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Optimal Monetary Policy and Macroprodential Regulation in a DSGE model for Peru

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ABSTRACT

We investigate the optimal transmission, interaction and estimation of monetary policy and macroprudential regulation in a dynamic open stochastic general equilibrium model (frictions represented by portfolio adjustment cost) where we compute optimal combinations of macroeconomic policies that can react in the short term to the business cycle and/or the financial cycle. We find that the optimal response of monetary policy to the international interest rate implies the use of foreign exchange reserves to reduce the volatility of the real exchange rate, non-tradable output, tradable inflation and the terms of trade. Therefore, the accumulation of foreign exchange reserves is optimal over time. Theoretically, the central bank should use a foreign exchange intervention rule, while the macroprudential regulator should use a countercyclical capital buffer that reacts to the rate of credit growth. Consequently, there are welfare gains from coordinating both policies. The model is estimated using Bayesian techniques for the Peruvian economy and shows that a model with a forward looking Taylor rule and a foreign exchange intervention rule that reacts strongly to changes in the real exchange rate best fits the observed sample.

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1 Introduction

This document evaluates the optimal transmission and interaction of monetary policy and macroprudential regulation in a New Keynesian open economy model with real and financial frictions. For this purpose, a set of macroeconomic instruments is established. First, the central bank uses a forward looking Taylor rule and a foreign exchange (FX) intervention rule. Second, the macroprudential authority sets a constant capital requirement ratio in accordance with Basel II and sets a variable capital requirement ratio in accordance with Basel III. While the government uses a conventional autoregressive fiscal rule.

Using Bayesian techniques like the Random Walk Metropolis-Hastings algorithm which uses Monte Carlo Markov Chains (denoted by RWMH-MCMC), the key parameters applied to Peruvian data are estimated. The results are classified using a utility function as a measure of well-being: the higher the welfare, the better the macroeconomic policy combination used (log Bayes factor). With this, it is possible to obtain the model with the optimal monetary policy and macroprudential regulation that describes the Peruvian economy from a quarterly sample from 2004 to 2019.

Recent economic downturns have led to a shift in prevailing thinking about macroeconomic and financial stability, with unconventional monetary policies, research pointing to the effectiveness of macroprudential regulations, and fiscal intervention, especially in developing countries. Also, the view that a flexible exchange rate regime and conventional monetary policy would be sufficient to mitigate the destabilizing effects of massive volatile capital flows has been misguided, as there are growing unregulated financial fragilities. Financial frictions based on imperfect financial integration with portfolio adjustment costs for households and banks exacerbate procyclicality in the financial system and the real economy. Also, an unregulated financial system is prone to excesses, so the macroprudential approach is designed to preserve the financial system in its entirety. Macroeconomic policies oriented towards proper management of the business cycle through the accumulation of international reserves by the monetary regulator[1] and countercyclical capital buffers by the macroprudential regulator have been shown to provide protection during periods of changes due to real and financial shocks.

Our primary findings suggest that the optimal response of unconventional monetary policy to an international interest rate shock involves a decrease in the amount of FX reserves destined to strengthen the real exchange rate, reducing the volatility of non-tradable inflation, inflation and non-tradable production. Furthermore, monetary and macroprudential policy must be coordinated for further welfare gains. On the financial side, with a central

[1]In Peru, the monetary regulator is the central bank, which manages international reserves made up of highly liquid and immediately available foreign assets.

bank that deploys a FX intervention rule, the optimal macroprudential anchor variable is the credit growth rate.

Theoretically, this research finds that the optimal interaction between central bank monetary policy and the banking regulator needs be coordinated. For the central bank, the optimal theoretical monetary policy is to use a FX intervention rule that complements the forward looking Taylor rule. If the policy is non-cooperative, the weight of the real exchange rate in the FX intervention rule must be a high parameter. Whereas, if the policy is non-cooperative, the weight of the real exchange rate in the FX intervention rule must be a low parameter.

For the banking regulator, it must use a variable capital requirement rate with an optimal anchor variable represented by the growth rate of bank credit.

Empirically, this research finds that the optimal interaction between Peruvian Central Bank of Reserve (BCRP) and Peruvian Banking and Insurance Superintendency (SBS) monetary policy is non-cooperative, but shares common objectives. For the BCRP, the optimal empirical monetary policy has been to use a FX intervention rule that complements the forward looking Taylor rule with a high coefficient associated with the FX intervention rule. For the SBS, in the sample it uses an average constant capital requirement rate of 9.3% and from 2022 through Legislative Decree 1531, it accepts counter-cyclical capital buffers as suggested by Basel III, with a period of valid until 2023. Therefore, it is enlightening to note that the implementation of this law may have welfare gains for the Peruvian economy.

This model incorporates an open economy FX intervention rule with a portfolio adjustment for foreign bonds similar to Faltermeier et al. (2022). On the financial side, financial frictions are incorporated through the accumulation and management of capital in the banking sector similar to Gerali et al. (2011) and sterilization bonds are issued that are imperfect substitutes (economies of scope between bonds) of investment loans in commercial bank portfolios similar to Agenor et al. (2022). What is new in this modeling arises from the addition of the macroprudential mechanism in financial decisions and the use of the RWMH-MCMC method to estimate the model with Peruvian data.

For better understanding, this document maintains a sequential structure. Section 2 presents the literature review up to 2022. Section 3 describes the New Keynesian model of open economy with financial frictions where agents, equilibrium and loss function are established. Section 4 presents the methodology to follow. Section 5 establishes the theoretical calibration, the prior parameters and the results. Sections 6 and 7 present the conclusions and recommendations respectively.

2 Literature review

This research is related to the widely studied literature on FX interventions and macroprudential regulation. To understand in detail the effects of these macroeconomic policies, our selection focuses on the portfolio balance channel where domestic and foreign assets are imperfect substitutes and unconventional monetary policies and macroprudential objectives are deployed. For them the following studies are classified by policy and methodology.

In recent years, there has been a resurgence of research related to the relevance of FX interventions based on theoretical micro-founded macroeconomic models on unconventional monetary policy. In this regard, we focus on the portfolio balance channel that has experienced a recent resurgence in research such as Kumhof (2010), Benes et al. (2015), Gabaix and Maggiori (2015), Liu and Spiegel (2015), Chang et al. (2015), Montoro and Ortiz (2016), Alla et al. (2020) and Davis et al. (2021). These authors argue that FX intervention can decrease the volatility of the exchange rate when there is imperfect substitution between domestic and foreign assets. Consequently, sterilized intervention increases the relative supply of domestic assets, raising the risk premium, causing the real exchange rate to depreciate and the current account (CA) to improve.

Agenor et. al.(2020) study the effects of FX intervention in a DSGE model with imperfect capital mobility and financial frictions. The authors show that FX intervention is important and can be expansionary through a commercial bank portfolio adjustment cost effect and can increase volatility and stability risks in the financial sector. Complete sterilization is optimal only when there is no bank portfolio effect. Optimal intervention is more aggressive when the monetary authority is able to choose the level of sterilization. Intervention and sterilization can be substitutes when the welfare function of the monetary authority depends on the cost of sterilization.

Additionally, Faltermeier et al. (2022) simulate that in the face of a commodity boom, the optimal monetary policy implies a change in the amount of international reserves directed at strengthening the real exchange rate and the main variables of interest. This macroeconomic policy resembles the real dynamics of foreign exchange reserves typical of many developing countries. Thus, the authors find that conventional monetary policy generates limited welfare gains in the face of commodity price shocks, as the Taylor rule alone is an ineffective instrument for addressing learning-by-doing externalities (LBD).

On the other hand, micro-founded macroeconomic models must be data-based to be useful for policy analysis. Consequently, researchers have developed alternative procedures to assess the effects of unconventional monetary policy in emerging countries. The widely used procedures take emphasis on the methodology of Dynamic Stochastic General Equilibrium

(DSGE) models and the use of Vector Autoregressive (VAR) methodology, obtaining separate theoretical and empirical results that can be complemented. In this sense, we emphasize recent studies such as Carrasco et al. (2021) and Castillo and Medina (2021) who argue that FX interventions reduce the variability of Gross Domestic Product (GDP) and the real exchange rate, yielding significant welfare gains when responding to external shocks, compared to a flexible exchange rate regime which is inefficient. In addition, they emphasize that these results point to the importance of FX reserves in insulating emerging economies from the global financial cycle.

The literature on the role of banks in DSGE models and financial frictions has grown rapidly since the 2008 financial crisis. Jeanne and Korinek (2010) and Mendoza and Bianchi (2011) establish a pecuniary externality with collateral constraints, which justifies the use of macroprudential policies to improve welfare. Gerali et al. (2010) explore the role of shocks related to the imperfectly competitive banking sector in a model with binding collateral constraints and interest rate stickiness. Then, using Bayesian techniques, the authors show that shocks originating in the banking sector explain most of the contraction of the 2008 crisis, while macroeconomic shocks are limited. Furthermore, an unexpected destruction of bank capital can have considerable effects on the economy.

In adittion, many articles have evaluated the introduction of macroprudential policy instruments in a DSGE model. However, most of these models focus on the interaction of macroprudential and monetary policies without delving into the impact on macroprudential policy itself as Angelini et al. (2012), who use a DSGE model that incorporates a banking sector that interacts with the real economy, find that find that macroprudential policy generates only modest benefits for macroeconomic stability when the business cycle is affected by supply shocks. Thus, the benefits of implementing a macroprudential policy tend to be considerable when financial shocks become relevant in macroeconomic dynamics. Consequently, a cooperative monetary regulator will assist the macroprudential authority to achieve broader welfare goals than just price stability.

The Basel Committee on Banking Supervision (BCBS, 2010) seeks to strengthen the macroprudential regulation, supervision and comprehensive risk management of banks in each economy and suggests the use of the credit/GDP gap as an important anchor variable for regulatory purposes. Regarding the procyclicality of risk, Basel III suggests building a "good time" capital buffer that can absorb unwanted losses in times of economic stress. This countercyclical capital buffer offers an additional benefit by moderating the growth of loans by increasing their cost for this credit. In agreement with this, Drehmann et al. (2011) nvestigate different variables as anchor and suggest that the best leading indicator is the credit/GDP gap, while the best coincident indicator is the bank spread. However, Repullo and Saurina (2011) recommend using output growth as the anchor variable, arguing that the use of the credit/GDP gap can increase the amplitude of the financial cycle.

In the Latin American context, Rojas (2017) shows through a theoretical model that a cyclical capital requirement proposed in Basel III generates important welfare gains with respect to the Basel II regime. Also, due to a financial shock, monetary policy should not respond to fluctuations in credit. Pozo (2020), discovers through a theoretical model that banks handle a financial crisis better the stricter the constant capital requirements are and that that a forward-looking rule doesn't work. In addition, greater welfare is generated when countercyclical buffers take into account the deviation of the credit/GDP ratio, or the percentage deviation of GDP (or credit). Lama and Medina (2020) report through a theoretical model that FX intervention, such as macroprudential policies, are complementary tools to conventional monetary policy and can reduce inflation and output volatility in a capital outflow scenario. Furthermore, FX intervention is the main tool in response to international interest rate shocks, while macroprudential policy stands out as a tool for domestic risk shocks.

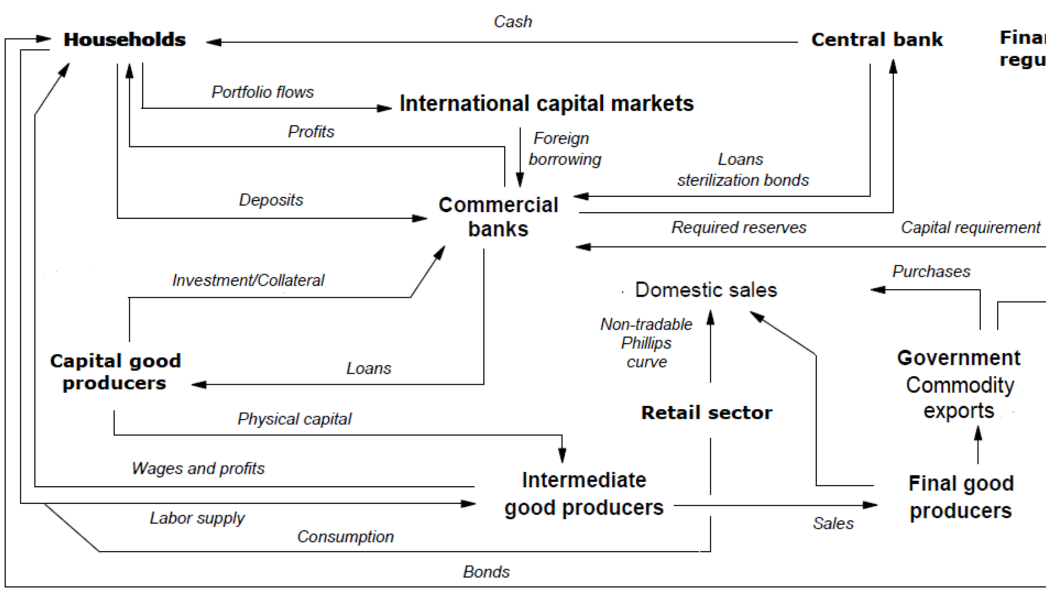
For Brazil, Ferreira and Nakame (2015) consider that countercyclical capital requirements are very effective to implement in practice, so capital requirements should respond to credit growth as the anchor variable. Carvalho and Castro (2017) calculate optimal combinations of macroprudential, fiscal, and monetary policy configurations that policy makers use to react to the business and/or financial cycle in a Bayesian DSGE model. The authors find that the gains from implementing a cyclical fiscal policy are only significant if the macroprudential policy reacts countercyclically to the financial cycle. This countercyclical buffer is optimal when a very forceful response to the credit gap is deployed.

Consequently, there is a lack of studies that can measure the impact and magnitude of unconventional monetary policy and macroprudential policy instruments in the Peruvian economy using DSGE models with Bayesian techniques. To fill this gap, we carried out this research that focuses on making a comparison between the micro-founded theoretical model and the Bayesian estimation with Peruvian data.

3 The microfounded model

Consider a New Keynesian DSGE with real and nominal rigidities, LBD externalities and commercial banks. The microfounded model is populated by several categories of agents: a continuum of representative households indexed by $h \in [0, 1]$, four types of firms, a continuum of commercial banks indexed by $l \in [0, 1]$, the government, the central bank and the macroprudential authority, which also operates as a financial regulator. Consequently, the central bank conducts monetary policy through a forward-looking Taylor rule and a FX intervention rule. The monetary authority intervenes on the spot market by buying or selling international reserves to mitigate the volatility of real exchange rate and thus fulfill its constitutional objective of preserving monetary stability. Importantly, the commercial banks bonds are imperfect substitutes to loans and are exposed to macroprudential regulation through a capital requirement rate. The behavior of households, firms, commodity export sector, commercial banks and the macroeconomic authority is described below.[2]

Figure 1: Model dynamics



3.1 Households

A continuum of households are indexed by $h \in [0, 1]$, and the priorities of each agent in their utility function are represented by smoothed consumption, work and real money holding:

[2] Details for each sector are provided in Appendix A.

$$U_t(h) = \mathbb{E}_t \left[\sum_{i=0}^{\infty} \beta^i u \left(C_{t+i}(h) - bC_{t+i-1}(h), L_{t+i}(h), \frac{M_{t+i}(h)}{P_{t+i}(h)} \right) \right] \tag{1}$$

Where β is the intertemporal discount factor, $b \in [0,1]$ is the habit formation parameter, $C_t(h)$ represents the consumption of the final good in the utility function, $L_t(h)$ is the labor supply and $M_t(h)$ is nominal money holding of household h. The household budget constraint can be represented:

$$\begin{aligned} P_t C_t(h) + M_t(h) + E_t\{d_{t.t+1}\mathcal{Q}_{t+1}(h)\} + D_t(h) + B_t(h) + \mathcal{E}_t B_t^*(h) = W_t(h) L_t(h) + M_{t-1}(h) \\ + \mathcal{Q}_t(h) + R_{t-1}^d D_{t-1}(h) + R_{t-1}^{bH} B_{t-1}(h) + \mathcal{E}_t B_{t-1}^*(h) R_{t-1}^* \Phi(B_t^*(h)) + \Pi_t(h) - T_t(h) \end{aligned} \tag{2}$$

Where $\mathcal{Q}_{t+1}(h)$ is a state-contingent domestic bond[3], $d_{t.t+1}$ is its price, $B_t(h)$ a non-contingent domestic bond, R_t^{bH} is the short-term gross interest rate on loans, $B_t^*(h)$ a non-contingent foreign bond, R_t^* the foreign gross interest rate, D_t is the nominal deposits, and R_t^d is the short-term gross interest rate on deposits. Households earn income by supplying labor at the wage rate $W_t(h)$, profits Π_t from firms and banks, and tax transfer from government T_t. $\mathcal{E}_t$ represents the nominal exchange rate that consists of the ratio of national currency to foreign currency, P_t the price of final consumption goods, and $\Phi(B_t^*(h))$ is a portfolio adjustment cost that provides an imperfect substitution between national and international assets (represented by bonds), restricting the lending capacity of households in foreign financial markets.

$$\lambda_t^H = \frac{1-b}{(1+\tau_{C,t}) P_t (C_t - bC_{t-1})} \tag{3}$$

$$L_t^{\nu} = W_t \lambda_t^H \tag{4}$$

$$\eta_m \left(m_t^d P_t\right)^{-1} = \lambda_t^H - \beta \mathbb{E}_t \lambda_{t+1}^H \tag{5}$$

Where λ_t^H is the Lagrange multiplier of the budget constraint, $\tau_{C,t}$ is the consumption tax, $m_t^d = M_t^d / P_t$ is the real money demand and η_m represents the relative share of cash in money. Equation (3), (4) and (5) are the first order conditions of consumption, labor supply and the real demand for cash respectively. In equilibrium $R_t^d = R_t^{bH}$.

[3]Following Faltermeier et al. (2017), the state-contingent domestic bond allows full insurance against income fluctuations between households, which implies that the marginal utility of income and consumption are the same across all households.

3.2 Wage Setting and Phillips curve (wage)

A representative firm combines different labor inputs through a Dixit–Stiglitz aggregator:

$$L_t = \left[\int_0^1 \left(L_t \left(h \right) \right)^{\frac{\epsilon_L - 1}{\epsilon_L}} dh \right]^{\frac{\epsilon_L}{\epsilon_L - 1}}$$

$$L_t \left(h \right) = \left(\frac{W_t \left(h \right)}{W_t} \right)^{-\epsilon_L} L_t \tag{6}$$

$$W_t = \left[\int_0^1 \left(W_t \left(h \right) \right)^{1-\epsilon_L} dh \right]^{\frac{1}{1-\epsilon_L}}$$

Where L_t is the aggregate labor supply, W_t is the aggregate wage rate and ϵ_L is the employment elasticity of substitution.

As in Calvo (1983), households set their wages in stages. Households renegotiates their salary contract through the fraction $(1 - \theta_W)$. Thus, households establish the optimal W_t^* that maximizes the expected utility subject to the budget constraint (2) and the labor demand schedule (6).

$$max \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \left(\beta \theta_W \right)^i u \left(C_{t+i|t}, L_{t+i|t} \right) \right\}$$

Where $C_{t+i|t}$ and $L_{t+i|t}$ are the consumption and labor in period $t + i$ respectively for households that choose wages optimally in period t.

With this, the equation of the Phillips curve (wage) in the New Keynesian theory is obtained.

$$log \left(\pi_t^W \right) = \beta log \left(\pi_{t+1}^W \right) + \kappa_W log \left(\frac{mc_t^W}{\overline{\overline{mc^W}}} \right) \tag{7}$$

Where π_t^W is the wage inflation, mc_t^W is the wage real marginal cost and $\kappa_W \equiv {}^{(1-\theta_W)(1-\beta\theta_W)}\!/_{\theta_W}$.

3.3 Firms

Following Faltermeier (2022), the model is composed of four types of firms. Final good (FG) producers, intermediate good (IG) producers, retailers and capital good (CG) producers.

3.3.1 The final goods sector

Firms combine tradable intermediate input $\left(q_t^T\right)$ and non-tradable intermediate input $\left(q_t^N\right)$ to produce $\left(Y_t^F\right)$ in a constant elasticity of substitution (CES) production function:

$$\left[Y_t^F\right]^{1-\frac{1}{\eta_Y}} = \alpha_Y^{1/\eta_Y}\left(q_t^T\right)^{1-\frac{1}{\eta_Y}} + \left(1-\alpha_Y\right)^{1/\eta_Y}\left(q_t^N\right)^{1-\frac{1}{\eta_Y}} \tag{8}$$

Where α_Y is the share of tradable inputs and η_Y is the elasticity of substitution between tradable and non-tradable inputs. The price of the final good is represented by:

$$\left[P_t\right]^{1-\eta_Y} = \alpha_Y\left(P_t^T\right)^{1-\eta_Y} + \left(1-\alpha_Y\right)\left(P_t^N\right)^{1-\eta_Y} \tag{9}$$

Where P_t^T is the price of tradable inputs and P_t^N is the price of non-tradable inputs.

3.3.2 The intermediate good sector

Using a Cobb-Douglas production function, a representative firm produces intermediate non-tradable goods, $\left(Y_t^N\right)$, with the following equation:

$$Y_t^N = A_t^N\left[K_t^N\right]^{\alpha_N}\left[L_t^N\right]^{1-\alpha_N} \tag{10}$$

Where α_N is the capital share in non-tradable sector, A_t^N is the non-tradable total factor productivity, K_t^N is the non-tradable capital input and L_t^N is the non-tradable labor input.

The production function of tradable firms is subject to LBD externalities. Therefore, it is possible to assume a continuous set of tradable companies indexed by $i \in [0,1]$ as follows:

$$Y_t^T(i) = A_t^T H_t^{\lambda_T}\left(\left[K_t^T(i)\right]^{\alpha_T}\left[L_t^T(i)\right]^{1-\alpha_T}\right)^{1-\lambda_T} \tag{11}$$

Where α_T is the capital share in tradable sector, λ_T is the share of organizational capital, A_t^T is total tradable factor productivity, while $K_t^T(i)$ is the individual demand for tradable capital and $L_t^T(i)$ is the individual demand for tradable labor. H_t is the level of organizational, which is very common to most companies in the tradable sector in emerging countries and its evolution can be represented by the following law of motion:

$$\frac{H_{t+1}}{\left[H_t\right]^{\phi_T}} = \left[Y_t^T\right]^{\mu_T} \tag{12}$$

In which $(1-\phi_T)$ represents the depreciation rate of organizational capital, and μ_T is the elasticity of organizational capital with respect to the aggregate tradable GDP. There are constant returns to scale, $\phi_T + \mu_T = 1$. In this framework, the source of the externality is given in the tradable aggregate production. Therefore, the aggregate efficiency of the tradable sector is reduced due to a decrease in organizational capital caused by a reduction in tradable output.[4]

3.3.3 The retail sector

Retail firms sell non-tradable goods $\left(q_t^N\right)$ by establishing two separate stages for better characterization. First, using a CES function, an assembler combines differentiated non-tradable intermediate goods $q_t^N(j)$, where $j \in [0,1]$:

$$\left[q_t^N\right]^{\frac{\epsilon_N-1}{\epsilon_N}} = \int_0^1 q_t^N(j)^{\frac{\epsilon_N-1}{\epsilon_N}} \, dj \tag{13}$$

Where ϵ_N is the elasticity of substitution between varieties of goods. The demand for the non-tradable intermediate good of j corresponds:

$$q_t^N(j) = \left(\frac{P_t^N(j)}{P_t^N}\right)^{-\epsilon_N} q_t^N \tag{14}$$

$$P_t^N = \left(\int_0^1 P_t^N(j)^{1-\epsilon_N} \, dj\right)^{\frac{1}{1-\epsilon_N}} \tag{15}$$

Second, retail firms buy the homogeneous intermediate non-tradable good and differentiate it into a continuum set of goods. Each retailer sets its price on a staggered fashion á la Calvo, forming sticky prices representative of this sector.

$$\mathbb{E}_t \left\{ \sum_{i=0}^{\infty} (\theta_N)^i \Lambda_{t,t+i} \left(P_t^{N*} - P_{t+i}^{WN}\right) q_{t+i}^N(j) \right\} \tag{16}$$

Where $\Lambda_{t,t+i}$ is the stochastic discount factor and P_t^{WN} is the wholesale price of the non-tradable intermediate good, which is established according to the production function given in (10). The evolution of the aggregate price of non-tradable goods is represented by:

$$P_t^N = \left[\theta_N \left(P_{t-1}^N\right)^{1-\epsilon_N} + (1-\theta_N)\left(P_t^{N*}\right)^{1-\epsilon_N}\right]^{\frac{1}{1-\epsilon_N}} \tag{17}$$

With this, the equation of the Phillips curve (non-tradable) in the New Keynesian theory is obtained.

[4] In symmetric equilibrium we have $Y_t^T(i) = Y_t^T$, $K_t^T(i) = K_t^T$ and $L_t^T(i) = L_t^T$ for all $i \in [0,1]$. The aggregate level of output, capital and labor in the tradable sector are given by $Y_t^T = \int_0^1 Y_t^T(i) \, di$, $K_t^T = \int_0^1 K_t^T(i) \, di$ and $L_t^T = \int_0^1 L_t^T(i) \, di$ respectively.

$$log\left(\pi_t^N\right) = \beta log\left(\pi_{t+1}^N\right) + \kappa_{pn} log\left(\frac{MC_t}{\overline{MC}}\right) \tag{18}$$

Where π_t^N is the non-tradable inflation, MC_t is the real marginal cost and $\kappa_{pn} \equiv {}^{(1-\theta_N)(1-\beta\theta_N)}\big/_{\theta_N}$.

3.3.4 The capital good sector

To produce IG in the tradable and non-tradable sector, firms produce and rent capital. Therefore, the aggregate investment is characterized in terms of the final good in an infinite horizon. For each sector $J = T, N$, the representative capital-producing firm solves the following problem:

$$V_t^J = max \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(R_{K,t+i}^J K_{t+i}^J - P_{t+i} I_{t+i}^J \right) \right\} \tag{19}$$

Then, the law of motion of physical capital is the constraint to take into account:

$$\Delta K_{t+1}^J + \delta K_t^J = \Psi\left(\frac{I_t^J}{I_{t-1}^J}\right) I_t^J \tag{20}$$

Where V_t^J is the present discounted value of profits, δ is the depreciation rate of capital for tradable and non-tradable sector, $R_{K,t}^J$ is the rental rate of capital for tradable and non-tradable sector, and $\Psi\left(\cdot\right)$is the friction that characterizes the adjustment cost of the investment.[5]

3.4 Commodity export sector

In this market, the commodity exports CX is fixed. In addition, it can be established that the commodity price P_t^x follows the autoregressive (AR) process:

$$\frac{P_t^x}{\left[P_{t-1}^x\right]^{\rho_{px}}} = \left[P_0^x\right]^{1-\rho_{px}} exp\left(\varepsilon_t^{px}\right) \tag{21}$$

Where $\varepsilon_t^{px} \sim N\left(0, \sigma_{px}^2\right)$ is a commodity price shock and ρ_{px} measures the persistence of commodity prices. Households fully receive the income from the commodity export sector which is given by $P_t^x \overline{CX}$.

[5]Investment adjustment cost meets: $\Psi\left(1\right) = 1$, $\Psi'\left(1\right) = 0$, $\Psi''\left(1\right) = -\phi < 0$. This assumption generates investment inertia that is consistent with a time-to-build specification.

3.5 The retail money market fund (RMMF)

In this market, the aim is to maximize the total nominal return of the portfolio in accordance with the following program:

$$max\mathbb{E}_t\left\{R_tB_t^G-\mathcal{E}_{t+1}R_t^*B_t^*\Phi\left(B_t^*\right)\right\}$$

Subject to the balance sheet constraint:

$$D_t^G=B_t^G-\mathcal{E}_tB_t^*$$

Where D_t^G is the nominal government deposits and B_t^G a non-contingent government bond.

For this market, the resulting first-order necessary conditions imply a modified UIP equation:

$$R_t=\frac{e_{t+1}P_{t+1}}{e_tP_t}R_t^*\Phi\left(B_t^*\right) \tag{22}$$

Where $e_t={}^{\mathcal{E}_t}/_{P_t}$ denotes the real exchange rate.

3.6 Commercial Banks

To understand how commercial banks operate, it is necessary to analyze their balance sheet, that is, the typical assets and liabilities of the commercial bank. The detail of this sheet indicates the uses given to these funds (assets) and the sources of commercial bank funds (liabilities and net worth). This is how commercial banks lend a portion of their liabilities to CG producers and hold reserves and central bank assets (represented by bonds), while their liabilities consist of household deposits, foreign borrowing (not covered), domestic borrowing, and bank capital.

Table 1: Commercial bank balance sheet

Assets	**Liabilities**
B_t^L	D_t
B_t^{CB}	$\mathcal{E}_tL_t^*$
RR_t	L_t^b
	K_t^b

Where B_t^L represents investment loans or credit, B_t^{CB} holdings of sterilization bonds issued by the monetary authority, RR_t required reserves, L_t^* foreign borrowing (represented in foreign-currency terms), L_t^b borrowing from the monetary authority and K_t^b net worth or bank capital.

Commercial bank $l's$ expected profits at end of period (or beginning of $t+1$) are defined as

$$\mathbb{E}_t J_{t+1}^B(l) = R_t^L B_t^L(l) + R_t^{CB} B_t^{CB}(l) + RR_t(l) - R_t^d D_{t+i}(l) - R_t L_t^b(l) - \mathcal{E}_{t+1} L_t^*(l) R_t^{FC} \\ - \Gamma\left(B_t(l), B_t^{CB}(l)\right) - K_{t+i}^b(l) - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(l)}{B_t^L(l)} - v_t(l)\right)^2 K_t^b(l) \quad (23)$$

Subject to:

Commercial bank $l's$ balance sheet:

$$B_t^L(l) + B_t^{CB}(l) + RR_t(l) = D_t(l) + \mathcal{E}_t L_t^*(l) + L_t^b(l) + K_t^b(l) \quad (24)$$

Where R_t^L is the gross interest rate on the loan extended by commercial banks, R_t^{CB} is the gross interest rate on central bank bonds, R_t is the monetary policy rate or called the marginal cost of borrowing from the monetary authority, R_t^{FC} is the cost of borrowing on international capital markets, and v_t is the capital-to-assets ratio, which is interpreted as a capital requirement imposed by the macroprudential regulator. The parameter κ_{Kb} denotes the quadratic cost paid by commercial banks when there is a deviation from the proposed target.

Commercial bank capital is accumulated according to the following equation:

$$K_t^b(l) = \left(1-\delta^b\right)\frac{K_{t-1}^b(l)}{\varepsilon_t^{Kb}} + \omega_b J_t^B(l) + K_t^b(l) \quad (25)$$

Where $J_t^b(l)$ are overall profits of commercial bank l in nominal terms and ε_t^{Kb} is a financial shock that reduces bank capital. The parameters $(1-\omega_b)$summarizes the dividend policy of the commercial bank, and δ^b measures resources used in managing commercial bank capital and conducting the overall banking intermediation activity.

Reserve requirement is determined according to:

$$RR_t(l) = \tau_{RR} D_t(l) \quad (26)$$

To illustrate the problem that the commercial bank faces when depositors withdraw their deposits, we assume that the bank has a sufficiently large reserve requirement and that all deposits are subject to a legal reserve requirement rate, $\tau_{RR} \in [0,1]$.

There is perfect substitution between deposits and liquidity of the monetary authority, while the deposit market remains in a situation of perfect competition. Therefore, we ensure that, $\forall l$, the following non-arbitrage condition is fulfilled:

$$i_t^d = (1 - \tau_{RR})\, i_t \tag{27}$$

On the contrary, the loan market behaves in monopolistic competition. Thus, the amount lent by CG producer, B_t^L, is a Dixit-Stiglitz basket of differentiated loans, each provided by commercial bank l, and the demand for loan type l, $B_t^L(l)$, is given by the downward-sloping curve:

$$B_t^L(l) = \left(\frac{1 + i_t^L(l)}{1 + i_t^L}\right)^{-\zeta^L} B_t^L \tag{28}$$

Where $\zeta^L > 1$ is the elasticity of substitution of investment loans.[6]

Commercial bank $l's$ cost of borrowing on international capital markets, R_{t+i}^{FC}, is defined as:

$$\frac{R_t^{FC}}{R_t^*} = 1 + \theta^{FC}\left(L_t^*(l)\right) \tag{29}$$

$$\theta^{FC}\left(L_t^*(l)\right) = \frac{\theta_0^{FC}}{2} L_t^*(l) \tag{30}$$

Where $\theta^{FC}\left(L_t^*(l)\right)$ is a premium that increases with the foreign-currency value of the amount borrowed and $\theta_0^{FC} > 0$ is the sensitivity of the premium.

In what follows, we establish the diewert cost function:

$$\Gamma\left(B_t^L(l), B_t^{CB}(l)\right) = \gamma_{B^{CB}} B_t^{CB}(l) + \gamma_B B_t^L(l) - 2\gamma\sqrt{B_t^L(l)\, B_t^{CB}(l)} \tag{31}$$

Where the term $\Gamma(.)$ measures the non-separable cost of managing loans and bonds from the monetary authority. Specifically, the function is assumed to be quasi-convex and strictly increasing in both arguments, so that $\Gamma_{B^L}, \Gamma_{B^{CB}} > 0, \Gamma_{B^L B^L}, \Gamma_{B^{CB} B^{CB}} \geq 0$; in addition, it is also assumed to be linearly homogeneous. Linear homogeneity indicates that, $\Gamma_{B^L B^{CB}} \leq 0$, with a reduction in the cost of loans due to greater holdings of bonds from the monetary authority. Therefore, there is a complementarity of costs or economies of scope, that is, lower asset management costs than the sum of the costs incurred when managing them separately. Also, $\gamma_{B^{CB}}$, γ_B, $\gamma > 0$.

Each commercial bank establishes foreign loans, the lending rate, and holdings of

[6] The aggregate level of investment loans and loan rate are given by $B_t^L = \left[\int_0^1 \left(B_t^L(l)^{(\zeta^L - 1)/\zeta^L}\, dl\right)\right]^{\zeta^L/(\zeta^L - 1)}$ and $1 + i_t^L = \left[\int_0^1 \left(\left(1 + i_t^L(l)\right)^{1-\zeta^L} dl\right)\right]^{1/(1-\zeta^L)}$ respectively.

monetary authority bonds, in order to maximize expected profits (23) subject to constraints (24)-(31). The feasible solution of the commercial banking optimization problem within a symmetric equilibrium corresponds:

$$R_t^L = \frac{\varsigma_b}{\varsigma_b - 1}\left\{R_t - \kappa_{Kb}\left(\frac{K_t^b}{B_t^L} - \upsilon_t\right)\left(\frac{K_t^b}{B_t^L}\right)^2 + \gamma_B - \gamma\left(\frac{B_t^{CB}}{B_t^L}\right)^{0.5}\right\} \tag{32}$$

$$L_t^* = \frac{R_t - R_t^*\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)}{\theta_0^{FC}R_t^*\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)} \tag{33}$$

$$\frac{B_t^{CB}}{B_t^L} = \frac{\gamma^2}{\left[R_t + \gamma_{B^{CB}} - R_t^{CB}\right]^2} \tag{34}$$

Thus, the ratio between monetary authority bonds and investment loans varies inversely with the differential between the monetary policy rate (augmented by the positive parameter $\gamma_{B^{CB}}$) and the rate of return on these bonds.

Substituting and operating the equation (34) in (32) the following can be obtained:

$$R_t^L = R_t - \kappa_{Kb}\left(\frac{K_t^b}{B_t^L} - \upsilon_t\right)\left(\frac{K_t^b}{B_t^L}\right)^2 + \gamma_B - \frac{\gamma^2}{R_t + \gamma_{B^{CB}} - R_t^{CB}} \tag{35}$$

For the macroprudential regulator, equation (35) can be seen as a loan supply schedule. When investment lending increases, the capital-asset ratio falls below υ_t, causing an increase in the commercial bank's lending rate. With this, negatively affecting consumption and investment due to the reduction in credit demand. For the central bank, there is a direct (cost) and indirect (commercial bank portfolio) effect on the lending rate due to an increase in the monetary policy rate.

In detail, the partial equilibrium effect is illustrated by equations (32), (34) and (35) in which there is an association between the sterilized intervention and the banking portfolio channel. Given an initial level of investment lending, if commercial banks increase the monetary authority's bond holdings they raise the bond-to-loan ratio. Being expansive, lowering the cost of managing loans, (32), and lowering the loan rate. On the other side, for commercial banks to voluntarily retain the additional bonds issued by the monetary authority, (34), requires an increase in their rate of return, (35), and a lower rate of return on alternative assets such as CG producer loans.

However, in general equilibrium, a lower lending rate causes investment to rise, that is aimed at reducing the inherent bond-loan ratio, mitigating the direct effect. With this, the responses of the monetary authority become relevant: if aggregate investment increases, it can raise aggregate demand and with it inflationary pressures, the monetary policy rate will increase in the forward looking Taylor rule, which can also dampen the initial effect of the drop on the loan rate. Consequently, it cannot be determined a priori whether the net effect on the loan rate is positive or not. In other words, as long as the diewert cost function defined in (31) is not linear ($\gamma > 0$), in general equilibrium, the bank portfolio channel (or bank balance sheet) of commercial banks is an empirical question that can be associated with an expansive or contractive effect in the production.

Considering the risk-sensitive capital regulation (established in Basel II), total investment loans B_t^L are risk-weighted:

$$B_t^L = \omega_t^L L_t^k$$

$$\omega_t^L = (1 - \rho_L)\, \bar{\omega}^L + (1 - \rho_L)\, \chi_L\, (Y_t - Y_{t-1}) + \rho_L \omega_{t-1}^L \tag{36}$$

Where L_t^k represents the unweighted investment loans, Y_t is the real GDP, and ω_t^L is the cyclical risk weight, which allows highlighting the difference between the capital-asset relationship and leverage.

In this model, macroprudential and monetary policies may be related, but each maintains independent roles. Using the forward looking Taylor rule, the monetary policy rate R_t has an immediate impact on deposit and loan rates, while the macroprudential instrument, v_t, has an immediate impact only on the lending rate. The two policymakers can manage their instruments separately and can drive a wedge between the lending and borrowing rates of commercial banks and ultimately have an independent effect on savers and borrowers.

3.7 Macroeconomic policy

3.7.1 Monetary authority

As noted above, the monetary authority provides liquid money to commercial banks through a permanent interbank facility. It also participates in the sterilized intervention and its final balance sheet is represented by:

$$\mathcal{E}_t F_t^* + L_t^b = m_t^s + B_t^{CB} + RR_t + NW_t \tag{37}$$

Where m_t^s is the real money supply and NW_t is the nominal value of the net worth of the monetary authority.

Adjustments in the stock of FX reserves satisfy the central bank's nominal budget constraint:

$$m_t^s = m_{t-1}^s + \left(1 - \kappa^F\right) \mathcal{E}_t \left(F_t^* - F_{t-1}^* R_{t-1}^*\right) + \left(L_t^b - R_t L_{t-1}^b\right) - \left(RR_t - RR_{t-1}\right) \tag{38}$$

It can be noted that changes in the domestic currency value of foreign exchange reserves do not have a direct effect on the real money supply with full sterilization $\left(\kappa^F = 1\right)$. In addition, sterilization implies the issuance of high-yield domestic liabilities while accumulation international reserves as a counterpart generates lower yield (because of the international interest rate), the monetary authority incurs a quasi-fiscal cost when it engages in sterilized operations. Established in terms of local currency per unit, this cost is represented by $R_t^{CB} - R_t^* \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}$ in gross terms. In addition, the total cost of the sterilized intervention in net terms, can be defined at the beginning of period as:

Alternatively, in net terms, the total cost of sterilization can be defined at the beginning of the period as:

$$SC_t = R_t^{CB} B_{t-1}^{CB} - \left[R_t^* \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} - 1 \right] e_t F_t^* \tag{39}$$

The central bank's monetary policy objective takes into account the loss function of the representative household and the cost of the sterilized intervention, as defined in (39), the optimal degree of real exchange rate strengthening and the optimal degree of sterilized intervention may be affected.

Monetary policy follows a forward looking Taylor rule:

$$\frac{R_t}{\bar{R}} = R_{t-1}^{\rho_R} \left(\frac{\pi_{t+1}^N}{\overline{\pi}} \right)^{\phi_\pi (1-\rho_R)} \left(\frac{Y_t}{\bar{Y}} \right)^{\phi_y (1-\rho_R)} \varepsilon_t^R \tag{40}$$

Where $\bar{R}$, $\overline{\pi}$, and $\bar{Y}$ are the steady state values of GDP, non-tradable inflation, and the gross nominal interest rate respectively. The parameters ϕ_π and ϕ_y denote the weights for non-tradable inflation and output in the interest rate rule respectively.

FX intervention rule (1):

$$\frac{F_t^*}{\overline{F}^*} = \left(\frac{F_{t-1}^*}{\overline{F}^*} \right)^{\rho_{F^*}} \left(\frac{Y_t}{\overline{Y}} \right)^{\gamma_y (1-\rho_{F^*})} \left(\frac{\pi_t^N}{\overline{\pi}} \right)^{\gamma_\pi (1-\rho_{F^*})} \tag{41}$$

Where $\overline{F}^*$ is the steady state stock of FX reserves, F_t^*. γ_y is the weight for output and γ_π is the weight for non-tradable inflation.

FX intervention rule (2):

$$\frac{F_t^*}{\overline{F}^*} = \left(\frac{F_{t-1}^*}{\overline{F}^*} \right)^{\rho_{F^*}} \left(\frac{e_t}{\overline{e}} \right)^{\gamma_e (1-\rho_{F^*})} \tag{42}$$

Where $\overline{e}$ is the steady state value of real exchange rate. The parameter γ_e denote the weight for real exchange rate in the FX intervention (2) rule.

A current real depreciation induces the monetary authority to sell currencies in the

FX market to strengthen and reduce the volatility of the domestic currency. As a result, its reserve stock falls and the current account deteriorates.

The baseline scenario establishes the following $\gamma_y = \gamma_\pi = \gamma_e = 0$, that is, the monetary authority does not intervene in the foreign exchange market. Subsequently, we optimally choose these coefficients and quantify the losses as a loss function measure to carry out a FX intervention policy in the face of international interest rate shocks.

3.7.2 The macroprudential authority

The Basel III regulatory framework establishes a countercyclical capital buffer (CCB) intended to prevent and mitigate severe disruptions during a local or global financial crisis. Therefore, two different forms of CCBs are evaluated ($\# = 1, 2$), which serve as an indicator of crisis or early warning, easy to calculate and efficient.

$$v_t = (1-\rho_v)\left[\bar{v} + v_t^{CCB,\#}\right] + \rho_v v_{t-1} \tag{43}$$

The first form of CCBs is based on the growth of the anchor variable. In general, as in Ferreira and Nakame (2015), the capital buffer takes the following form:

$$v_t^{CCB(1)} = \chi_v \left(\frac{X_t}{X_{t-1}}\right) \tag{44}$$

Where $X_t \in \left\{L_t^k, Y_t, {}^{L_t^k}/_{Y_t}, B_t^L\right\}$ and χ_v is the sensibility of the anchor variable. According to this macroprudential policy, if each time the economy experiences positive growth in the variable, X_t, commercial banks require more capital per unit of equity.

The second form consists of CCBs as suggested in Basel III, which establishes the gap between the credit/GDP ratio and its long-term trend. In general, the capital buffer takes the following form:

$$v_t^{CCB(2)} = \chi_v \left(\frac{X_t}{\overline{X}}\right) \tag{45}$$

According to this macroprudential policy, if each time the variable, X_t, is above its long-term value, the macroprudential regulator mandates commercial banks to increase their buffers in proportion to the relative deviation of commercial banks from their long-term value.

3.8 Market clearing conditions

Aggregate labor is given by:

$$L_t = L_t^N + L_t^T \tag{46}$$

Aggregate Investment:

$$I_t = I_t^N + I_t^T \tag{47}$$

Market equilibrium for non-tradable goods:

$$Y_t^N = q_t^N \varXi_t^N \tag{48}$$

Aggregate domestic demand for final goods is given by:

$$Y_t^F = C_t + I_t^J + \Psi\left(\frac{I_t^J}{I_{t-1}^J}\right) + G_t \tag{49}$$

Where G_t is government spending.

Real GDP equilibrium:

$$Y_t \equiv P_0^N Y_t^N + P_0^T Y_t^T + P_0^x \overline{CX} \tag{50}$$

Tradable goods maintain the law of one price:

$$P_t^T = \mathcal{E}_t P_t^* \tag{51}$$

Trade balance to GDP:

$$log\left(TBY_t\right) = \frac{Y_t^T - q_t^T}{Y_t} \tag{52}$$

Real money market equilibrium:

$$m_t^d = m_t^s \tag{53}$$

Balance of payments:

$$F_t^* + B_t^* - L_t^* = P_t^X CX_t + Y_t^T - q_t^T + R_{t-1}^*\left[F_{t-1}^* + B_{t-1}^* \varPhi\left(B_{t-1}^*\right) - L_{t-1}^* \theta^{FC}\left(L_{t-1}^*\right)\right] \tag{54}$$

Where $NFA_t = F_t^* + B_t^* - L_t^*$ is the net foreign asset (NFA) position of the domestic economy.

Current Account/GDP:

$$log\left(\frac{CA}{Y}_t\right) = \frac{Y_t^T - q_t^T}{\overline{Y}} \tag{55}$$

Combining the central bank and government budget constraints, we obtain the joint public sector budget constraint:

$$G_t + m^s_{t-1} + RR_{t-1} + R^{bH}_{t-1}B_{t-1} + (1-\kappa_F)\,\mathcal{E}_t\left(F^*_t - F^*_{t-1}R^*_{t-1}\right) + B^{CB}_{t-1}R^{CB}_{t-1} - L^b_t R_{t-1} = m^s_t + RR_t + B_t + B^{CB}_t - L^b_t + \tau_{C,t}P_tC_t + J^B_t \quad (56)$$

3.9 AR shocks

Tradable productivity shock:

$$A^T_t = (1-\rho_{AT})\,log\left(A^T\right) + \rho_{AT}A^T_{t-1} + \epsilon^{AT}_t\sigma_{AT} \quad (57)$$

Non-tradable productivity shock:

$$A^N_t = (1-\rho_{AN})\,log\left(A^N\right) + \rho_{AN}A^N_{t-1} + \epsilon^{AN}_t\sigma_{AN} \quad (58)$$

Foreing interest rate shock:

$$R^*_t = (1-\rho_{R^*})\,log\left(R^*\right) + R^*_{t-1}\rho_{R^*} + \epsilon^{R^*}_t\sigma_{R^*} \quad (59)$$

Commodity price shock:

$$P^X_t = (1-\rho_{px})\,log\left(P^X_0\right) + \rho_{px}P^X_{t-1} + \epsilon^{px}_t\sigma_{px} \quad (60)$$

Consumption tax shock:

$$\tau_{C,t} = (1-\rho_{\tau_C})\,log\left(\tau_{C,0}\right) + \rho_{\tau_C}\tau_{C,t-1} + \epsilon^{\tau_C}_t\sigma_{\tau_C} \quad (61)$$

Bank capital shock:

$$\varepsilon^{Kb}_t = \left(1-\rho_{\varepsilon^{Kb}_t}\right)log\left(1\right) + \rho_{\varepsilon^{Kb}_t}\varepsilon^{Kb}_{t-1} + \epsilon^{\varepsilon^{Kb}}_t\sigma_{\varepsilon^{Kb}} \quad (62)$$

Fiscal policy instrument shock:

$$G_t = (1-\rho_G)\,log\left(G_0\right) + \rho_G G_{t-1} + \epsilon^G_t\sigma_G \quad (63)$$

Where ρ_i and ε^i_t are he autocorrelation coefficient and the innovation of each shock presented. Note that innovations are $\varepsilon^i_t \sim N\left(0, \sigma^2_i\right)$.

3.10 Welfare maximization

In a non-cooperative context, the optimal monetary policy can be calculated numerically using the following central bank (CB) loss function:

$$\mathcal{L}_t^{CB} = \sigma_\pi^2 + \kappa_{Y,CB}\sigma_Y^2 + \kappa_R\sigma_{\Delta R}^2 \tag{64}$$

Where σ_π^2, σ_Y^2 and $\sigma_{\Delta R}^2$ denote the variability with the use of asymptotic variances of inflation, output, and changes in the monetary policy instrument, respectively. The weights κ_i characterize the preferences of the policymaker on these variables. A positive κ_i is justified by the need to keep the movements of the monetary policy rate "understandable", since, if there is no cost for this rate, optimal monetary policies will tend to generate considerable variability in the monetary rule.

Following standard practice, the macroprudential regulator is concerned about the volatility of the macroprudential policy instrument in its charge. Consequently, the loss function to be minimized is established as:

$$\mathcal{L}_t^{MR} = \sigma_{B/Y}^2 + \kappa_{Y,MR}\sigma_Y^2 + \kappa_v\sigma_{\Delta v}^2 \tag{65}$$

Where $\sigma_{B/Y}^2$, $\sigma_{B^L}^2$and $\sigma_{\Delta v}^2$ are the asymptotic volatility of credit/GDP ratio, and changes in the macroprudential instrument, respectively. The presence of of credit/GDP ratio volatility in the regulator's objective function represents a measure of credit risk-weighted assets.

Finally, in a cooperative context, it is possible to model the interaction of both authorities, setting the sum of the loss functions (64) and (65):

$$\mathcal{L}_t = \mathcal{L}_t^{CB} + \mathcal{L}_t^{MR} = \sigma_\pi^2 + \sigma_{B/Y}^2 + (\kappa_{Y,CB} + \kappa_{Y,MR})\,\sigma_Y^2 + \kappa_R\sigma_{\Delta R}^2 + \kappa_v\sigma_{\Delta v}^2 \tag{66}$$

Consequently, the preference parameters of policy makers are set at $\kappa_{Y,CB} = 0.5$, $\kappa_{Y,MR} = 0.5$, $\kappa_R = 0.1$, and $\kappa_v = 0.1$.

4 Estimation

The model is estimated using Bayesian techniques with data from the Peruvian economy. We use the Matlab package Dynare 4.6.4 to obtain all the results in this investigation. We outline the method for taking the model to the data. In principle, the prior information reflect strongly sustained beliefs about the validity of the model. The prior are based on research that estimates DSGE models for Peru.

4.1 Random Walk Metrópolis-Hastings algorithm

To obtain the posterior estimates, we choose a starting point Θ_0
Repetitions are performed for $j = 1, ..., N$

- Generate candidate $\tilde{\Theta}$ from proposal density $q(\Theta_{j-1}, \tilde{\Theta})$ and u from a uniform distribution $\mathcal{U}(0,1)$.
- If $\tilde{\Theta}$ is valid parameters draw (steady state exist, Blanchad-Kahn conditions satisfied etc.) and $u < q(\Theta_{j-1}, \tilde{\Theta})$ with

$$\mathfrak{p} = \left\{ min \left[\frac{p(\tilde{\Theta}|y^T)q(\tilde{\Theta}, \Theta_{j-1})}{p(\Theta_{j-1}|y^T)q(\Theta_{j-1}, \tilde{\Theta})}, 1 \right] \quad if \quad \pi(\Theta_{j-1})q(\Theta_{j-1}, \tilde{\Theta}) > 0 \right. \tag{67}$$

- Otherwise, set $\Theta_j = \tilde{\Theta}$ (implies setting $\pi(\tilde{\Theta}) = 0$ if draw invalid)

Return the values $\{\Theta_0, ..., \Theta_N\}$

After the effect of the initial values has subsided and the chain has passed the transitory stage, subsequent draws can be considered draws from the posterior. The convergence rate is sensitive to $\mathcal{H}$. Therefore, $\mathcal{H} = 100,000$ draws are made.

4.2 Bayes Factor

For each policy mix in the model, the posterior marginal density is calculated using the modified harmonic mean estimator of Gekewe (1998). Therefore, the Bayes factor is considered as a tool to determine which policy mix best explains the behavior of the set of variables. The main tool for model comparison is the difference between the marginal log probabilities for two alternative macroeconomic policy specifications, the log Bayes factor, given by:

$$logBF_{12} = logp_1 \left(\mathrm{y}_{1:T} \right) - logp_2 \left(\mathrm{y}_{2:T} \right) \tag{68}$$

Considering that $\sum_{k=1} p_k = 1$.

Where BF_{12} is the Bayes factor and p_k is the posterior probability of the macroeconomic policy mix of model k. A positive value of $logBF_{12}$ indicates support for model specification 1 relative to model specification 2 and larger positive values implies stronger support.

5 Calibration

5.1 The steady state and calibration

Table 2: Calibrated parameters

	Description	Value
Real sector		
β	Discount factor	0.99
b	Habit formation	0.7
υ	Inverse of labor supply elasticity	1
α_Y	Share of tradable inputs - FG sector	0.3
η_Y	Elasticity of substitution - FG sector	1
θ_N	Calvo probability - Non-tradable sector	0.75
θ_W	Calvo probability - Wages	0.75
κ_N	Slope of the Phillips curve - Non-tradable sector	0.0858
κ_W	Slope of the Phillips curve - Wages	0.0858
α_N	Capital share - Non-tradable sector	0.3
α_T	Capital share - Tradable sector	0.3
δ	Depreciation rate	0.025
ϕ	Investment adjustment cost	2.5
λ_T	Share of organizational capital	0.34
$1-\phi_T$	Depreciation rate of organizational capital	0.41
ϕ_{B^*}	Portfolio adjustment cost parameter	0.04
Policy rules		
τ_{RR}	Required reserve rate	0.1
ρ_R	Interest rate smoothing coefficient	0.1
ϕ_y	Monetary policy response to output	0.125
ρ_v	Inertia in the adjustment of the capital buffer	0.9
χ_v	Sensibility of the anchor variable	10

(Table 2 continued)	Description	Value
Financial sector		
κ_{Kb}	Cost for adjusting capital-asset ratio	11.06
δ^b	Depreciation rate of bank capital	0.02
ρ_L	Persistence weighting function loans	0.92
χ_L	Sensitivity of weights on loans to output	-10
ς_b	Elasticity of substitution, loan to CG producers	4.5
θ_0^{FC}	Sensitivity of premium, bank foreign borrowing	1
$\gamma_{B^{CB}}$	Direct cost parameter, sterilization bonds	1
γ_{B^L}	Direct cost parameter, loans	0.1
γ	Joint cost parameter, sterilization bonds and loans	0.1

The model is calibrated to match the key characteristics of the Peruvian economy that it is a commodity-exporting country. Table 2 shows the calibration based on various sources, each period in the DSGE model equals one quarter.

In the real sector, we set the intertemporal discount factor $\beta = 0.99$ which considers a steady-state risk-free rate of 4 percent. The parameter representing habit formation is set at $b = 0.7$. The inverse of the Frisch elasticity of labor supply is set at $\upsilon = 1$. The share of tradable inputs is set at $\alpha_Y = 0.3$. The elasticity of substitution between tradable and non-tradable inputs is set at $\eta_Y = 1$.

Taking nominal rigidities into account, the probabilities for wage and price rigidities consider an average duration of $1/(1-\theta_i)$ quarters, $\theta_N = \theta_T = 0.75$. The slope of the Phillips curve of non-tradable sector and wages are set at $\kappa_N = \kappa_W = 0.0858$. The capital share of tradable and non-tradable sectors are set at $\alpha_N = \alpha_T = 0.3$, which is a very conventional parameter for emerging economies. An annual depreciation rate of 10 percent is also established, which is consistent with a 2.5 percent quarterly depreciation rate used in the real business cycle research. In addition, we consider a value for the investment adjustment cost of of $\phi = 2.5$.

For the LBD parameters, the share of organizational capital in the tradable production function is set to $\lambda_T = 0.34$, the depreciation rate of organizational capital is set at $1 - \phi_T = 0.41$ and the portfolio adjustment cost is set at $\phi_{B^*} = 0.04$.

For the monetary authority, the required reserve ratio is set at $\tau_{RR} = 0.1$, which consists of an average of the analyzed sample. The interest rate smoothing coefficient is set at $\rho_R = 0.1$. In this sense, the monetary policy response to GDP is set at $\phi_y = 0.125$.

Regarding the macroprudential regulator, the inertia in the adjustment of CCB is set at $\rho = 0.9$. The sensibility of the anchor variable is set at $\chi_v = 10$, which consists of an increase in capital requirements in good times and a decrease in recessions.

In the financial sector, we set the cost for adjusting capital-asset ratio at $\kappa_{Kb} = 11.06$. The depreciation rate of bank capital is set at $\delta^b = 0.02$, which considers a 8 percent annual bank depreciation rate. The parameters ρ_L and χ_L are 0.92 and -10 respectively, and the steady state weight $\bar{\omega}^L$ is set at 1.

For commercial banks, the elasticity of substitution between differentiated loans is set at ς_b, which consists of a spread between the monetary policy rate and the loan rate evident in developing countries. The parameters in the diewert cost function, $\gamma_{B^{CB}}$, γ_B, γ are set at 1, 0.1, and 0.1, respectively.

5.2 Estimation and empirical moments

Considering the standard literature, our priors are listed in Table 3. The policy parameters that govern the forward looking Taylor rule maintain a Beta distribution with limits [0.1], and a gamma distribution with limits $[0, +\infty]$. While the policy parameter that governs the FX intervention rule maintains a Normal distribution, whose limits are contained in the real space, $\mathbb{R}$. The autocorrelation coefficients maintain a Beta distribution. The standard deviations (Std dev) of the shocks are characterized by an Inverse Gamma distribution, whose limits are contained in the non-negative orthante of the real space, $\mathbb{R}^+$. In addition, conventional priors are imposed over standard deviation parameters.

Table 3: Prior distributions

	Distribution	mean	Std dev
Policy parameters			
ρ_R	Beta	0.1	0.01
ϕ_π	Gamma	1.5/7/17.3	0.01
ϕ_y	Gamma	0.125	0.01
γ_q	Normal	-24.8/-0.1	0.01
Autoregressive shocks			
ρ_{AT}	Beta	0.85	0.01
ρ_{AN}	Beta	0.95	0.01
ρ_{R^*}	Beta	0.95	0.01
ρ_{px}	Beta	0.95	0.01
ρ_{τ_C}	Beta	0.95	0.01
$\rho_{\varepsilon_{Kb}}$	Beta	0.81	0.01
ρ_G	Beta	0.95	0.01
Standard deviation shocks			
σ_{AT}	Inverse Gamma	10	Inf
σ_{AN}	Inverse Gamma	0.1	Inf
σ_{F^*}	Inverse Gamma	1.0	Inf
σ_{R^*}	Inverse Gamma	0.1	Inf
σ_{px}	Inverse Gamma	0.1	Inf
σ_{τ_C}	Inverse Gamma	0.1	Inf
$\sigma_{\varepsilon_{Kb}}$	Inverse Gamma	0.1	Inf
σ_G	Inverse Gamma	10	Inf

5.3 Welfare and optimized rules

Table 4: Optimized rules

	ϕ_π	γ_π	γ_y	γ_q	$\mathcal{L}^{CB}$	$\mathcal{L}^{MR}$	$\mathcal{L}$
Baseline model	1.5	0	0	0	0.0551	0.3472	0.4023
Baseline model and FXI rule (2)	1.5	0	0	-24.8	0.0547	0.3438	0.3985
	1.5	0	0	-0.1	0.0552	0.3462	0.3924
$\Delta\mathcal{W}_{B(1)}$					0.73%	0.98%	0.94%
$\Delta\mathcal{W}_{B(2)}$					-0.18%	0.29%	2.46%
Non-cooperative							
Optimal monetary rule	17.3	0	0	0	0.0445	0.3410	0.3855
Optimal monetary rule and FXI rule (1)	17.3	0	-1.4	0	0.0415	0.3542	0.3957
Optimal monetary rule and FXI rule (2)	17.3	0	0	-24.8	0.0416	0.3563	0.3979
$\Delta\mathcal{W}_{NC(1)}$					6.74%	-3.87%	-2.65%
$\Delta\mathcal{W}_{NC(2)}$					6.52%	-4.49%	-3.22%
Cooperative							
Optimal monetary rule	7	0	0	0	0.0445	0.3401	0.3846
Optimal monetary rule and FXI rule (1)	7	4.7	0	0	0.0442	0.3395	0.3837
Optimal monetary rule and FXI rule (2)	7	0	0	-0.1	0.0446	0.3398	0.3844
$\Delta\mathcal{W}_{C(1)}$					0.67%	0.18%	0.23%
$\Delta\mathcal{W}_{C(2)}$					-0.22%	0.09%	0.05%

Note: Welfare gains are $\Delta\mathcal{W}_i = -\Delta\mathcal{L}_i^j$.

Table 3 shows the monetary policy coefficients that minimize the loss function of the forward looking Taylor rule and the FX intervention rule. The main coefficients in the baseline model are proposed by Taylor (1993) and the parameters of the FX intervention rule are estimated in the model through an optimization process.

We can notice that it is preferred to add the FXI rule (2) to the base model. If the objective is only to stabilize the central bank's macroeconomic variables, the use of a FX intervention rule minimizes the loss function. If the parameter associated with the sensitivity of the real exchange rate of the FXI rule (2) is high, the welfare gain for society is 0.73%. If the parameter associated with the sensitivity of the real exchange rate of the FXI rule (2) is low, the welfare gain for society is -0.18%. So the central bank must be forceful if it wants to achieve its objectives.

In a non-cooperative context, only an optimized conventional monetary policy is preferred. If the objective is only to stabilize central bank macroeconomic variables, the optimal monetary policy is an optimized monetary rule and an FXI rule, either (1) or (2), both are marginally similar with welfare gains of 6.74% and 6.52%, respectively. Uncoordinated monetary policy and commercial banks with a monopolistically competitive lending rate market produce a high loss function using an FXI rule.

In a cooperative context, it is preferred to add an FXI rule to the optimized monetary rule. With common monetary and macroprudential objectives, the optimal monetary policy is an optimized monetary rule and an FXI rule, either (1) or (2), both are marginally similar with joint welfare gains of 0.23% and 0.05%, respectively. Consequently, both policies must be coordinated so that there is greater efficiency in the economy.

Table 5: Monetary and Macroprudential Regulation

	Monetary rule			FXI rule		
	$\phi_\pi = 1.5$	$\phi_\pi = 7$	$\phi_\pi = 17.3$	$\phi_\pi = 1.5$ $\gamma_q = -24.8$	$\phi_\pi = 7$ $\gamma_q = -0.1$	$\phi_\pi = 17.3$ $\gamma_q = -24.8$
Baseline model				$\mathcal{L}^{MR}$		
$\bar{v} = 9.3\%$	0.6246	0.6211	0.6228	0.6190	0.6210	0.6351
MR CCB(1)				$\mathcal{L}^{MR}$		
Credit growth	0.5110	0.5078	0.5095	0.5055	0.5076	0.5220
Credit-to-GDP growth	0.5121	0.5083	0.5100	0.5063	0.5082	0.5223
GDP growth	0.5123	0.5085	0.5101	0.5066	0.5083	0.5223
Risk-weighted Credit growth	0.5116	0.5080	0.5097	00.5059	0.5078	0.5220
MR CCB(2)				$\mathcal{L}^{MR}$		
Credit gap	0.5269	0.5253	0.5276	0.5216	0.5252	0.5412
Credit-to-GDP gap	0.5237	0.5199	0.5217	0.5179	0.5197	0.5348
GDP gap	0.5135	0.5104	0.5121	0.5077	0.5102	0.5241
Risk-weighted Credit gap	0.5245	0.5216	0.5236	0.5190	0.5214	0.5371

To gain a better understanding of the differences in the effectiveness of different macroprudential policy instruments compared to monetary policy, we simulate scenarios in which the MR tightens macroprudential policy. In the baseline model, capital requirement decisions are represented by a fixed rate, $\bar{v} = 9.3\%$. This is a correct representation of the Peruvian regulatory framework during our sample period, in which Peru had adhered to the Basel II accords, and when capital requirement ratios remained broadly unchanged. Consequently, to compare the impact of a mechanical CCB rule with a traditional capital requirement rule, an innovation, ϵ_t^v, is added to each equation:

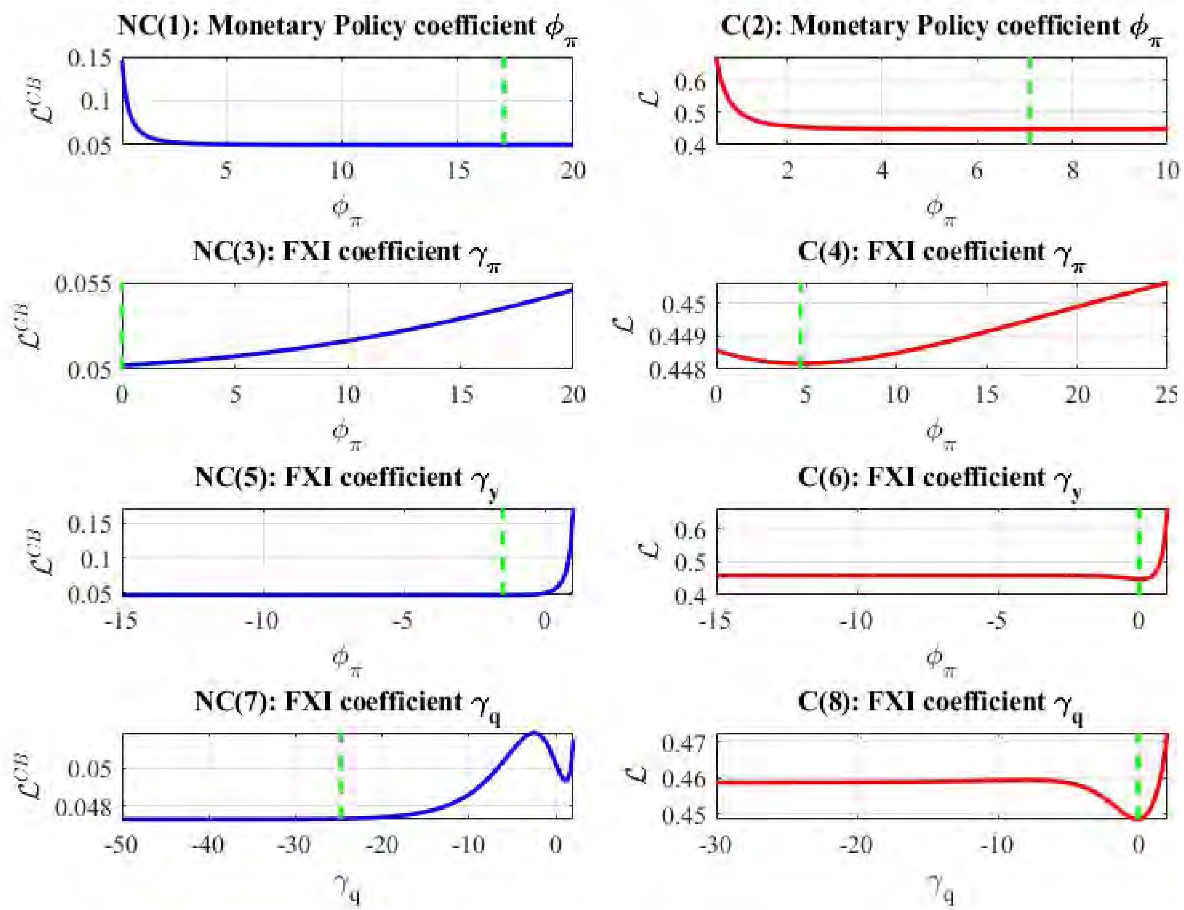
$$v_t = (1 - \rho_v)\left[\bar{v} + v_t^{CCB,\#}\right] + \rho_v v_{t-1} + \epsilon_t^v \tag{69}$$

$$v_t = \bar{v} + \epsilon_t^v \tag{70}$$

Table 4 suggests that the introduction of CCBs generates greater welfare and, depending on the monetary policy configuration, this measure increases. Credit growth is the anchor variable that produces greater welfare within CCB(1). The gap variables grouped in CCB(2) are the variables that have a greater loss. The latter are still better choices compared to a fixed capital requirement rate.

Note that the most effective macroprudential regulation in terms of welfare is through a forward looking Taylor rule and an FXI rule. In addition, the optimal anchor variable continues to be credit growth and the parameter associated with the exchange rate of the FXI rule is high. Therefore, it can be asserted that, in order to mitigate the volatility of the financial cycle, each competent policymaker must consider the behavior of credit growth (commercial bank investment loans) and the real exchange rate.

Figure 2: Optimized parameters



Note: The figure shows the business cycle loss function for alternative parameterizations of the monetary policy rule and foreign exchange intervention (FXI) rule. The solid blue lines show the CB loss for the alternative parameters considering each rule in a non-cooperative (NC) context. While the solid red lines show the welfare loss for the alternative parameters in a cooperative context (C).

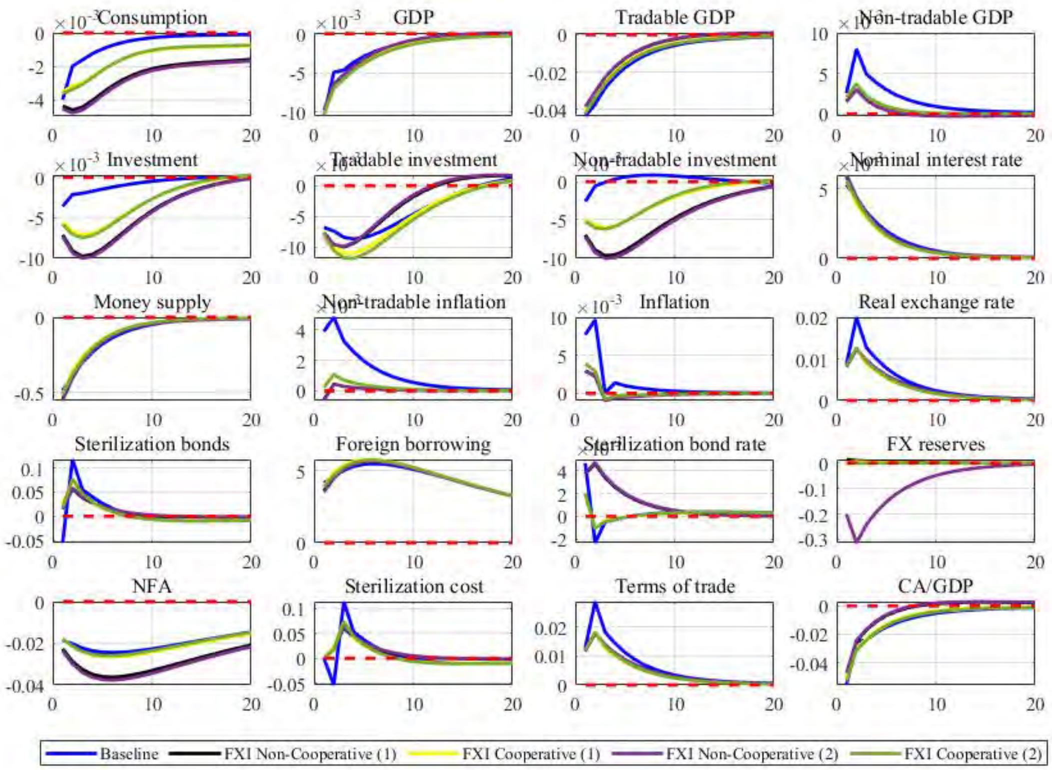
Figure 2 shows a broad sensitivity analysis for the parameters set in the optimized monetary rule and the FXI rule. The first (second) column shows the influence of various alternative values of the coefficients of the monetary policy rule ϕ_π, γ_π, γ_y and γ_q on the loss function of the central bank (both authorities) in a non-cooperative (cooperative) context. Consequently, both columns show that increasing the magnitude of the various coefficients of conventional and unconventional monetary policy helps reduce the welfare loss from business cycles.

NC(1) and C(2) show the magnitude of the impact of parameter ϕ_π of the monetary rule on the loss function. The sensitivity analysis illustrates that there are greater welfare gains by increasing the magnitude of the parameter in the two contexts analyzed. Note that the magnitude of the weight on non-tradable inflation is greater in a non-cooperative context, $\phi_\pi = 17.3$. This is because it is more costly for the central bank to contain inflation in the absence of coordination and the presence of financial frictions.

NC(3) to C(6) present the impact of the parameters γ_π and γ_y of the FXI rule (1) on the loss function. The sensitivity analysis illustrates that there are similar welfare gains by increasing the absolute magnitude of the parameter γ_y in a non-cooperative context and there are similar welfare gains by increasing the absolute magnitude of the parameter γ_π in a cooperative context.

NC(7) and C(8) show the magnitude of the impact of parameter γ_q of the FXI rule (2) on the loss function. The sensitivity analysis illustrates that a smaller loss function is generated by increasing the absolute magnitude of this parameter in the two contexts. Note that the magnitude of the weight on the real exchange rate is greater in a non-cooperative context, $\gamma_q = -24.8$. Because the financial cycle is not adequately contained, the monetary authority considers the use of foreign exchange reserves to reduce the inherent volatility of the real exchange rate, and thus reduce the welfare loss associated with financial frictions that amplify the financial and business cycle.

Figure 3: Policy response to a positive international interest rate shock



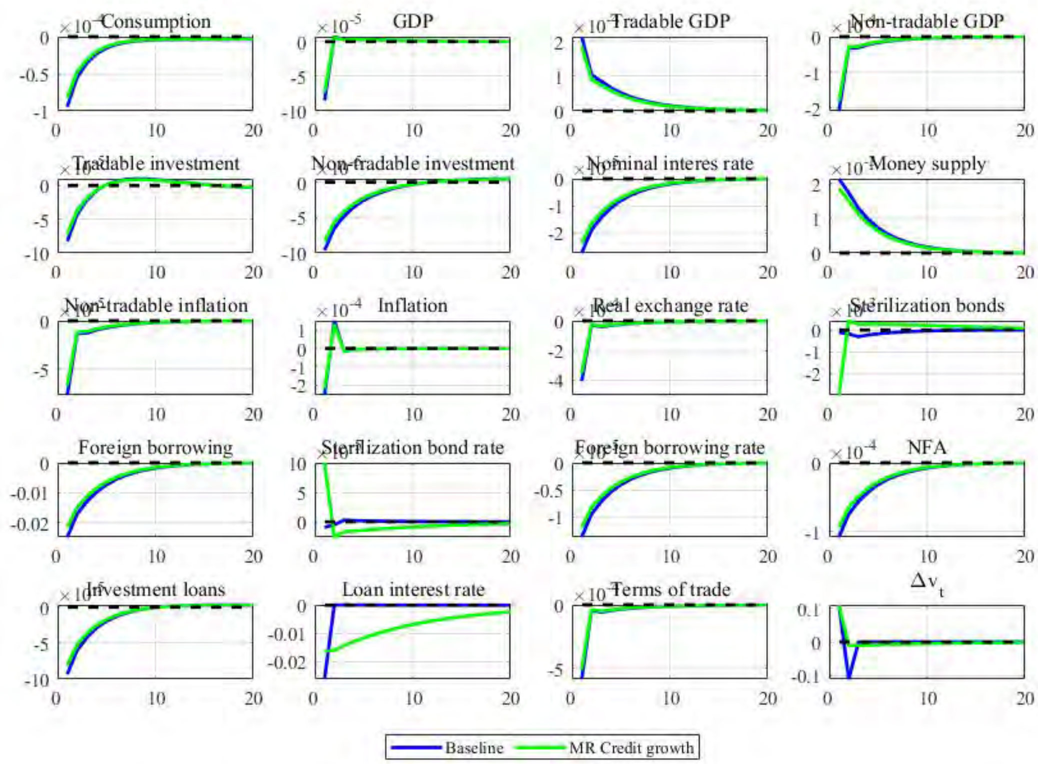
Note: The figure displays Impulse Response Functions (IRFs) of the main variables of the model in the event of an increase of 10 percentage points in the international interest rate. The solid blue line shows the IRFs of the baseline framework. The solid black and yellow lines show the IRFs of the FXI rule (1), non-cooperative and cooperative, respectively. The solid violet and green lines show the IRFs of the FXI rule (2), non-cooperative and cooperative, respectively.

The transmission channel of monetary policy instruments reveals important facts about how far the configuration of these policies can go. Figure 3 shows the model dynamics under baseline model and FX intervention rules. Conveniently, when cooperative or non-cooperative FX intervention is implemented, there are significant gains (a minor loss function) from stabilization in the DSGE model.

An increase in the international interest rate generates an outflow of accumulated capital towards international markets, which leads to a depreciation of the real exchange rate, increasing the competitive capacity of the economy. In the domestic country the terms of trade increase, inflation increases. Through the forward looking Taylor rule, the nominal interest rate increases, generating a fall in consumption, investment and GDP. Thus, the monetary authority desaccumulates reserves through its FX intervention rule (2) causing the real exchange rate to appreciate and non-tradable GDP, non-tradable inflation and terms of trade to be less volatile. In other words, the initial effect of the increase in the international interest rate is mitigated but not canceled. Consequently, the efficient accumulation of FX reserves is implemented progressively over time.

In the absence of sterilization, the money supply decreases pari passu with the sale of foreign exchange reserves resulting from the depreciation of the currency. In addition, with the increase in the monetary policy rate, there is an increase in the deposit rate and the level of deposits, while investment loans decrease. The final result is an outflow of capital, a real depreciation, less liquidity, a contraction of credit and aggregate demand (the latter through lower aggregate consumption and investment).

Figure 4: Capital requirement shock

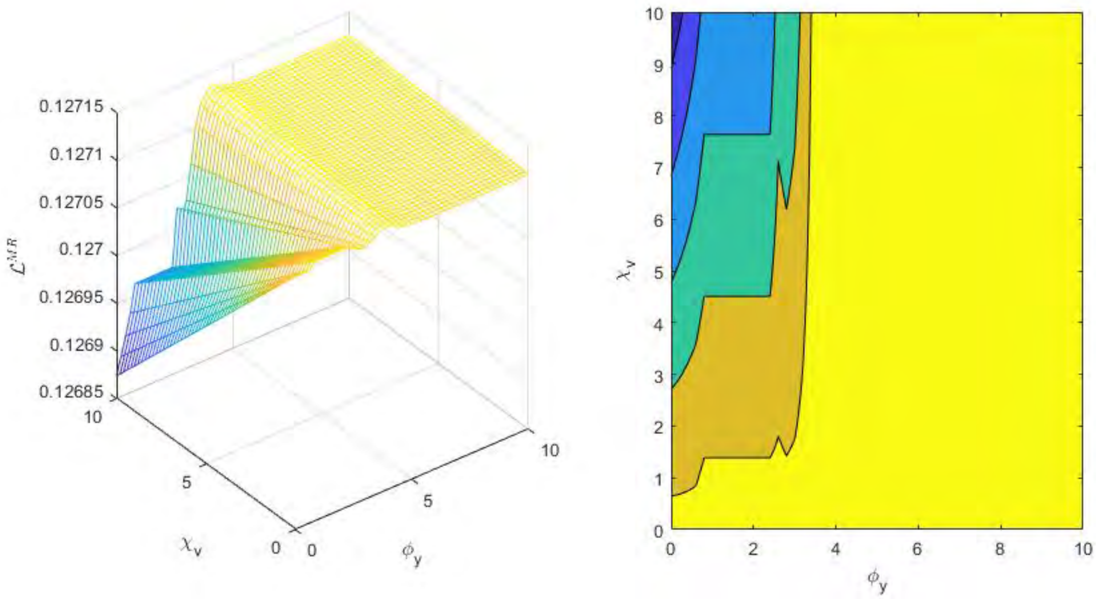


Note: The figure displays IRFs of key variables to a 10 percentage points increase in reserve requirement. The solid green line shows the IRFs of the credit growth rate as the anchor variable for the MR.

Figure 4 shows that an increase in the capital requirement rate causes the interest rate on loans to decrease, corporate borrowing (credit) to decrease, which causes investment, consumption, and GDP to decrease as well. Due to these lower credits in the economy, economic activity in general contracted and non-tradable inflation, inflation and the real exchange rate decreased. With a capital requirement rate with a credit growth anchor variable, volatility is lower.

Therefore, commercial banks should raise capital in buoyant financial cycles (high credit), relaxing the requirement in downturns.

Figure 5: Welfare loss, anchor variable credit growth



Note: Left panel shows the MR loss when the anchor variable is credit growth. Right panel shows the contour plot containing the isolines of matrix $\mathcal{L}^{MR}$, where the ϕ_y-χ_v plane are coordinates for the values in MR loss.

Figure 5 shows that the higher χ_v and the lower ϕ_y, the higher welfare (lower the loss function) of the macroprudential regulator, which implies that the CCBs response to the anchor variable must be strong. According to Ferreira and Nakame (2015), there is no need for conventional monetary policy to react. A CCB is an important financial instrument, with far-reaching consequences for commercial banks and the real economy.

5.4 Posterior estimates

Table 6: Model comparison

Model	Log data density	Log Bayes Factor
Baseline model	-204.6186	0.0000
Baseline model and FXI rule (2), $\gamma_q = -24.8$	-201.9735	1.1488
Baseline model and FXI rule (2), $\gamma_q = -0.1$	-202.2442	1.0312
Non-cooperative		
Optimal monetary rule	-237.1297	-14.1194
Optimal monetary rule and FXI rule (2)	-235.7650	-13.5267
Cooperative		
Optimal monetary rule	-268.1857	-27.6068
Optimal monetary rule and FXI rule (2)	-270.3320	-28.5390

The monetary policy configuration that best explains the behavior of the Peruvian economy is a Taylor rule and an FXI rule with a high coefficient associated with the real exchange rate. In addition, the optimal monetary policy is non-cooperative, since the Organic Law of the BCRP makes it explicit that the only objective pursued is price stability. Therefore, under this scenario, monetary policy is not necessarily used to smooth the financial cycle (credit volatility).[7] Table 6 shows that the Log Bayes Factor favors the base model and an FXI (2) rule, $\gamma_q = -24.8$, over the other policy configurations.

[7] The Peruvian macroprudential regulation reports that the ratio of commercial bank capital to assets is 9.3% on average within the sample used. Therefore, the estimate establishes a fixed capital requirement scenario.

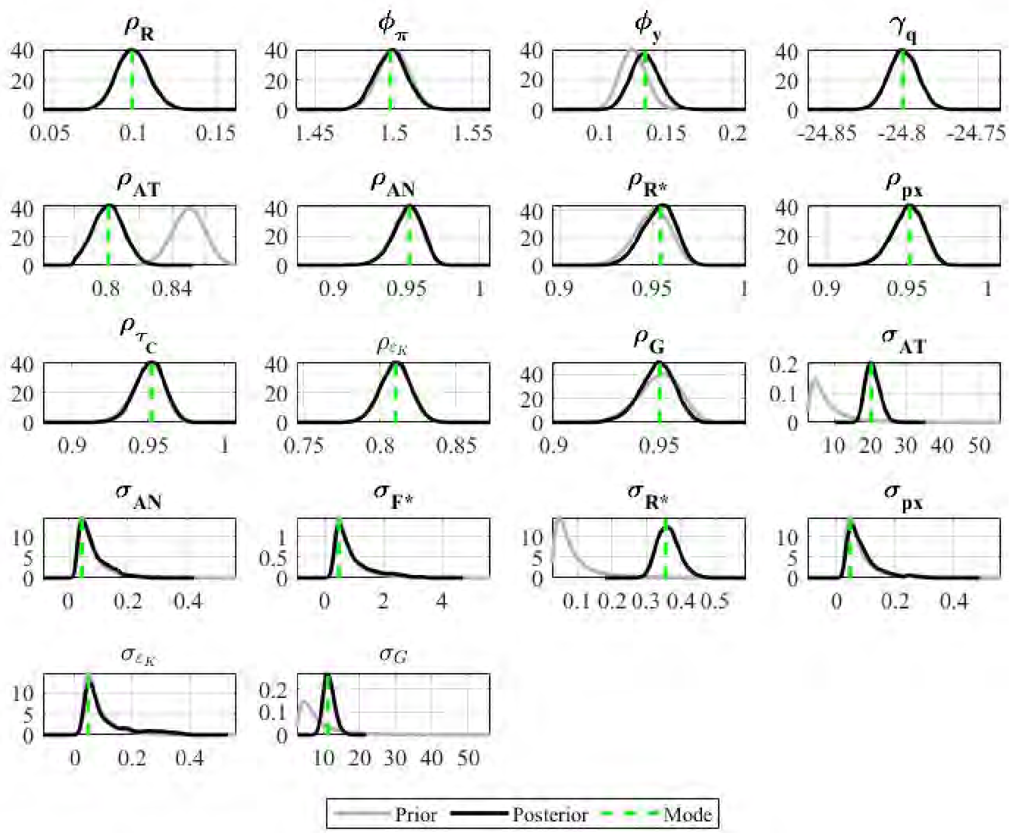
Table 7: Estimates

	Mode	Mean	Credible set	
Policy parameters				
ρ_R	0.0991	0.0997	0.0840	0.1161
ϕ_π	1.4980	1.4984	1.4819	1.5151
ϕ_y	0.1341	0.1339	0.1158	0.1513
γ_q	-24.8000	-24.7999	-24.8157	-24.7838
Autoregressive shocks				
ρ_{AT}	0.8012	0.8012	0.7861	0.8163
ρ_{AN}	0.9519	0.9505	0.9348	0.9669
ρ_{R^*}	0.9549	0.9535	0.9390	0.9677
ρ_{px}	0.9519	0.9504	0.9349	0.9665
ρ_{τ_C}	0.9519	0.9507	0.9350	0.9663
$\rho_{\varepsilon_{Kb}}$	0.8104	0.8102	0.7939	0.8262
ρ_G	0.9504	0.9489	0.9357	0.9626
Standard deviation shocks				
σ_{AT}	21.3441	20.7008	17.5599	23.8824
σ_{AN}	0.0460	0.0814	0.0244	0.1487
σ_{F^*}	0.4613	0.9270	0.2429	1.8862
σ_{R^*}	0.3560	0.3632	0.3106	0.4144
σ_{px}	0.0461	0.0878	0.0252	0.1611
σ_{τ_C}	0.0460	0.1034	0.0223	0.2416
$\sigma_{\varepsilon_{Kb}}$	0.0461	0.0942	0.0235	0.1837
σ_G	11.2737	11.5738	8.9942	14.0046

Table 7 and Figure 6 show the posterior moments of the main policy parameters, the autocorrelation coefficients, and the standard deviations of the shocks. In this table, we preset the mode, the posterior mean estimates, and the 90% highest posterior density credible set (inferior and superior respectively).

Note that if the posterior estimate looks like the prior, then the prior is a very accurate reflection of the information in the data or is only weakly identified and the data does not provide much information to update the prior. For the policy parameters and autocorrelation coefficients, the posterior estimates are similar to the prior mean. In σ_{AT} and σ_G, the prior mean is lower than its posterior estimates. Consequently, it implies a high volatility in the tradable productivity and the fiscal policy instrument shock respectively.

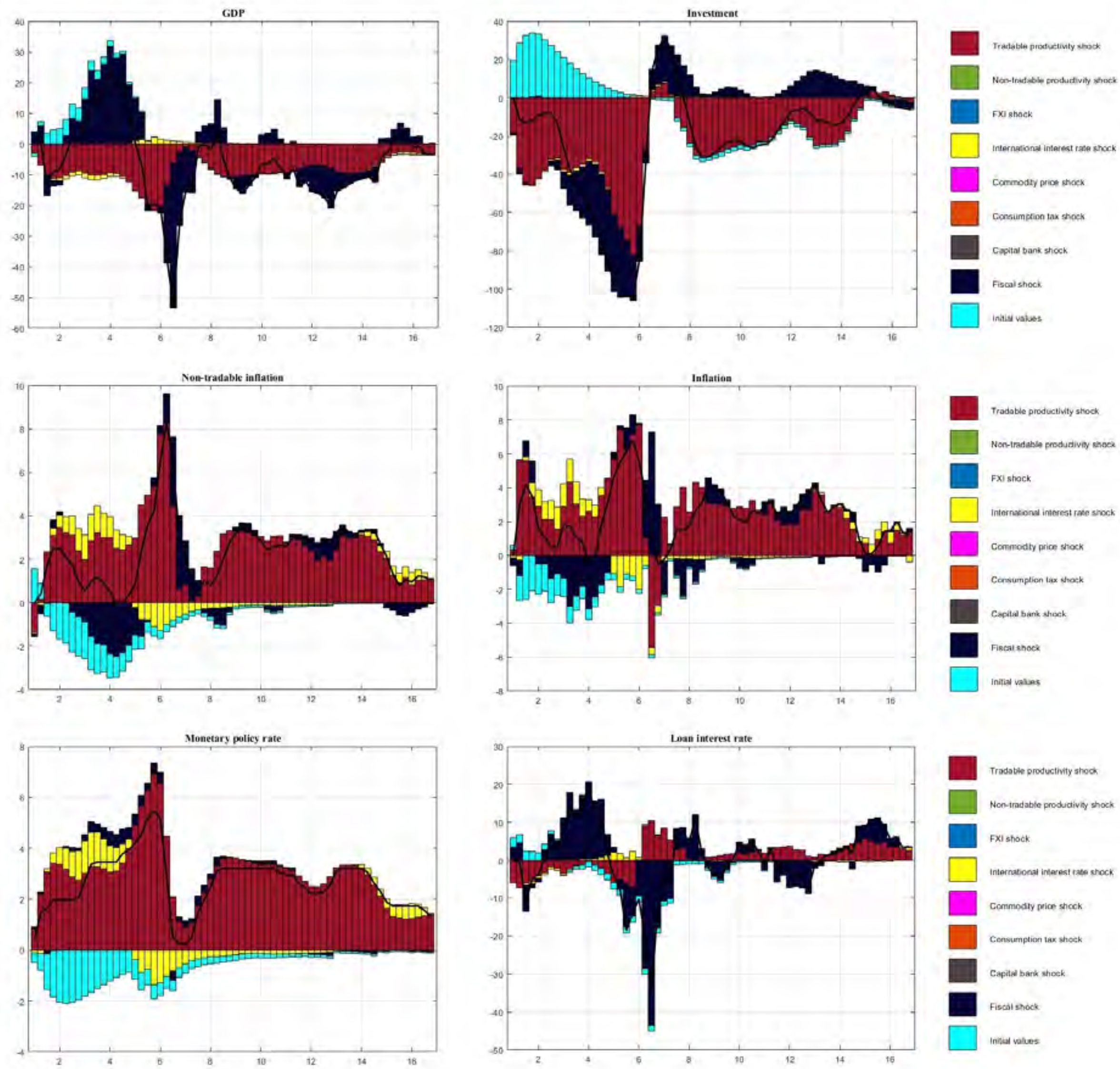
Figure 6: Estimated parameters



Note: The grey line shows the prior density, the black line shows the density of the posterior distribution and the green vertical line indicates the posterior mode.

Figure 7 illustrates the historical variance shock decomposition of the variables. The colored bars represent the contribution of each shock to the evolution of the variables. The historical variance decomposition shows that variables suffered mostly tradable productivity shocks, international interest rate shocks and fiscal shocks throughout its recent history.

Figure 7: Historical variance shock decomposition



Note: The figure shows the historical variance shock decomposition of GDP, investment, non-tradable inflation, inflation, the monetary policy rate, and the commercial bank loan interest rate (black solid line). The sample, 2004Q1-2019Q4, corresponds to the explicit inflation targeting scheme.

6 Conclusions

International interest rate shocks are transmitted through the real exchange rate. Therefore, an FXI rule (1) and an FXI rule (2) are efficient to stabilize the real exchange rate and thus reduce the volatility of non-tradable GDP, non-tradable inflation, inflation and the terms of trade. The FXI rule (1) is marginally better, but its implementation in an economy like Peru is questionable. This is because the use of the time series of the variables associated with the FXI rule (1) are calculated quarterly, generating a delay in the decisions of policy makers. So the FXI (2) rule is currently a suitable rule.

Theoretically, the optimal monetary policy configuration considers that the magnitude of the weight of non-tradeable inflation in the Taylor rule is greater (ϕ_π greater) in a non-cooperative context. Also, the magnitude of the real exchange rate weight in FXI rule (2) should be larger (γ_q larger) in a non-cooperative context. Quantitatively, starting from the base model and the optimal non-cooperative rule, the welfare gains from the introduction of the FXI rule (2) are 0.73% and 6.52%, respectively. Consequently, under a uncoordinated policy, the central bank must react more to inflation and the real exchange rate to minimize the loss function and meet its objectives.

In the financial sector, the results show that a high value of the sensitivity of the anchor variable reduces the volatility of investment loans, generating greater welfare. With an FXI (2) rule in place, optimal macroprudential regulation uses a CCB that reacts to commercial bank credit growth. Therefore, it is theoretically proposed that a capital requirement rate with a CCB not only reinforces the effectiveness of monetary policy, but also aligns the objectives of the central bank with those of the macroprudential regulator in the financial system. Consequently, a capital requirement rate with a CCB is a very important policy instrument, with far-reaching consequences for the financial sector and the real economy.

Empirically, our model indicates that the monetary and macroprudential policy settings that best fit the Peruvian data are a conventional forward looking Taylor rule and a foreign exchange intervention rule that strongly reacts to the real exchange rate. This is consistent with the Peruvian reality because the central bank performs FX intervention very frequently and the macroprudential regulator maintains a constant capital requirement rate. Therefore, both regulators pursue their own objectives in a non-cooperative manner.

Our results focus on financial frictions represented by portfolio adjustment costs and commercial banks in monopolistic competition in the loan rate market. But the conclusions obtained in this research may be applicable to other financial entities that carry out very similar activities, such as savings banks and cooperatives. We conclude that the proposed DSGE representation can replicate key theoretical and empirical facts observed in the financial and business cycle.

7 Recommendations

Complementing what was found in the theoretical model and the empirical Bayesian result, it is recommended that the central bank and the macroprudential regulator use a coordinated policy to meet their objectives. The BCRP must continue to use a monetary policy with a Taylor rule and an FX intervention rule that reacts forcefully to the real exchange rate. Whereas, the SBS, which uses a fixed reserve requirement, is advised to use a CCB rule that reacts to credit growth.

Therefore, an improved mandate for the BCRP and the SBS would be desirable in order to foster the willingness and capacity of both regulators to act. The implementation of joint work groups to improve coordination between the BCRP and the SBS would reduce the volatility of the main macroeconomic variables, help improve accountability and safeguard the institutional rules currently in force. In doing so, it is also important to preserve the independence of the policy functions of the BCRP and the SBS.

The policies established in this research take into account the organic law of the BCRP and Legislative Decree 1531 for the SBS. Monetary rules exclusively pursue price stability (rules do not react to credit), while the macroprudential rule accepts CCBs based on Basel III (financial variables have better performance in the rule). Theoretically, these rules generate greater welfare for society, so empirically it remains to put these results into practice.

Bibliography

Agenor, P. R., Jackson, T. P., and Pereira, L. (2020). Foreign exchange intervention and financial stability. BIS Working Papers 889, Bank for International Settlements.

Alla, Z., Espinoza, R. A., and Ghosh, A. R. (2020). FX intervention in the new keynesian model. *Journal of Money, Credit and Banking*, 52(7):1755–1791.

Angelini, P., Neri, S., and Panetta, F. (2014). The interaction between capital requirements and monetary policy. *Journal of Money, Credit and Banking*, 46(6):1073–1112.

Basel Committee on Banking Supervision (2010). Basel III: A global regulatory framework for more resilient banks and banking systems. Bank for international settlements.

Benes, J., Berg, A., Portillo, R., and Vavra, D. (2015). Modeling sterilized interventions and balance sheet effects of monetary policy in a new-keynesian framework. *Open Economies Review*, 26:81–108.

Bianchi, J. and Mendoza, E. (2011). Overborrowing, Financial Crises and 'Macro-prudential' Policy. IMF Working Papers 2011/024, International Monetary Fund.

Carrasco, A. and Hoyle, D. F. (2021). External shocks and FX intervention policy in emerging economies. IDB Working Paper Series 1243, Inter-American Development Bank.

Carvalho, F. A. and Castro, M. R. (2017). Macroprudential policy transmission and interaction with fiscal and monetary policy in an emerging economy: A DSGE model for brazil. *Macroeconomics and Finance in Emerging Market Economies*, 10(3):215–259.

Castillo, P. and Medina, J. P. (2021). Foreign exchange intervention, capital flows, and liability dollarization. Working Paper series 2021-006, Banco Central de Reservas del Peru.

Chang, C., Liu, Z., and Spiegel, M. M. (2015). Capital controls and optimal chinese monetary policy. *Journal of Monetary Economics*, 74:1–15.

Christiano, L. J., Eichenbaum, M. S., and Trabandt, M. (2018). On DSGE Models. *Journal of Economic Perspectives*, 32(3):113–40.

Davis, J. S., Fujiwara, I., Huang, K. X., and Wang, J. (2021). Foreign exchange reserves as a tool for capital account management. *Journal of Monetary Economics*, 117:473–488.

Drehmann, M., Borio, C., Gambacorta, L., Jiminez, G., and Trucharte, C. (2010). Countercyclical capital buffers: exploring options. BIS Working Papers 317, Bank for International Settlements.

Faltermeier, J., Lama, R., and Medina, J. P. (2017). Foreign Exchange Intervention and the Dutch Disease. IMF Working Papers 17/70, International Monetary Fund.

Faltermeier, J., Lama, R., and Medina, J. P. (2022). Foreign exchange intervention for commodity booms and busts. *European Economic Review*, 143:104018.

Ferreira, L. N. and Nakane, M. I. (2015). Macroprudential policy in a DSGE model: anchoring the countercyclical capital buffer. Working Paper 2015, Banco Central do Brasil.

Gabaix, X. and Maggiori, M. (2015). International Liquidity and Exchange Rate Dynamics *. *The Quarterly Journal of Economics*, 130(3):1369–1420.

García-Cicco, J. and Kawamura, E. (2015). Dealing with the Dutch disease: Fiscal rules and macro-prudential policies. *Journal of International Money and Finance*, 55:205–239.

Gerali, A., Neri, S., Sessa, L., and Signoretti, F. M. (2010). Credit and banking in a DSGE model of the euro area. *Journal of Money, Credit and Banking*, 42(s1):107–141.

Hashimzade, N. and Thornton, M. A. (2013). *Handbook of Research Methods and Applications in Empirical Macroeconomics*. Edward Elgar Publishing, Northampton, Massachussets.

Jeanne, O. and Korinek, A. (2010). Excessive volatility in capital flows: A pigouvian taxation approach. *American Economic Review*, 100(2):403–407.

Kumhof, M. (2010). On the theory of sterilized foreign exchange intervention. *Journal of Economic Dynamics and Control*, 34(8):1403–1420.

Lama, R. and Medina, J. P. (2020). Mundell meets poole: Managing capital flows with multiple instruments in emerging economies. *Journal of International Money and Finance*, 109:102193.

Liu, Z. and Spiegel, M. M. (2015). Optimal monetary policy and capital account restrictions in a small open economy. *IMF Economic Review*, 63:298–324.

Motoro, C. and Ortiz, M. (2016). Foreign exchange intervention and monetary policy design: a market microstructure analysis. Working Paper series 2016-008, Banco Central de Reservas del Peru.

Pozo, J. (2020). The effects of countercyclical capital buffers on macroeconomic and financial stability. Working Paper series 2020-012, Banco Central de Reservas del Peru.

Repullo, R. and Saurina, J. (2011). The countercyclical capital buffer of Basel III: A critical assessment. CEPR Press Discussion Paper 8304, CEPR.

Rojas, C. (2017). Politicas monetarias y macroprudencial optimas post Basilea III. *Revista Estudios Economicos*, (33):57–94.

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy*, 39(1):195–214.

Appendix A

A.1. Model derivation

Households

The domestic household problem is to maximize the expected value of lifetime utility:

$$U_t(h) = \mathbb{E}_t\left[\sum_{i=0}^{\infty}\beta^i u\left(C_{t+i}(h) - bC_{t+i-1}(h), L_{t+i}(h), \frac{M_{t+i}(h)}{P_{t+i}(h)}\right)\right]$$

$$u\left(C_{t+i}(h) - bC_{t+i-1}(h), L_{t+i}(h), \frac{M_{t+i}(h)}{P_{t+i}(h)}\right)$$
$$= ln\left(C_{t+i}(h) - bC_{t+i-1}(h)\right) - \frac{L_{t+i}^{1+\nu}(h)}{1+\nu} + \eta_m ln\left(m_{t+i}^d(h)\right) \quad (71)$$

Total tax transfer from government are as follows:

$$T_t(h) = \tau_{C,t}P_tC_t(h) + Tr_t(h) \quad (72)$$

Where Tr_t are lump-sum transfers, which we consider to be zero.

Combining (2) and (72), household h faces a budget constraint in period t which can be represented by:

$$(1+\tau_{C,t})P_tC_t(h) + M_t(h) + E_t\{d_{t.t+1}\mathcal{Q}_{t+1}(h)\} + D_t(h) + B_t(h) + \mathcal{E}_tB_t^*(h) = W_t(h)L_t(h)$$
$$+ M_{t-1}(h) + \mathcal{Q}_t(h) + R_{t-1}^dD_{t-1}(h) + R_{t-1}^{bH}B_{t-1}(h) + \mathcal{E}_tB_{t-1}^*(h)R_{t-1}^*\Phi\left(B_t^*(h)\right) + \Pi_t(h)$$

First order conditions (FOCs):

$$\frac{\partial\mathcal{L}^H}{\partial C_t} = \frac{1-b}{(C_t - bC_{t-1})} - \lambda_t^H(1+\tau_{C,t})P_t = 0 \quad (73)$$

$$\frac{\partial\mathcal{L}^H}{\partial L_t} = -L_t^\nu + W_t\lambda_t^H = 0 \quad (74)$$

$$\frac{\partial\mathcal{L}^H}{\partial M_t} = \frac{\eta_m}{m_t^dP_t} - \lambda_t^H + \beta\mathbb{E}_t\lambda_{t+1}^H = 0 \quad (75)$$

$$\frac{\partial\mathcal{L}^H}{\partial D_t} = -\lambda_t^H + \beta\mathbb{E}_t\lambda_{t+1}^HR_t^d = 0 \quad (76)$$

$$\frac{\partial \mathcal{L}^H}{\partial B_t} = -\lambda_t^H + \beta \mathbb{E}_t \lambda_{t+1}^H R_t^{bH} = 0 \tag{77}$$

$$\frac{\partial \mathcal{L}^H}{\partial B_t^*} = -\mathcal{E}_t \lambda_t^H + \beta \mathbb{E}_t \mathcal{E}_{t+1} \lambda_{t+1}^H R_t^* \Phi' \left(B_t^*\right) = 0 \tag{78}$$

Combining (73) with (77) yields the domestic Euler equation:

$$\frac{1-b}{\left(1+\tau_{C,t}\right) P_t \left(C_t - bC_{t-1}\right)} = \beta \mathbb{E}_t \frac{1-b}{\left(1+\tau_{C,t+1}\right) P_{t+1} \left(C_{t+1} - bC_t\right)} R_t^{bH}$$

$$1 = \beta \mathbb{E}_t \frac{\left(1+\tau_{C,t}\right) P_t}{\left(1+\tau_{C,t+1}\right) P_{t+1}} \frac{\left(C_t - bC_{t-1}\right)}{\left(C_{t+1} - bC_t\right)} R_t^{bH} \tag{79}$$

Real wages are sticky as in Blanchard and Gali (2007) and Shimer (2012), then we derive the labor supply function:

$$\frac{W_t}{P_t} = \left(\left(1+\tau_{C,t}\right) w_t^*\right)^{1-\xi_w} \left(\frac{W_{t-1}}{P_{t-1}}\right)^{\xi_w}$$

$$\frac{W_t}{P_t} = \left(-\left(1+\tau_{C,t}\right) \frac{-L_t^\nu}{\frac{1-b}{\left(C_t - bC_{t-1}\right)}}\right)^{1-\xi_w} \left(\frac{W_{t-1}}{P_{t-1}}\right)^{\xi_w}$$

$$\frac{W_t}{P_t} = \left(\frac{\left(1+\tau_{C,t}\right)\left(C_t - bC_{t-1}\right) L_t^\nu}{1-b}\right)^{1-\xi_w} \left(\frac{W_{t-1}}{P_{t-1}}\right)^{\xi_w}$$

$$\frac{W_t}{P_t} = \left(\psi \left(1+\tau_{C,t}\right)\left(C_t - bC_{t-1}\right) L_t^\nu\right)^{1-\xi_w} \left(\frac{W_{t-1}}{P_{t-1}}\right)^{\xi_w} \tag{80}$$

Where $\xi_w \in [0,1]$ is the degree of inertia in real wages and $w_t^* = -{}^{u_{L,t}}/_{u_{C,t}}$ is the equilibrium real wage determined by the household's marginal rate of substitution between consumption and leisure.

FOC, deposits:

$$\lambda_t^H = \beta \mathbb{E}_t \lambda_{t+1}^H R_t^d \tag{81}$$

Wage Setting process

The aggregate wage rate is given by:

$$\left(\frac{W_t}{W_{t-1}}\right)^{1-\epsilon_L} = \theta_W + \left(1-\theta_W\right)\left(\frac{W_t^*}{W_{t-1}}\right)^{1-\epsilon_L}$$

Log-linearized around the zero-wage inflation steady state:

$$(1-\epsilon_L)\, log\left(\pi_t^W\right) = (1-\epsilon_L)(1-\theta_W)\left(log\left(W_t^*\right) - log\left(W_{t-1}\right)\right)$$

$$log\left(\pi_t^W\right) = (1-\theta_W)\left(log\left(W_t^*\right) - log\left(W_{t-1}\right)\right)$$

Rewrite the difference equation for optimal wage price setting and use aggregate dynamics to obtain:

$$(1-\theta_W)^{-1} log\left(\pi_t^W\right) = (1-\theta_W)^{-1}\beta\theta_W \mathbb{E}_t log\left(\pi_{t+1}^W\right) + (1-\beta\theta_W)\, log\left(\frac{mc_t^W}{\overline{mc^W}}\right) + log\left(\pi_t^W\right)$$

Phillips Curve (wage) equation in New-Keynesian theory.

$$log\left(\pi_t^W\right) = \beta\mathbb{E}_t log\left(\pi_{t+1}^W\right) + \kappa_W log\left(\frac{mc_t^W}{\overline{mc^W}}\right)$$

Where $\kappa_W \equiv {}^{(1-\theta_W)(1-\beta\theta_W)}/_{\theta_W}$.

Commercial Banks

Commercial bank's Profits:

$$\begin{aligned}\mathbb{E}_t J_{t+1}^B = R_t^L B_t^L + R_t^{CB} B_t^{CB} + RR_t^d + RR_t^b - R_t^d D_t - R_t L_t^b - \mathcal{E}_{t+1} L_t^* R_t^{FC} \\ - \gamma_{B^{CB}} B_t^{CB} - \gamma_B B_t^L + 2\gamma\sqrt{B_t^L B_t^{CB}} \\ - K_t^b - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t^L} - v_t\right)^2 K_t^b \quad (82)\end{aligned}$$

Commercial bank's Balance Sheet

$$B_t^L + B_t^{CB} + RR_t = D_t + \mathcal{E}_t L_t^* + L_t^b + K_t^b$$

Commercial bank Capital law of motion

$$K_t^b = \left(1-\delta^b\right)\frac{K_{t-1}^b}{\varepsilon_t^{Kb}} + \omega_b J_t^B + K_t^b$$

Commercial bank cost of borrowing on world capital markets

$$R_t^{FC} = R_t^* \left(1 + \frac{\theta_0^{FC}}{2} L_t^*\right) \tag{83}$$

Deposit rate

$$i_t^d = (1 - \tau_{RR})\, i_t$$

$$1 + i_t^d = (1 - \tau_{RR})\, i_t + 1 - \tau_{RR} + \tau_{RR}$$

$$R_t^d = i_t - \tau_{RR} i_t + 1 - \tau_{RR} + \tau_{RR}$$

$$R_t^d = R_t - \tau_{RR} i_t - \tau_{RR} + \tau_{RR}$$

$$R_t^d = R_t - R_t \tau_{RR} + \tau_{RR}$$

Deposit rate in gross term

$$R_t^d = (1 - \tau_{RR})\, R_t + \tau_{RR} \tag{84}$$

Legal reserve requirement

$$RR_t = \tau_{RR} D_t$$

The Lagrangian of commercial banks is:

$$\begin{aligned}\mathcal{L}^B = R_t^L B_t^L + R_t^{CB} B_t^{CB} + \left(\tau_{RR} - R_t^d\right) D_t + R_t L_t^b - \mathbb{E}_t \mathcal{E}_{t+1} R_t^* \left(1 + \frac{\theta_0^{FC}}{2} L_t^*\right) L_t^* \\ - \gamma_{B^{CB}} B_t^{CB} - \gamma_B B_t^L + 2\gamma \sqrt{B_t^L B_t^{CB}} - K_t^b - \frac{\kappa_{Kb}}{2} \left(\frac{K_t^b}{B_t^L} - \upsilon_t\right)^2 K_t^b \\ + \lambda_t^B \left\{-D_t - \mathcal{E}_t L_t^* - L_t^b - K_t^b + B_t^L + B_t^{CB} + \tau_{RR} D_t\right\}\end{aligned}$$

FOC, deposits:

$$\frac{\partial \mathcal{L}^B}{\partial D_t} = -R_t^d + \tau_{RR} - \lambda_t^B + \tau_{RR} \lambda_t^B = 0$$

$$-(1 - \tau_{RR})\, R_t - \tau_{RR} + \tau_{RR} = \lambda_t^B (1 - \tau_{RR})$$

$$-\left(1-\tau_{RR}\right)R_t = \lambda_t^B\left(1-\tau_{RR}\right)$$

$$-R_t = \lambda_t^B$$

FOC, investment loans:

$$\frac{\partial\mathcal{L}^B}{\partial B_t^L} = R_t^L\frac{\varsigma_b-1}{\varsigma_b} - \gamma_B + \gamma\left(\frac{B_t^{CB}}{B_t^L}\right)^{0.5} + \kappa_{Kb}\left(\frac{K_t^b}{B_t^L} - \upsilon_t\right)\left(\frac{K_t^b}{B_t^L}\right)^2 + \lambda_t^B = 0$$

$$R_t^L\frac{\varsigma_b-1}{\varsigma_b} = \gamma_B - \gamma\left(\frac{B_t^{CB}}{B_t^L}\right)^{0.5} - \kappa_{Kb}\left(\frac{K_t^b}{B_t^L} - \upsilon_t\right)\left(\frac{K_t^b}{B_t^L}\right)^2 + R_t$$

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$$R_t^L = \frac{\varsigma_b}{\varsigma_b-1}\left\{R_t - \kappa_{Kb}\left(\frac{K_t^b}{B_t^L} - \upsilon_t\right)\left(\frac{K_t^b}{B_t^L}\right)^2 + \gamma_B - \gamma\left(\frac{B_t^{CB}}{B_t^L}\right)^{0.5}\right\}$$

FOC, foreign borrowing:

$$-\mathbb{E}_t\mathcal{E}_{t+1}R_t^*L_t^* - \frac{\theta_0^{FC}}{2}\mathbb{E}_t\mathcal{E}_{t+1}R_t^*L_t^{*2} - \mathcal{E}_t\lambda_t^B L_t^*$$

$$\frac{\partial\mathcal{L}^B}{\partial L_t^*} = -\mathcal{E}_{t+1}R_t^* - \theta_0^{FC}R_t^*\mathcal{E}_{t+1}L_t^* - \mathcal{E}_t\lambda_t^B = 0$$

$$\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)R_t^* + \theta_0^{FC}R_t^*\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)L_t^* = R_t$$

$$\theta_0^{FC}R_t^*\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)L_t^* = R_t - \mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)R_t^*$$

Foreign bond

$$L_t^* = \frac{R_t - R_t^*\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)}{\theta_0^{FC}R_t^*\mathbb{E}_t\left(\mathcal{E}_{t+1}/\mathcal{E}_t\right)}$$

FOC, sterilization bonds issued by the central bank:

$$\frac{\partial\mathcal{L}^B}{\partial B_t^{CB}} = R_t^{CB} - \gamma_{B^{CB}} + \gamma\left(\frac{B_t^L}{B_t^{CB}}\right)^{0.5} + \lambda_t^B = 0$$

$$\gamma\left(\frac{B_t^L}{B_t^{CB}}\right)^{0.5} = -\lambda_t^B + \gamma_{B^{CB}} - R_t^{CB}$$

$$\gamma^2\left(\frac{B_t^L}{B_t^{CB}}\right) = \left[-\lambda_t^B + \gamma_{B^{CB}} - R_t^{CB}\right]^2$$

Sterilization bonds by central bank

$$\frac{B_t^{CB}}{B_t^L} = \frac{\gamma^2}{\left[R_t + \gamma_{B^{CB}} - R_t^{CB}\right]^2}$$

Non-tradable Phillips curve

The aggregate price of non-tradable goods is given by:

$$\left(\frac{P_t^N}{P_{t-1}^N}\right)^{1-\epsilon_N} = \theta_N + (1-\theta_N)\left(\frac{P_t^{N*}}{P_t^N}\right)^{1-\epsilon_N}$$

Log-linearized around the zero-non-tradable inflation steady state:

$$(1-\epsilon_N)\, log\left(\pi_t^N\right) = (1-\epsilon_N)(1-\theta_N)\left(log\left(P_t^{N*}\right) - log\left(P_{t-1}^N\right)\right)$$

$$log\left(\pi_t^N\right) = (1-\theta_N)\left(log\left(P_t^{N*}\right) - log\left(P_{t-1}^N\right)\right)$$

Rewrite the difference equation for optimal non-tradable price setting and use aggregate dynamics to obtain:

$$(1-\theta_N)^{-1} log\left(\pi_t^N\right) = (1-\theta_N)^{-1} \beta\theta_N \mathbb{E}_t log\left(\pi_{t+1}^N\right) + (1-\beta\theta_N)\, log\left(\frac{MC_t}{\overline{MC}}\right) + log\left(\pi_t^N\right)$$

Phillips Curve (non-tradable inflation) equation in New-Keynesian theory.

$$log\left(\pi_t^N\right) = \beta log\left(\pi_{t+1}^N\right) + \kappa_{pn} log\left(\frac{MC_t}{\overline{MC}}\right) \tag{85}$$

Where $\kappa_{pn} \equiv {}^{(1-\theta_N)(1-\beta\theta_N)}/_{\theta_N}$.