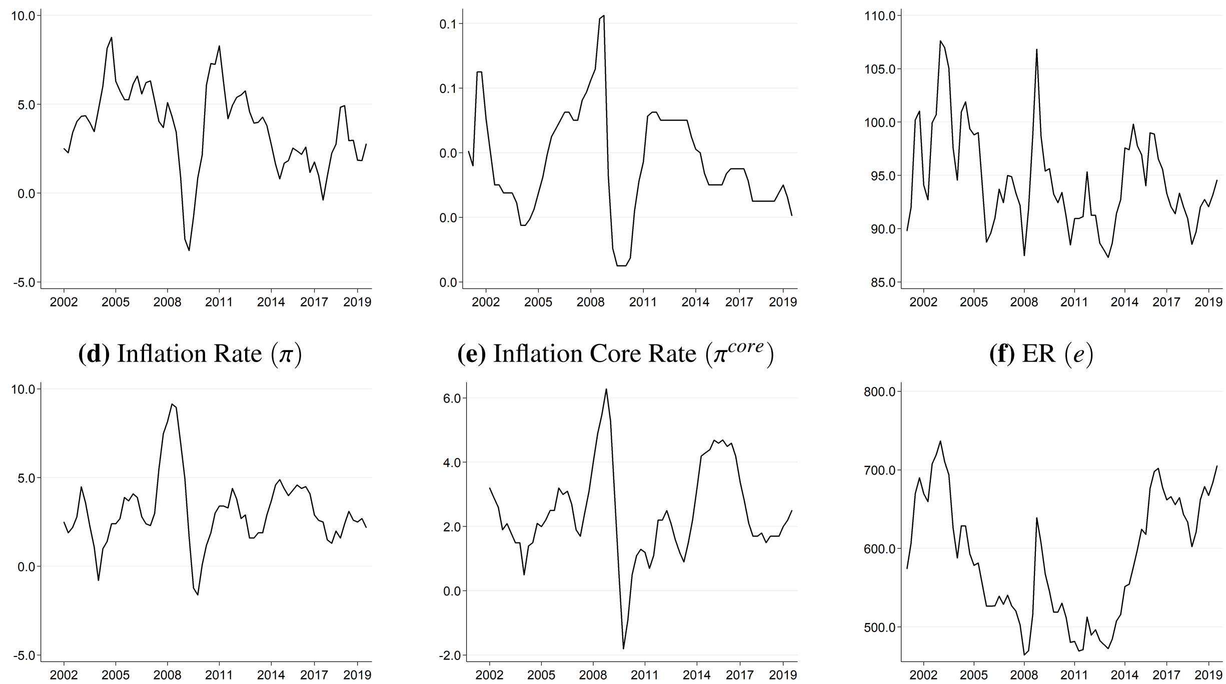
$$\varepsilon_t^x = \rho^{\varepsilon^x} \varepsilon_{t-1}^x + \nu_t^x \tag{14}$$

3 Data

This section describes the database that we will use in the estimation of our model. First, we show the untransformed data (see figure 1, 2, and 3). The macroeconomic block includes GDP, inflation, core inflation, the monetary policy rate of the Central Bank of Chile, the real and nominal exchange rate. This block also includes external variables such as GDP and inflation for the US and the Federal Funds rate.

For the financial block, we will consider bank loans as credit, the interest rate of those loans, a measure of credit risk, and the degree of capitalization of the banking system. The total credit is equal to the sum of commercial and consumer loans. The lending interest rate is a simple average between the rates for loans at 30-89 days, 90 days, 1 year, 1 to 3 years, and over three years. Credit risk is measured by loan-loss provisions. The use of loss-loan-provision as an indicator of credit risk is well known Jara et al. (2007). Following a Alfaro and Sagner (2011), Matus et al. (2009)

Figure 1: Main macro variables

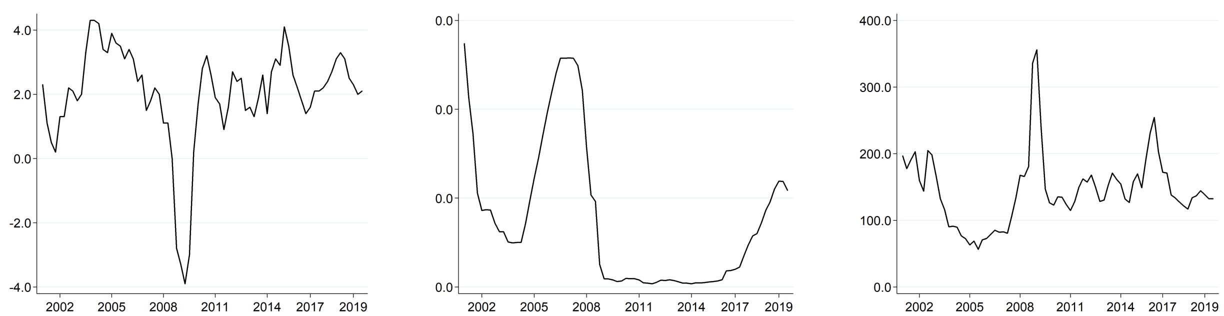


(a) GDP growth (Δy) **(b)** MPR (i) **(c)** RER (q)

(d) Inflation Rate (π) **(e)** Inflation Core Rate (π^{core}) **(f)** ER (e)

Notes: These figures show the main macro variables used in the analysis. Panel A shows the real y-o-y variation of the GDP. Panel B shows the monetary policy rate. Panel C shows the real exchange rate. Panels D and E show the y-o-y inflation rate of the CPI and the CPI EFE (excluding food and energy). Finally, panel F shows the nominal exchange rate. Source: Central Bank of Chile.

Figure 2: External Variables



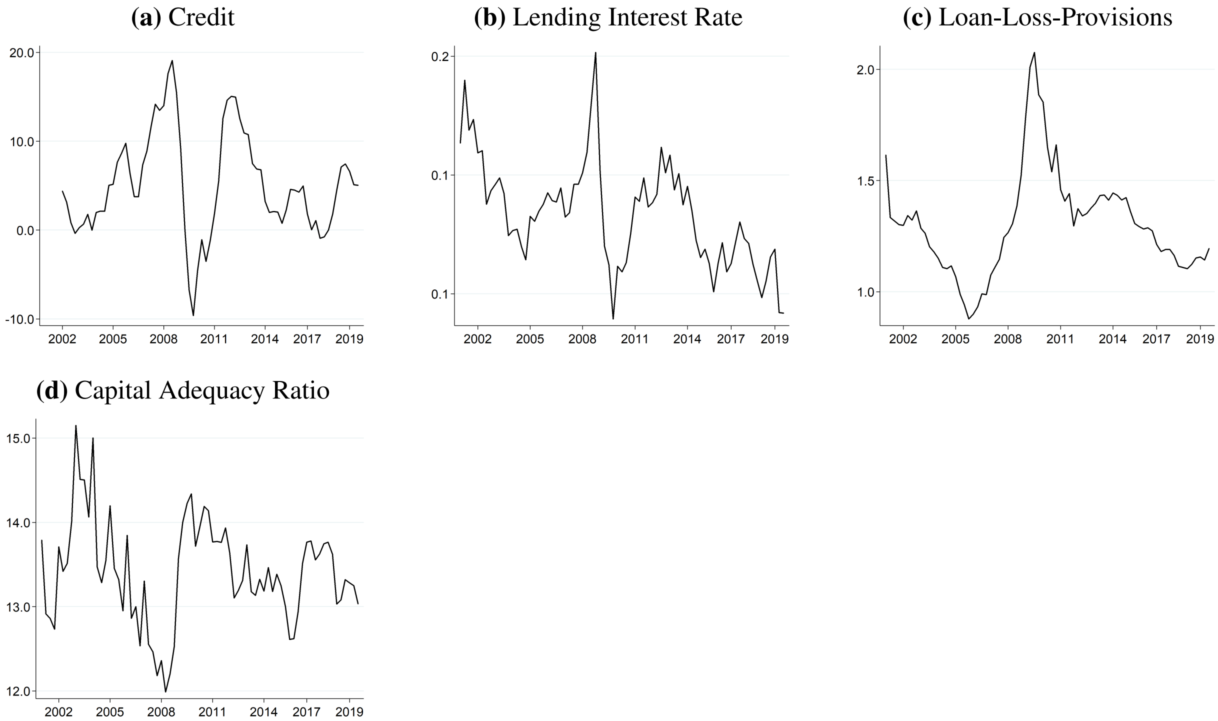
(a) US GDP **(b)** US MPR **(c)** EMBI

Notes: These figures show external variables used in the analysis. Panel A shows the real y-o-y variation for the US GDP. Panel B shows the US monetary policy rate. Finally, panel C shows the Emerging Markets Bonds Index from Chile. Source: Authors' calculations.

and especially for regulatory changes Matus. (2015) we calculate loss-loan-provision as the cumulative sum in 12 months of the delta stock provisions over the total loans.

Finally, the last variable present in the financial block, the capital adequacy ratio (CAR), is the ratio of effective equity to risk-weighted assets. All the data described in this section correspond to the system level and are seasonally adjusted. Data are at a quarterly frequency and cover the first quarter of 2002 through the fourth quarter of 2019. The source for this information is the Central Bank of Chile (CBC), except for the loan-loss provisions and the capital adequacy ratio, which is obtained from the Financial Market Commission (FMC[8]).

Figure 3: Financial Variables

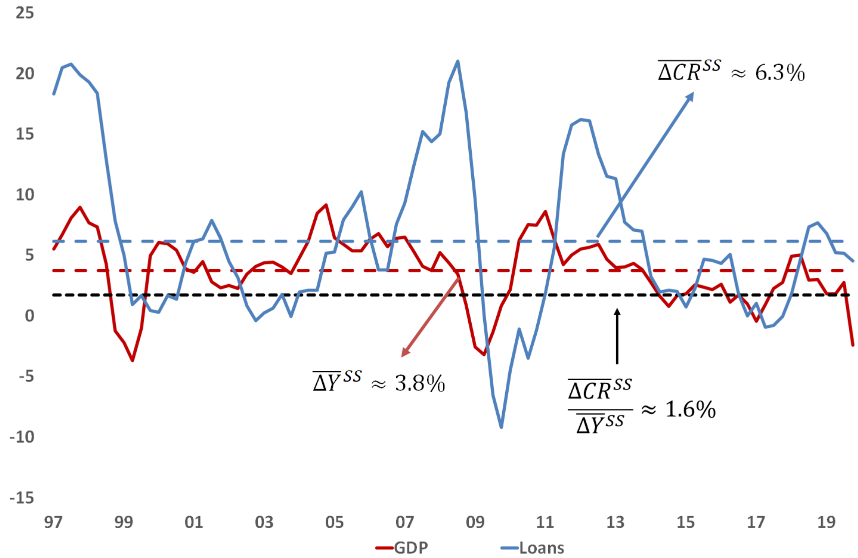


Notes: These figures show financial variables used in the analysis. Panel A shows the real y-o-y variation for credit (consumer plus commercial). Panel b shows the relevant interest rate for the loans in panel A. This interest rate is a simple average between the rates for loans at 30-89 days, 90 days, 1 year, 1 to 3 years, and over three years. Panel C shows loss-loan-provision. This is the cumulative sum in 12 months of the delta stock provisions over the total loans, for more details, see Alfaro and Sagner (2011); Matus. (2015); Matus et al. (2009). Finally, panel D shows the capital adequacy ratio (CAR), which corresponds to effective equity and risk-weighted assets. Source: Authors' calculations.

The last step is to define the value for the empirical relationship between the output and credit growth rates. This ratio will be useful to give the long-term convergence values for the trends. Figure 4 allows us to deduce the key values for $\Delta\bar{Y}^{ss} = 3.8\%$, $\Delta\bar{CR}^{ss} = 6.3\%$. The value for $\Delta\bar{r}r^{ss} = 0.5\%$ is obtained from Arroyo-Marioli et al. (2020) by estimating the real neutral interest rate with the GDP growth using the calibration developed by Laubach and Williams (2016).

[8] www.cmfchile.cl

Figure 4: Relationship between the growth rate of credit (Credit) and GDP growth (GDP) for the Chilean economy over the period 1997-2019.



Notes: The figure shows the relationship between the growth rate of credit (Credit) and GDP growth (GDP) for the Chilean economy over the period 1997-2019. The solid blue line in the figure shows the real annual growth of total bank loans. The red solid line shows real annual GDP growth. The blue and red dotted lines show the average real growth rate over the period 1996-2019 for total bank loans ($\Delta \bar{CR}^{ss} = 6.2\%$) and GDP ($\Delta \bar{Y}^{ss} = 3.8\%$). The black dotted line shows the ratio of the average growth rate of loans to the average growth rate of GDP ($\Delta \bar{CR}^{ss}/\Delta \bar{Y}^{ss} = 6.2\%/3.8\% = 1.6\%$). Total bank loans are the sum of commercial and consumer loans. Real loans are equal to nominal loans deflated by the ratio of nominal to real GDP. All series, in levels, are seasonally adjusted. For more details about $\Delta \bar{Y}^{ss}$. and $\Delta \bar{CR}^{ss}$ see Arroyo-Marioli et al. (2020). Source: Authors' calculations based on information published by the Central Bank of Chile.

3.a Observed Variables

To estimate the model, we convert the variables. The following variables were identified for the macroeconomic block: a) the output gap ($\hat{y}$), b) the quarterly growth of the real GDP (Δy_{obs}), c) inflation rate (π), d) inflation core rate (π^{core}), f) MPR (i), g) real exchange rate (q), h) quarterly growth of the US GDP (Δy^*_{obs}), i) external output gap ($\hat{y}*$) , j) external real interest rate ($i*$), k) external inflation (π^*) and l) risk premium ρ^{embi}. For the financial block we observed: m) spread (SPR), n) loan interest rate (il), o) the credit gap ($\hat{cr}$), p) quarterly growth of the real loan (Δcr_{obs}), q) delinquency index (LLP) and, r) the capital adequacy ratio (CAR). The following relationships are used to get these variables

$$\hat{y} = log\left(\frac{GDP}{GDP^{pot}}\right) \qquad (15)$$

$$\Delta \bar{Y}_t = 3\%/4 + \xi_t^{\bar{Y}_t} \qquad (17)$$

$$\Delta y_{obs} = \Delta \bar{Y}_t + (\hat{y}_t - \hat{y}_{t-1}) \qquad (16)$$

$$\pi_t = \Delta log(CPI_t) - \bar{\pi} \qquad (18)$$

$$\pi_t^{core} = \Delta log(CPI_t^{core}) - \bar{\pi} \quad (19)$$

$$i_t = MPR_t \quad (20)$$

$$\hat{q}_t = log\left(\frac{RER_t}{RER^{trend}}\right) \quad (21)$$

$$\hat{y}^* = log\left(\frac{USGDP_t}{USGDP^{trend}}\right) \quad (22)$$

$$i_t^* = FFR - \bar{\pi}^* \quad (23)$$

$$\rho_t^{embi} = log\left(\frac{EMBI_t}{EMBI^{trend}}\right)/10000 \quad (24)$$

$$il_t^{loan} = il_{obs_t}^{loan} - il_{trend}^{loan} \quad (25)$$

$$\hat{cr} = log\left(\frac{Loans}{Loans^{Pot}}\right) \quad (26)$$

$$\Delta cr_{obs} = \Delta\bar{CR}_t + (\hat{cr}_t - \hat{cr}_{t-1}) \quad (27)$$

$$\Delta\bar{CR}_t = 6\%/4 + \xi_t^{\bar{CR}_t} \quad (28)$$

$$LLP_t = LLP_t^{obs} - LLP^{trend}, \quad (29)$$

$$CAR_t = CAR_t^{obs} - 8\% \quad (30)$$

where GDP^{Pot} denotes potential GDP estimated via multivariate filters potential, $Loans^{Pot}$ denotes potential credit estimated through Hodrick-Prescott filter and *trends* stands for the data means.

4 Model Estimation

The model is estimated using Bayesian techniques described by An and Schorfheide (2007). We use data from the first quarter of 2001 to the fourth quarter of 2019. The estimation period also includes the structural breakdown caused by the international financial crisis and the policy measures adopted. Bayesian techniques are particularly useful for these types of situations if it is known that a structural change has occurred. Because the information may be included in some way while this does not happen with the classical estimation methods. Another interesting point of the Bayesian methods is that it allows the estimation of the complete set of parameters of the model, instead of the usual process of calibration of models or of econometric estimation of the equations, which are based on the individual estimation of each parameter. In addition, the Bayesian approach also makes use of **a-priori** information. In this study, means and variances of the parameters **a-priori** are chosen to take into account micro-founded models that have been widely studied in the literature. This information could improve the efficiency of estimates and address concerns about how to include existing knowledge of the local economy in a formal framework and compare results with previously developed models, as in Medina et al. (2005) and Arroyo-Marioli et al. (2020). For the financial block, there is no concise on the priors. Specifically, for the financial block variables: bank loans, loans rate, and the priors are obtained through univariate linear regressions, see Aguirre and Blanco (2015); Nuguer et al. (2016); Samano (2011). Based on this approach, we interpret the parameter as random, and the data set as fixed: both characteristics are relevant when the sample size is small (2001Q3-2019Q4) and there are structural breaks (nominalization of the MPR and financial crisis). Thus, in short, within the parameters to be estimated, a valuable criterion for determining the ranges of many of the prior coefficients is the assessment of those who initially modelled the MEP. In the financial block, the averages of the **a-priori** distributions reflect our own appreciation, especially in those parameters for which more research is still required for gathering significant empirical evidence.

Our model nests the standard new Keynesian model, but for estimation, we use financial data. This is because our emphasis is to match the financial sector data. Thus, we can assess the effects of financial shocks on macroeconomic variables and also have economically and statistically meaningful results to quantify feedbacks effects.

The posterior estimates were obtained with the Metropolis-Hasting algorithm in which the variance was refined to have an acceptance approximately between 20%-30%. The results are derived from one million replications of the posterior distribution. Table 1 shows the priors (distribution, mean and standard deviation) and the posterior (mean and the values of the 5th and 95th percentiles of the distribution). Less relevant parameters are not reported. We can observe that there is a sufficient difference between the prior and the posterior parameters computed by the Bayesian estimation and the most important parameters are identified (see the appendix).

Table 1: Parameters, priors and posterior.

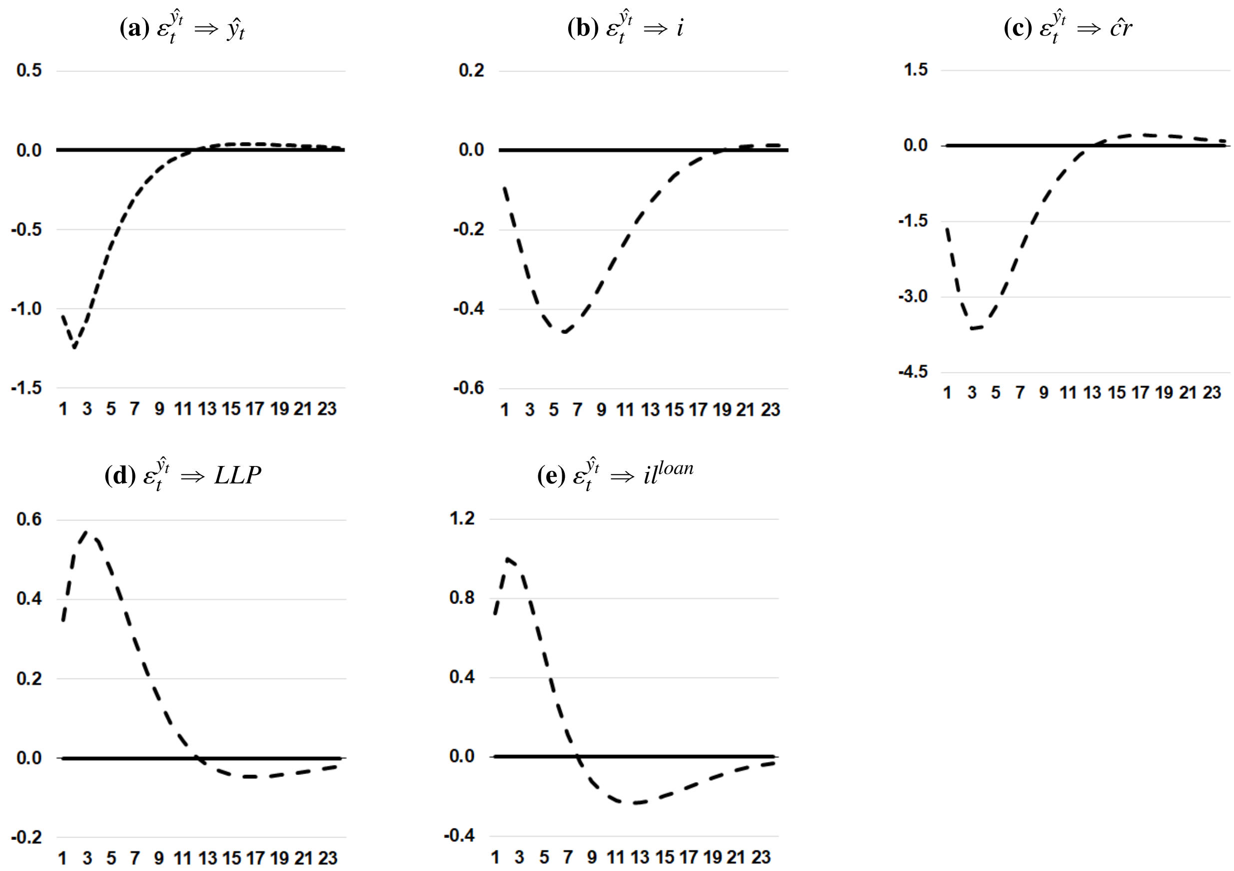
Equation	Parameter	Prior Dist.	Prior Media	Prior Std.	Posterior Media	Posterior Int. 90 % prob
IS	α_1	Beta	0.50	0.15	0.17	0.12 / 0.22
	α_2	Beta	0.12	0.05	0.13	0.04 / 0.21
	α_3	Beta	0.07	0.04	0.02	0.00 / 0.05
	α_4	Beta	0.18	0.08	0.16	0.05 / 0.26
	α_5	Beta	0.46	0.05	0.54	0.46 / 0.62
Phillips's curve	β_1	Beta	0.20	0.10	0.16	0.10 / 0.22
	β_2	Beta	0.05	0.02	0.11	0.04 / 0.18
	β_3	Beta	0.06	0.04	0.06	0.00 / 0.12
RER	γ_1	Beta	0.60	0.15	0.84	0.81 / 0.93
Taylor rule	ϕ_i	Beta	0.75	0.10	0.43	0.28 / 0.57
	ϕ_π	Norm	1.50	0.25	1.65	1.49 / 1.79
	ϕ_y	Norm	0.13	0.03	0.13	0.09 / 0.17
Lending rate	η_1	Norm	1.50	0.10	1.64	1.49 / 1.79
	η_2	Norm	0.50	0.10	0.68	0.53 / 0.83
	η_3	Norm	0.30	0.10	0.37	0.24 / 0.47
Credit	θ_1	Beta	0.85	0.10	0.97	0.93 / 0.98
	θ_2	Norm	0.70	0.10	0.80	0.69 / 0.92
	θ_3	Norm	0.35	0.10	0.37	0.19 / 0.51
Loan-Loss-Provision	ϑ_1	Beta	0.75	0.10	0.80	0.69 / 0.92
	ϑ_2	Beta	0.50	0.10	0.66	0.53 / 0.79
	ϑ_3	Norm	0.03	0.10	0.02	0.01 / 0.04

Notes: The table shows the parameters, priors, and posterior of the model. We estimate the model using Bayesian methods from the first quarter of 2001 to the fourth quarter of 2019. The priors for the macroblock are standard and come from the traditional literature, see Medina et al. (2005) and Arroyo-Marioli et al. (2020). There is no consensus about the priors for the financial block yet. For loans, we use univariate linear regressions to obtain them. For the other variables see Aguirre and Blanco (2015); Ehrenbergerová and Malovaná (2019); Nuguer et al. (2016); Samano (2011). The prior distributions are beta distribution (B) on the open interval (0,1) and normal distribution on R. The remaining parameters are available in Table A1. Source: Authors' calculations.

5 Results

We find that posterior mean are in the range of estimates observed in the literature. We see a high persistence for the activity, $1-\alpha_1$. We also find that the forward-looking component has an impact in the IS equation, α_1. In the Phillips Curve, the persistence component, $1-\beta_1$, is the most important, and the forward-looking inflation, β_1 has a minor impact. The output gap, β_2, and the exchange rate, β_3, contribute to a lesser extent. Regarding the financial block, we find that the monetary policy rate (MPR) is an important factor for the determination of how much Banks will charge to their clients, η_1, followed by the credit risk, η_2, and the capital requirement η_3. Therefore, if the regulatory institutions require a higher capital level to banks, the cost will be transferred to the users through a higher interest rate. On the credit risk side, both persistence (θ_1), the gap (θ_2)

Figure 5: Activity Shock

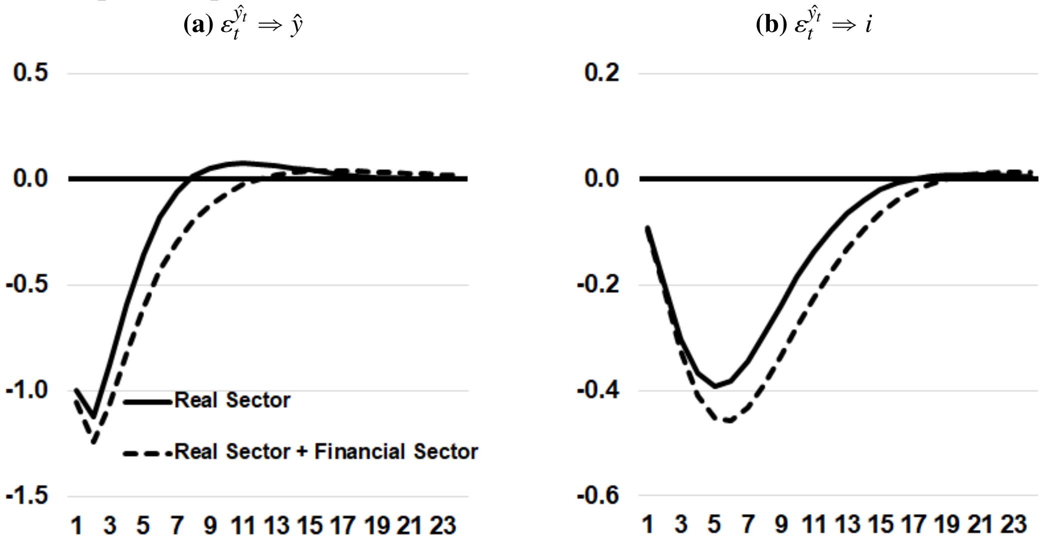


Notes: The figure shows the response of the endogenous variables to an activity shock that decreases the output gap $\hat{y}$ by 1%. We consider the following endogenous variables: monetary policy rate (MPR, panel b), credit (panel c), loan-loss-provision (LLP, panel d), lending interest rate (panel e). Given the activity shock, the output gap decreases by 1.2pp; MPR decreases by 0.46pp; real credit decreases by 3.6pp; credit risk increases by 0.57pp; and lending interest rate increases by 0.96pp. Source: Authors' calculations.

and, the credit granted (θ_3) have a similar impact.

To understand the model and the relationship between the financial sector and the rest of the economy we analyse the impulse response functions. Figure 5 shows the dynamics of the model, evaluated in the posterior mean of parameters, subject to a negative activity shock that decreases the output gap by 1% with respect to its potential level. First, the MPR decreases in response to the new level of output gap to stimulate the aggregate demand. The real credit follows the same behavior, decreasing more than 3% at the end of the first year. The lending interest rate increases in response to the higher credit risk, which in turn increases the loan-loss provisions. This positive effect dominates due to the deterioration in the bank loan portfolio and the drop in the output gap. Since is not possible to see the accelerating effect of the feedback-loop caused by the deterioration

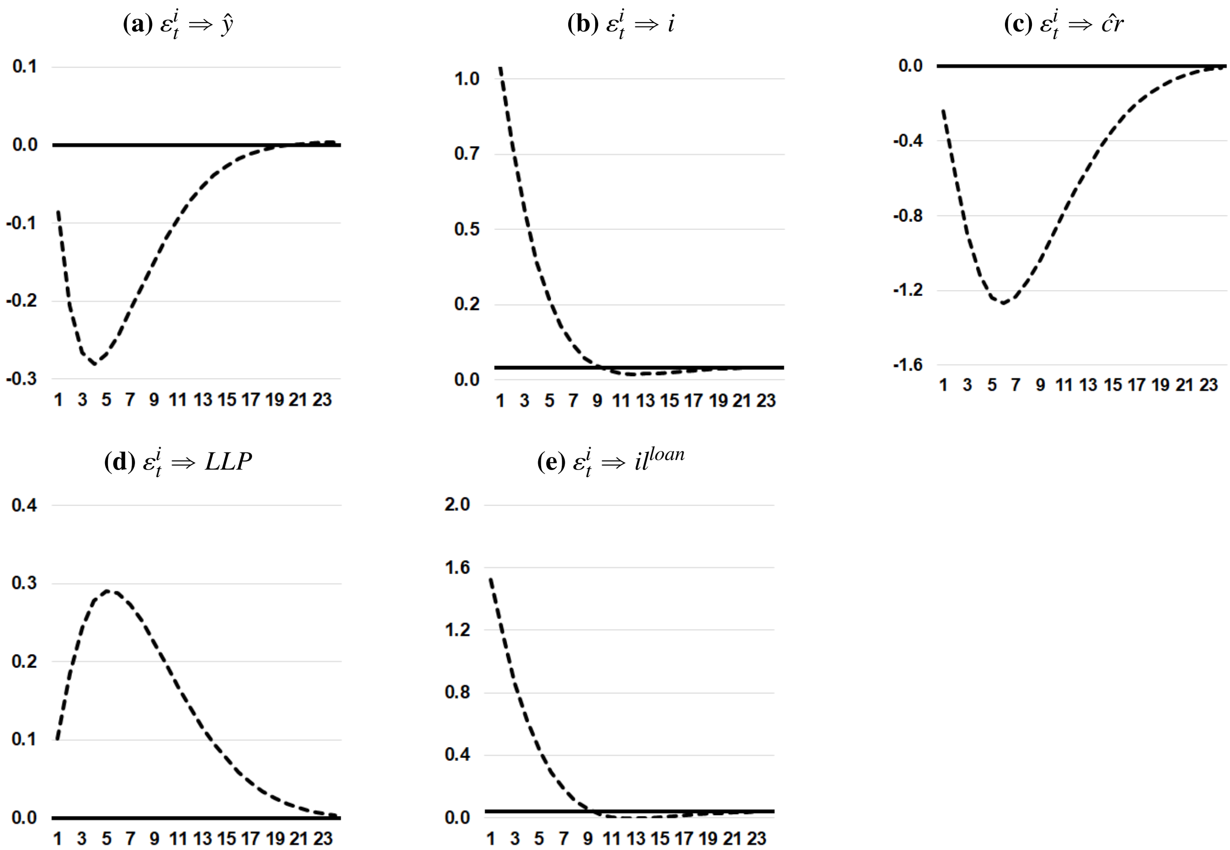
Figure 6: Impulse response function for two scenarios (with and without the financial sector).



Notes: The figure shows the dynamics of the output gap and monetary policy rate under a negative activity shock that decreases the output gap by 1% with respect to its potential level. We consider two scenarios, with and without the financial sector. The output gap falls 1.24pp (dotted line) versus 1.12pp (solid line). Source: Authors' calculations.

in financial conditions, we study the impulse responses when considering a model without the financial sector. To do this, we reproduce figure 5 (a)-(b) for a model with and without the financial sector. Figure 6 shows then the impulse response function for both the output gap and the monetary policy rate (MPR) when there is a negative activity shock. We see that without the financial sector, the fall of the output gap is lower than the response with the financial sector. This is because of the negative feedback loop between economic activity and worsening financial conditions. A negative activity shock makes the financial sector react by increasing the interest rate, which in turn feeds back to the real economy decreasing, even more, the output gap. This is why we observe an amplification mechanism under the model with a financial block.

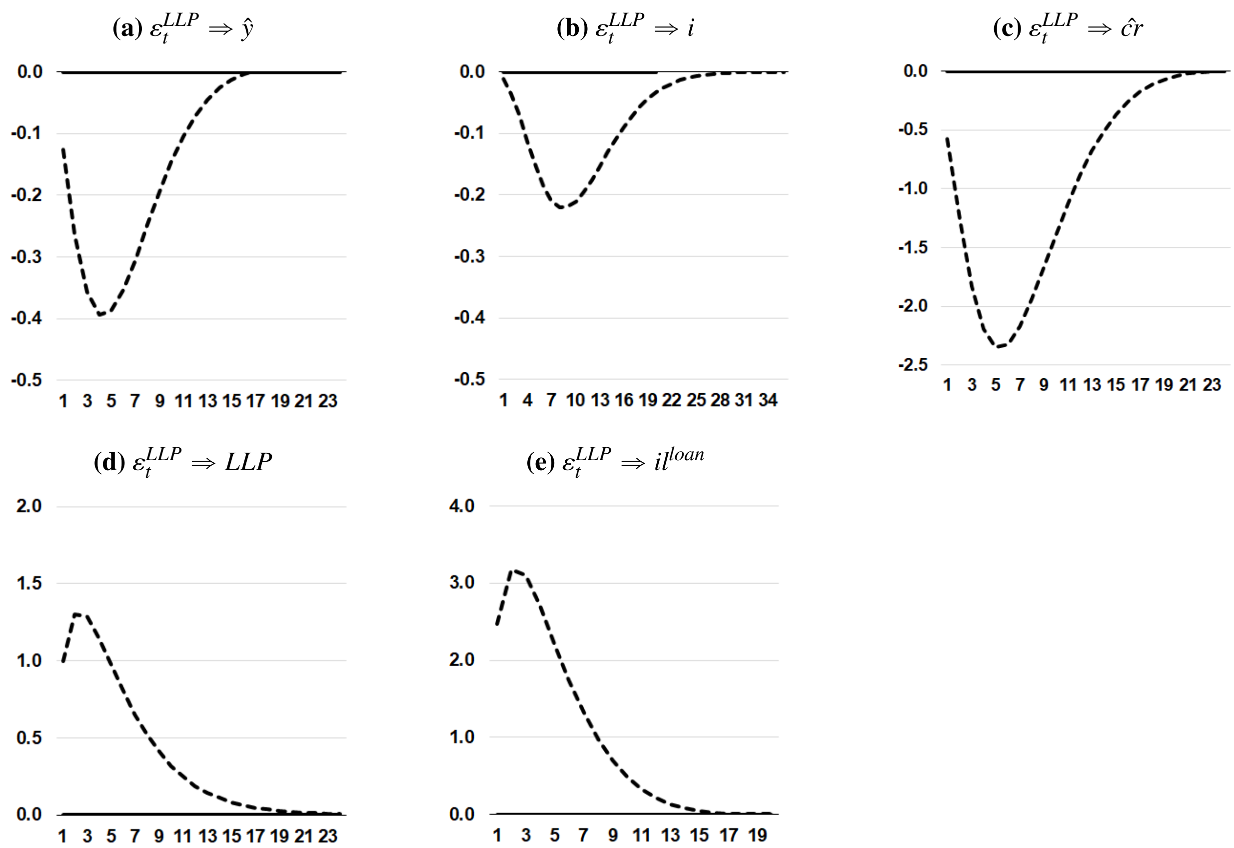
Figure 7: Monetary Policy Shock



Notes: The figure shows the response of the endogenous variables to a monetary policy shock that increases the monetary policy rate (MPR) by 100 base points. We consider the following endogenous variables: output gap (panel a), credit (panel c), loan-loss-provision (LLP, panel d), lending interest rate (panel e). Given the monetary policy shock, the output gap decreases by 0.28pp; real credit decreases by 1.27pp; credit risk increases by 0.29pp; and lending interest rate increases by 1.5pp. Source: Authors' calculations.

Figure 7 shows impulse response function for a monetary policy shock. In this case, the output gap falls (initially) 0.1pp with respect to its potential level. In the financial block, this monetary shock has a direct impact on the lending rate (1.43pp), which translates into an increase in the credit spread that feeds back the output gap causing an additional fall (0.28pp). There is also a clear effect on the volume of credit, which experiences a contraction (-1.27pp) that persists for a considerable length of time. The immediate impact on credit is greater than that of the output gap and over the periods this difference is amplified, demonstrating, as expected, a greater effect on credit than the activity. Finally, the monetary shock also has an impact on credit risk (+0.30pp). The increase in the base rate implies an increase in debt roll-over costs, which increases the risk of default. This translates into a momentary increase in spending on provisions above its equilibrium level, which translates into a higher cost of credit, which tends to moderate its demand.

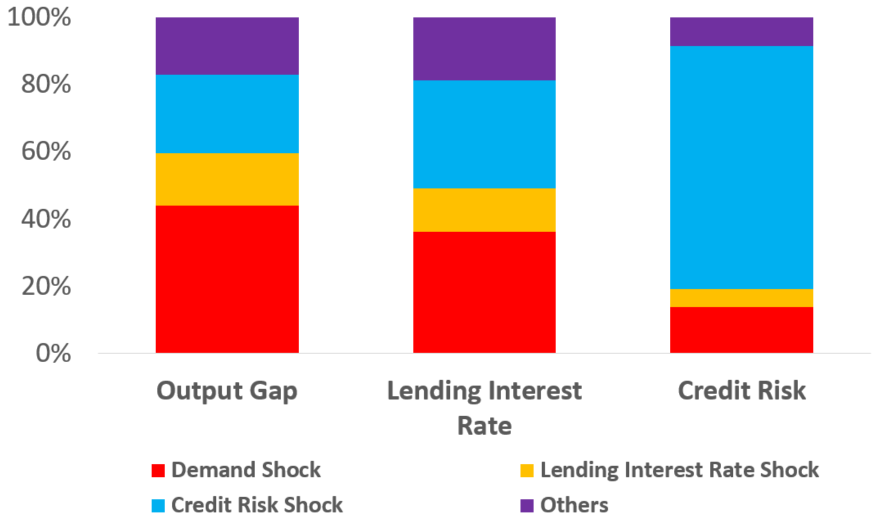
Figure 8: Credit Risk Shock



Notes: The figure shows the response of the endogenous variables to a credit risk shock that increases the loan-loss-provision by 100 base points. We consider the following endogenous variables: output gap (panel a), monetary policy rate (MPR, panel b), credit (panel c), loan-loss-provision (LLP, panel d), lending interest rate (panel e). Given the credit risk shock, the output gap decrease by 0.39pp; MPR decreases by -0.22pp; credit decreases by 2.3pp; loan-loss-provision increases by 1.3pp; and lending interest rate increases by 3.2pp. Source: Authors' calculations.

Figure 8 shows the impulse response functions for a credit risk shock. In this case, the output gap falls 0.39pp with respect to its potential level. In the financial block, this shock has a direct impact on the lending rate (+3.18pp), which translates into an increase in the spread that feeds back the output gap causing an additional fall. There is also a clear effect on the volume of credit, which experiences a contraction (-2.35pp) that persists for around two years. The immediate impact of the credit risk shock on credit is greater than the one of the output gap and this difference is amplified over the years, demonstrating, as expected, a greater effect of the shock on credit than activity. Finally, the shock has an impact on the MPR (-0.19pp). The initial effect on loan-loss-provisions can be interpreted as follows: after the initial rise in expenses (which may be caused by a higher uncertainty derived for an unusual and sudden event, such as Covid-19 or a crisis triggered abroad, among others) that generates a contraction in both output and credit (because of the higher lending

Figure 9: Unconditional Variance Decomposition



Notes: The figure shows the decomposition of the unconditional variance of the output gap, lending interest rate and credit risk based on the mean of the model posterior distribution shown in Table 1. Source: Authors' calculations.

rate of banks), banks start to decrease the lending rate. As credit normalizes, the negative financial feedback fades away and economic growth returns to its equilibrium values.

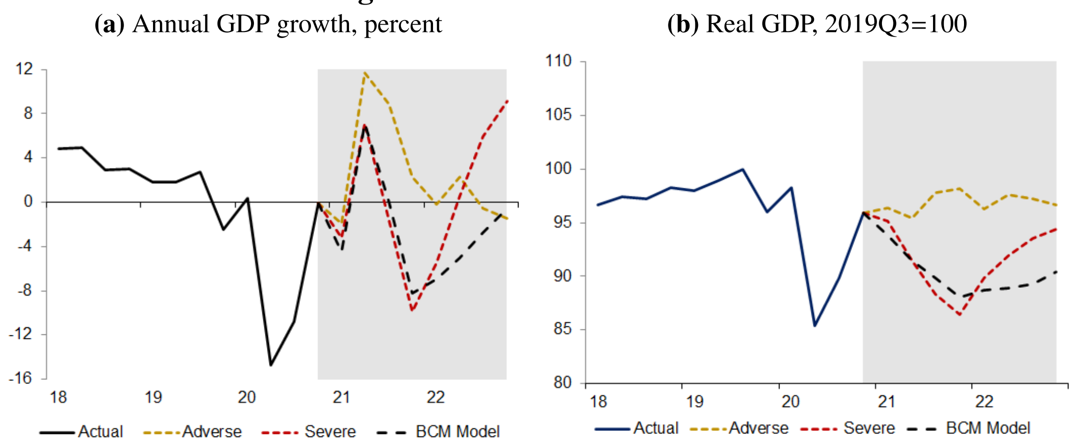
6 Variance Decomposition

Variance decomposition allows us to understand the behavior of real and financial variables that are at the core of our model. We find that financial variables are relevant to explain interest rates and economic activity dynamics. In particular, figure 9 shows the decomposition of the unconditional variance of the output gap, lending interest rate, and credit risk based on the mean of the model posterior distribution shown in Table 1. From that figure, we note that fluctuations of the output gap are mainly driven by demand shocks (44%), credit risk shocks (23%), lending interest rate shock (16%) and others shock (17%) (which gathers all shocks in the model that are no described in detail), thus reflecting the importance of the financial feedback. A similar situation occurs when decomposing the lending interest rate, which is propelled mainly by demand (36%) and credit risk shocks (32%) and, to a lesser extent, the lending interest rate shock (13%). Finally, in the case of the credit risk roughly all variations are explained by credit risk shocks (73%). To understand that result, we should look at the prior and posterior mean of ϑ_1 (auto-regressive process) and ϑ_2 (the sensitivity of the credit risk to the output gap) from equation (9). From our estimations, we find that the posterior mean is $\vartheta_1 = 0.80$ and $\vartheta_2 = 0.66$. Both values are significantly higher than their prior value.

7 Development of stress test scenarios

We finally compare our model's performance to develop several stress test scenarios for the economic activity against the currently used by the CBCh. Figure 10 shows the annual GDP growth trajectory under two scenarios presented in the financial stability report (adverse and severe) and the scenarios built in our baseline model (BCM model). The severe scenario, in the period prior to the Covid-19 health emergency, refers to one that combines elements from previous periods of macro-financial instability. In this configuration, a sharp drop in economic activity was considered, similar to that of the global financial crisis, and a reduction in trend growth, such as that observed after the Asian crisis. In the most recent exercises, however, severe scenarios related to the evolution of the pandemic have been drawn up. Meanwhile, the adverse scenario consists of the fifth percentile of the distribution of economic activity projections. In other words, it is situated in the pessimistic range of the estimates of models intended for the conduct of monetary policy. In this paper, we built our scenario assuming a 2 s.d. shock to the output gap. The model developed in this paper captures similar dynamics as the CBCh stress testing model under the severe scenario. We also observe a slower mean-reversion of the stress test scenario after reaching the lowest peak of 8% when compared to the severe scenario. Beyond the similarities in the orders of magnitude of the dynamics with the stress test scenarios of previous crises, the model presented here allows complementing the design of the stress test scenarios since by having fewer accounting identities in the financial part that can make it rigid - such as the model of stress exercises -, or other specific elements of the macro component that are considered in alternative models, which are omitted in this model, offer relevant advantages.

Figure 10: Stress Test Scenarios.



Notes: This figure shows the real and annual GDP growth for the period 2018-2020. Panel (a) and (b) compare the scenario adverse and severe (CBCh) with our model (BCM). Data is seasonally adjusted, and the shaded area indicates the test window. Source: Authors' calculations.

8 Conclusions

The objective of this paper is to provide a useful and flexible tool for the elaboration of stress test scenarios for the Chilean economy. Our contribution aims to extend the standard semi-structural New-Keynesian model by nesting a set of equations for the main financial variables, i.e., interest rate, credit volume, credit risk, and interest rate spreads, emphasizing the relationship and feedback effect from the real sector to the financial sector and vice versa through the interest rate spread. The flexibility of this model comes from the fact that this a simplified model, in terms of macro-dynamics.

We estimate the extended model by using data from the first quarter of 2001 to the fourth quarter of 2019. The estimation period also includes the structural break caused by the international financial crisis and the policy measures taken. We find that the reaction of aggregate demand to different shocks (real and financial) is larger in the extended than in the standard model because the transmission of shocks is reinforced in the financial sector through interest rate differentials. To quantify this effect, we compare a negative activity shock that decreases the output gap by 1pp concerning its potential level and find that, in the extended model, the output gap falls by 1.24pp, i.e., in the extended model the shocks are amplified by the presence of financial accelerator. We also conclude that the credit risk shock, which is not present in the standard model, is key for designing stress test scenarios because of its high impact and persistence on the output gap.

Finally, we argue that our semi-structural New-Keynesian model may be used to design stress test scenarios. Because of its flexibility and good performance in designing stress test scenarios, it is well suited to be used as a tool to design new scenarios and to combine it with other methodologies in a simple manner.

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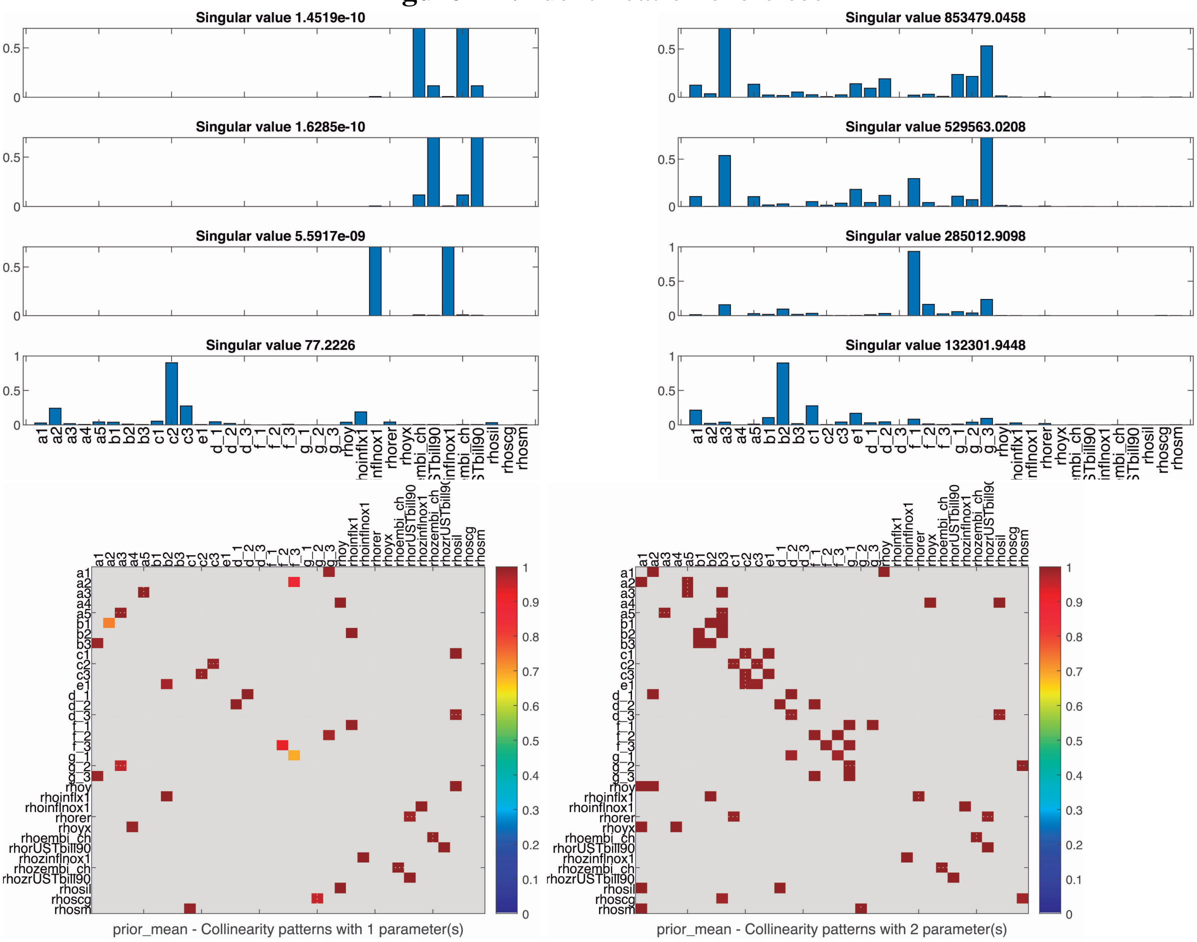
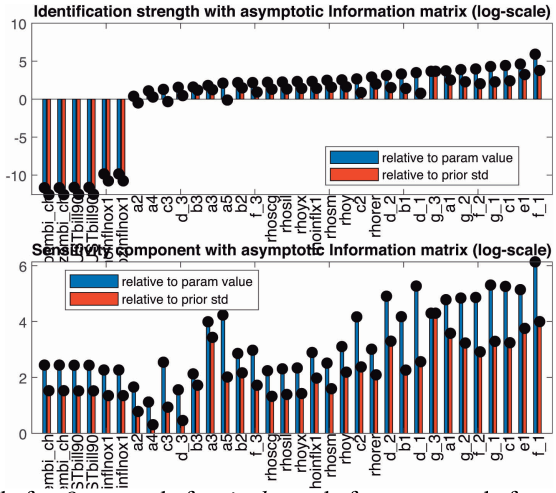
APPENDIX

Parameters Identifications

We run three exercises to test the local identification of the parameters associated with the model (by using the dynare identification package). The results indicate that all parameters are identified. However, the parameters associated with AR(1) processes have a smaller identification strength when compared to the rest of the parameters. This is not at odds with Iskrev (2010). He argues that the parameters have little or no identification power if the effects of the parameters are undetectable or indistinguishable from each other. Since the AR(1) parameters follow a similar dynamic, the correlation between them is high and thus, the identification power of those parameters is lower.

Figure A1: Identification exercises





Notes: *a* stands for α; *b* stands for β; *c* stands for ϕ; *d* stands for η; *e* stands for γ; *f* stands for θ; *g* stands for ϑ; *rho* stands for ρ. Source: Authors' calculations.

Table A1: Parameters, priors and posterior for auto-regressive processes and shocks.

Equation	Parameter	Dist.	Prior Media	Prior Std.	Posterior Media	Posterior Int. 90 % prob
External Output-gap	ρ^{y^*}	Beta	0.3	0.2	0.04	0.02/0.05
External Interest Rate	ρ^{rr^*}	Beta	0.3	0.2	0.21	0.20/0.22
Risk Premium	ρ^{embi}	Beta	0.3	0.2	0.39	0.38/0.40
Shocks	$\rho^{\varepsilon^{\hat{y}}}$	Beta	0.3	0.2	0.15	0.13/0.18
	$\rho^{\varepsilon^{\pi^{core}}}$	Beta	0.3	0.2	0.02	0.02/0.03
	$\rho^{\varepsilon^{q}}$	Beta	0.3	0.2	0.19	0.19/0.20
	$\rho^{\varepsilon^{i}}$	Beta	0.3	0.2	0.42	0.41/0.42
	$\rho^{\varepsilon^{embi}}$	Beta	0.3	0.2	0.26	0.24/0.28
	$\rho^{\varepsilon^{rr*}}$	Beta	0.3	0.2	0.41	0.41/0.41
	$\rho^{\varepsilon^{iloan}}$	Beta	0.3	0.2	0.45	0.44/0.46
	$\rho^{\varepsilon^{\hat{cr}}}$	Beta	0.3	0.2	0.13	0.10/0.15
	$\rho^{\varepsilon^{LLP}}$	Beta	0.3	0.2	0.31	0.29/0.34

Notes: The table shows the parameters, priors, and posterior for auto-regressive processes. We estimate the model using Bayesian methods from the first quarter of 2001 to the fourth quarter of 2019. The prior distributions are beta distribution (B) on the open interval (0,1). Source: Authors' calculations.

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