Incorporating financial stability considerations in policy analysis: a model for Latin American countries*

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Abstract

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1 Introduction

This paper summarizes a joint project undertaken by staff members from the central banks of Chile, Colombia, Mexico and Peru, under the auspices of the Consultative Council for the Americas (CCA) Research Network on “Introducing financial stability considerations into central bank policy models”, and coordinated by the Representative Office for the Americas of the Bank for International Settlements. This Research Network was aimed to strengthen the quantitative model infrastructure that central banks use in policy decisions by introducing financial transmission mechanisms and evaluating policies that support financial stability.

The project’s objective is to provide a model that can capture some salient characteristics of these countries and that, at the same time, can be useful for policy analysis. One noteworthy aspect of the countries under study is their exposure to commodity price fluctuations: the four economies are commodity exporters and, consequently, commodity price fluctuations appear to have substantial impact on their business cycles fluctuations. A second aspect is their exposure to financial factors. The four economies depend heavily on capital flows and external financing conditions; at the same time, their domestic financial system is less developed than in advanced economies and it is mostly concentrated in the banking sector. Entrepreneurs tend to face high borrowing costs, which in some cases depend on factors such as imperfect competition or regulation. For our project, we develop a model that attempts to capture these observations.

Likewise, our model attempts to shed light not only on conventionally defined monetary policy, but also on financial stability considerations and macroprudential policies. This wider scope is warranted given the increasing importance of "unconventional" monetary policy in Latin America, including countries that have adopted Inflation Targeting as the main monetary policy framework (Céspedes, Chang, and Velasco 2014).

The next section of this paper describes the basic characteristics of our model, emphasizing the specific assumptions we have made in order to capture the empirical regularities just mentioned. The third section presents the results from the estimation of the model for each country. A fourth section presents policy exercises with the estimated model. In particular, we analyse the effects of a sudden drop in commodity prices and tighter external financial conditions, and the implications of using other policy instruments alternative to the short term interest rate.

2 The model

A survey to the central bank participating in the project identified ingredients that a model should ideally include to capture the empirical regularities of the countries under focus:

- Small open economy
- Production with labour and capital as inputs
- Tradable, non-tradable and commodity sectors
- Nominal rigidities and indexation in prices and wages

- Incomplete pass-through in prices of imported goods
- Banking sector financing with financial frictions that generate time-varying interest rate spreads
- Traditional real rigidities to capture the dynamics of the data, such as: investment adjustment costs, habit formation in consumption and variable capital utilisation.
- Monetary policy performed using the short term interest rate as the policy instrument, following a Taylor rule.
- Modelling of trends.

Other ingredients, such as non-Ricardian agents needed to capture the effects of fiscal policy on aggregate activity were not considered relevant for the purpose of the model.

Existing small open economy models incorporate many but not all of these features. Our strategy to take one of them, the baseline model of Christiano, Trabandt and Walentin (2011, henceforth CTW) as a starting point, and extend it in two sustantive directions: (i) to accommodate domestic financial intermediaries (banks), so as to enrich the modeling of interest rate spreads and allow for a discussion of macroprudential policies, and (ii) to include a commodity sector. Below we focus on these extensions.

2.1 Modeling the financial sector and interest rate spreads[1]

The baseline CTW model does not include domestic financial intermediaries: households borrow or lend from the rest of the world and accumulate productive capital. For our purposes, and especially if we are to discuss macroprudential policy, this is a key omission. Hence we needed to reformulate the structure of the domestic economy and financial flows.

Our model assumes that capital is accumulated not by households but by a set of agents called entrepreneurs. There is also a set of financial intermediaries or banks, that collect deposits from households and lend to entrepreneurs. This structure gives rise to two domestic spreads: the difference between the interest rates that banks pay on deposits and the safe rate (that is, the rate on safe government bonds); and the difference between the bank's lending rate and the deposit rate. The two spreads naturally affect consumption and investment decisions.

Given this, a major decision is how to model the determination of the two spreads. Ideally, the spreads would be given by the solution of a widely accepted theoretical model of banks, built from first principles. Currently, however, no such theory exists, so in order to proceed we make reduced form assumptions on the determination of spreads. Following Alpanda, Cateau and Meh (2014, ACM hereon), we then assume that spreads increase with measures of debtor's leverage. This is a pseudo-structural approach to the idea that spreads reflect the costs of lenders' monitoring borrowers, and hence increase with leverage. This approach is pragmatic regarding the source of financial frictions; it is also flexible and rich of the relevant financial variables that can be considered, and thus of the macroprudential instruments that one can study. However, an important caveat is that this approach is not fully micro-founded,

[1] This section was prepared by Francisco Adame and Julio Carrillo (Bank of Mexico).

and the functional forms used to introduce credit-market imperfections may rise concerns for policy evaluation exercises.

We provide the main details next.

2.1.1 Households

There is a continuum mass one of households indexed by $h \in [0,1]$, who choose consumption $(c_{h,t})$, nominal bank deposits $(L^D_{h,t})$, nominal domestic and foreign government bond holdings ($B_{h,t}$ and $B^*_{h,t}$, respectively), and nominal wages $(W_{h,t})$ to maximize their lifetime utility. The objective of the household is thus

$$\max_{c_{h,t},L^D_{h,t},B_{h,t},B^*_{h,t},W_{h,t}} \mathrm{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[\zeta^c_\tau \ln\left(c_{h,\tau} - bc_{h,\tau-1}\right) - \zeta^h_\tau \psi \frac{\left(H_{h,\tau}\right)^{1+\sigma_h}}{1+\sigma_h} \right]$$

subject to

$$\begin{aligned} & c_{h,\tau} + \left(1+\Upsilon^D_t\right) \frac{L^D_{h,\tau}}{P_\tau} + \frac{B_{h,\tau}}{P_\tau R_\tau} + \frac{S_\tau B^*_{h,\tau}}{P_\tau \Phi_\tau R^*_\tau} \\ \leq \; & \frac{W_{h,\tau}}{P_\tau} H_{h,\tau} + R_{D,\tau-1} \frac{L^D_{h,\tau-1}}{P_\tau} + \frac{B_{h,\tau-1}}{P_\tau} + \frac{S_\tau B^*_{h,\tau-1}}{P_\tau} + \frac{\Lambda_{h,\tau}}{P_\tau} \end{aligned} \tag{2.1}$$

where b is a parameter controlling external habits, σ_h^{-1} is the Frisch elasticity of labor supply, ψ is a normalizing constant that ensures a certain level of labor at the deterministic steady-state, ζ^c_τ and ζ^h_τ are preference shocks affecting consumption demand and labor supply, H_t is the aggregated labor input, $\Lambda_t = -TR_t + \Pi_t + D^B_t + D^E_t + \mathcal{AD}_{h,t}$, denotes nominal net lump-sum taxes from the government (TR_t), nominal profits from the productive sector (Π_t), nominal dividends from banks and entrepreneurs (D^B_t, D^E_t), and Arrow-Debreu state-contingent securities $(\mathcal{AD}_{j,t})$ that ensures that every household start each period with the same wealth. In turn, P_t is the price index of the final good, S_t is the nominal exchange rate, Φ_t is the country risk premium, and $R_{D,t}$ is the interest rate paid on deposits. Finally, $1+\Upsilon^D_t$ is cost that households pay for monitoring their deposits.

Our specification of the Φ_t and $1+\Upsilon^D_t$ merit further explanation. Our assumption on the country risk premium is:

$$\Phi_t = \overline{\Phi} \exp\left\{ -\widetilde{\phi}_a \left(a_t - \overline{a}\right) - \widetilde{\phi}_s \left[R^*_t - R_t - \left(R^* - R\right)\right] + \widetilde{\phi}_t + \widetilde{\phi}_{cp,t} \right\} \tag{2.2}$$

where a_t is the normalized (detrended) stock of foreign assets, $\widetilde{\phi}_t$ is an unobserved risk shock, and $\widetilde{\phi}_{cp,t}$ is an observed shock to the country premium. This is as in CTW: the dependence of Φ_t on $a_t - \overline{a}$ ensures that there is a unique steady state value of a_t, while the dependence on the relative level of the interest rate $R^*_t - R_t$ allows for delayed exchange rate overshooting. But we also add a steady state differential $\bar{\Phi}$, as well as the country risk shock. We assume that the observable country spread corresponds to the term $\overline{\Phi} \exp\left\{ -\widetilde{\phi}_a \left(a_t - \overline{a}\right) + \widetilde{\phi}_{cp,t} \right\}$, which has an endogenous component reflecting fundamentals (as reflected by a_t) and an exogenous component reflecting deviations from fundamentals. According to the estimation for the model, observed and unobserved country risk shocks are important drivers of real exchange rate fluctuations in our sample of countries.

More importantly, the term $1+\Upsilon_t^D$ allows for the deposit interest rate to deviate from the safe rate, as we will see. In the spirit of ACM, we assume that this spread (the *bank funding spread*) depends on the balance sheet of the banking system:

$$1+\Upsilon_t^D = \left(\frac{\gamma_{t-j}}{capb_{t-j}/L_{t-j}^E}\right)^{\chi_D} \exp\left(\tilde{\varepsilon}_{D,t}\right),$$

where $\tilde{\varepsilon}_{D,t}$ is an AR(1) shock, χ_D is the elasticity of monitoring costs with respect to the bank capital gap, L_t^E is the total nominal value of bank loans given to entrepreneurs, $capb_t$ is the bank capital in nominal terms, γ_t is the capital requirement ratio, and j is a lag indicator, which by default we set to $j=0$. At the steady state, we assume that realized bank-capital-to-loans ratio, $\frac{capb}{L^E}$, equals γ.

The first order conditions of the representative household then include:[2]

$$\backslash c_{j,t} \quad : \quad \frac{\zeta_t^c}{c_t - bc_{t-1}} - \beta b \mathrm{E}_t\left\{\frac{\zeta_{t+1}^c}{c_{t+1}-bc_t}\right\} = \lambda_{P,t} \tag{2.3}$$

$$\backslash L_{j,t}^D \quad : \quad \lambda_{P,t}\frac{1+\Upsilon_t^D}{R_{D,t}} = \beta \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\pi_{t+1}}\right\} \tag{2.4}$$

$$\backslash B_{j,t} \quad : \quad \lambda_{P,t}\frac{1}{R_t} = \beta \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\pi_{t+1}}\right\} \tag{2.5}$$

$$\backslash B_{j,t}^* \quad : \quad \lambda_{P,t}\frac{1}{\Phi R_t^*} = \beta \mathrm{E}_t\left\{\lambda_{P,t+1}\frac{S_{t+1}}{S_t \pi_{t+1}}\right\} \tag{2.6}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ is the final-good *gross* inflation rate, and $\lambda_{P,t}$ is the lagrange multipier of the household problem. So we see that, as claimed,

$$R_{D,t} = R_t\left(1+\Upsilon_t^D\right). \tag{2.7}$$

2.1.2 Entrepreneurs

There is a mass one of entrepreneurs indexed by $i \in [0,1]$. These agents act as small business units, owned by households, whose main purpose in period t is to buy the stock of capital $K_{i,t}$ from capital producers at price P_t^k. Entrepreneurs also decide how much to borrow from banks (L_{it}^E) and how much to pay to households as dividends (D_{it}^E).

In time $t+1$, entrepreneurs rent their capital $K_{i,t}$ to the productive sector at the nominal rate Z_{t+1}, and sell the non-depreciated capital $(1-\delta)K_{i,t}$ at price P_{t+1}^k; δ is the depreciation rate of capital. Their objective is to maximize the discounted stream of real dividends, subject

[2] Notice that the presence of state-contingent securities ensures that all households begin a period with the same wealth and therefore choose the same level of consumption, deposit and bond holdings. Therefore, we can drop the subscript h in the first order conditions (FOCs) listed here.

to their relevant cash-flow condition. An entrepreneur's problem is thus

$$\max_{D_{i,t}^E,k_{i,t},l_{i,t}^E} \mathrm{E}_t \sum_{\tau=t}^{\infty} \beta_E^{\tau-t} \frac{\lambda_{P,\tau}}{\lambda_{P,t}} \left[\upsilon_{E,\tau} \frac{D_{i,\tau}^E}{P_\tau} \right]$$

subjet to

$$\begin{aligned} & \frac{D_{i,\tau}^E}{P_\tau} + \frac{P_\tau^k}{P_\tau}\left[K_{i,\tau} - (1-\delta)K_{i,\tau-1} + \tau_k \delta K_{i,\tau-1}\right] + R_{E,\tau-1}\frac{L_{i,\tau-1}^E}{P_\tau} \\ \leq\ & (1-\tau_k)\frac{Z_\tau}{P_\tau}K_{i,\tau-1} + \frac{L_{i,\tau}^E}{P_\tau} - \frac{\vartheta^e}{2}\left(\frac{D_{i,\tau}^E/D_{i,\tau-1}^E}{\pi_\tau} - \mu_a\right)^2 \frac{D_\tau^E}{P_\tau}, \end{aligned} \tag{2.8}$$

where $\upsilon_{E,\tau}$ is a shock that distorts the valuation of real dividends, $R_{E,t-1}$ is the nominal interest rate of bank loans, μ_a is the steady state growth rate of technological progress (i.e., $\mu_a = \frac{\bar{a}_t}{\bar{a}_{t-1}}$, where $\bar{a}_t$ is the level of technology that would prevail if there were no shocks), τ_k is a tax on capital, and ϑ^e is a level parameter governing the adjustment costs of real dividends. Notice that dividends adjustments costs are proportional to the aggregate level of entrepreneurs dividends, given by D_t^E. Adjustment costs are introduced by Alpanda et al. (2014) and Jermann and Quadrini (2012) to capture the smoothness of dividends observed in the corporate finance literature.

Defining $d_{i,t}^E \equiv \frac{D_{i,t}^E}{P_t}$, $d_t^E \equiv \frac{D_t^E}{P_t}$, $p_t^k \equiv \frac{P_t^h}{P_t}$, $\ell_{i,t}^E \equiv \frac{L_{i,t}^E}{P_t}$ and $z_t \equiv \frac{Z_t}{P_t}$, the FOC for the bank's optimization include;

$$\begin{aligned} \backslash d_{i,t}^E \quad &: \quad \left(\frac{d_t^E}{d_{t-1}^E} - \mu_a\right)\frac{d_t^E}{d_{t-1}^E} = \frac{1}{\vartheta^E}\left(\frac{\upsilon_{E,t}}{\lambda_{E,t}} - 1\right) \\ & \quad +\beta_E \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\frac{\lambda_{E,t+1}}{\lambda_{E,t}}\left(\frac{d_{t+1}^E}{d_t^E} - \mu_a\right)\left(\frac{d_{t+1}^E}{d_t^E}\right)^2\right\}, \end{aligned} \tag{2.9}$$

$$\backslash \ell_{i,t}^E \quad : \quad 1 = \beta_E \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\frac{\lambda_{E,t+1}}{\lambda_{E,t}}\frac{R_{E,t}}{\pi_{t+1}}\right\}, \tag{2.10}$$

$$\backslash K_{i,t} \quad : \quad 1 = \beta_E \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\frac{\lambda_{E,t+1}}{\lambda_{E,t}}\frac{R_{t+1}^k}{\pi_{t+1}}\right\}. \tag{2.11}$$

where $\lambda_{E,t}$ is the Lagrange multiplier on the normalized version of (2.8)

Notice that the last expression can be used to define the equilibrium rate of return to capital, where

$$\frac{R_{t+1}^k}{\pi_{t+1}} \equiv \frac{(1-\tau_k)\, z_{t+1} + p_{t+1}^k\left(1 - \delta\left(1+\tau_k\right)\right)}{p_t^k}$$

Also, the real net worth of entrepreneurs is then defined as

$$n_{it} = \frac{P_t^k}{P_t}K_{i,t} - \frac{L_{i,t}^E}{P_t} \tag{2.12}$$

2.1.3 Banks

A continuum of competitive banks, indexed by $j \in [0,1]$, use deposits and own retained earnings to finance one-period-maturity loans to entrepreneurs. The objective of a representative bank is to maximize the present value of real dividends payouts, i.e.

$$\max_{D_{j,t}^B, l_{j,t}^E, l_{j,t}^D} \mathrm{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \frac{\lambda_{P,\tau}}{\lambda_{P,t}} \left[\upsilon_{B,\tau} \frac{D_{j,\tau}^B}{P_\tau} \right],$$

subject to the bank cash-flow condition, in real terms, i.e.

$$\begin{aligned} & \frac{D_{j,\tau}^B}{P_\tau} + R_{D,\tau-1} \frac{L_{j,\tau-1}^D}{P_\tau} + \left(1+\Upsilon_\tau^E\right) \frac{L_{j,\tau}^E}{P_\tau} \\ \leq \; & R_{E,\tau-1} \frac{L_{j,\tau-1}^E}{P_\tau} + \frac{L_{j,\tau}^D}{P_\tau} - \frac{\vartheta^b}{2} \left(\frac{D_{j,\tau}^B / D_{j,\tau-1}^B}{\pi_\tau} - \mu_a \right)^2 \frac{D_\tau^B}{P_\tau}, \end{aligned} \tag{2.13}$$

where $D_{j,t}^B$ are nominal dividends, $L_{j,t}^E$ are loans to entrepreneurs, $L_{j,t}^D$ are deposits received from households, $R_{E,t}$ is the interest rate of loans, and ϑ^b is a level parameter that governs the quadratic costs of adjusting bank real dividends. Notice that the bank stochastic discount factor is $\left(\beta^E\right)^{\tau-t} \frac{\lambda_{P,\tau}}{\lambda_{P,t}}$, as households are the shareholders of the bank, but banks apply a higher discount rate than households.[3]

Finally, Υ_t^E represents monitoring costs incurred by the bank when extending loans to entrepreneurs, and is assumed to be given by

$$1+\Upsilon_t^E = (1+\Upsilon_{t-1}^E)^{\chi_{E,1}} \left[\chi_{E,0} \left(\frac{(1-m_{t-j})}{n_{t-j} / \left(p_{t-j}^k K_{t-j} \right)} \right)^{\chi_{E,3}} \right]^{1-\chi_{E,1}} \exp\left(\widetilde{\varepsilon}_{E,t}\right), \tag{2.14}$$

where $\chi_{E,0}$ is a level parameter that determines the lending spread at the steady state, $\chi_{E,1}$ is a parameter governing persistence, and $\chi_{E,3}$ is the elasticity of monitoring costs with respect to borrower leverage. In turn, K_t is total stock of capital of entrepreneurs at time t (that can be rented to firms only in time $t+1$), and m_t is the regulatory loan-to-value ratio of entrepreneurs. j is a lag indicator, which by default we set to $j=0$.

At the steady state, we assume that the realised debt-to-asset ratio, $\frac{\ell^E}{p^k K}$, equals m. Notice that monitoring costs depend on the aggregate networth of entrepreneurs, given by (in real terms)

$$n_t = p_t^k K_t - \frac{L_t^E}{P_t},$$

and the balance sheet of all banks, in real terms, is given by

$$\frac{L_t^E}{P_t} = \frac{L_t^D}{P_t} + \frac{capb_t}{P_t}. \tag{2.15}$$

[3] This follows ACM. Intuituvely, while all agents are forward looking, we need to assume that their discount factors differ in order to have a defined flow of funds allocation at the steady state. Thus, households and banks discount the future at rate $\beta_P = \beta_B = \beta$, and entrepreneurs do so at rate β_E. With $\beta > \beta_E$, we ensure that at the steady state households save, banks lend and keep positive dividends, and entrepreneurs borrow.

Finally, $\widetilde{\varepsilon}_{E,t}$ is an exogenous shock to monitoring costs which follows an AR(1) process. Let $\ell^D_{j,t} = \frac{L^D_{j,t}}{P_t}$, $d^B_{j,t} \equiv \frac{D^B_{j,t}}{P_t}$, and $d^B_t \equiv \frac{D^B_t}{P_t}$. Thus, the first order conditions of the bank are the following (since all banks face the same problem, we drop the subindex j; notice that each bank maximizes w.r.t. $d^B_{j,t}$, and not w.r.t. d^B_t, which is the sector aggregate)

$$\backslash d^B_{j,t} \quad : \quad \left(\frac{d^B_t}{d^B_{t-1}} - \mu_a\right)\frac{d^B_t}{d^B_{t-1}} = \frac{1}{\vartheta^b}\left(\frac{\upsilon_{B,t}}{\lambda_{B,t}} - 1\right) \tag{2.16}$$

$$+\beta \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\frac{\lambda_{B,t+1}}{\lambda_{B,t}}\left(\frac{d^B_{t+1}}{d^B_t} - \mu_a\right)\left(\frac{d^B_{t+1}}{d^B_t}\right)^2\right\},$$

$$\backslash \ell^D_{j,t} \quad : \quad / \ 1 = \beta \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\frac{\lambda_{B,t+1}}{\lambda_{B,t}}\frac{R_{D,t}}{\pi_{t+1}}\right\}, \tag{2.17}$$

$$\backslash \ell^E_{j,t} \quad : \quad 1 + \Upsilon^E_t = \beta \mathrm{E}_t\left\{\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\frac{\lambda_{B,t+1}}{\lambda_{B,t}}\frac{R_{E,t}}{\pi_{t+1}}\right\}. \tag{2.18}$$

The latter FOC imply that the lending spread is given by:

$$R_{E,t} = R_{D,t}\left(1 + \Upsilon^E_t\right). \tag{2.19}$$

Replacing equation (2.7) into (2.19) gives an expression for the total spread of the loans interest rate over the safe rate R_t.

We simulate the responses of the model to a 1% exogenous increase in monitoring costs incurred by the banks (Ψ^E_t) with persistence parameter $\rho_E = 0.5$. We use the baseline calibration from CTW and the additional parameters are $\chi_{E,3} = 0.1, \chi_{E,1} = 0.8, \chi_D = 1, \vartheta^e = 0.5$ and $\vartheta^b = 0.5$. Figure 2.1 shows the results. The exogenous increase in banks monitoring costs generate an increase in the lending spread and a reduction in credit. Also output, consumption, investment, exports and imports decrease, althouth the current account shows a surplus. In addition, both the price of capital, entrepreneurs networth and bank capitalisation decreases, which amplifies the effect on lending rates through a financial accelerator effect. The policy rates decreases following a reduction in consumer price inflation.

2.2 The commodity sector[4]

As mentioned, the countries participating in this project are major commodity exporters, and hence commodity price fluctuations are a main driver of business cycles in those countries. Hence, it is important to model the macroeconomic impact of commodity price and output fluctuations.

We include a commodity sector in the spirit of recent work by Medina and Soto (2007), Medina, Munro and Soto (2007), Hevia and Nicolini (2013), Catao and Chang (2013), and Garcia-Cicco, Kirchner and Justel (2014). In this sector, there is is a set of competitive firms

[4] This section was prepared by Markus Kirchner and Javier García-Cicco (Central Bank of Chile)

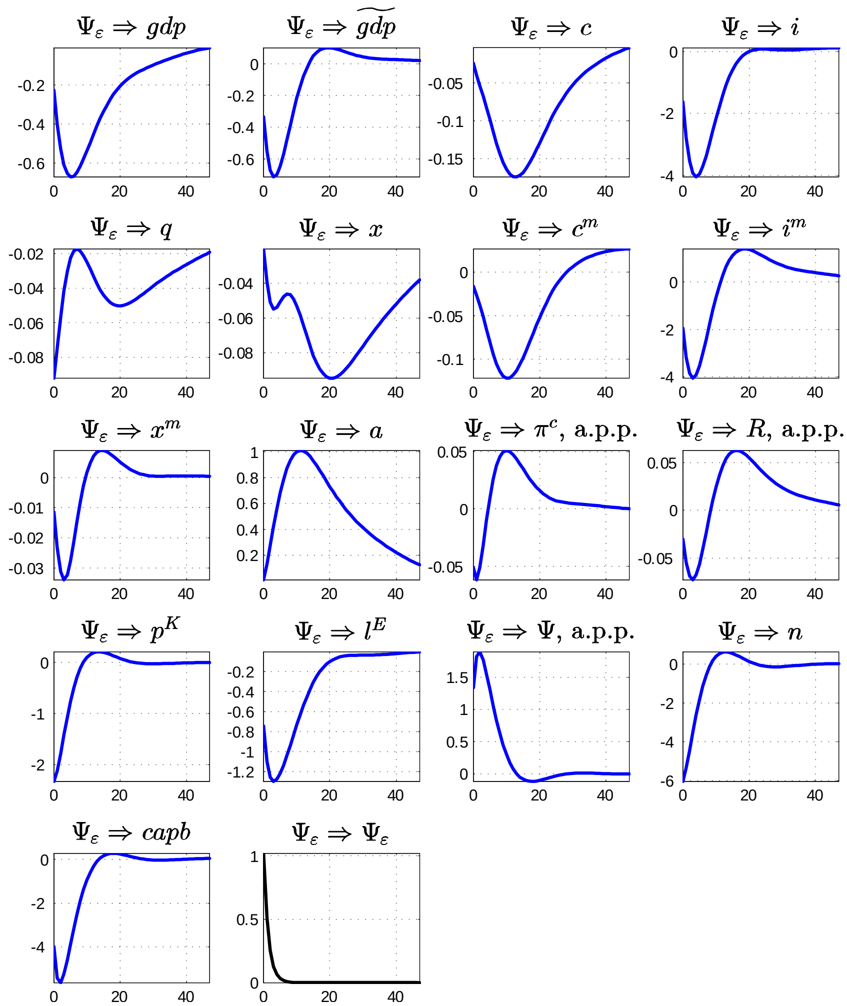

Figure 2.1: Impulse responses to a credit spread shock. CTW Model with Financial Sector.

that produce a homogeneous commodity good that is entirely exported abroad. Commodity producers take prices as given and demand is also exogenous. Therefore, commodity production has a pure income effect on domestic aggregate demand, which has expansive effects on the rest of the economy. Also, we further assume that a fraction of factor payments of commodity income is transferred abroad to foreign agents, which reduces its impact on the current account. This simple way of modelling the commodity sector allows us to capture most of the characteristics in the countries analysed.

More precisely, a firm in the commodity export sector is endowed with a quantity Y_t^{Co} of exports. Y_t^{Co} is assumed to evolve exogenously along the balanced growth path of the economy. The entire production is sold abroad at a given foreign price P_t^{Co*}. The associated real foreign price, $p_t^{Co*} = P_t^{Co*}/P_t^*$, is assumed to evolve exogenously. In terms of domestic currency, the income generated in the commodity sector is therefore given by $S_t P_t^{Co*} Y_t^{Co}$, where S_t is the nominal exchange rate. We assume that domestic agents receive a share $\chi \in [0, 1]$ of this income and that the remaining share goes to foreign investors.[5]

The precise assumptions are:

$$\ln y_t^{Co} = (1 - \rho_{y^{Co}}) \ln y^{Co} + \rho_{y^{Co}} \ln y_{t-1}^{Co} + \varepsilon_t^{y^{Co}}/100, \tag{2.20}$$

$$\ln p_t^{Co*} = (1 - \rho_{p^{Co*}}) \ln p^{Co*} + \rho_{p^{Co*}} \ln p_{t-1}^{Co*} + \varepsilon_t^{p^{Co*}}/100, \tag{2.21}$$

where $\varepsilon_t^{y^{Co}} \sim NID(0, \sigma^2_{y^{Co}})$ and $\varepsilon_t^{p^{Co*}} \sim NID(0, \sigma^2_{p^{Co*}})$, where $y_t^{Co} = Y_t^{Co}/z_t^+$ denotes real, scaled commodity output ($y_t^{Co} = Y_t^{Co}/z_t^+$, with z_t^+ an appropriate trend term).

The introduction of the commodity sector affects the evolution of net foreign assets, as shown by the link between net exports and the current account. From the definition of the current account, expenses on new purchases of net foreign assets, A_{t+1}^*, plus factor payments of commodity income to foreign agents and expenses on imports must equal income from exports and from previously purchased net foreign assets:

$$\begin{aligned} S_t A_{t+1}^* &+ \textit{factor payments of commodity income}_t + \textit{expenses on imports}_t \\ &= \textit{receipts from exports}_t + R_{t-1}^* \Phi_{t-1} S_t A_t^*. \end{aligned} \tag{2.22}$$

Factor payments of commodity income equal the share $1 - \chi$ of the income generated in the commodity sector that goes to foreign agents:

$$\textit{factor payments of commodity income}_t = (1 - \chi) S_t P_t^{Co*} Y_t^{Co}. \tag{2.23}$$

and the receipts from exports equal exports of the homogenous domestic good plus exports of the commodity good:

$$\textit{receipts from exports}_t = S_t P_t^x X_t + S_t P_t^{Co*} Y_t^{Co}. \tag{2.24}$$

In net, only the share of income from commodity exports received by domestic agents ($\chi S_t P_t^{Co*} Y_t^{Co}$.) affects the accumulation of net foreign assets.

[5] Since Ricardian equivalence holds in the model, it does not matter whether the government or private agents receive the share χ of the income generated in the commodity sector.

Also, the production of the commodity sector affects the evolution of the gross domestic product (GDP) and the GDP deflator. According to the definition of GDP, it equals to the production of the domestic homogeneous good minus capital utilisation costs plus the commodity production:

$$GDP_t = Y_t - a(u_t) K_t + Y_t^{Co} \tag{2.25}$$

Similarly, nominal GDP is defined by:

$$p_t^{gdp} GDP_t = Y_t - a(u_t) \overline{K}_t + q_t p_t^c p_t^{Co^*} Y_t^{Co} \tag{2.26}$$

where p_t^{gdp} and p_t^c are the relative price of the gdp deflator and the consumption basket with respect to the price of the homogeneous final good, and q_t is the real exchange rate. An increase in income from commodity production increases both total GDP and its price deflator.

We simulate the responses of the model to a 10% commodity price shock with persistence parameter $\rho_{p^{Co*}} = 0.95$. The additional parameters are $\chi = 0.61$ and $\eta_{y^{Co}} = 0.1$, and are taken from García-Cicco, Kirchner, and Justel (2014).[6] We also set $\delta = 0.015$ for this exercise and thus do not match the ratio of investment to GDP as in CTW, since it turned out that with the given calibration of $\eta_{y^{Co}}$ (and taking $\eta_i = 0.18$ from CTW) the value of δ obtained from the numerical solver would be larger than one. All other parameters are set to the values from the CTW model.

Figure 2.2 shows the results. The unexpected increase in the commodity price generates a positive income effect for domestic agents, which explains why the shock generates an expansion of consumption, investment and output (while government consumption, which is exogenous, does not respond to this shock by assumption - not shown in the figure). The shock furthermore generates a real exchange rate appreciation, and an associated increase in consumption and investment imports, and a decrease in non-commodity exports and raw imports used for these exports. Due to the real appreciation, inflation decreases under the given calibration and the associated response of the short-term interest rate through the Taylor rule is negative. It is interesting to note that the response of the utilization costs variable matters for the size of the response of real GDP (gdp_t vs. $\widetilde{gdp}_t$), which only tends to follow the response of non-commodity output if utilization costs are not subtracted from total output.

Finally, note that the impulse response dynamics due to the commodity price shock depend of course on the values of the structural parameters of the model. For example, it may be the case that under some other combination of parameters (substitution elasticities, Calvo probabilities, etc.), for instance based on an estimation of the model with the commodity sector, the response of inflation to the shock is positive and not negative as in Figure 2.2.

The presence of financial frictions amplifies the size of the endogenous variables responses to a commodity price shock, as it is shown in Figure **??**. The blue line depicts the case where financial frictions are absent, while the dashed red line shows the case where financial frictions are present. For output, we observe that with the current calibration (see previous section for the financial sector calibration) it initially falls in the financial frictions case, and it eventually overshoots the no financial frictions scenario. The responses of consumption, CPI inflation, and

[6] García-Cicco, J., M. Kirchner, and S. Justel (2014): "Financial Frictions and the Transmission of Foreign Shocks in Chile," Working Papers Central Bank of Chile 722.

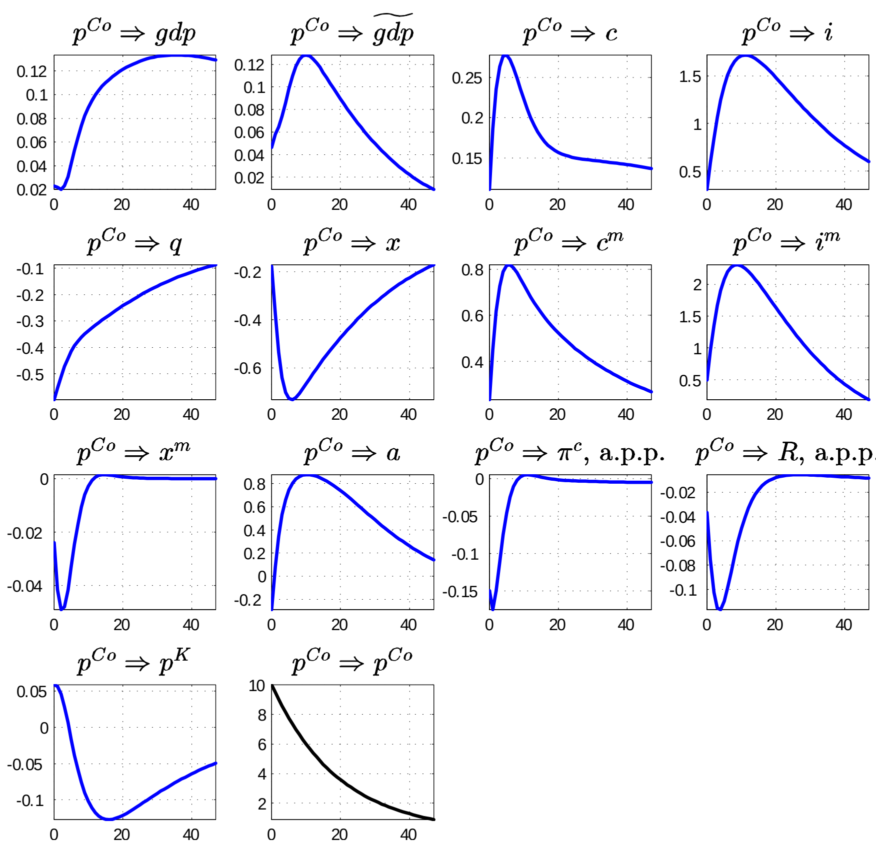

Figure 2.2: Impulse responses to a commodity price shock, CTW Model with Commodity Sector.

the nominal interest rate are clearly amplified, while the increase of investment is dampened. This effect on investment is explained by the decrease in the price of capital, that happens in the medium term even if financial frictions are not present. The latter has a negative impact on entrepreneur networth, which in turn increases the monitoring costs incurred by banks, and tighthen credit conditions. Notice that the fall in entrepreneurs networth could be moderated (or even reversed) if entrepreneurs would receive a proportion of the extra reveneus generated by the commodity sector. Finally, the differences between gdp_t and $\widetilde{gdp}_t$ indicate that the capital utilization costs are not negligable when there are shocks in the price of commodities.

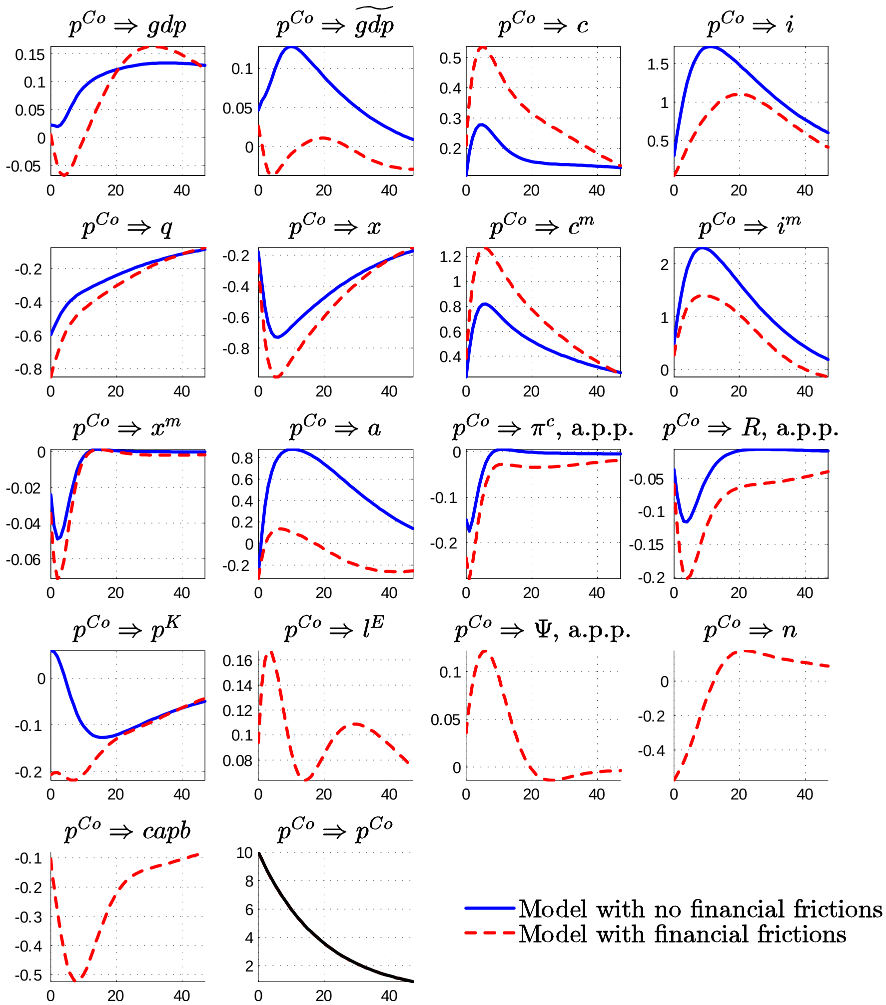

Figure 2.3: Impulse responses to a commodity price shock, CTW Model with Commodity Sector and Financial Sector.

3 Estimation and policy analysis for Chile

After this section's Appendix.

4 Estimation and policy analysis for Colombia

After section of Chile.

5 Estimation and policy analysis for Mexico

After section of Colombia.

6 Estimation and policy analysis for Peru

After section of Mexico.

7 Conclusions

TBC

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A Appendix: the set of equations [7,8]

A.1 Endogenous equations

The set of (84) equations of the endogenous variables of the model is composed by :

Equations of the financial sector

1.- Banks

1.1.-Spread in the banking sector, from maximization of household ($R_{D,t}$)

$$R_{D,t} = R_t \left(1 + \Upsilon_t^D\right) \tag{A-1}$$

1.2.- Balance sheet of the banks ($capb_t$)

$$capb_t = l_t^E - l_t^D + \tilde{\varepsilon}_{cap,t} \tag{A-2}$$

1.3.- Deposits' Monitoring cost (Υ_t^D)

$$1 + \Upsilon_t^D = \left(\frac{\gamma_{t-j}}{capb_{t-j}/L_{t-j}^E}\right)^{\chi_D} \exp\left(\tilde{\varepsilon}_{D,t}\right), \tag{A-3}$$

for $j \geq 0$

1.4.- Bank's FOC on dividends ($\lambda_{B,t}$)

$$\begin{aligned} &\left(\frac{d_t^B}{d_{t-1}^B}\mu_{z^+,t} - \mu_a\right)\frac{d_t^B}{d_{t-1}^B}\mu_{z^+,t} \qquad \text{(A-4)} \\ = \; &\frac{1}{\vartheta^b}\left(\frac{\upsilon_{B,t}}{\psi_{z^+,t}^B} - 1\right) + \beta \mathrm{E}_t\left[\frac{\psi_{z^+,t+1}}{\psi_{z^+,t}}\frac{\lambda_{B,t+1}}{\lambda_{B,t}}\left(\frac{d_{t+1}^B}{d_t^B}\mu_{z^+,t+1} - \mu_a\right)\left(\frac{d_{t+1}^B}{d_t^B}\right)^2 \mu_{z^+,t+1}\right], \end{aligned}$$

1.5.- Bank's Flow of funds of the banks (d_t^B)

$$\begin{aligned} &d_t^B + \frac{R_{D,t-1}}{\pi_t}\frac{l_{t-1}^D}{\mu_{z^+,t}} + \left(1 + \Upsilon_t^E\right) l_t^E \qquad \text{(A-5)} \\ = \; &\frac{R_{E,t-1}}{\pi_t}\frac{l_{t-1}^E}{\mu_{z^+,t}} + l_t^D - \frac{\vartheta^b}{2}\left(\frac{d_t^B}{d_{t-1}^B}\mu_{z^+,t} - \mu_a\right)^2 d_t^B, \end{aligned}$$

[7] We have modifed the code for the baseline version of the model in CTW. The CTW codes of the CTW are available at: http://faculty.wcas.northwestern.edu/~lchrist/course/Korea_2012/CTW.html, and the technical appendices are available at: http://www.riksbank.se/en/Press-and-published/Published-from-the-Riksbank/Other-reports/Working-Paper-Series/2007/No-214-Introducing-Financial-Frictions-and-Unemployment-into-a-Small-Open-Economy-Model-Revised/Equations Below, equations in **bold** correspond to those of the dynare codes, and equations in *italics* to those of the CTW working paper or appendix. Only as a reference, variables in braces correspond to those that each equation is useful to solve

[8] The non-stationary real variables have been scaled by z_t^+ and the nominal prices have been expressed in terms of relative prices. For more details see CTW 2011.

1.6.- Bank's FOC on deposits (l_t^E)

$$1 = \beta \mathrm{E}_t \left(\frac{\psi_{z^+,t+1}}{\psi_{z^+,t}} \frac{\lambda_{B,t+1}}{\lambda_{B,t}} \frac{1}{\mu_{z^+,t}} \frac{R_{D,t}}{\pi_{t+1}} \right), \tag{A-6}$$

2.- Entrepreneurs
2.1.-Spread for entrepreneurs sector, from maximization of banks ($R_{E,t}$)

$$R_{E,t} = R_{D,t} \left(1 + \Upsilon_t^E\right) \tag{A-7}$$

2.2.- Entrepreneur's banlance sheet (n_t)

$$n_t = p_t^k k_t - l_t^E \tag{A-8}$$

2.3.- Entrepreneurs' Monitoring cost (Υ_t^E)

$$1 + \Upsilon_t^E = (1 + \Upsilon_{t-1}^E)^{\chi_{E,1}} \left[\chi_{E,0} \left(\frac{(1 - m_{t-q})}{n_{t-q} / \left(p_{t-q}^k K_{t-q}\right)} \right)^{\chi_{E,3}} \right]^{1-\chi_{E,1}} \exp\left(\widetilde{\varepsilon}_{E,t}\right), \tag{A-9}$$

for $q \geq 0$
2.4.- Entrepreneur's Flow of funds (d_t^E)

$$\begin{aligned} & d_t^E + p_{k',t} \left[k_t - (1-\delta) \frac{k_{t-1}}{\mu_{z^+,t}\mu_{\Psi,t}} + \tau_k \delta \frac{k_{t-1}}{\mu_{z^+,t}\mu_{\Psi,t}} \right] + \frac{R_{E,t-1}}{\pi_t} \frac{l_{t-1}^E}{\mu_{z^+,t}} \\ = \;& (1-\tau_k) \left[\overline{r}_t^k - p_t^i a_t'\left(u_t\right) \frac{k_{t-1}}{\mu_{z^+,t}\mu_{\Psi,t}} \right] + l_t^E - \frac{\vartheta^e}{2} \left(\frac{d_t^E}{d_{t-1}^E} \mu_{z^+,t} - \mu_a \right)^2 d_t^E, \end{aligned} \tag{A-10}$$

2.5.- Entrepreneur's FOC on dividends ($\lambda_{E,t}$)

$$\begin{aligned} & \left(\frac{d_t^E}{d_{t-1}^E} \mu_{z^+,t} - \mu_a \right) \frac{d_t^E}{d_{t-1}^E} \mu_{z^+,t} \\ = \frac{1}{\vartheta^E} \left(\frac{\upsilon_{E,t}}{\psi_{z^+,t}^E} - 1 \right) \quad & + \beta_E \mathrm{E}_t \left[\frac{\psi_{z^+,t+1}}{\psi_{z^+,t}} \frac{\lambda_{E,t+1}}{\lambda_{E,t}} \left(\frac{d_{t+1}^E}{d_t^E} \mu_{z^+,t+1} - \mu_a \right) \left(\frac{d_{t+1}^E}{d_t^E} \right)^2 \mu_{z^+,t+1} \right], \end{aligned} \tag{A-11}$$

2.6.- Entrepreneur's FOC on loans (l_t^E)

$$1 = \beta_E \mathrm{E}_t \left[\frac{\psi_{z^+,t+1}}{\psi_{z^+,t}} \frac{\lambda_{E,t+1}}{\lambda_{E,t}} \frac{1}{\mu_{z^+,t}} \frac{R_{E,t}}{\pi_{t+1}} \right], \tag{A-12}$$

Equations of the commodity sector:
Definition of GDP:

$$gdp_t = y_t - a(u_t) \frac{\bar{k}_t}{\mu_{\psi,t}\mu_{z^+,t}} + y_t^{Co} \tag{A-13}$$

Definition of the GPD deflator:

$$p_t^{gdp} gdp_t = y_t - a(u_t)\frac{\bar{k}_t}{\mu_{\psi,t}\mu_{z^+,t}} + q_t p_t^c p_t^{Co*} y_t^{Co} \tag{A-14}$$

Set of equations of the CTW model modified with commodities[9]

[**1;** *2.4*] Domestic homog. good marginal costs

$\{mc_t = \text{lmcU}\}$:

$$mc_t = \tau_t^d \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} \left(r_t^k\right)^{\alpha} \left(\overline{w}_t R_t^f\right)^{1-\alpha} \frac{1}{\epsilon_t} \tag{A-15}$$

[**2**; *2.5*] 2nd definition of MC - Marginal production costs using labour

$\{H_t = \text{lHU}\}$:

$$mc_t = \tau_t^d \frac{\left(\mu_{\Psi,t}\right)^{\alpha} \overline{w}_t R_t^f}{\epsilon_t (1-\alpha) \left(\frac{k_t}{\mu_{z^+,t}}/H_t\right)^{\alpha}} \tag{A-16}$$

[**3..7**; *B.10..B.14*] Non-linear pricing equations for domestic intermediate goods producer Auxiliary variables price setting domestic goods $\left\{F_t^d = \text{lFdU}, K_t^d = \text{lKdU}\right\}$:

$$E_t\left[\psi_{z^+,t} y_t + \beta\xi_d \left(\frac{\widetilde{\pi}_{d,t+1}}{\pi_{t+1}}\right)^{\frac{1}{1-\lambda_d}} F_{t+1}^d - F_t^d\right] = 0 \tag{A-17}$$

$$E_t\left[\lambda_d \psi_{z^+,t} y_t mc_t + \beta\xi_d \left(\frac{\widetilde{\pi}_{d,t+1}}{\pi_{t+1}}\right)^{\frac{\lambda_d}{1-\lambda_d}} K_{t+1}^d - K_t^d\right] = 0 \tag{A-18}$$

Price dispertion domestic goods $\{p_t^\circ = \text{lphaloU}\}$:

$$\left(p_t^\circ\right)^{\frac{\lambda_d}{1-\lambda_d}} = (1-\xi_d)\left[\frac{1-\xi_d\left(\frac{\widetilde{\pi}_{d,t}}{\pi_t}\right)^{\frac{1}{1-\lambda_d}}}{1-\xi_d}\right]^{\lambda_d} + \xi_d\left(\frac{\widetilde{\pi}_{d,t}}{\pi_t} p_{t-1}^\circ\right)^{\frac{\lambda_d}{1-\lambda_d}} \tag{A-19}$$

Domestic goods inflation rate $\{\pi_t = \text{lpiU}\}$

$$\left[\frac{1-\xi_d\left(\frac{\widetilde{\pi}_{d,t}}{\pi_t}\right)^{\frac{1}{1-\lambda_d}}}{1-\xi_d}\right]^{(1-\lambda_d)} = \frac{K_t^d}{F_t^d} \tag{A-20}$$

Domestic goods indexation rule $\{\widetilde{\pi}_{d,t}/\pi_t = \text{lpitildeppiU}\}$

$$\widetilde{\pi}_{d,t} = \left(\pi_{t-1}\right)^{\kappa_d} \left(\overline{\pi}_t^c\right)^{1-\kappa_d-\varkappa_d} \left(\widehat{\pi}\right)^{\varkappa_d} \tag{A-21}$$

[**8..12**; *B.16..B.19,2.27*] Non-linear pricing equations for export goods producer

[9] Equations marked with (*) have been modified with respect to CTW.

Auxiliary variables price setting export goods $\{F_{x,t} = \text{lFxU}, K_{x,t} = \text{lKxU}\}$:

$$E_t \left[\psi_{z^+,t} q_t p_t^c p_t^x x_t + \beta \xi_x \left(\frac{\widetilde{\pi}_{t+1}^x}{\pi_{t+1}^x} \right)^{\frac{1}{1-\lambda_x}} F_{t+1}^x - F_t^x \right] = 0 \tag{A-22}$$

$$E_t \left[\lambda_x \psi_{z^+,t} q_t p_t^c p_t^x x_t mc_t^x + \beta \xi_x \left(\frac{\widetilde{\pi}_{t+1}^x}{\pi_{t+1}^x} \right)^{\frac{\lambda_x}{1-\lambda_x}} K_{t+1}^x - K_t^x \right] = 0 \tag{A-23}$$

Price dispertion export goods $\{p_t^{\circ x} = \text{lphaloxU}\}$

$$(p_t^{\circ x})^{\frac{\lambda_x}{1-\lambda_x}} = (1 - \xi_x) \left[\frac{1 - \xi_x \left(\frac{\widetilde{\pi}_t^x}{\pi_t^x} \right)^{\frac{1}{1-\lambda_x}}}{1 - \xi_x} \right]^{\lambda_x} + \xi_x \left(\frac{\widetilde{\pi}_t^x}{\pi_t^x} p_{t-1}^{\circ x} \right)^{\frac{\lambda_x}{1-\lambda_x}} \tag{A-24}$$

Export goods inflation rate $\{\pi_t^x = \text{lpixU}\}$

$$\left[\frac{1 - \xi_x \left(\frac{\widetilde{\pi}_t^x}{\pi_t^x} \right)^{\frac{1}{1-\lambda_x}}}{1 - \xi_x} \right]^{(1-\lambda_x)} = \frac{K_t^x}{F_t^x} \tag{A-25}$$

Export goods indexation rule $\{\widetilde{\pi}_t^x / \pi_t^x = \text{lpitildexpiU}\}$

$$\widetilde{\pi}_t^x = \left(\pi_{t-1}^x \right)^{\kappa_x} \left(\overline{\pi}_t^c \right)^{1-\kappa_x-\varkappa_x} \left(\widehat{\pi} \right)^{\varkappa_x} \tag{A-26}$$

[**13..17,18..20,23..27**; *B.25..B.28, 2.32*] Non-linear pricing equations for consumption, export-inputs and investment importers (for $j = c, i, x$)

Auxiliary variables investment importers price setting $\{F_{m,j,t} = \text{lFmjU}, K_{m,j,t} = \text{lKmjU}\}$:

$$E_t \left[\psi_{z^+,t} p_t^{m,j} \Xi_t^j + \beta \xi_{m,j} \left(\frac{\widetilde{\pi}_{t+1}^{m,j}}{\pi_{t+1}^{m,j}} \right)^{\frac{1}{1-\lambda_{m,j}}} F_{m,j,t+1} - F_{m,j,t} \right] = 0 \tag{A-27}$$

$$E_t \left[\lambda_x \psi_{z^+,t} p_t^{m,j} mc_t^{m,j} \Xi_t^j + \beta \xi_x \left(\frac{\widetilde{\pi}_{t+1}^{m,j}}{\pi_{t+1}^{m,j}} \right)^{\frac{\lambda m.j}{1-\lambda_{m.j}}} K_{m,j,t+1} - K_{m,j,t} \right] = 0 \tag{A-28}$$

where $\Xi_t^j = \{c_t^m \text{ if } j = c, i_t^m \text{ if } j = i, x_t^m \text{ if } j = x\}$.

Price dispersion investment importers $\left\{ p_t^{\circ m,j} = \text{lphalomjU};\ j = c, i, x \right\}$

$$\left(p_t^{\circ m,j} \right)^{\frac{\lambda_{m,j}}{1-\lambda_{m,j}}} = \left(1 - \xi_{m,j} \right) \left[\frac{1 - \xi_{m,j} \left(\frac{\widetilde{\pi}_t^{m,j}}{\pi_t^{m,j}} \right)^{\frac{1}{1-\lambda_{m,j}}}}{1 - \xi_{m,j}} \right]^{\lambda_{m,j}} + \xi_{m,j} \left(\frac{\widetilde{\pi}_t^{m,j}}{\pi_t^{m,j}} p_{t-1}^{\circ m,j} \right)^{\frac{\lambda_{m,j}}{1-\lambda_{m,j}}} \tag{A-29}$$

Investment importers inflation rate $\left\{\pi_t^{m,j} = \text{lpimjU};\ j = c, i, x\right\}$

$$\left[\frac{1-\xi_{m,j}\left(\frac{\widetilde{\pi}_t^{m,j}}{\pi_t^{m,j}}\right)^{\frac{1}{1-\lambda_{m,j}}}}{1-\xi_{m,j}}\right]^{(1-\lambda_{m,j})} = \frac{K_t^{m,j}}{F_t^{m,j}} \tag{A-30}$$

Investment importers indexation rule $\left\{\widetilde{\pi}_t^{m,j} = \text{lpitildemjpiU};\ j = c, i, x\right\}$

$$\widetilde{\pi}_t^{m,j} = \left(\pi_{t-1}^{m,j}\right)^{\kappa_{m,j}} \left(\overline{\pi}_t^{c}\right)^{1-\kappa_{m,j}-\varkappa_{m,j}} \left(\widehat{\pi}\right)^{\varkappa_{m,j}} \tag{A-31}$$

[**28**; *2.32*] Domestic consumption inflation $\{\pi_t^c = \text{lpicU}\}$:

$$\pi_t^c = \pi_t \left[\frac{(1-\omega_c) + \omega_c \left(p_t^{m,c}\right)^{1-\eta_c}}{(1-\omega_c) + \omega_c \left(p_{t-1}^{m,c}\right)^{1-\eta_c}}\right]^{\frac{1}{1-\eta_c}} \tag{A-32}$$

[**29**; *2.12*] Domestic investment inflation $\left\{\pi_t^i = \text{lpiiU}\right\}$:

$$\pi_t^i = \frac{\pi_t}{\mu_{\Psi,t}} \left[\frac{(1-\omega_i) + \omega_i \left(p_t^{m,i}\right)^{1-\eta_i}}{(1-\omega_i) + \omega_i \left(p_{t-1}^{m,i}\right)^{1-\eta_i}}\right]^{\frac{1}{1-\eta_i}} \tag{A-33}$$

[**30**; *2.16*] Law of motion of physical capital $\left\{\overline{k}_{t+1} = \text{lkbarU}\right\}$

$$\overline{k}_{t+1} = \frac{1-\delta}{\mu_{z^+,t}\mu_{\Psi,t}}\overline{k}_t + \Upsilon_t \left[1 - \widetilde{S}\left(\frac{\mu_{z^+,t}\mu_{\Psi,t} i_t}{i_{t-1}}\right)\right] i_t \tag{A-34}$$

[**31**; *2.39*] Household consumption FOC $\{c_t = \text{lcU}\}$

$$\frac{\zeta_t^c}{c_t - bc_{t-1}\frac{1}{\mu_{z^+,t}}} - \beta b E_t\left(\frac{\zeta_{t+1}^c}{c_{t+1}\mu_{z^+,t+1} - bc_t}\right) - \psi_{z^+,t} p_t^c \left(1+\tau^c\right) = 0 \tag{A-35}$$

[**32**; *2.42*] Household capital FOC$\left\{p_{k',t} = \text{lpkprimeU}\right\}$ **(*)**:

$$\psi_{z^+,t}\lambda_{E,t} = \beta E_t\left(\psi_{z^+,t+1}\lambda_{E,t+1}\frac{R_{t+1}^k}{\pi_{t+1}\mu_{z^+,t+1}}\right) \tag{A-36}$$

[**35**; *2.43*] Household investment FOC $\{i_t = \text{liU}\}$

$$\begin{aligned} 0 \;=\; & -\psi_{z^+,t}p_t^i + \psi_{z^+,t}p_{k',t}\Upsilon_t\left[1 - \widetilde{S}\left(\mu_{z^+,t}\mu_{\Psi,t}\frac{i_t}{i_{t-1}}\right) - \widetilde{S}'\left(\mu_{z^+,t}\mu_{\Psi,t}\frac{i_t}{i_{t-1}}\right)\mu_{z^+,t}\mu_{\Psi,t}\frac{i_t}{i_{t-1}}\right] \\ & +\beta\psi_{z^+,t+1}p_{k',t+1}\Upsilon_{t+1}\widetilde{S}'\left(\mu_{z^+,t+1}\mu_{\Psi,t+1}\frac{i_{t+1}}{i_t}\right)\left(\frac{i_{t+1}}{i_t}\right)^2\mu_{z^+,t+1}\mu_{\Psi,t+1} \end{aligned} \tag{A-37}$$

[**36**; *2.44*] Household capital util. FOC $\{u_t = \text{luU}\}$

$$\overline{r}_t^k = p_t^i a'(u_t) \tag{A-38}$$

where $a'(u_t) = \sigma_b \sigma_a u_t + \sigma_b (1-\sigma_a)$.

[**37;** *2.47*] Household foreign assets FOC $\{s_t = \text{lsU}\}$ **(*)**

$$\psi_{z^+,t} = \beta E_t \left[\frac{\psi_{z^+,t+1}}{\mu_{z^+,t+1}} \frac{s_{t+1}R_t^*\Phi_t - \tau^b (s_{t+1}R_t^*\Phi_t - \pi_{t+1})}{\pi_{t+1}} \right] \tag{A-39}$$

where $\Phi_t = \overline{\Phi} \exp\left\{ -\widetilde{\phi}_a (a_t - \overline{a}) - \widetilde{\phi}_s [R_t^* - R_t - (R^* - R)] + \widetilde{\phi}_t + \widetilde{\phi}_{cp,t} \right\}$ is the risk adjustment of the foreign asset return (equation 2.48 of the working paper), which includes a steady state country premium ($\overline{\Phi}$) and a observed shock to the country premium ($\widetilde{\phi}_{cp,t}$).

[**38**; *2.45*] Household domestic assets FOC $\left\{\psi_{z^+,t} = \text{lpsizplusU}\right\}$

$$\psi_{z^+,t} = \beta E_t \left[\frac{\psi_{z^+,t+1}}{\mu_{z^+,t+1}} \frac{R_t - \tau^b (R_t - \pi_{t+1})}{\pi_{t+1}} \right] \tag{A-40}$$

[**39..43**; *B33..B35, B31, 2.35*] Equilibrium conditions for sticky wages

Auxiliary variables wage setting $\{F_{w,t} = \text{lFwU}, K_{w,t}{=}\text{lKwU}\}$:

$$F_{w,t} = \frac{\psi_{z^+,t}}{\lambda_w} (w_t^\circ)^{-\frac{\lambda_w}{1-\lambda_w}} h_t \frac{1-\tau_t^y}{1+\tau^w} + \beta \xi_w E_t \left[\left(\frac{\overline{w}_{t+1}}{\overline{w}_t} \right) \left(\frac{\widetilde{\pi}_{w,t+1}}{\pi_{w,t+1}} \right)^{\frac{1}{1-\lambda_w}} F_{w,t+1} \right] \tag{A-41}$$

$$K_{w,t} = \zeta_t^h \left[(w_t^\circ)^{-\frac{\lambda_w}{1-\lambda_w}} h_t \right]^{1+\sigma_L} + \beta \xi_w E_t \left[\left(\frac{\widetilde{\pi}_{w,t+1}}{\pi_{w,t+1}} \right)^{\frac{\lambda_w}{1-\lambda_w}(1+\sigma_L)} K_{w,t+1} \right] \tag{A-42}$$

Wage inflation $\{\pi_{w,t} = \text{lpiwU}\}$:

$$\frac{\overline{w}_t}{A_L} \left[\frac{1 - \xi_w \left(\frac{\widetilde{\pi}_t^w}{\pi_t^w} \right)^{\frac{1}{1-\lambda_w}}}{1-\xi_w} \right]^{1-\lambda_w(1+\sigma_L)} = \frac{K_{w,t}}{F_{w,t}} \tag{A-43}$$

Wage dispersion $\{w_t^\circ = \text{lwhaloU}\}$:

$$(w_t^\circ)^{\frac{\lambda_w}{1-\lambda_w}} = (1-\xi_w) \left[\frac{1 - \xi_w \left(\frac{\widetilde{\pi}_t^w}{\pi_t^w} \right)^{\frac{1}{1-\lambda_w}}}{1-\xi_w} \right]^{\lambda_w} + \xi_w \left(\frac{\widetilde{\pi}_{w,t}}{\pi_{w,t}} w_{t-1}^\circ \right)^{\frac{\lambda_w}{1-\lambda_w}} \tag{A-44}$$

Wage indexation rule $\{\widetilde{\pi}_{w,t}/\pi_{w,t} = \text{lpitildewpiU}\}$:

$$\widetilde{\pi}_{w,t} = \left(\pi_{t-1}^c\right)^{\kappa_w} \left(\overline{\pi}_t^c\right)^{1-\kappa_w-\varkappa_w} (\widehat{\pi})^{\varkappa_w} (\mu_{z^+})^{\vartheta_w} \tag{A-45}$$

[**76**; *2.49*] Taylor rule $\{R_t = \text{lRU}\}$ **(*)**

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\overline{\pi}_t^c}{\overline{\pi}^c}\right)\left(\frac{\pi_t^c}{\overline{\pi}_t^c}\right)^{r_\pi}\left(\frac{gdp_t}{\overline{gdp}}\right)^{r_y}\left(\frac{gdp_t}{gdp_{t-1}}\right)^{r_{\Delta y}}\right]^{1-\rho_R} \exp\left(\varepsilon_{R,t}/100\right) \quad \text{(A-46)}$$

[**77**; *2.51*] Adjusted resources constraint $\{y_t = \text{lyU}\}$:

$$\begin{aligned} y_t &= g_t + (1-\omega_c)\left(p_t^c\right)^{\eta_c} c_t + (1-\omega_i)\left(p_t^i\right)^{\eta_i}\left[i_t + a(u_t)\frac{\overline{k}_t}{\mu_{\Psi,t}\mu_{z^+,t}}\right] \\ &\quad + (1-\omega_x)\left[1-\omega_x+\omega_x\left(p_t^{m,x}\right)^{1-\eta_x}\right]^{\frac{\eta_x}{1-\eta_x}}\left(p_t^{\circ x}\right)^{\frac{-\lambda_x}{\lambda_x-1}}\left(p^x\right)^{-\eta_f} y_t^* \end{aligned} \quad \text{(A-47)}$$

[**78**; *2.52*] Current account $\{a_t = \text{aU}\}$ **(*)**:

$$\begin{aligned} & a_t + q_t p_t^c R_t^{v,*}\left[c_t^m\left(p_t^{\circ m,c}\right)^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}} + i_t^m\left(p_t^{\circ m,i}\right)^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} + x_t^m\left(p_t^{\circ m,x}\right)^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}}\right] \\ = \; & q_t p_t^c p_t^x x_t + R_{t-1}^*\Phi_{t-1}s_t\frac{a_{t-1}}{\pi_t\mu_{z^+,t}} + \chi q_t p_t^c p_t^{Co*} y_t^{Co} \end{aligned} \quad \text{(A-48)}$$

where $\Phi_t = \overline{\Phi}\exp\left\{-\widetilde{\phi}_a\left(a_t-\overline{a}\right) - \widetilde{\phi}_s\left[R_t^* - R_t - (R^*-R)\right] + \widetilde{\phi}_t + \widetilde{\phi}_{cp,t}\right\}$ is the risk adjustment of the foreign asset return (equation 2.48 of the working paper), which includes a steady state country premium ($\overline{\Phi}$) and a observed shock to the country premium ($\widetilde{\phi}_{cp,t}$).

[**79**; *2.20*] Marginal costs of final export goods $\{mc_t^x = \text{lmcxU}\}$

$$mc_t^x = \frac{\tau_t^x R_t^x}{q_t p_t^c p_t^x}\left[1-\omega_x+\omega_x\left(p_t^{m,x}\right)^{1-\eta_x}\right]^{\frac{1}{1-\eta_x}} \quad \text{(A-49)}$$

[**80..82**; *B.24*] Marginal costs of consumption, investment, export importers $\left\{mc_t^{m,j} = \text{lmcmjU}; j = c,i,x\right\}$:

$$mc_t^{m,j} = \tau_t^{m,j}\frac{q_t p_t^c}{p_t^{m,j}}R_t^{v,*} \quad \text{(A-50)}$$

[**83**; *B.39*] Real GDP, defined from the production side $\left\{r_t^k = \text{lrkbarU}\right\}$

$$y_t = \left(p_t^{\circ}\right)^{\frac{\lambda_d}{\lambda_{d-1}}}\left[\epsilon_t\left(\frac{k_t}{\mu_{\Psi,t}\mu_{z^+,t}}\right)^{\alpha}H_t^{1-\alpha} - \phi\right] \quad \text{(A-51)}$$

[**84**; *B3*] Functional form for the capital utilization alpha $\{\alpha(u_t) = \text{aofuU}\}$:

$$a(u_t) = 0.5\sigma_b\sigma_a u_t^2 + \sigma_b(1-\sigma_a)u_t + \sigma_b(\sigma_a/2-1) \quad \text{(A-52)}$$

[**85**; *2.3*] Definition of Rf $\left\{R_t^f = \text{lRfU}\right\}$

$$R_t^f = v^f R_t + 1 - v^f \quad \text{(A-53)}$$

[**86**; *2.29*] Definition of Rnustar $\left\{R_t^{v,*} = \text{lRnustarU}\right\}$

$$R_t^{v,*} = v^* R_t + 1 - v^* \tag{A-54}$$

[**87**; *B15*] Total foreign export demand $\{x_t = \text{lxU}\}$

$$x_t = (p_t^x)^{-\eta_f}\, y_t^* \tag{A-55}$$

[**88**; *2.11*] Relative price of final consumption good $\{p_t^c = \text{lpcU}\}$:

$$p_t^c = \left[1 - \omega_c + \omega_c\, (p_t^{m,c})^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}} \tag{A-56}$$

[**89**; *2.15*] Relative price of final investment good $\left\{p_t^i = \text{lpinvestU}\right\}$:

$$p_t^i = \left[1 - \omega_i + \omega_i \left(p_t^{m,i}\right)^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}} \tag{A-57}$$

[**90**; *2.21*] Definition of Rx $\{R_t^x = \text{lRxU}\}$:

$$R_t^x = v^x R_t + 1 - v^x \tag{A-58}$$

[91; B39-note] Capital services$\{k_t = \text{lkU}\}$

$$k_t = \overline{k}_t u_t \tag{A-59}$$

[**92..96**, *B40..B44*] Dynamics of pmx, pmc, pmi, pmx and the real exchange rate $\left\{p_t^{m,x} = \text{lpmxU}, p_t^{m,c} = \text{lpmcU}, p_t^{m,i} = \text{lpmiU}, p_t^x = \text{lpxU}, q_t = \text{lqU}\right\}$:

$$\frac{p_t^{m,x}}{p_{t-1}^{m,x}} = \frac{\pi_t^{m,x}}{\pi_t} \tag{A-60}$$

$$\frac{p_t^{m,c}}{p_{t-1}^{m,c}} = \frac{\pi_t^{m,c}}{\pi_t} \tag{A-61}$$

$$\frac{p_t^{m,i}}{p_{t-1}^{m,i}} = \frac{\pi_t^{m,i}}{\pi_t} \tag{A-62}$$

$$\frac{p_t^{x}}{p_{t-1}^{x}} = \frac{\pi_t^{x}}{\pi_t^*} \tag{A-63}$$

$$\frac{q_t}{q_{t-1}} = \frac{s_t \pi_t^*}{\pi_t^c} \tag{A-64}$$

[**97..98**; *B4..B5*] Dummy variables for investment const function and its derivative

$\left\{\widetilde{S}_t = \text{StildeU}, \widetilde{S}'_t = \text{SprimetildeU}\right\}$:

$$S(x) = \frac{1}{2}\left\{\exp\left[\sqrt{S''}\,(x-\mu_{z^+}\mu_\Psi)\right] + \exp\left[-\sqrt{S''}\,(x-\mu_{z^+}\mu_\Psi)\right] - 2\right\} \quad \text{(A-65)}$$

$$S'(x) = \frac{1}{2}\sqrt{S''}\left\{\exp\left[\sqrt{S''}\,(x-\mu_{z^+}\mu_\Psi)\right] - \exp\left[-\sqrt{S''}\,(x-\mu_{z^+}\mu_\Psi)\right]\right\} \quad \text{(A-66)}$$

[**99**; *2.45*] Definition of rate of return of capital $\left\{R_t^k = \text{lRkU}\right\}$

$$R_t^k = \frac{\pi_t}{\mu_{\Psi,t}} \frac{\left(1-\tau^k\right)\left[u_t \bar{r}_t^k - p_t^i a(u_t)\right] + (1-\delta)\,p_{k',t} + \tau^k \delta \frac{\mu_{\Psi,t}}{\pi_t} p_{k',t-1}}{p_{k',t-1}} \quad \text{(A-67)}$$

where in the code CTW use the FOC for capital utilisation: $\bar{r}_t^k = p_t^i a'(u_t)$.
[**100**; *B30*] Relation between smallh and H $\{h_t = \text{lsmallhU}\}$

$$h_t = \left(w_t^{\circ}\right)^{\frac{\lambda_w}{1-\lambda_w}} H_t \quad \text{(A-68)}$$

[**101**; *2.10*] Imported consumption $\{c_t^m = \text{lcmU}\}$:

$$c_t^m = \omega_c \left(\frac{p_t^c}{p_t^{m,c}}\right)^{\eta_c} c_t \quad \text{(A-69)}$$

where $p_t^c = P_t^c/P_t$ and $p_t^{m,c} = P_t^{m,c}/P_t$
[**102**; *2.14*] Imported investment $\{i_t^m = \text{limU}\}$:

$$i_t^m = \omega_i \left(\frac{p_t^i}{p_t^{m,i}}\right)^{\eta_i} \left(i_t + \alpha(u_t)\frac{\bar{k}_t}{\mu_{\Psi,t}\mu_{z^+,t}}\right) \quad \text{(A-70)}$$

[**103**; *B.22*] Imported export inputs $\{x_t^m = \text{lxmU}\}$

$$x_t^m = \omega_x \left(\frac{\left[1-\omega_x + \omega_x \left(p_t^{m,x}\right)^{1-\eta_x}\right]^{\frac{1}{1-\eta_x}}}{p_t^{m,x}}\right)^{\eta_x} \left(p_t^{\circ x}\right)^{\frac{-\lambda_x}{\lambda_x - 1}} \left(p^x\right)^{-\eta_f} y_t^* \quad \text{(A-71)}$$

[**104**; *B.29*] $\{\overline{w}_t = \text{lwbarU}\}$

$$\pi_{w,t} = \frac{\overline{w}_t}{\overline{w}_{t-1}} \mu_{z^+,t+1} \pi_{t+1} \quad \text{(A-72)}$$

A.2 Equations for the law of motions of exogenous processes

[**105**] Composite technology growth $\left\{\ln \mu_{z^+,t} = \text{lmuzplusU}\right\}$

$$\ln \mu_{z^+,t} = \frac{\alpha}{1-\alpha} \ln \mu_{\Psi,t} + \ln \mu_{z,t}$$

[**106..110**] Mark-up domestic, exports, imported consumption, imported investment and imported export goods.
$\left\{\ln \tau_t^d = \text{ltaudU}, \ln \tau_t^x = \text{ltauxU}, \ln \tau_t^{m,c} = \text{ltaumcU}, \ln \tau_t^{m,i} = \text{ltaumiU}, \ln \tau_t^{m,x} = \text{ltaumxU}\right\}$

$$\begin{aligned}
\ln \tau_t^d - \ln \tau^d &= \rho_{\tau^d} \left(\ln \tau_{t-1}^d - \ln \tau^d\right) + \varepsilon_{\tau^d,t}/10 \\
\ln \tau_t^x - \ln \tau^x &= \rho_{\tau^x} \left(\ln \tau_{t-1}^x - \ln \tau^x\right) + \varepsilon_{\tau^x,t}/10 \\
\ln \tau_t^{m,c} - \ln \tau^{m,c} &= \rho_{\tau^{m,c}} \left(\ln \tau_{t-1}^{m,c} - \ln \tau^{m,c}\right) + \varepsilon_{\tau^{m,c},t}/10 \\
\ln \tau_t^{m,i} - \ln \tau^{m,i} &= \rho_{\tau^{m,i}} \left(\ln \tau_{t-1}^{m,i} - \ln \tau^{m,i}\right) + \varepsilon_{\tau^{m,i},t}/10 \\
\ln \tau_t^{m,x} - \ln \tau^{m,x} &= \rho_{\tau^{m,x}} \left(\ln \tau_{t-1}^{m,x} - \ln \tau^{m,x}\right) + \varepsilon_{\tau^{m,x},t}/10
\end{aligned}$$

[**111**] Stationary neutral technology shock $\{\ln \epsilon_t = \text{lepsilonU}\}$

$$\ln \epsilon_t = (1-\rho_\epsilon) \ln \epsilon + \rho_\epsilon \ln \epsilon_{t-1} + \varepsilon_{\epsilon,t}/100$$

[**112**] Investment specific technology shock $\{\ln \Upsilon_t = \text{lUpsilonU}\}$

$$\ln \Upsilon_t = (1-\rho_\Upsilon) \ln \Upsilon + \rho_\Upsilon \ln \Upsilon_{t-1} + \varepsilon_{\Psi,t}/10$$

[**113..114**] Preference shocks, consumption and labour $\left\{\ln \zeta_t^c = \text{lzetacU}, \ln \zeta_t^h = \text{lzetahU}\right\}$

$$\begin{aligned}
\ln \zeta_t^c &= \left(1-\rho_{\zeta^c}\right) \ln \zeta^c + \rho_{\zeta^c} \ln \zeta_{t-1}^c + \varepsilon_{\zeta^c,t}/10 \\
\ln \zeta_t^h &= \left(1-\rho_{\zeta^h}\right) \ln \zeta^h + \rho_{\zeta^h} \ln \zeta_{t-1}^h + \varepsilon_{\zeta^h,t}/10
\end{aligned}$$

[**115..119**, *pp. 22 wp*] Foreign variables (foreign output, inflation and interest rate, technology unit root shock and investment specific unit root shock) $\left\{\ln y_t^* = \text{lstarU}, \pi_t^* = \text{lpistarU}, R_t^* = \text{Rstar}, \ln\left(\mu_{z,t}\right) = \right.$

$$\begin{pmatrix} \ln\left(\frac{y_t^*}{y^*}\right) \\ \pi_t^* - \pi^* \\ R_t^* - R^* \\ \ln\left(\frac{\mu_{z,t}}{\mu_z}\right) \\ \ln\left(\frac{\mu_{\psi,t}}{\mu_\psi}\right) \end{pmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{24}\frac{\alpha}{1-\alpha} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{34}\frac{\alpha}{1-\alpha} \\ 0 & 0 & 0 & \rho_{\mu_z} & 0 \\ 0 & 0 & 0 & 0 & \rho_{\mu_\psi} \end{bmatrix} \begin{pmatrix} \ln\left(\frac{y_{t-1}^*}{y^*}\right) \\ \pi_{t-1}^* - \pi^* \\ R_{t-1}^* - R^* \\ \ln\left(\frac{\mu_{z,t-1}}{\mu_z}\right) \\ \ln\left(\frac{\mu_{\psi,t-1}}{\mu_\psi}\right) \end{pmatrix}$$

$$+ \begin{bmatrix} \sigma_{y^*} & 0 & 0 & 0 & 0 \\ c_{21} & \sigma_{\pi^*} & 0 & c_{24} & c_{24}\frac{\alpha}{1-\alpha} \\ c_{31} & c_{32} & \sigma_{R^*} & c_{34} & c_{34}\frac{\alpha}{1-\alpha} \\ 0 & 0 & 0 & \sigma_{\mu_z} & 0 \\ 0 & 0 & 0 & 0 & \sigma_{\mu_\psi} \end{bmatrix} \begin{pmatrix} \varepsilon_{y^*,t} \\ \varepsilon_{\pi^*,t} \\ \varepsilon_{R^*,t} \\ \varepsilon_{\mu_z,t} \\ \varepsilon_{\mu_\psi,t} \end{pmatrix}$$

[**120..121**] Fiscal shocks (taxes and government expenditures) $\{\ln \tau_t^y = \text{ltauyU}, \ln g_t = \text{lgU}\}$

$$\begin{aligned}\ln \tau_t^y &= (1-\rho_{\tau^y})\ln \tau^y + \rho_{\tau^y}\ln \tau_{t-1}^y + \varepsilon_{\tau^y,t}/100 \\ \ln g_t &= \left(1-\rho_g\right)\ln g + \rho_g \ln g_{t-1} + \varepsilon_{g,t}/100\end{aligned}$$

[**122**] Risk adjustment - foreign asset return $\{\ln \phi_t = \text{phitildeU}\}$

$$\ln \phi_t = \left(1-\rho_\phi\right)\ln \phi + \rho_\phi \ln \phi_{t-1} + \varepsilon_{\phi,t}/100$$

[**123**] Inflation target shock $\{\ln \overline{\pi}_t^c = \text{lpitargetU}\}$

$$\ln \overline{\pi}_t^c = (1-\rho_\pi)\ln \overline{\pi}^c + \rho_\pi \ln \overline{\pi}_{t-1}^c + \varepsilon_{\overline{\pi}^c,t}/1000$$

Exogenous equations of the financial sector

Bank dividends shock ($\upsilon_{B,t}$) **(*)**

$$\upsilon_{B,t} = \rho_{\upsilon_B}\upsilon_{B,t-1} + \tilde{\varepsilon}_{\upsilon_B,t}/10 \quad \text{(A-73)}$$

Deposit spread shock ($\tilde{\varepsilon}_{D,t}$) **(*)**

$$\tilde{\varepsilon}_{D,t} = \rho_D \tilde{\varepsilon}_{D,t-1} + e_{D,t}/100 \quad \text{(A-74)}$$

Bank capital shock ($\tilde{\varepsilon}_{cap,t}$) **(*)**

$$\tilde{\varepsilon}_{cap,t} = \rho_{cap}\tilde{\varepsilon}_{cap,t-1} + e_{cap,t}/100 \quad \text{(A-75)}$$

Entrepreneurs' dividends shock ($\upsilon_{E,t}$) **(*)**

$$\upsilon_{E,t} = \rho_{\upsilon_E}\upsilon_{E,t-1} + \tilde{\varepsilon}_{\upsilon_E,t}/100 \quad \text{(A-76)}$$

Entrepreneurs spread shock ($\tilde{\varepsilon}_{E,t}$) **(*)**

$$\tilde{\varepsilon}_{E,t} = \rho_E \tilde{\varepsilon}_{E,t-1} + e_{E,t}/100 \quad \text{(A-77)}$$

Observed country risk premium shock ($\widetilde{\phi}_{cp,t}$) **(*)**

$$\widetilde{\phi}_{cp,t} = \rho_{\varepsilon_{\widetilde{\phi}_{cp}}}\widetilde{\phi}_{cp,t-1} + \varepsilon_{\widetilde{\phi}_{cp},t}/100 \quad \text{(A-78)}$$

Exogenous equations of the commodity sector:

Commodity production (y_t^{Co}) **(*)**

$$\ln y_t^{Co} = (1-\rho_{y^{Co}})\ln y^{Co} + \rho_{y^{Co}}\ln y_{t-1}^{Co} + \varepsilon_t^{y^{Co}}/100, \quad \text{(A-79)}$$

Real commodity price (p_t^{Co*}) **(*)**

$$\ln p_t^{Co*} = (1-\rho_{p^{Co*}})\ln p^{Co*} + \rho_{p^{Co*}}\ln p_{t-1}^{Co*} + \varepsilon_t^{p^{Co*}}/100,$$

B Appendix: the commodity sector

The introduction of the commodity sector affects the evolution of net foreign assets. As in CTW, we begin by developing the link between net exports and the current account. Expenses on imports, new purchases of net foreign assets, A^*_{t+1}, plus factor payments of commodity income to foreign agents must equal income from exports and from previously purchased net foreign assets:

$$\begin{aligned} S_t A^*_{t+1} + \textit{factor payments of commodity income}_t + \textit{expenses on imports}_t \\ = \textit{receipts from exports}_t + R^*_{t-1}\Phi_{t-1} S_t A^*_t. \end{aligned}$$

Expenses on imports correspond to the purchases of specialized importers for the consumption, investment and export sectors:

$$\textit{expenses on imports}_t = S_t P^*_t R^{\nu,*}_t \left(C^m_t (\mathring{p}^{m,c}_t)^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}} + I^m_t (\mathring{p}^{m,i}_t)^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} + X^m_t (\mathring{p}^{m,x}_t)^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}} \right).$$

Receipts from exports equal exports of the homogenous domestic good plus exports of the commodity good:

$$\textit{receipts from exports}_t = S_t P^x_t X_t + S_t P^{Co*}_t Y^{Co}_t.$$

Factor payments of commodity income equal the share $1-\chi$ of the income generated in the commodity sector that goes to foreign agents:

$$\textit{factor payments of commodity income}_t = (1-\chi) S_t P^{Co*}_t Y^{Co}_t.$$

With the appropriate scaling, we therefore obtain

$$\begin{aligned} a_t + q_t p^c_t R^{\nu,*}_t \left(c^m_t (\mathring{p}^{m,c}_t)^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}} + i^m_t (\mathring{p}^{m,i}_t)^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} + x^m_t (\mathring{p}^{m,x}_t)^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}} \right) \\ = q_t p^c_t (p^x_t x_t + \chi p^{Co*}_t y^{Co}_t) + s_t R^*_{t-1}\Phi_{t-1} \frac{a_{t-1}}{\pi_t \mu_{z^+,t}}, \qquad \text{(B-1)} \end{aligned}$$

where $a_t = S_t A^*_{t+1}/(P_t z^+_t)$, $q_t = S_t P^*_t / P^c_t$, $p^c_t = P^c_t / P_t$, $p^x_t = P^x_t / P^*_t$, $s_t = S_t / S_{t-1}$, $\pi_t = P_t / P_{t-1}$ and $\mu_{z^+,t} = z^+_t$.

To match real GDP to the data we first subtract capital utilization costs from y_t (scaled output of the domestic homogenous good), as in CTW, and then add commodity production:

$$gdp_t = y_t - a(u_t) \frac{\bar{k}_t}{\mu_{\psi,t}\mu_{z^+,t}} + y^{Co}_t. \qquad \text{(B-2)}$$

To eventually be able to match ratios with respect to nominal GDP, $P^{gdp}_t GDP_t$, we scale the latter by $P_t z^+_t$ to obtain

$$p^{gdp}_t gdp_t = y_t - a(u_t) \frac{\bar{k}_t}{\mu_{\psi,t}\mu_{z^+,t}} + q_t p^c_t p^{Co*}_t y^{Co}_t, \qquad \text{(B-3)}$$

where $gdp_t = GDP_t/z_t^+$ and $p_t^{gdp} = P_t^{gdp}/P_t$. We also use the following alternative definitions without subtracting utilization costs:

$$\widetilde{gdp}_t = y_t + y_t^{Co}, \tag{B-4}$$

$$\widetilde{p}_t^{gdp}\widetilde{gdp}_t = y_t + q_t p_t^c p_t^{Co*} y_t^{Co}. \tag{B-5}$$

C Appendix: the steady state

C.1 The financial sector extension

From the household problem we have that

$$\begin{aligned} 1+\Upsilon^{D} &= 1, \text{ and} \\ R_{D} &= R=\frac{\pi}{\beta} \end{aligned}$$

From the entrepreneurs problem

$$\begin{aligned} 1-m &= \frac{n}{p^{k}K}, && \text{(C-1)} \\ p^{k}K &= n+\ell^{E}, && \text{(C-2)} \\ d^{E} &= \left(1-\frac{R_{E}}{\pi}\right)\ell^{E}+\left[\begin{array}{c}(1-\tau_{k})\,z \\ -p_{\tau}^{k}\left(1-(1-\delta)+\tau_{k}\delta\right)\end{array}\right]K && \text{(C-3)} \\ \lambda_{E} &= 1, && \text{(C-4)} \\ R_{E} &= \frac{\pi}{\beta_{E}}, && \text{(C-5)} \\ R^{k} &= \frac{\pi}{\beta_{E}} && \text{(C-6)} \end{aligned}$$

From the banks problem

$$\begin{aligned} \frac{\widetilde{capb}}{\ell^{E}} &= \gamma, \text{ where } \widetilde{capb}=\frac{capb}{P} && \text{(C-7)} \\ d^{B}+\frac{R_{D}}{\pi}\ell^{D}+\left(1+\Upsilon^{E}\right)\ell^{E} &= \frac{R_{E}}{\pi}\ell^{E}+\ell^{D}, && \text{(C-8)} \\ 1+\Upsilon^{E} &= \chi_{E,0}, && \text{(C-9)} \\ \widetilde{capb} &= \ell^{E}-\ell^{D}, && \text{(C-10)} \\ \lambda_{B} &= 1, && \text{(C-11)} \\ R_{D} &= \frac{\pi}{\beta} && \text{(C-12)} \\ \frac{R_{E}}{\pi} &= \frac{1+\Upsilon^{E}}{\beta}, \text{ or} && \text{(C-13)} \\ R_{E} &= \left(1+\Upsilon^{E}\right)R_{D} && \text{(C-14)} \end{aligned}$$

C.1.1 Recursive strategy

1. We set the β_E that is consistent with the observed lending spread $1+\Upsilon^E$ between the deposit rate and lending rate:

$$\begin{aligned} R_E &= \frac{\pi}{\beta_E} \\ &= \left(1+\Upsilon^E\right)\frac{\pi}{\beta}, \text{ which implies} \\ \beta_E &= \frac{\beta}{1+\Upsilon^E}. \end{aligned}$$

2. The deposit and lending interest rates are

$$\begin{aligned} R_D &= R, \\ R_E &= R_D\left(1+\Upsilon^E\right). \end{aligned}$$

3. The implied capital returns are:

$$R^k = \frac{\pi}{\beta_E} \text{ and } z = \text{ (known parameters)}$$

4. Calibrate γ and m. For instance, in Mexico $\gamma = 8\%$, and $m = .65$, according to the banking regulation authority.

5. Loans and bank capital are thus equal to

$$\begin{aligned} \ell^E &= m \times p^k K \\ \widetilde{capb} &= \gamma \times \ell^E \end{aligned}$$

6. Using the definition of bank capital, we find then the steady state value for deposits:

$$\ell^D = \ell^E - \widetilde{capb}$$

7. Bank dividends are now

$$d^B = \left(\frac{R_E}{\pi} - \left(1+\Upsilon^E\right)\right)\ell^E - \left(\frac{R_D}{\pi} - 1\right)\ell^D.$$

8. And entrepreneur dividends are (you need to detrend for corresponding terms)

$$d^E = \left(1 - \frac{R_E}{\pi}\right)\ell^E + \left[\begin{array}{c} (1-\tau_k)\,z \\ -p^k_\tau\left(1-(1-\delta)+\tau_k\delta\right) \end{array}\right] K.$$

9. Entreprenerus networth is given by

$$n = p^k K - \ell^E.$$

C.2 The commodity sector extension

The solution of the steady state is modified as follows. First, the (scaled) shares of government consumption, investment, net foreign assets, non-commodity exports and commodity exports over nominal GDP are:

$$\begin{aligned}
\eta_{g,t} &\equiv \frac{P_t G_t}{P_t^{gdp} GDP_t} = \frac{g_t}{p_t^{gdp} gdp_t}, \\
\eta_{i,t} &\equiv \frac{P_t^i I_t}{P_t^{gdp} GDP_t} = \frac{p_t^i i_t}{p_t^{gdp} gdp_t}, \\
\eta_{a,t} &\equiv \frac{S_t A_{t+1}^*}{P_t^{gdp} GDP_t} = \frac{a_t}{p_t^{gdp} gdp_t}, \\
\eta_{x,t} &\equiv \frac{S_t P_t^x X_t}{P_t^{gdp} GDP_t} = \frac{q_t p_t^c p_t^x x_t}{p_t^{gdp} gdp_t}, \\
\eta_{y^{Co},t} &\equiv \frac{S_t P_t^{Co*} Y_t^{Co}}{P_t^{gdp} GDP_t} = \frac{q_t p_t^c p_t^{Co*} y_t^{Co}}{p_t^{gdp} gdp_t}.
\end{aligned}$$

Those shares are taken as given in steady state as well as the normalization $p^{Co*} = 1$. Second, we derive the equation for total labour. From the adjusted resources constraint and the fact that $\alpha(u) = 0$:

$$\begin{aligned}
y - g - (1-\omega_i)\left(p^i\right)^{\eta_i} i &= (1-\omega_c)\left(p^c\right)^{\eta_c} c \\
&\quad + (1-\omega_x)\left[1-\omega_x+\omega_x\left(p^{m,x}\right)^{1-\eta_x}\right]^{\frac{\eta_x}{1-\eta_x}} \left(\mathring{p}^x\right)^{\frac{-\lambda_x}{\lambda_x-1}} \left(p^x\right)^{-\eta_f} y^*.
\end{aligned}$$

Making use of the following equation,

$$i = \frac{\bar{k}\left(1-\frac{1-\delta}{\mu_{z+}\mu_\Psi}\right)}{\Upsilon}, \tag{C-15}$$

the fact that $\bar{k} = k$ for $u = 1$, the definitions $kh = k/H$, $\theta_{cH} \equiv cH^{\sigma_L}$, $\theta_y \equiv y/H$, $g \equiv \eta_g p^{gdp} gdp$, and the fact that $p^{gdp} gdp = y/(1-\eta_{y^{Co}})$:

$$\begin{aligned}
&\left[\left(1-\frac{\eta_g}{1-\eta_{y^{Co}}}\right)\theta_y - (1-\omega_i)\left(p^i\right)^{\eta_i}\left(1-\frac{1-\delta}{\mu_{z+}\mu_\Psi}\right)\frac{k/H}{\Upsilon}\right] H \\
= \;& (1-\omega_c)\left(p^c\right)^{\eta_c}\theta_{cH} H^{-\sigma_L} \\
&+ \left[(1-\omega_x)\left[1-\omega_x+\omega_x\left(p^{m,x}\right)^{1-\eta_x}\right]^{\frac{\eta_x}{1-\eta_x}}\left(\mathring{p}^x\right)^{\frac{-\lambda_x}{\lambda_x-1}}\left(p^x\right)^{-\eta_f}\right] y^*.
\end{aligned}$$

After using the respective definitions of α_4, α_5 and α_6, this is equal to (the definition of α_4 changes):

$$\alpha_4 H = \alpha_5 H^{-\sigma_L} + \alpha_6 y^*.$$

Third, we derive the equation for foreign output. From (B-1):

$$
\begin{aligned}
& \frac{p^x}{R^{\nu,*}}x+\chi\frac{p^{Co*}}{R^{\nu,*}}y^{Co}+\left(\frac{R^*\frac{\Phi s}{\pi\mu_{z+}}-1}{qp^cR^{\nu,*}}\right)a \\
= & \; c^m(\mathring{p}^{m,c})^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}}+i^m(\mathring{p}^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}}+x^m(\mathring{p}^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}}.
\end{aligned}
$$

Making use of the following equations,

$$
\begin{aligned}
x &= (p^x)^{-\eta_f}y^*, \\
c^m &= \omega_c\left(\frac{p^c}{p^{m,c}}\right)^{\eta_c}c, \\
i^m &= \omega_i\left(\frac{p^i}{p^{m,i}}\right)^{\eta_i}\left(i+\alpha(u)\frac{\overline{k}}{\mu_\Psi\mu_{z^+}}\right), \\
x^m &= \omega_x\left(\frac{\left[1-\omega_x+\omega_x(p^{m,x})^{1-\eta_x}\right]^{\frac{1}{1-\eta_x}}}{p^{m,x}}\right)^{\eta_x}(\mathring{p}^x)^{\frac{-\lambda_x}{\lambda_x-1}}(p^x)^{-\eta_f}y^*,
\end{aligned}
$$

and the fact that $\alpha(u)=0$:

$$
\begin{aligned}
& \frac{p^x}{R^{\nu,*}}(p^x)^{-\eta_f}y^*+\chi\frac{p^{Co*}y^{Co}}{R^{\nu,*}}+\left(\frac{R^*\frac{\Phi s}{\pi\mu_{z+}}-1}{qp^cR^{\nu,*}}\right)a \\
= & \left[\begin{array}{c}
\omega_c\left(\frac{p^c}{p^{m,c}}\right)^{\eta_c}c(\mathring{p}^{m,c})^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}}+\omega_i\left(\frac{p^i}{p^{m,i}}\right)^{\eta_i}i(\mathring{p}^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} \\
+\omega_x\left(\frac{\left[1-\omega_x+\omega_x(p^{m,x})^{1-\eta_x}\right]^{\frac{1}{1-\eta_x}}}{p^{m,x}}\right)^{\eta_x}(\mathring{p}^x)^{\frac{-\lambda_x}{\lambda_x-1}}(p^x)^{-\eta_f}y^*(\mathring{p}^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}}
\end{array}\right].
\end{aligned}
$$

Making use of (C-15), the fact that $\bar{k}=k$ for $u=1$, the definitions $kh=k/H$, $\theta_{cH}\equiv cH^{\sigma_L}$, $\theta_y\equiv y/H$, $a\equiv\eta_a p^{gdp}gdp$ and $p^{Co*}y^{Co}\equiv\eta_{y^{Co}}p^{gdp}gdp/(qp^c)$, the fact that $p^{gdp}gdp=y/(1-\eta_{y^{Co}})$, and rearranging:

$$
\begin{aligned}
& \left[\frac{(p^x)^{1-\eta_f}}{R^{\nu,*}}-\omega_x\left(\frac{\left[1-\omega_x+\omega_x(p^{m,x})^{1-\eta_x}\right]^{\frac{1}{1-\eta_x}}}{p^{m,x}}\right)^{\eta_x}(\mathring{p}^x)^{\frac{-\lambda_x}{\lambda_x-1}}(p^x)^{-\eta_f}(\mathring{p}^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}}\right]y^*= \\
& \left[\omega_c\left(\frac{p^c}{p^{m,c}}\right)^{\eta_c}\theta_{cH}(\mathring{p}^{m,c})^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}}\right]H^{-\sigma_L} \\
& +\left[\omega_i\left(\frac{p^i}{p^{m,i}}\right)^{\eta_i}(\mathring{p}^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}}\left(1-\frac{1-\delta}{\mu_{z^+}\mu_\Psi}\right)\frac{k/H}{\Upsilon}-\chi\frac{1}{qp^cR^{\nu,*}}\frac{\eta_{y^{Co}}\theta_y}{1-\eta_{y^{Co}}}+\left(\frac{1-R^*\frac{\Phi s}{\pi\mu_{z+}}}{qp^cR^{\nu,*}}\right)\frac{\eta_a\theta_y}{1-\eta_{y^{Co}}}\right]H.
\end{aligned}
$$

After using the respective definitions of α_1, α_2 and α_3, this is equal to (the definition of α_2 changes):

$$\alpha_3y^*=\alpha_1H^{-\sigma_L}+\alpha_2H.$$

From here onwards, the steady state solution is identical to the baseline model. At the end, we add:

$$
\begin{aligned}
g &= \frac{\eta_g}{1-\eta_{y^{Co}}} y, \\
a &= \frac{\eta_a}{1-\eta_{y^{Co}}} y, \\
y^{Co} &= \frac{\eta_{y^{Co}}}{(1-\eta_{y^{Co}})} \frac{y}{qp^c p^{Co*}}, \\
gdp &= y + y^{Co}, \\
p^{gdp} &= \frac{y + qp^c p^{Co*} y^{Co}}{gdp}.
\end{aligned}
$$

Two of the equations of the numerical solver for A_L (disutility of work), δ (depreciation rate) and $\tilde{\varphi} = qp^c$ (real exchange rate) also change, as follows:

$$
\begin{aligned}
0 &= \frac{p^i i}{p^{gdp} gdp} - \eta_i = \frac{p^i i(1-\eta_{y^{Co}})}{y} - \eta_i, \\
0 &= \frac{qp^c p^x x}{p^{gdp} gdp} - \eta_x = \frac{(p^x)^{1-\eta_f}\, y^* \tilde{\varphi}(1-\eta_{y^{Co}})}{y} - \eta_x.
\end{aligned}
$$

When $\eta_{y^{Co}} = 0$, we obtain the steady state equations of the baseline model.

C Estimation and policy analysis for each country

Estimation and Policy Analysis for Chile*

December 15, 2014

1 Estimation

1.1 Estimation strategy

1.1.1 Data

The model is estimated with 25 observable time series for Chile: the growth rates of real GDP ($\Delta \log Y_t$), private consumption ($\Delta \log C_t$), investment ($\Delta \log I_t$), government consumption ($\Delta \log G_t$), exports ($\Delta \log X_t$), imports ($\Delta \log M_t$), the real effective exchange rate ($\Delta \log q_t$) and CPI based real wages ($\Delta \log W_t$), total hours worked, i.e. average hours worked times the employment rate ($\hat{h}_t$), real GDP in the mining sector as a proxy of commodity production/exports (y_t^{Co}), domestic inflation based on the GDP deflator (π_t), CPI inflation (π_t^c), tradable CPI inflation as a proxy for imported consumption price inflation ($\pi_t^{m,c}$), investment price inflation based on the investment deflator (π_t^i), the short-term monetary policy rate (R_t), the EMBI global Chile spread as a proxy for the observed country premium (cp_t), the average 3-month secondary market interest rate (prime rates) as a proxy for the interest rate paid on deposits (R_t^D), the average 3-month interest rate on total bank loans as a proxy for the interest rate paid by entrepreneurs (R_t^E), the growth rates of real bank loans ($\Delta \log L_t^E$), banks' networth ($\Delta \log capb_t$) and firms' networth ($\Delta \log n_t$), all deflated by the CPI, the growth rate of a trade-weighted average of commercial partners' real GDP ($\Delta \log Y_t^*$) and a trade-weighted foreign inflation rate (π_t^*), both computed according to BIS methodology, the short-term LIBOR as a proxy for the foreign interest rate (R_t^*), and the price of refined copper deflated by the foreign price index as a proxy for the price of the exported commodity (p_t^{Co*}). The source of this data is the BIS, the Chilean Superintendency of Banks and Financial Institutions and the Central Bank of Chile.[1] The sample period is 2001Q3-2014Q1, which is the period in which the Central Bank of Chile's *de jure* inflation target has been in place with a short-term nominal interest rate as the main instrument of monetary policy.[2]

A number of additional transformations are made for the estimation. All growth rates are quarterly log differences. The inflation and interest rates are annualized quarterly rates. To account for the trends in the data, some of which are different from the model's balanced growth path and average values, the growth rates and interest rates are demeaned. The only exceptions are hours worked and commodity production which are detrended by fitting log-linear trends, since those variables exhibit pronounced trends that are not explained by the model. All transformed series are multiplied by 100.[3]

1.1.2 Shocks and measurement errors

We activate the same 16 structural shocks from the baseline model as in CTW, plus the observed country premium shock, the shocks to commodity production and prices, and the two financial shocks to the banks'

*Technical note for the joint project of the BIS CCA Research Network on "Incorporating financial stability considerations into central bank policy models". For questions and comments, please contact Markus Kirchner (mkirchner@bcentral.cl) or Javier García-Cicco (jgarcia-cicco@bcentral.cl).

[1]Banks' and firms' networth is computed as the difference of total assets and liabilities. Firms' assets and liabilities are consolidated items from Chilean FECU reports ("Ficha Estadística Codificada Uniforme") until 2008 and International Financial Reporting Standards afterwards, with some FECU data in the years 2009-10. Financial services and mining sectors are excluded. To avoid double counting of assets and liabilities, parent and subsidiary companies are identified and only subsidiary assets and liabilities are counted. Banks' assets and liabilities are however not available in consolidated form.

[2]The secondary market interest rate is only available from 2003Q2 onwards. We therefore use the missing observations Kalman filter to infer the missing data from 2001Q3-2003Q1 treating it as an unobserved state.

[3]Unlike CTW, we do not express real quantities in per capita terms because quarterly population figures for Chile are not available from official sources. Instead, we assume that population growth is constant over time and demean the variables.

Table 1: Calibrated parameters: Chile.

Parameter	Value	Description
α	0.301	Capital share in production
β	0.999	Discount factor
σ_L	1	Inverse Frisch elasticity
η_c	1.5	Elasticity of subst., domestic and imported consumption
ω_i	0.26	Import share in investment goods
ω_c	0.2	Import share in consumption goods
ω_x	0.05	Import share in non-commodity export goods
$\tilde{\phi}_a$	0.01	Elasticity of country risk to net asset position
η_g	0.12	Steady state government consumption share of GDP
η_a	0.33	Steady state NFA position to GDP ratio
$\eta_{y^{Co}}$	0.15	Steady state mining exports to GDP ratio
χ	0.56	Domestic ownership in commodity sector
τ_k	0.2	Capital tax rate
τ_w	0	Payroll tax rate
τ_c	0.19	Consumption tax rate
τ_y	0.07	Labor income tax rate
τ_b	0	Bond tax rate
μ_z	1.006	Steady state gross growth rate of neutral technology
μ_ψ	1	Steady state gross growth rate of investment technology
$\bar{\pi}$	1.0075	Steady state gross inflation target
π^*	1.004	Steady state gross foreign inflation rate
$\bar{\Phi}$	1.0035	Steady state country premium
λ_j	1.1	Price and wage markups for $j = d; x; m, c; m, i; m, x; w$
ϑ_w	1	Wage indexation to real growth trend
$\varkappa^j$	$1 - \kappa_j$	Indexation to inflation target for $j = d; x; m, c; m, i; m, x; w$
$\breve{\pi}$	1.0075	Third indexing base
Ψ^E	3.25/400	Spread loans to deposit interest rate
m	0.51	Regulatory loan-to-value ratio
Ψ^D	0.52/400	Spread deposits to CB interest rate
γ	0.08	Regulatory capital requirement

and entrepreneurs' interest rate spreads.[4] In total, we thus have 21 structural shocks. We further allow for some degree of measurement errors on all variables except the nominal interest rates and the foreign variables. The unconditional variances of the i.i.d. measurement errors are calibrated to 25% of the variance of the observed series for banks' and firms' networth and bank loans, since those series are relatively incomplete proxies for their model counterparts, and 10% of the variance of the observed series for the remaining variables.

1.1.3 Calibration and priors

Table 1 displays the calibrated parameters. Some of the calibrated values are identical to the ones used by CTW. This concerns the elasticity of country risk to the NFA position $\tilde{\phi}_a$, the fraction of time spent working $L\varsigma$, and the fraction of wage indexation to the real growth trend ϑ_w. Most of the remaining calibrated parameters are set to match available statistics or estimates for the Chilean economy. The capital share in production α is set to 0.301 to match a capital-output ratio of around 3 on an annual basis (see Henríquez, 2008). The subjective discount factor β and the tax rates on bonds τ_b are calibrated to yield an annual real interest rate of about 2.8% and the steady state foreign inflation rate is calibrated to yield a steady state foreign interest rate around 4.5% (matching the estimates by Fuentes and Gredig, 2008). The remaining tax rates are set according to OECD estimates of average tax rates in Chile. The different import shares ω_i, ω_c and ω_x are calibrated to match available information from input-output tables for the years 2008-2011. To calibrate the government consumption share of GDP, the net foreign asset position to GDP ratio and the steady state growth rate of technology, we match historical averages from 1996-2013. We further let the composite of technology growth μ_{z^+} equal the average growth rate of GDP (4.4% from 1996-2013) net of labor force growth of approximately 2%, and, as in CTW, we set the investment-specific technology growth rate μ_ψ to 1. The steady state inflation target rate is set to the one publicly stated by the Central Bank of

[4] We also tried activating unit-root investment specific technology shocks, but their estimated variance was small and their addition did not improve the fit of the model according to the Laplace approximation of the marginal likelihood at the posterior mode.

Table 2: Priors and posteriors of estimated parameters: Chile.

Parameter	Description	Prior			Posterior			
		Distr.	Mean	s.d.	Mean	s.d.	5%	95%
ξ_d	Calvo, domestic	β	0.75	0.075	0.847	0.028	0.800	0.892
ξ_x	Calvo, exports	β	0.75	0.075	0.664	0.051	0.580	0.748
ξ_{mc}	Calvo, imported consumption	β	0.75	0.075	0.869	0.030	0.813	0.914
ξ_{mi}	Calvo, imported investment	β	0.75	0.075	0.941	0.017	0.915	0.967
ξ_{mx}	Calvo, imported exports	β	0.66	0.10	0.601	0.072	0.487	0.720
ξ_w	Calvo, wages	β	0.75	0.075	0.708	0.054	0.620	0.796
κ_d	Indexation, domestic	β	0.50	0.15	0.501	0.134	0.281	0.721
κ_x	Indexation, exports	β	0.50	0.15	0.289	0.113	0.110	0.468
κ_{mc}	Indexation, imported consumption	β	0.50	0.15	0.678	0.108	0.506	0.856
κ_{mi}	Indexation, imported investment	β	0.50	0.15	0.919	0.039	0.862	0.977
κ_{mx}	Indexation, imported exports	β	0.50	0.15	0.534	0.136	0.309	0.759
κ_w	Indexation, wages	β	0.50	0.15	0.220	0.083	0.089	0.352
b	Habit in consumption	β	0.65	0.15	0.714	0.050	0.632	0.793
$S''/10$	Investment adjustment costs	Γ	0.50	0.15	0.205	0.066	0.098	0.309
σ_a	Variable capital utilization	Γ	0.20	0.025	0.280	0.034	0.223	0.334
ρ_R	Taylor rule, lagged interest rate	β	0.80	0.10	0.783	0.026	0.742	0.825
r_π	Taylor rule, inflation	N	1.70	0.15	1.686	0.124	1.479	1.885
$r_{\Delta y}$	Taylor rule, output growth	N	0.125	0.05	0.125	0.046	0.050	0.199
η_x	Elasticity of subst., exports	$\Gamma_{>1}$	1.50	0.25	1.693	0.260	1.274	2.120
η_i	Elasticity of subst., investment	$\Gamma_{>1}$	1.50	0.25	1.393	0.204	1.042	1.684
η_f	Elasticity of subst., foreign	$\Gamma_{>1}$	1.50	0.25	1.253	0.150	1.000	1.455
$\tilde{\phi}_s$	Country risk adjustment coefficient	Γ	1.25	0.10	1.169	0.086	1.028	1.310
$100\chi_D$	Monit. cost elast., deposit spread	Inv-Γ	0.50	Inf	0.688	0.256	0.279	1.079
$10\chi_E$	Monit. cost elast., credit spread	Inv-Γ	0.50	Inf	0.158	0.035	0.103	0.211
ρ_E	Persistence param., credit spread	β	0.50	0.075	0.426	0.061	0.327	0.527
κ_B	Dividend adj. costs, banks	Inv-Γ	0.50	Inf	0.139	0.039	0.084	0.195
κ_E	Dividend adj. costs, entreprens.	Inv-Γ	0.50	Inf	2.922	2.041	0.509	5.920
ρ_{μ_z}	Persistence, unit-root tech.	β	0.50	0.075	0.539	0.074	0.417	0.661
ρ_ϵ	Persistence, stationary tech.	β	0.85	0.075	0.873	0.061	0.783	0.968
ρ_Υ	Persistence, MEI	β	0.85	0.075	0.695	0.083	0.560	0.833
ρ_{ζ^c}	Persistence, consumption prefs.	β	0.85	0.075	0.745	0.071	0.633	0.859
ρ_{ζ^h}	Persistence, labor prefs.	β	0.85	0.075	0.802	0.079	0.676	0.929
$\rho_{\tilde{\phi}_s}$	Persistence, country risk premium	β	0.85	0.075	0.844	0.072	0.735	0.961
$\rho_{\tilde{\phi}_{cp}}$	Persistence, obs. country risk prem.	β	0.85	0.075	0.930	0.031	0.884	0.973
$\rho_{\tilde{\varepsilon}_D}$	Persistence, deposit spread	β	0.50	0.075	0.518	0.070	0.403	0.634
$\rho_{\tilde{\varepsilon}_E}$	Persistence, credit spread	β	0.50	0.075	0.424	0.062	0.323	0.526
ρ_g	Persistence, gov. expenditures	β	0.85	0.075	0.828	0.078	0.714	0.956
$\rho_{y^{Co}}$	Persistence, commodity production	β	0.85	0.075	0.773	0.074	0.654	0.896
$\rho_{p^{Co,*}}$	Persistence, commodity price	N	0.50	0.50	0.881	0.025	0.841	0.923
a_{11}	Foreign VAR parameter	N	0.50	0.50	0.828	0.088	0.691	0.965
a_{22}	Foreign VAR parameter	N	0.00	0.50	0.282	0.100	0.117	0.447
a_{33}	Foreign VAR parameter	N	0.50	0.50	0.872	0.075	0.765	0.990
a_{12}	Foreign VAR parameter	N	0.00	0.50	0.133	0.042	0.064	0.200
a_{13}	Foreign VAR parameter	N	0.00	0.50	-0.029	0.209	-0.375	0.313
a_{21}	Foreign VAR parameter	N	0.00	0.50	-0.073	0.140	-0.321	0.140
a_{23}	Foreign VAR parameter	N	0.00	0.50	-0.283	0.259	-0.713	0.143
a_{24}	Foreign VAR parameter	N	0.00	0.50	0.073	0.470	-0.679	0.861
a_{31}	Foreign VAR parameter	N	0.00	0.50	0.015	0.026	-0.026	0.057
a_{32}	Foreign VAR parameter	N	0.00	0.50	0.016	0.009	0.001	0.031
a_{34}	Foreign VAR parameter	N	0.00	0.50	0.290	0.146	0.085	0.517
c_{21}	Foreign VAR parameter	N	0.00	0.50	1.037	0.389	0.405	1.681
c_{31}	Foreign VAR parameter	N	0.00	0.50	0.084	0.036	0.025	0.143
c_{32}	Foreign VAR parameter	N	0.00	0.50	-0.012	0.008	-0.026	0.001
c_{24}	Foreign VAR parameter	N	0.00	0.50	-0.190	0.504	-1.017	0.635
c_{34}	Foreign VAR parameter	N	0.00	0.50	0.344	0.145	0.127	0.569

Note: This table shows the priors and posteriors based on 1,000,000 draws from the Metropolis-Hastings (MH) algorithm, discarding the first 500,000 draws. The mean and covariance matrix of the proposal density for the MH algorithm were the maximum of the posterior distribution and the negative inverse Hessian around that maximum obtained with Marco Ratto's numerical optimization routine. Following CTW, the parameters were scaled to obtain the same order of magnitude of the parameters. The inverse Hessian was scaled to obtain an average acceptance rate from the MH algorithm of approximately 23.4% (see Roberts, Gelman, and Gilks, 1997). The computations were conducted using Dynare 4.4.2.

Table 3: Priors and posteriors of estimated shock standard deviations: Chile.

Parameter	Description	Prior			Posterior			
		Distr.	Mean	s.d.	Mean	s.d.	5%	95%
$100\sigma_{\mu_z}$	Unit-root tech.	Inv-Γ	0.15	Inf	0.224	0.077	0.101	0.346
$100\sigma_{\epsilon}$	Stationary tech.	Inv-Γ	0.50	Inf	0.921	0.117	0.729	1.102
$10\sigma_{\Upsilon}$	MEI	Inv-Γ	0.15	Inf	0.375	0.117	0.195	0.561
$10\sigma_{\zeta^c}$	Consumption preferences	Inv-Γ	0.15	Inf	0.271	0.057	0.185	0.360
$10\sigma_{\zeta^h}$	Labor preferences	Inv-Γ	0.15	Inf	0.868	0.413	0.281	1.444
$100\sigma_{\tilde{\phi}}$	Country risk premium	Inv-Γ	0.15	Inf	0.484	0.241	0.102	0.822
$100\sigma_{\tilde{\phi}_{cp}}$	Observed country risk premium	Inv-Γ	0.15	Inf	0.104	0.010	0.087	0.120
$100\sigma_{\tilde{\varepsilon}_D}$	Deposit spread	Inv-Γ	0.15	Inf	0.085	0.010	0.069	0.100
$100\sigma_{\tilde{\varepsilon}_E}$	Credit spread	Inv-Γ	0.15	Inf	0.193	0.019	0.161	0.224
$100\sigma_{\varepsilon_R}$	Monetary policy	Inv-Γ	0.15	Inf	0.187	0.022	0.150	0.221
$100\sigma_{\varepsilon_g}$	Gov. expenditures	Inv-Γ	0.50	Inf	1.406	0.160	1.141	1.662
$100\sigma_{y^{Co}}$	Commodity production	Inv-Γ	0.50	Inf	2.996	0.315	2.496	3.486
$10\sigma_{p^{Co,*}}$	Commodity price	Inv-Γ	0.50	Inf	1.484	0.151	1.244	1.730
σ_{τ^d}	Markup, domestic	Inv-Γ	0.50	Inf	0.329	0.122	0.153	0.498
σ_{τ^x}	Markup, exports	Inv-Γ	0.50	Inf	0.258	0.083	0.135	0.377
$\sigma_{\tau^{m,c}}$	Markup, imported consumption	Inv-Γ	0.50	Inf	0.733	0.446	0.281	1.119
$\sigma_{\tau^{m,i}}$	Markup, imported investment	Inv-Γ	0.50	Inf	5.322	2.366	1.633	8.737
$\sigma_{\tau^{m,x}}$	Markup, imported exports	Inv-Γ	0.50	Inf	1.800	0.960	0.408	3.272
$100\sigma_{y^*}$	Foreign GDP	Inv-Γ	0.50	Inf	0.551	0.072	0.433	0.665
$100\sigma_{\pi^*}$	Foreign inflation	Inv-Γ	0.50	Inf	1.829	0.219	1.476	2.178
$1000\sigma_{R^*}$	Foreign interest rate	Inv-Γ	1.50	Inf	0.646	0.143	0.408	0.871

Note: See Table 2.

Chile, i.e. 3% on an annual basis. The steady state country premium is calibrated to 140 basis points on an annual basis, i.e. the average value of the EMBI global Chile spread over the sample period.

Regarding the parameters of the commodity sector, we match an average mining exports to GDP ratio of 15% and set the domestic ownership share χ to 0.56, which corresponds to the average share of exports by Codelco, the Chilean state-owned copper company, in total copper exports from 2001-2013 according to data from Cochilco, the Chilean copper commission, i.e. 33%, plus fiscal income from taxes applying the general tax on foreign companies in Chile ($\tau = 0.35$): $\chi = 0.33 + \tau(1 - 0.33) = 0.56$.[5] With respect to the parameters of the financial sector, we match an average loans-to-deposit rate spread of 325 annual basis points and an average deposit-to-monetary-policy rate spread of 52 basis over the sample period. The regulatory loan-to-value ratio is set to 51% to match an average firm leverage ratio of 2.05 since 2001, while the capital requirement is set to 8%, which implies an average bank leverage ratio of 13.

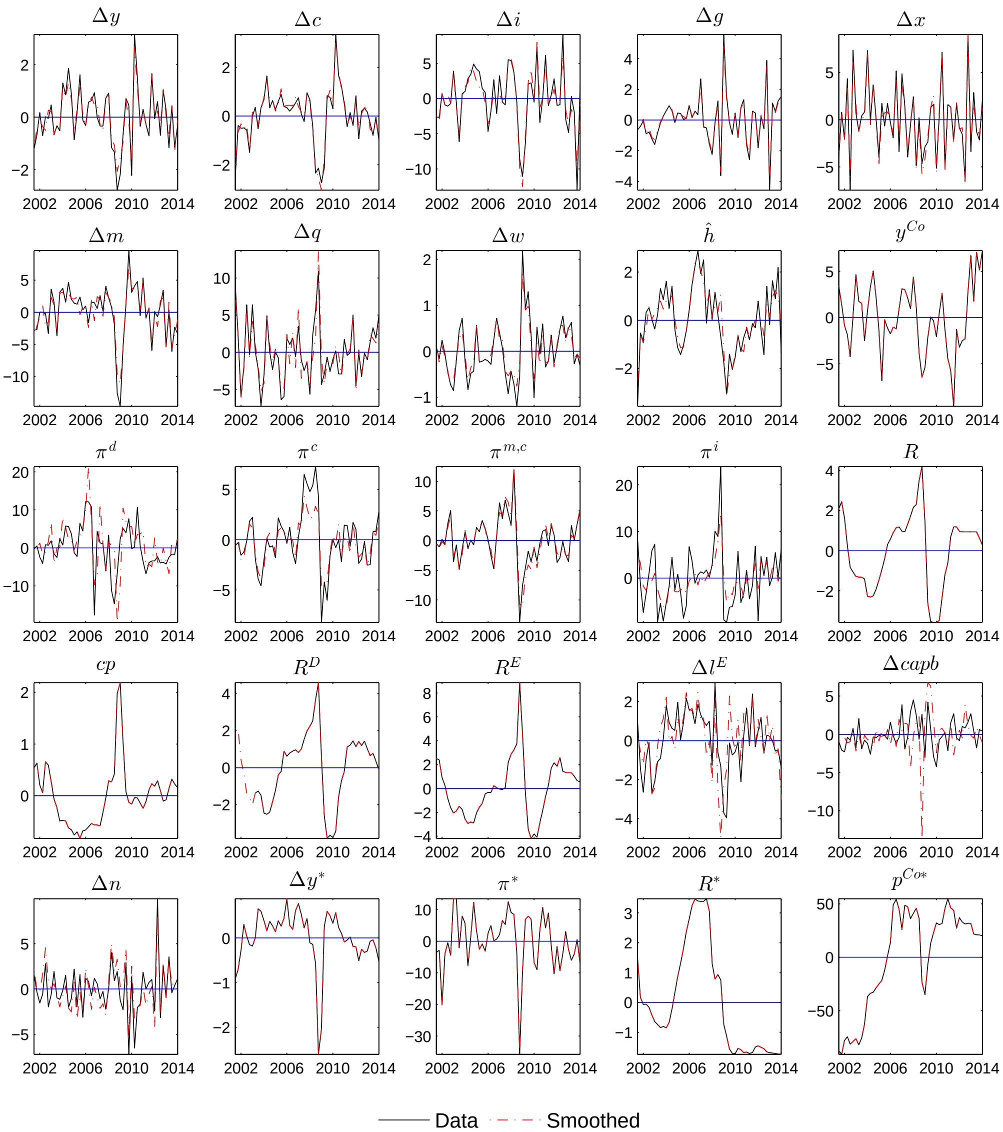
Some other parameters that are not related to available statistics are calibrated in line with related studies and macro models for Chile. This concerns the price and wage markups, λ_j for $j = d; x; m, c; m, i; m, x; w$, which we set to 1.1, following Medina and Soto (2007). As CTW and most related studies, we also assume that the third indexing base, $\breve{\pi}$, is equal to the steady state inflation target and that the share of indexation to that third indexing base is equal to $1 - \varkappa^j$ for $j = d; x; m, c; m, i; m, x; w$, where the $\varkappa^j$ are the estimated indexation parameters on lagged inflation and wages. Hence, there is full indexation and no steady state price and wage dispersion. In addition, we do not estimate the labor supply elasticity σ_L but calibrate it to 1, since this parameter was not well identified in the estimation (identical to prior). Another parameter that is not estimated is the substitution elasticity for domestic and imported consumption goods, which converged to values close to 1 in the estimation creating numerical problems. We therefore simply set this parameter to 1.5, in the ballpark of existing estimates (see Adolfson *et al.*, 2008, for a related discussion).

Finally, three steady state ratios are chosen to be exactly matched throughout the estimation, which are the same as in CTW: an investment share of GDP of 23% according to national accounts data from 1996-2013 (recalibrating the depreciation rate δ), an average *non-commodity exports* share of 20% (recalibrating the steady state real exchange rate $\tilde{\varphi}$), and the fraction of time spent on working which is set to 0.25 (recalibrating the disutility of work parameter A_L).

The parameters that are not calibrated are estimated by Bayesian methods. Our priors for Chile are displayed in Tables 2 and 3. The priors for the parameters from the financial sector equations were centered

[5] Note that domestic private ownership in the Chilean mining sector is negligible, since private ownership is mainly though FDI and foreign companies have significant ownership shares in domestic firms.

Figure 1: Observed data vs. smoothed variables: Chile, 2001Q3-2014Q1.



Note: This figure shows the observed data and the corresponding smoothed model variables, computed by the Kalman smoother at the posterior mean of the estimated parameters.

around OLS estimates of those equations. The selection of most of the remaining estimated parameters and their priors is in line with CTW, so we do not discuss this further.[6]

1.2 Estimation results and goodness of fit

1.2.1 Posterior parameter values

The posterior estimates for Chile are reported in Tables 2 and 3. We briefly discuss the results for the key parameters associated to the financial sector and commodity sector. On the financial sector side, most of the parameters are well identified. The estimated elasticity of the deposit spread to banks' leverage (parameter χ_D) is relatively high compared to the prior, while the elasticity of the credit spread to entrepreneurs' leverage (χ_E) is relatively low. The endogenous persistence of the credit spread (ρ_E) is also relatively low and, simi-

[6]There are a few exceptions to this rule. As discussed earlier, we calibrate the inverse Frisch elasticity of labor supply σ_L and the substitution elasticity for domestic and imported consumption goods η_c, while we estimate the Calvo probability for wage adjustments ξ_w, which is calibrated in CTW. In addition, we take as target variable for output in the monetary policy rule the growth rate of real GDP instead of its level, and estimate the feedback coefficient on the growth rate. The reason is that the coefficient on output in the version in levels was close to zero or negative in the estimation, while for the version in growth rates this coefficient was positive, thus lending support for that specification for our data set. Finally, we use a tighter prior on the variable capacity utilization cost parameter σ_a.

Table 4: Posterior predictive checking for std. deviations and correlations with real GDP growth: Chile.

Variable	Description	s.d.			Correl. with GDP growth		
		Data	Model mean	Model 95% CI	Data	Model mean	Model 95% CI
Δy	GDP growth	1.1	1.5	$(1.2, 1.9)$			
Δc	Priv. consumption growth	1.1	1.1	$(0.8, 1.4)^\star$	0.67	0.34	$(0.01, 0.61)$
Δi	Investment growth	4.6	4.6	$(3.4, 6.2)^\star$	0.46	0.42	$(0.13, 0.65)^\star$
Δg	Gov. consumption growth	1.7	1.6	$(1.3, 1.9)^\star$	-0.09	0.12	$(-0.19, 0.40)^\star$
Δx	Exports growth	3.5	6.1	$(4.8, 7.5)$	0.51	0.48	$(0.23, 0.70)^\star$
Δm	Imports growth	4.4	3.9	$(3.0, 4.8)^\star$	0.50	-0.16	$(-0.45, 0.16)$
Δq	Real exchange rate growth	3.5	3.7	$(3.0, 4.6)^\star$	-0.20	0.03	$(-0.27, 0.33)^\star$
Δw	Real wage growth	0.6	0.8	$(0.6, 1.0)^\star$	-0.06	0.21	$(-0.12, 0.50)^\star$
$\hat{h}$	Hours worked	1.4	3.8	$(2.4, 5.7)$	0.14	0.29	$(-0.01, 0.55)^\star$
y^{Co}	Commodity/mining prod.	3.8	4.3	$(2.9, 6.2)^\star$	0.36	0.13	$(-0.24, 0.48)^\star$
π^d	CPI inflation	6.3	9.5	$(7.5, 11.6)$	0.27	-0.11	$(-0.40, 0.19)$
π^c	GDP inflation	3.2	3.5	$(2.6, 4.6)^\star$	-0.01	-0.19	$(-0.50, 0.16)^\star$
$\pi^{m,c}$	Cons. imports inflation	4.2	6.4	$(4.7, 8.5)$	0.13	0.06	$(-0.29, 0.41)^\star$
π^i	Investment inflation	6.5	5.6	$(3.9, 7.9)^\star$	-0.10	-0.07	$(-0.40, 0.28)^\star$
R	Monetary policy rate	1.9	3	$(1.7, 4.6)^\star$	-0.36	-0.13	$(-0.47, 0.26)^\star$
cp	EMBI global Chile spread	0.6	0.8	$(0.4, 1.4)^\star$	-0.50	0.00	$(-0.37, 0.37)$
R^D	Deposit rate	2	2.9	$(1.7, 4.6)^\star$	-0.33	-0.09	$(-0.45, 0.30)^\star$
R^E	Credit rate	2.6	3.4	$(2.0, 5.3)^\star$	-0.48	-0.05	$(-0.41, 0.34)$
Δl^E	Loans growth	1.4	5.1	$(3.9, 6.7)$	0.23	0.63	$(0.40, 0.80)$
$\Delta capb$	Banks' networth growth	2	4.8	$(3.8, 6.0)$	-0.04	-0.01	$(-0.31, 0.29)^\star$
Δn	Entreprs.' networth growth	2.8	3.1	$(2.5, 3.8)^\star$	-0.23	-0.04	$(-0.34, 0.26)^\star$
Δy^*	Foreign GDP growth	0.6	0.7	$(0.5, 0.8)^\star$	0.51	0.15	$(-0.16, 0.44)$
π^*	Foreign inflation	8.6	7.9	$(6.1, 9.8)^\star$	0.26	0.14	$(-0.19, 0.44)^\star$
R^*	Foreign interest rate	1.9	1.5	$(0.8, 2.5)^\star$	0.03	0.04	$(-0.34, 0.42)^\star$
p^{Co*}	Commodity/copper price	36.3	25.6	$(15.3, 40.0)^\star$	0.10	0.01	$(-0.36, 0.38)^\star$

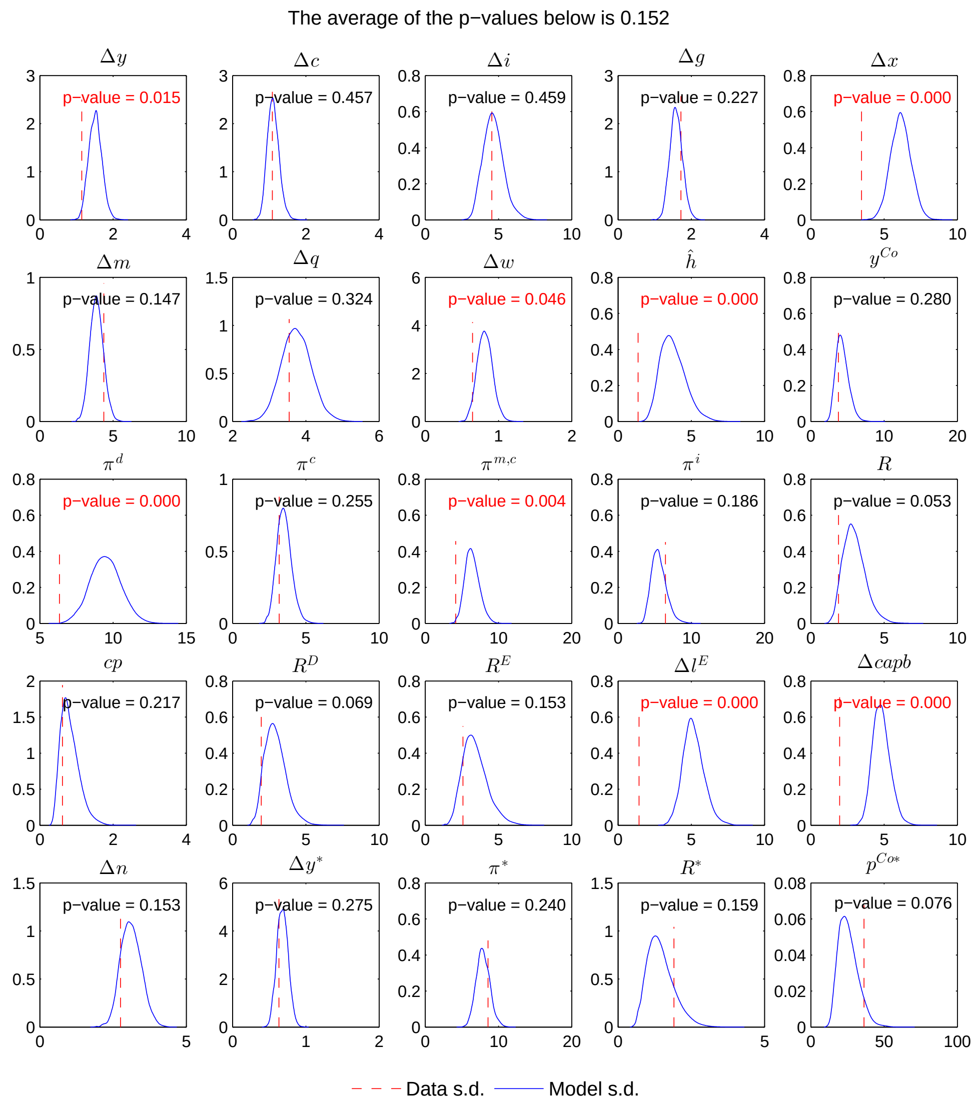
Note: This table shows the standard deviations and correlations with real GDP growth of the observed variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 5,000 draws of the moments from the model at the posterior mean of the estimated parameters, each draw with 44 observations, as in the original (adjusted) sample, with 200 burn-in periods. The $\star$ denotes those data moments that are likely to be generated by the model (i.e. those that are inside the confidence interval).

larly, the exogenous shocks to the spreads have relatively low degrees of persistence ($\rho_{\tilde{\varepsilon}_D}$, which is however not very well identified, and $\rho_{\tilde{\varepsilon}_E}$). Instead, the dividend adjustment costs elasticity for entrepreneurs are relatively high (κ_E), unlike the banks' adjustment costs elasticity which is lower (κ_B). Regarding the estimated standard deviations, shocks to the entrepreneurs' credit spread have a higher volatility than shocks to the deposit spread. With respect to the parameters associated with the commodity sector, commodity/copper price shocks have relatively high estimated degrees of persistence and volatility ($\rho_{p^{Co,*}}$ and $\sigma_{p^{Co,*}}$) while commodity/mining production is less persistent and volatile ($\rho_{y^{Co}}$ and $\sigma_{y^{Co}}$).

1.2.2 Data vs. smoothed variables

To assess the goodness of fit of the model, Figure 1 shows the observed data for Chile and the corresponding smoothed variables from the model. Conditional upon the calibrated measurement errors, the model tracks the in-sample dynamics of most variables quite well. This is especially so for the national income accounts data (real GDP, consumption, investment, exports and imports), but also the evolution of the real exchange rate, real wages and hours worked are matched relatively closely. Regarding the inflation series, the model somewhat overstates the volatility of the GDP deflator, while it understates the volatility of the investment deflator. Imported consumption inflation is explained relatively well, but the model seems to have some problems in explaining the relatively high CPI inflation observed during the 2007-08 period; otherwise, CPI inflation is matched fairly well. With respect to the financial data, the model exaggerates the volatility of bank networth, while it does a better job in explaining the evolution of firm networth. Credit growth is also somewhat more volatile in the model than in the data.

Figure 2: Posterior predictive checking for standard deviations: Chile.

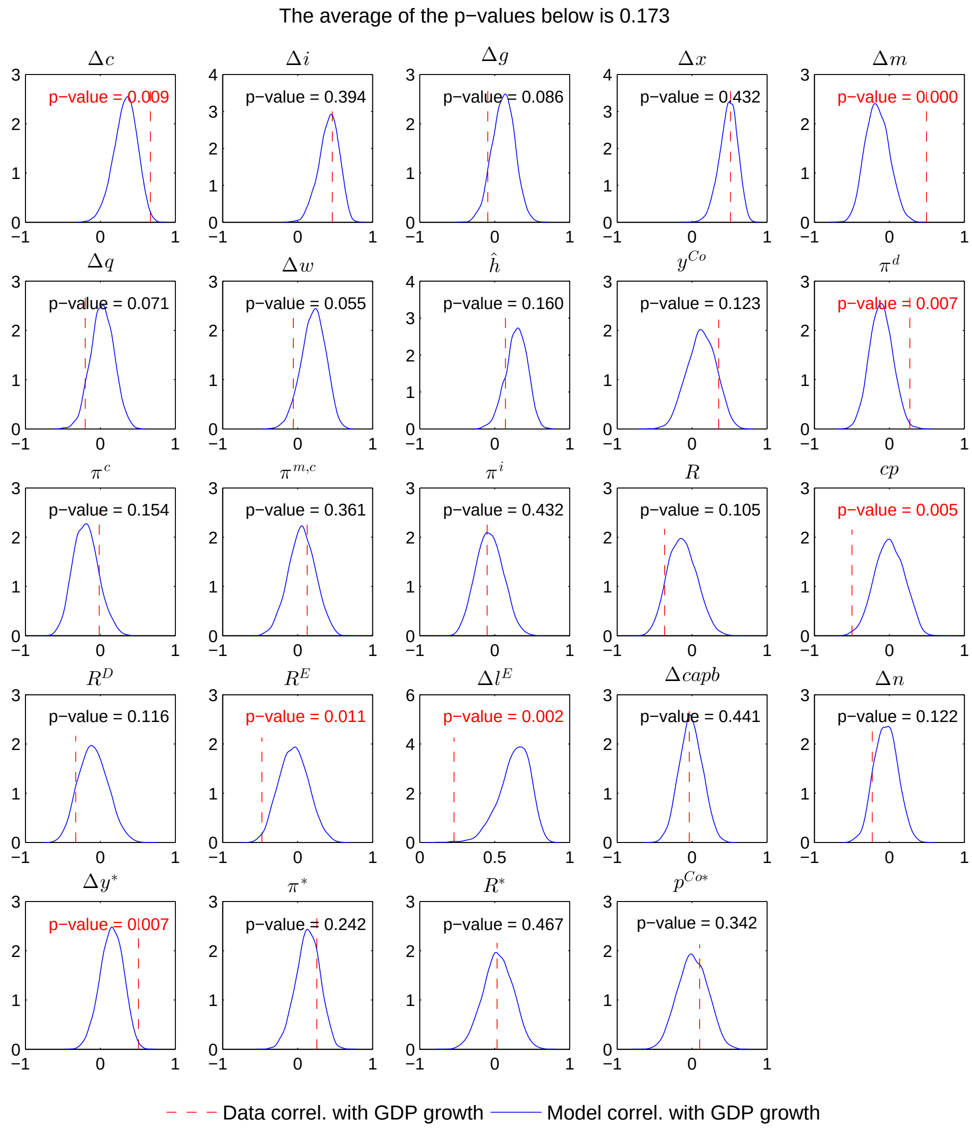


Note: This figure shows the standard deviations of the observed variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 5,000 draws of the moments from the model at the posterior mean of the estimated parameters, each draw with 44 observations, as in the original (adjusted) sample, with 200 burn-in periods. The p-values correspond to the test of equality of the standard deviations.

1.2.3 Comparison of moments

To further assess the goodness of fit of the model in terms of its ability to match empirical moments for Chilean data, we performed a posterior predictive exercise that consisted of simulating the standard deviations and correlations with real GDP growth of the observed variables from the model. Table 4 displays the moments in the data and the simulated moments from the model (means and 95% confidence intervals) while Figures 2 and 3 show the distributions of the moments and the p-values of the test of equality of moments. According to the results from Table 4, the model matches the volatility of most variables including the various interest rates. However, the volatility of some variables is exaggerated by the model, including exports growth, hours worked and real wage growth (as a result, output volatility is also exaggerated), imported consumption inflation and domestic inflation, and the growth rates of loans and bank networth. Some of those results may be related to the relatively high estimated volatility of markup shocks. In terms of the correlations with real GDP growth, the model matches it relatively well, with only a few exceptions including the credit rate which is less countercyclical in the model than in the data and credit growth which is more procyclical in the model than in the data. According to the results in Figures 2 and 3, we cannot reject the null hypothesis of equality of moments for most variables, as indicated by the average of the p-values of this test. Overall, subject to a few limitations, the model thus fits the Chilean data relatively well.

Figure 3: Posterior predictive checking for correlations with real GDP growth: Chile.



Note: See Figure 2. This figure shows the correlations with real GDP growth of the observed variables and compares them to a distribution of the same moments derived from the model.

1.2.4 Variance decomposition

Table 5 shows the unconditional variance decomposition of selected variables at the posterior mean of the estimated parameters. Apart from the contribution of the individual shocks, we also computed the overall contribution of the foreign shocks (including exports and imports price markup shocks). The results show that foreign shocks explain a significant fraction of the variance of most variables and in particular output, CPI inflation, the policy rate, the real exchange rate and the current account, as well as the financial variables. Imported price markup shocks for investment are among the most important foreign shocks, which may be related to the high import share of investment in Chile. Country risk shocks (observed and unobserved) are also important drivers of most variables, but less so of the financial variables which seem more related to domestic factors, as indicated by the importance of exogenous shocks to the credit spread. Regarding the role of the commodity sector, commodity/copper price shocks explain a significant fraction of exchange rate volatility, inflation, consumption and the policy rate.

Table 5: Unconditional variance decomposition: Chile.

Shock	Description	Δy	Δc	Δi	Δq	π^c	R	a	Δl^E	Ψ	$\Delta capb$	Δn
$\mu_{z,t}$	Unit-root tech.	2.5	2.1	0.0	2.0	0.2	0.4	2.5	1.4	0.7	0.3	0.0
ϵ_t	Stationary tech.	3.9	5.0	3.2	2.1	6.5	9.5	2.3	12.7	0.8	1.6	0.5
Υ_t	MEI	15.6	2.1	53.0	0.3	1.3	2.7	6.0	9.4	7.5	1.3	14.4
ζ_t^c	Consumption prefs.	4.7	50.4	0.7	1.6	1.4	2.8	0.1	2.1	1.0	0.4	0.2
ζ_t^h	Labor prefs.	2.0	5.1	1.6	2.2	5.2	9.2	4.0	0.7	0.5	0.2	0.3
$\tilde{\phi}_t$	Country risk premium	0.7	2.0	1.9	40.6	6.4	10.6	30.4	0.2	0.6	0.4	0.3
$\tilde{\phi}_{cp,t}$	Obs. country risk prem.	0.3	2.6	1.3	19.3	5.2	9.5	32.3	0.1	0.3	0.2	0.2
$\tilde{\varepsilon}_{D,t}$	Deposit spread	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.9	0.1	0.4
$\tilde{\varepsilon}_{E,t}$	Credit spread	0.4	0.0	1.9	0.0	0.0	0.0	0.1	0.5	37.0	75.4	4.8
$\varepsilon_{R,t}$	Monetary policy	1.7	1.8	2.8	0.3	0.4	8.2	0.8	1.5	0.4	1.1	4.9
g_t	Gov. expenditures	1.1	0.0	0.0	0.0	0.0	0.1	0.0	0.6	0.1	0.1	0.0
y_t^{Co}	Commod./mining prod.	10.7	0.2	0.0	0.2	0.1	0.2	0.1	0.0	0.0	0.0	0.0
p_t^{Co*}	Commod./copper price	0.1	11.0	1.1	14.8	6.7	14.6	1.7	0.2	0.3	0.1	0.1
τ_t^d	Markup, domestic	8.8	3.4	4.6	0.4	35.2	14.2	0.1	30.0	3.4	3.6	2.7
τ_t^x	Markup, exports	16.1	0.0	0.1	0.0	0.0	0.1	0.0	7.9	0.5	0.6	0.3
$\tau_t^{m,c}$	Markup, imported cons.	0.3	2.4	2.7	1.2	21.6	13.8	1.9	1.3	1.9	0.6	3.5
$\tau_t^{m,i}$	Markup, imported inv.	7.5	0.2	16.9	0.7	0.9	1.2	14.7	20.2	40.8	3.0	57.1
$\tau_t^{m,x}$	Markup, imported exp.	14.8	0.2	0.0	0.4	0.1	0.4	0.5	7.4	0.4	0.5	0.2
y_t^*	Foreign GDP	1.3	0.1	0.2	0.7	0.4	0.7	0.6	0.6	0.2	0.1	0.1
π_t^*	Foreign inflation	1.5	1.0	0.3	1.8	1.0	1.9	1.4	0.7	0.1	0.1	0.0
R_t^*	Foreign interest rate	0.0	0.0	0.0	0.3	0.1	0.1	0.3	0.0	0.0	0.0	0.0
	7 foreign	6.4	18.8	4.8	79.5	19.9	37.8	69.3	3.1	2.1	1.1	0.7
	All foreign	45.2	21.6	24.5	81.7	42.6	53.1	86.4	39.9	45.6	5.8	61.7

Note: This table shows the contribution of the different shocks to the unconditional variances of the respective variables in %, computed at the posterior mean of the estimated parameters. The 7 foreign shocks are $\mu_{z,t}$, $\tilde{\phi}_t$, $\tilde{\phi}_{cp,t}$, p_t^{Co*}, y_t^*, π_t^* and R_t^*. All foreign shocks are these 7 shocks plus τ_t^x, $\tau_t^{m,c}$, $\tau_t^{m,i}$ and $\tau_t^{m,x}$. The selected variables in the columns of the table are the growth rates of real GDP (Δy), private consumption (Δc) and investment (Δy), CPI inflation (π^c), the monetary policy rate (R), real exchange rate growth (Δq), the current account (a), credit growth (Δl^E), the total spread ($\Psi = \Psi^D \Psi^E$), and the growth rates of banks' networth ($\Delta capb$) and entrepreneurs' networth (Δn).

2 Policy analysis

2.1 Sudden decrease in commodity price

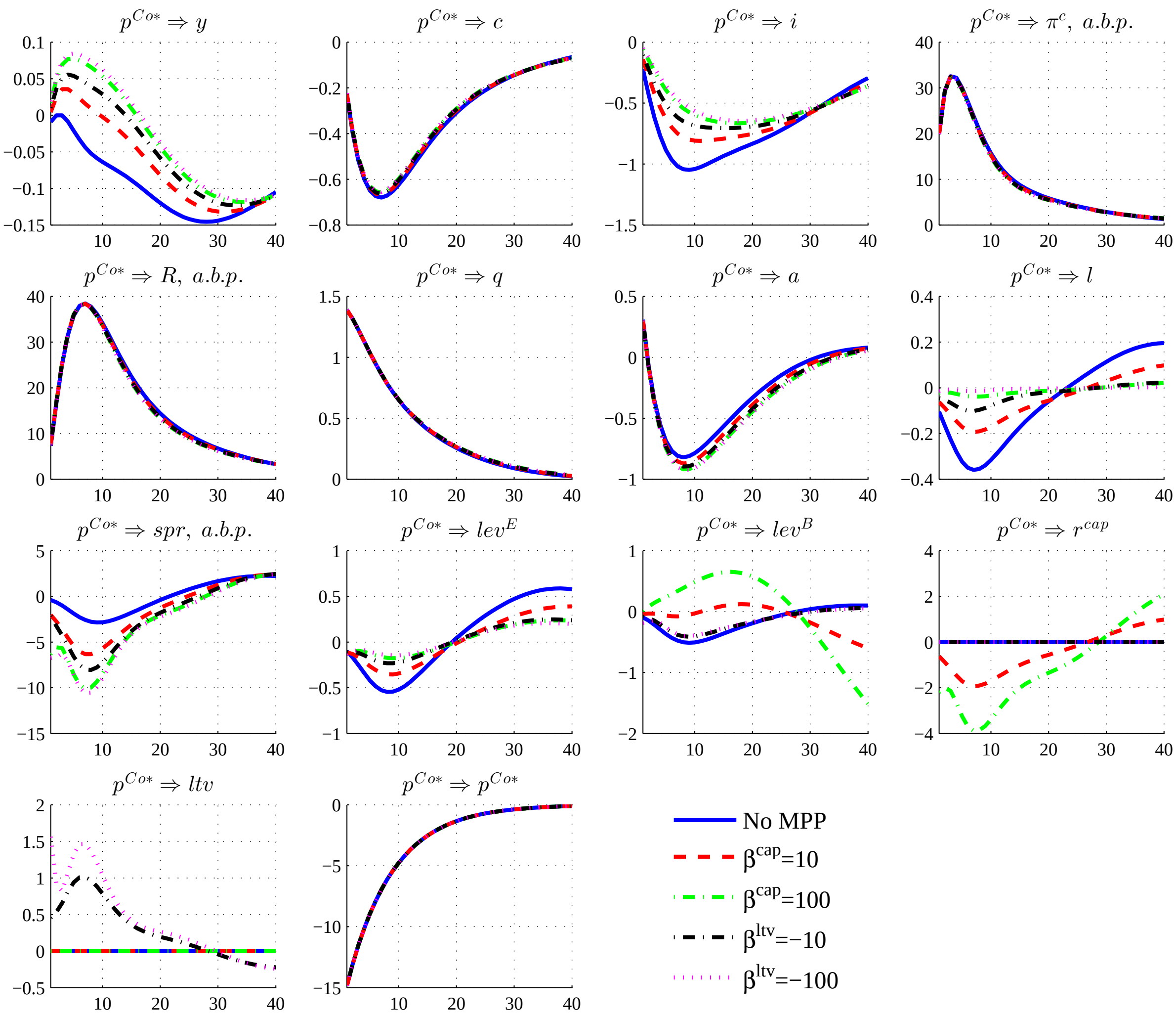
We now conduct a number of policy experiments using the estimated model. First, Figure 4 shows the estimated impulse responses to a negative commodity price shock of one standard deviation. We distinguish two cases, one where the only policy variable at work is the short-term interest rate ("No MPP") and alternative scenarios where in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to a simple feedback rule that has the alternative policy instruments respond to the deviation of real credit from steady state. The shock implies a negative wealth effect that generates a fall in consumption, investment and (non-commodity) output, but also a real exchange rate depreciation that increases foreign prices faced by domestic agents and therefore also CPI inflation due to the pass-through. On the financial sector side, credit falls but there is also a fall in leverage that generates initially lower credit spreads. The alternative policies are seen to limit the impact of the shock on credit by easening financial conditions as reflected by lower credit spreads.

2.2 Increase in foreign interest rate

The next scenario is a sudden increase in the foreign interest rate by 1%. Figure 5 shows the impulse responses for this scenario. In general, this shock has relatively small effects according to the estimated model. Investment falls but there is an initial increase in output associated with higher exports (due to the real exchange rate depreciation). In addition, the shock implies an increase in credit spreads due to higher leverage ratios and a higher policy rate (due to higher inflation caused by the exchange rate depreciation), but despite the latter credit increases. Therefore, we choose as a feedback rule to analyze alternative policies for this case one that responds to the total credit spread.[7] The results further show that the alternative

[7] Notice that private consumption increases in response to this shock. This effect may be related to a positive wealth effect given that domestic households are net foreign creditors in steady state.

Figure 4: Impulse responses to a negative commodity price shock: Chile.



Note: This figure shows the impulse responses of selected variables to a negative one-standard deviation commodity price shock in period 1. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\mathrm{INST}_t = \mathrm{INST} + \beta(\mathrm{VAR}_t - \mathrm{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is real credit.

policies, through stabilizing credit spreads, have a positive effect on investment which falls by less than in the case where the short-term interest rate is the only policy variable at work.

Finally, we analyze the implications of an announced increase in the foreign interest rate. Figure 6 shows this case, where the interest rate increase (1%) occurs in period 3 but is known in period 1. The results are overall similar as in the case of the surprise interest rate shock.

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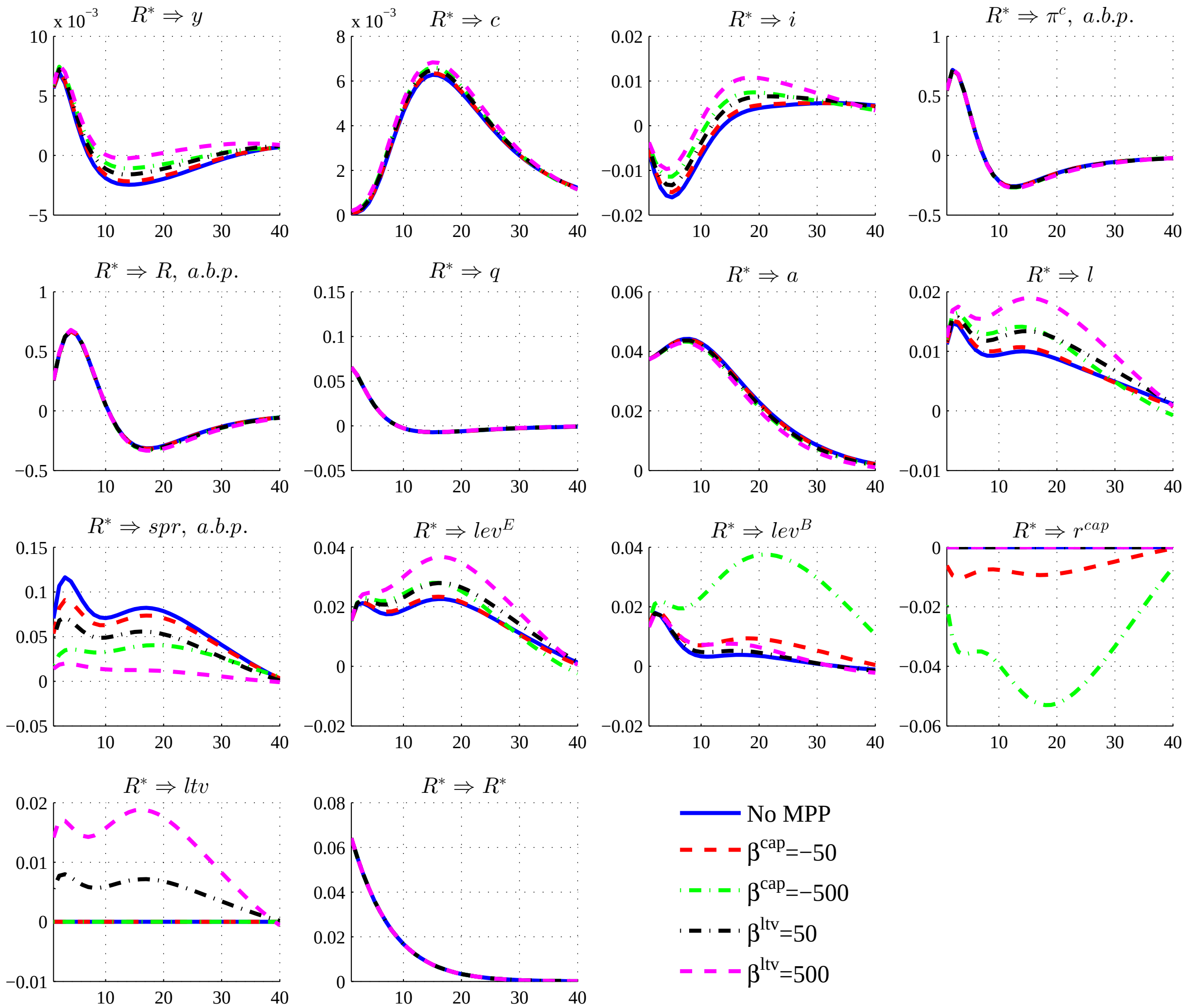
Figure 5: Impulse responses to a foreign interest rate shock: Chile.



Note: This figure shows the impulse responses of selected variables to a 1% foreign interest rate shock in period 1. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is the total credit spread.

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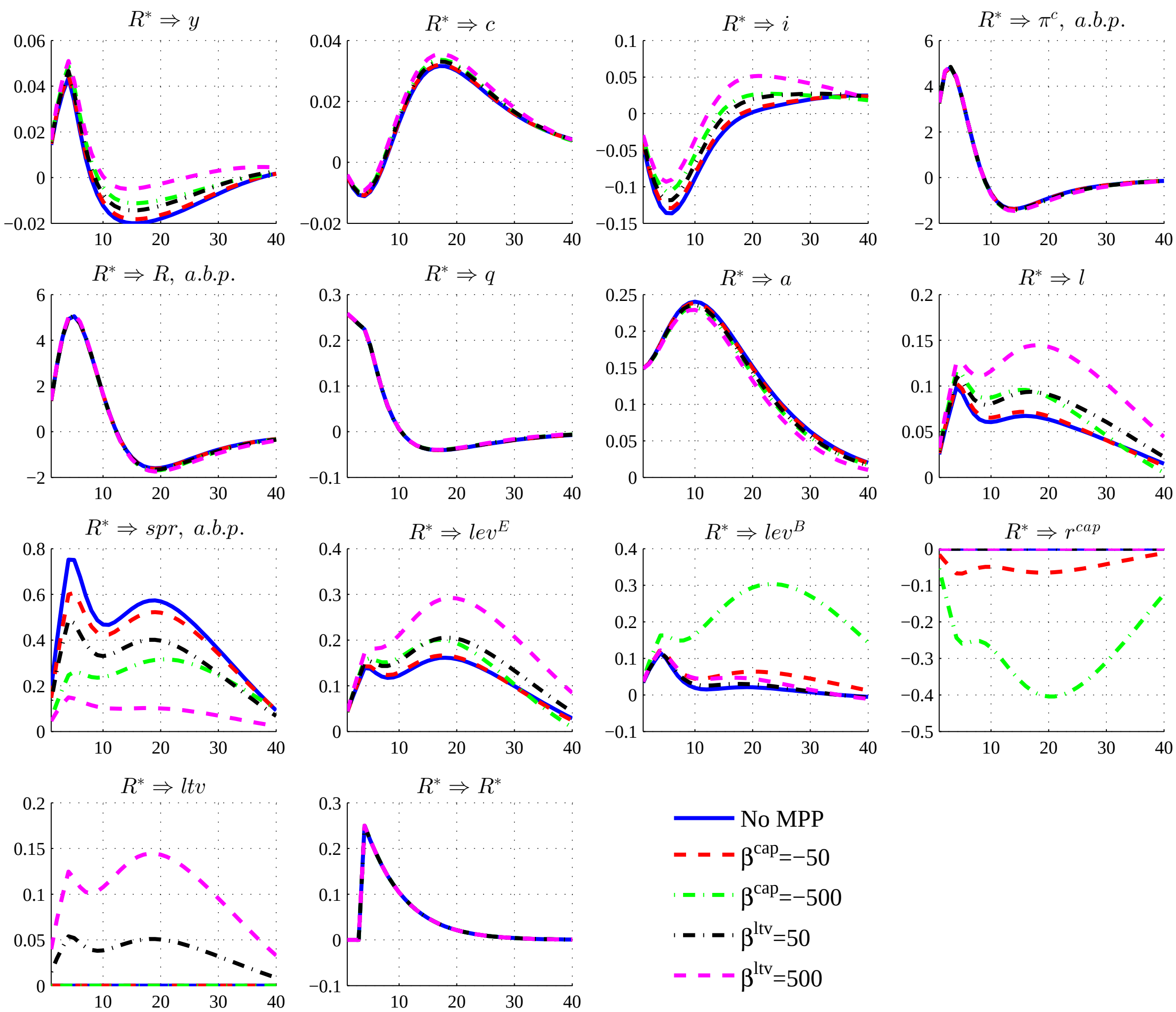
Figure 6: Impulse responses to an announced foreign interest rate shock: Chile.



Note: This figure shows the impulse responses of selected variables to an announced 1% foreign interest rate shock in period 3. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is the total credit spread.

Estimation and Policy Analysis for Colombia*

December 18, 2014

1 Estimation

1.1 Estimation strategy

1.1.1 Data

The model is estimated with 25 observable time series for Colombia: the growth rates of real GDP ($\Delta \log Y_t$), private consumption ($\Delta \log C_t$), gross capital formation ($\Delta \log I_t$), government consumption ($\Delta \log G_t$), exports ($\Delta \log X_t$), imports ($\Delta \log M_t$), real wages ($\Delta \log w_t$), average hours worked ($\hat{h}_t$), real GDP in the mining sector as a proxy of commodity production/exports (y_t^{Co}), domestic inflation based on the GDP deflator (π_t), CPI inflation (π_t^c), tradable CPI inflation as a proxy for imported consumption price inflation ($\pi_t^{m,c}$), investment price inflation based on the investment deflator (π_t^i), imports price inflation based on the imports deflator (π_t^m), the short-term monetary policy rate (R_t), the EMBI global Colombia spread as a proxy for the observed country premium (cp_t), lending rate as the average 3-month interest rate on total bank loans (R_t^E), the growth rates of real bank commercial loans deflated by the CPI ($\Delta \log L_t^E$), total banks loans over banks' networth as a proxy for bank leverage (lev_t^b), real stock prices as a proxy for firms' networth (n_t). Real effective exchange rate ($\Delta \log q_t$), the growth rate of a trade-weighted average of commercial partners' real GDP ($\Delta \log Y_t^*$) and a trade-weighted foreign inflation rate (π_t^*), all computed according to BIS methodology, the short-term LIBOR as a proxy for the foreign interest rate (R_t^*), and the commodity price is computed as a weighted average for all commodities exported by Colombia, it is deflated by the foreign price index, (p_t^{Co*}).

The source of this data is the BIS, the Colombian Superintendency of Financial Institutions, Colombian department of statistics and the Central Bank of Colombia. The sample period is 2001Q2-2014Q1. All growth rates are quarterly log differences. The inflation and interest rates are annualized quarterly rates. To account for the trends in the data, some of which are different from the model's balanced growth path and average values, the growth rates and interest rates are demeaned. Series for price and production of commodities, the real stock price and bank's leverage are linearly detrended because these series exhibit trends that are not explained by the model.

1.1.2 Shocks and measurement errors

There are 16 structural shocks from the baseline model as in CTW, the observed country premium shock, shocks to commodity production and prices, and two financial shocks to the banks' and entrepreneurs' interest rate spreads. Therefore the model was estimated with 21 structural shocks. We further allow for some degree of measurement errors on all variables except the nominal interest rates and the foreign variables. The unconditional variances of the i.i.d. measurement errors are calibrated to 10% of the variance of the observed series for all the remaining variables.

1.1.3 Calibration and priors

Table 1 displays the calibrated parameters. Some of the calibrated values are identical to the ones used by CTW. This concerns the elasticity of country risk to the NFA position $\tilde{\phi}_a$ and the fraction of wage indexation to the real growth trend ϑ_w. Most of the remaining calibrated parameters are set to match available statistics or estimates for the Colombian economy.

*Technical note for the joint project of the BIS CCA Research Network on "Incorporating financial stability considerations into central bank policy models". For questions and comments, please contact Diego Rodríguez (drodrigu@banrep.gov.co) or Franz Hamann (fhamansa@banrep.gov.co).

Table 1: Calibrated parameters: Colombia.

Parameter	Value	Description
α	0.2338	Capital share in production
β	0.9938	Discount factor
σ_L	1.0000	Inverse Frisch elasticity
η_c	1.5000	Elasticity of subst., domestic and imported consumption
ω_i	0.1500	Import share in investment goods
ω_c	0.1200	Import share in consumption goods
ω_x	0.1800	Import share in non-commodity export goods
$\tilde{\phi}_a$	0.0100	Elasticity of country risk to net asset position
η_g	0.1500	Steady state government consumption share of GDP
η_a	-0.2500	Steady state NFA position to GDP ratio
$\eta_{y^{Co}}$	0.0746	Steady state mining exports to GDP ratio
χ	0.6420	Domestic ownership in commodity sector
τ_k	0.1000	Capital tax rate
τ_w	0.0000	Payroll tax rate
τ_c	0.0731	Consumption tax rate
τ_y	0.0277	Labor income tax rate
τ_b	0.0000	Bond tax rate
μ_z	1.0086	Steady state gross growth rate of neutral technology
μ_ψ	1.0000	Steady state gross growth rate of investment technology
$\bar{\pi}$	1.0075	Steady state gross inflation target
π^*	1.0040	Steady state gross foreign inflation rate
$\bar{\Phi}$	1.0050	Steady state country premium
λ_j	1.1000	Price and wage markups for $j = d; x; m, c; m, i; m, x; w$
ϑ_w	1.0000	Wage indexation to real growth trend
$\varkappa^j$	$1 - \kappa_j$	Indexation to inflation target for $j = d; x; m, c; m, i; m, x; w$
$\breve{\pi}$	1.0075	Third indexing base
Ψ^E	0.0077	Spread loans to deposit interest rate
m	0.6500	Regulatory loan-to-value ratio
Ψ^D	0.0025	Spread deposits to CB interest rate
γ	0.0800	Regulatory capital requirement

The capital share in production α is set to 0.2338 to match a capital-output ratio of around 8 on an quarterly basis (see Parra, 2008). The values for the subjective discount factor β, the different import shares ω_i, ω_c and ω_x, the net foreign asset position to GDP ratio, η_a, the fraction of time spent working, $L\varsigma$ and the steady state growth rate of technology, μ_z are calibrated according to the estimates of Bonaldi et. al. (2011). The government consumption share of GDP, η_g and the tax rates are set according to the implicit tax rates estimates by Rincon et. al. (2014). Similarly, the parameters of the commodity sector, $\eta_{y^{Co}}$ and χ, are also obtained from the estimates of Rincon et. al. (2014).

The steady state foreign inflation rate is calibrated to yield a steady state foreign interest rate around 4.5%. The steady state inflation target rate is set to the one publicly stated by the Central Bank of Colombia, i.e. 3% on an annual basis. The steady state country premium is calibrated to 200 basis points on an annual basis, i.e. the average value of the EMBI global Colombia spread over the sample period.

With respect to the parameters of the financial sector, the loans-to-deposit rate spread is set to 300 annual basis points and deposit-to-monetary-policy rate spread is set to 100 basis. The regulatory loan-to-value ratio is set to 65% and the capital requirement is set to 8%. The price and wage markups, λ_j for $j = d; x; m, c; m, i; m, x; w$, which we set to 1.1. As CTW and most related studies, we also assume that the third indexing base, $\breve{\pi}$, is equal to the steady state inflation target and that the share of indexation to that third indexing base is equal to $1 - \varkappa^j$ for $j = d; x; m, c; m, i; m, x; w$, where the $\varkappa^j$ are the estimated indexation parameters on lagged inflation and wages. Hence, there is full indexation and no steady state price and wage dispersion. The labor supply elasticity σ_L is set to 1 and the substitution elasticity for domestic and imported consumption goods is set to 1.5. Similarly to Adolfson *et al.*, 2008.

1.2 Estimation results and goodness of fit

1.2.1 Posterior parameter values

The parameters not calibrated are estimated using bayesian techniques. The priors and posterior estimates are reported in Tables 2 and 3. The parameters for the deposit and credit spread exogenous processes are well identified. The parameter of the deposit spread shock $\rho_{\tilde{\varepsilon}_D}$, is around 0.85 and the parameter of the credit spread shock, $\rho_{\tilde{\varepsilon}_E}$ is 0.557, implying long lasting effects of these type of shocks. The estimated standard deviations for these shocks are also well identified with relative low values. With the information used, the elasticity of the deposit spread, χ_D is not well identified, the posterior density is similar to the prior density, this may be fix if the spread for the deposit rate is included as an observable variable. On the other hand, the parameters associated to the credit spread are well identified, the estimation for the elasticity of the credit spread with respect to entrepreneur's capital, χ_E is quite low and the estimate for the autoregresive parameter, ρ_E is high.

The estimated parameters for the commodity sector are well identified. The estimation shows some persistence of the shocks ($\rho_{y^{Co}} = 0.74$ and $\rho_{p^{Co,*}} = 0.66$) with relative high values for the standard deviations.

1.2.2 Data vs. smoothed variables

To assess the goodness of fit of the model, Figure 1 shows the observed data for Colombia and the corresponding smoothed variables from the model. Conditional on the calibrated measurement error for the observed variables, the model reproduces the dynamic for almost all the observed variables. The investment time series for quantities and prices are extremely volatile relative to the output counterparts, the consequently high values for the measurement errors explain the poor goodness of fit for these variables. The ability of the model to reproduce the financial variables is low relative to the real variables.

1.2.3 Comparison of moments

To further assess the goodness of fit of the model in terms of its ability to match empirical moments, we performed a posterior predictive exercise that consisted of simulating the standard deviations and correlations with real GDP growth of the observed variables from the model. Table 4 displays the moments in the data and the simulated moments from the model (means and 95% confidence intervals) while Figures 2 and 3 show the distributions of the moments and the p-values of the test of equality of moments.

According to the results from Table 4, the model is able to reproduce the volatility of almost all GDP components, the only variable in which the model overstates the volatility is the non commodity exports. This may be a consequence of the demand function for exports included in the model that responds directly to global GDP. The volatility of hours worked is also overstate by the model, this may be consequence of the labor supply function that includes the income effect generating extra volatility for this variable. Finally note that all the financial variables volatility is exaggerated by the model.

The results in Figures 2 and 3, show the average p-value for the test of equality in standard deviations and correlations. The results imply good fit of the model in almost all variables.

1.2.4 Variance decomposition

Table 5 shows the unconditional variance decomposition of selected variables at the posterior mean of the estimated parameters. The results show that the investment efficiency shock is the most important explaining the variance of output. Another important shock is the credit spread, this shock explains almost 20% of the GDP theoretical variance and 23% of the credit variance. The shocks associated to the commodity sector explain only 3% of the GDP variance. Another important result is the effect that has the country risk premium shock on the real exchange rate (52%). Finally, it is important to note the effects of mark-up shocks, these type of shocks explain around 20% of the variance of inflation.

2 Policy analysis

2.1 Sudden decrease in commodity price

We now conduct a number of policy experiments using the estimated model. First, Figure 4 shows the estimated impulse responses to a negative commodity price shock of one standard deviation. We distinguish two cases, one where the only policy variable at work is the short-term interest rate ("No MPP") and alternative scenarios where

Table 2: Priors and posteriors of estimated parameters: Colombia.

Parameter	Description	Prior			Posterior			
		Distr.	Mean	s.d.	Mean	s.d.	5%	95%
ξ_d	Calvo, domestic	β	0.750	0.075	0.753	0.029	0.681	0.824
ξ_x	Calvo, exports	β	0.750	0.075	0.690	0.028	0.605	0.781
ξ_{mc}	Calvo, imported consumption	β	0.750	0.075	0.857	0.011	0.825	0.890
ξ_{mi}	Calvo, imported investment	β	0.750	0.075	0.668	0.026	0.612	0.724
ξ_{mx}	Calvo, imported exports	β	0.660	0.100	0.653	0.041	0.574	0.724
ξ_w	Calvo, wages	β	0.750	0.075	0.410	0.026	0.304	0.514
κ_d	Indexation, domestic	β	0.500	0.150	0.470	0.101	0.273	0.676
κ_x	Indexation, exports	β	0.500	0.150	0.306	0.105	0.125	0.481
κ_{mc}	Indexation, imported consumption	β	0.500	0.150	0.495	0.124	0.284	0.700
κ_{mi}	Indexation, imported investment	β	0.500	0.150	0.491	0.115	0.277	0.701
κ_{mx}	Indexation, imported exports	β	0.500	0.150	0.587	0.141	0.383	0.802
κ_w	Indexation, wages	β	0.500	0.150	0.490	0.101	0.251	0.732
b	Habit in consumption	β	0.650	0.150	0.700	0.048	0.606	0.798
$S''/10$	Investment adjustment costs	Γ	0.500	0.150	0.171	0.044	0.083	0.260
σ_a	Variable capital utilization	Γ	0.200	0.075	0.303	0.055	0.168	0.436
ρ_R	Taylor rule, lagged interest rate	β	0.800	0.100	0.808	0.025	0.767	0.853
r_π	Taylor rule, inflation	N	1.700	0.150	1.730	0.128	1.535	1.923
$r_{\Delta y}$	Taylor rule, output growth	N	0.125	0.050	0.162	0.043	0.084	0.245
η_x	Elasticity of subst., exports	$\Gamma_{>1}$	1.500	0.250	1.464	0.243	1.086	1.808
η_i	Elasticity of subst., investment	$\Gamma_{>1}$	1.500	0.250	1.963	0.173	1.527	2.400
η_f	Elasticity of subst., foreign	$\Gamma_{>1}$	1.500	0.250	1.099	0.066	1.000	1.215
$\tilde{\phi}_s$	Country risk adjustment coefficient	Γ	1.250	0.100	1.130	0.074	0.990	1.272
$10\chi_D$	Monit. cost elast., deposit spread	Inv-Γ	0.100	Inf	0.163	0.187	0.020	0.514
$10\chi_E$	Monit. cost elast., credit spread	Inv-Γ	0.200	Inf	0.086	0.024	0.046	0.125
ρ_E	Persistence param., credit spread	β	0.500	0.075	0.841	0.042	0.792	0.890
κ_B	Dividend adj. costs, banks	Inv-Γ	0.500	Inf	1.177	0.160	0.115	3.083
κ_E	Dividend adj. costs, entreprens.	Inv-Γ	0.500	Inf	1.320	0.390	0.310	2.627
ρ_{μ_z}	Persistence, unit-root tech.	β	0.500	0.075	0.534	0.074	0.415	0.655
ρ_ϵ	Persistence, stationary tech.	β	0.850	0.075	0.839	0.066	0.742	0.935
ρ_Υ	Persistence, MEI	β	0.850	0.075	0.958	0.021	0.926	0.990
ρ_{ζ^c}	Persistence, consumption prefs.	β	0.850	0.075	0.815	0.058	0.715	0.915
ρ_{ζ^h}	Persistence, labor prefs.	β	0.850	0.075	0.505	0.082	0.372	0.637
$\rho_{\tilde{\phi}_s}$	Persistence, country risk premium	β	0.850	0.075	0.773	0.064	0.644	0.915
$\rho_{\tilde{\phi}_{cp}}$	Persistence, obs. country risk prem.	β	0.850	0.075	0.826	0.032	0.768	0.885
$\rho_{\tilde{\varepsilon}_D}$	Persistence, deposit spread	β	0.500	0.075	0.815	0.034	0.755	0.890
$\rho_{\tilde{\varepsilon}_E}$	Persistence, credit spread	β	0.500	0.075	0.557	0.051	0.462	0.650
ρ_g	Persistence, gov. expenditures	β	0.850	0.075	0.824	0.073	0.714	0.936
$\rho_{y^{Co}}$	Persistence, commodity production	β	0.850	0.075	0.744	0.067	0.608	0.878
$\rho_{p^{Co,*}}$	Persistence, commodity price	N	0.500	0.500	0.662	0.087	0.516	0.816
a_{11}	Foreign VAR parameter	N	0.500	0.500	0.984	0.084	0.751	1.210
a_{22}	Foreign VAR parameter	N	0.000	0.500	0.076	0.093	-0.106	0.268
a_{33}	Foreign VAR parameter	N	0.500	0.500	0.764	0.122	0.509	1.078
a_{12}	Foreign VAR parameter	N	0.000	0.500	0.110	0.033	0.045	0.170
a_{13}	Foreign VAR parameter	N	0.000	0.500	-0.239	0.267	-1.006	0.650
a_{21}	Foreign VAR parameter	N	0.000	0.500	0.006	0.118	-0.297	0.320
a_{23}	Foreign VAR parameter	N	0.000	0.500	0.135	0.148	-0.486	0.746
a_{24}	Foreign VAR parameter	N	0.000	0.500	0.289	0.268	-0.447	1.010
a_{31}	Foreign VAR parameter	N	0.000	0.500	0.069	0.053	-0.050	0.167
a_{32}	Foreign VAR parameter	N	0.000	0.500	0.013	0.008	0.000	0.026
a_{34}	Foreign VAR parameter	N	0.000	0.500	0.092	0.106	-0.072	0.250
c_{21}	Foreign VAR parameter	N	0.000	0.500	0.571	0.325	-0.204	1.314
c_{31}	Foreign VAR parameter	N	0.000	0.500	0.075	0.046	-0.023	0.179
c_{32}	Foreign VAR parameter	N	0.000	0.500	-0.009	0.008	-0.025	0.007
c_{24}	Foreign VAR parameter	N	0.000	0.500	0.276	0.221	-0.656	1.192
c_{34}	Foreign VAR parameter	N	0.000	0.500	0.136	0.087	-0.022	0.290

Note: This table shows the priors and posteriors based on 1,000,000 draws from the Metropolis-Hastings (MH) algorithm, discarding

Table 3: Priors and posteriors of estimated shock standard deviations: Colombia.

Parameter	Description	Prior			Posterior			
		Distr.	Mean	s.d.	Mean	s.d.	5%	95%
$100\sigma_{\mu_z}$	Unit-root tech.	Inv-Γ	0.150	Inf	0.313	0.063	0.185	0.439
$100\sigma_{\epsilon}$	Stationary tech.	Inv-Γ	0.500	Inf	0.973	0.107	0.768	1.168
$10\sigma_{\Upsilon}$	MEI	Inv-Γ	0.150	Inf	0.394	0.082	0.247	0.533
$10\sigma_{\zeta^c}$	Consumption preferences	Inv-Γ	0.150	Inf	0.240	0.048	0.154	0.322
$10\sigma_{\zeta^h}$	Labor preferences	Inv-Γ	0.150	Inf	1.681	0.239	0.768	2.470
$100\sigma_{\tilde{\phi}}$	Country risk premium	Inv-Γ	0.150	Inf	0.876	0.197	0.282	1.409
$100\sigma_{\tilde{\phi}_{cp}}$	Observed country risk premium	Inv-Γ	0.150	Inf	0.186	0.018	0.156	0.215
$100\sigma_{\tilde{\varepsilon}_D}$	Deposit spread	Inv-Γ	0.150	Inf	0.284	0.048	0.216	0.352
$100\sigma_{\tilde{\varepsilon}_E}$	Credit spread	Inv-Γ	0.150	Inf	0.145	0.028	0.095	0.195
$100\sigma_{\varepsilon_R}$	Monetary policy	Inv-Γ	0.150	Inf	0.169	0.016	0.136	0.201
$100\sigma_{\varepsilon_g}$	Gov. expenditures	Inv-Γ	0.500	Inf	1.435	0.102	1.162	1.687
$100\sigma_{y^{Co}}$	Commodity production	Inv-Γ	0.500	Inf	2.521	0.113	2.120	2.898
$10\sigma_{p^{Co,*}}$	Commodity price	Inv-Γ	0.500	Inf	1.001	0.086	0.835	1.167
σ_{τ^d}	Markup, domestic	Inv-Γ	0.500	Inf	0.626	0.689	0.276	0.960
σ_{τ^x}	Markup, exports	Inv-Γ	0.500	Inf	3.656	0.350	1.898	5.227
$\sigma_{\tau^{m,c}}$	Markup, imported consumption	Inv-Γ	0.500	Inf	2.286	0.210	1.114	3.483
$\sigma_{\tau^{m,i}}$	Markup, imported investment	Inv-Γ	0.500	Inf	5.655	0.280	4.530	6.825
$\sigma_{\tau^{m,x}}$	Markup, imported exports	Inv-Γ	0.500	Inf	5.636	0.395	2.986	7.805
$100\sigma_{y^*}$	Foreign GDP	Inv-Γ	0.500	Inf	0.392	0.057	0.262	0.523
$100\sigma_{\pi^*}$	Foreign inflation	Inv-Γ	0.500	Inf	1.769	0.159	1.468	2.064
$1000\sigma_{R^*}$	Foreign interest rate	Inv-Γ	1.500	Inf	0.705	0.126	0.491	0.936

Note: See Table 2.

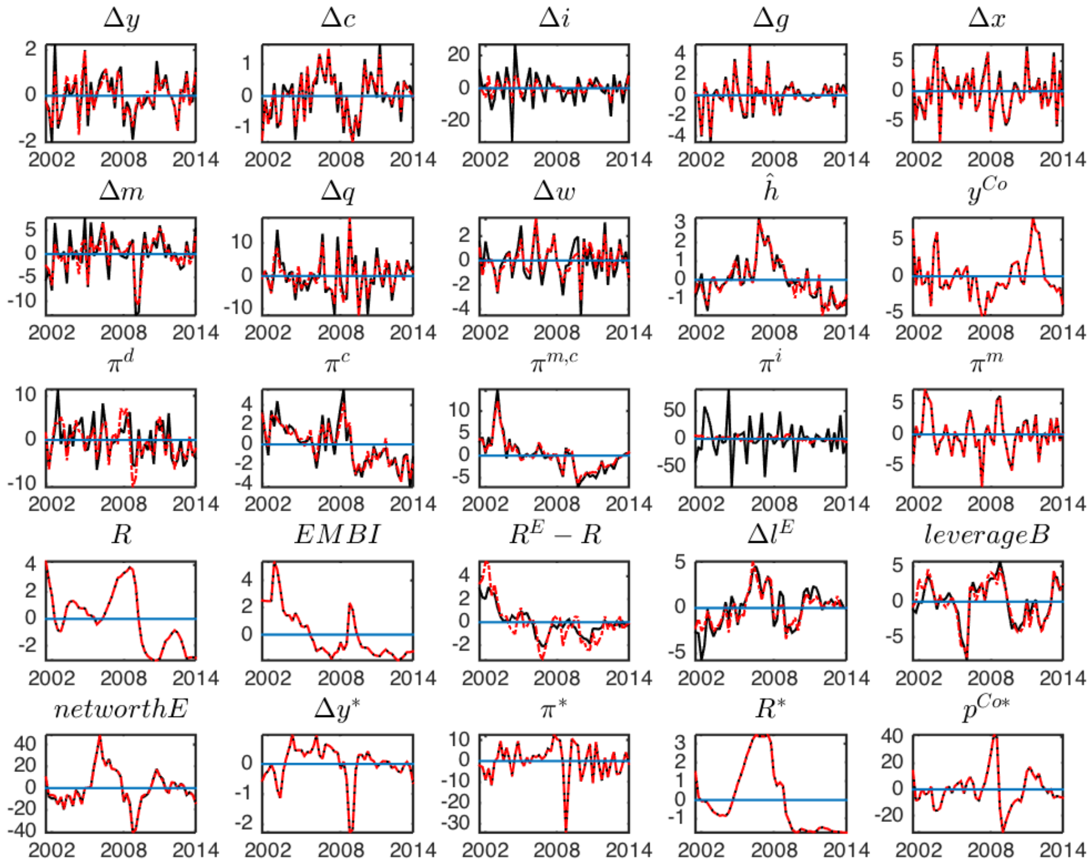
in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to a simple feedback rule that has the alternative policy instruments respond to the deviation of real credit from steady state. The shock implies a negative wealth effect that generates a fall in consumption, investment. The shock also generates a real exchange rate depreciation that increases foreign prices faced by domestic agents and therefore also CPI inflation due to the pass-through. The depreciation of the real exchange rate expand exports of non commodity goods generating an increase in the non-commodity output. On the financial sector side, the demand for credit falls and also a fall in leverage that lower credit spreads. The alternative policies are seen to limit the impact of the shock on credit by easing financial conditions as reflected by lower credit spreads.

2.2 Increase in foreign interest rate

The next scenario is a sudden increase in the foreign interest rate by 1%. Figure 5 shows the impulse responses for this scenario. In general, this shock has relatively small effects according to the estimated model. Output, consumption and investment falls. The real exchange rate depreciates affecting inflation. The reduction in investment affects credit y consequently reduce credit spreads. The macroprudencial policies avoid the reduction on credit reducing further the spreads. The policies generate an increase in investment that reduces the negative effect of the shock generating an increase in output.

Finally, we analyze the implications of an announced increase in the foreign interest rate. Figure 6 shows this case, where the interest rate increase (1%) occurs in period 3 but is known in period 1. In this case, since the agents are aware of the future increase in the external interest rate, they anticipated the negative effects of the shock an increase the demand for credit, this implies an increase in current investment financed with credit that will boost current output. Once the shock is received, the same channels of the unanticipated shock are in place. The macroprudencial policies smooth the path of credit reducing the increase in investment.

Figure 1: Observed data vs. smoothed variables: Colombia, 2001Q2-2014Q1.



Note: This figure shows the observed data and the corresponding smoothed model variables, computed by the Kalman smoother at the posterior mean of the estimated parameters.

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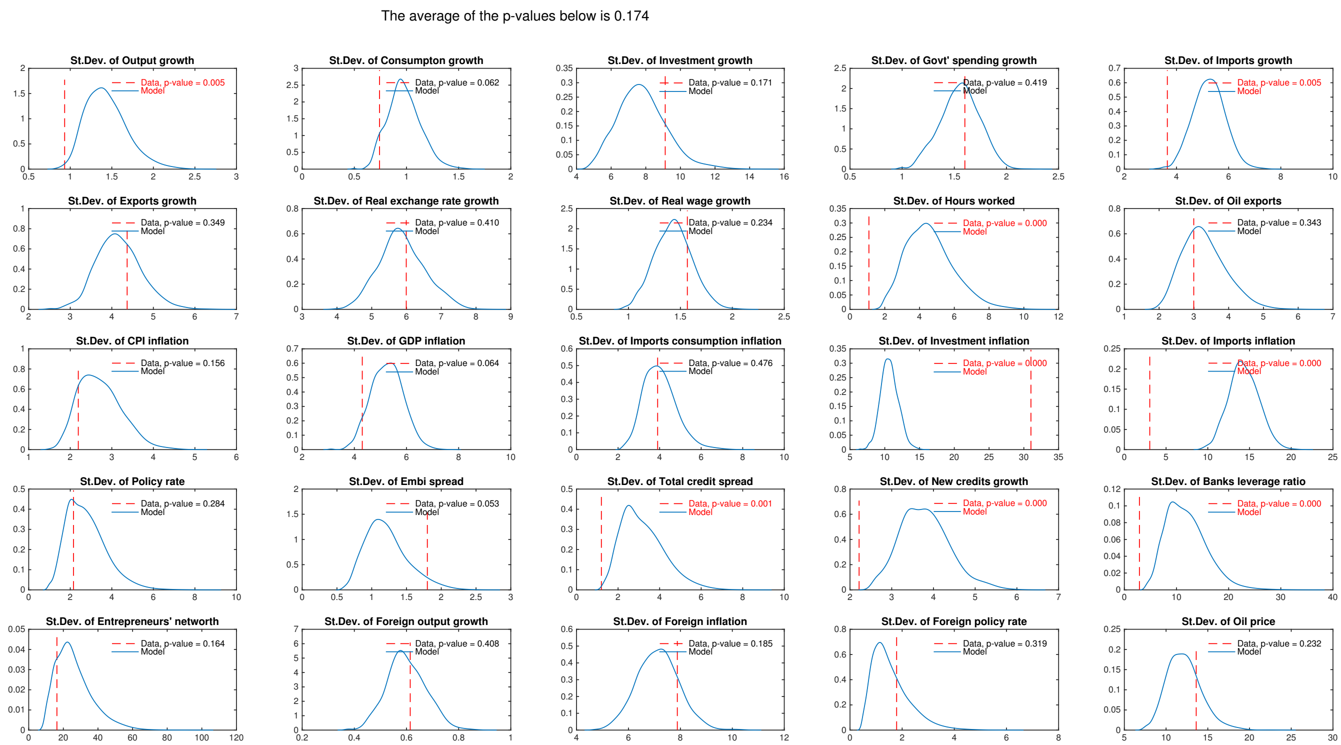
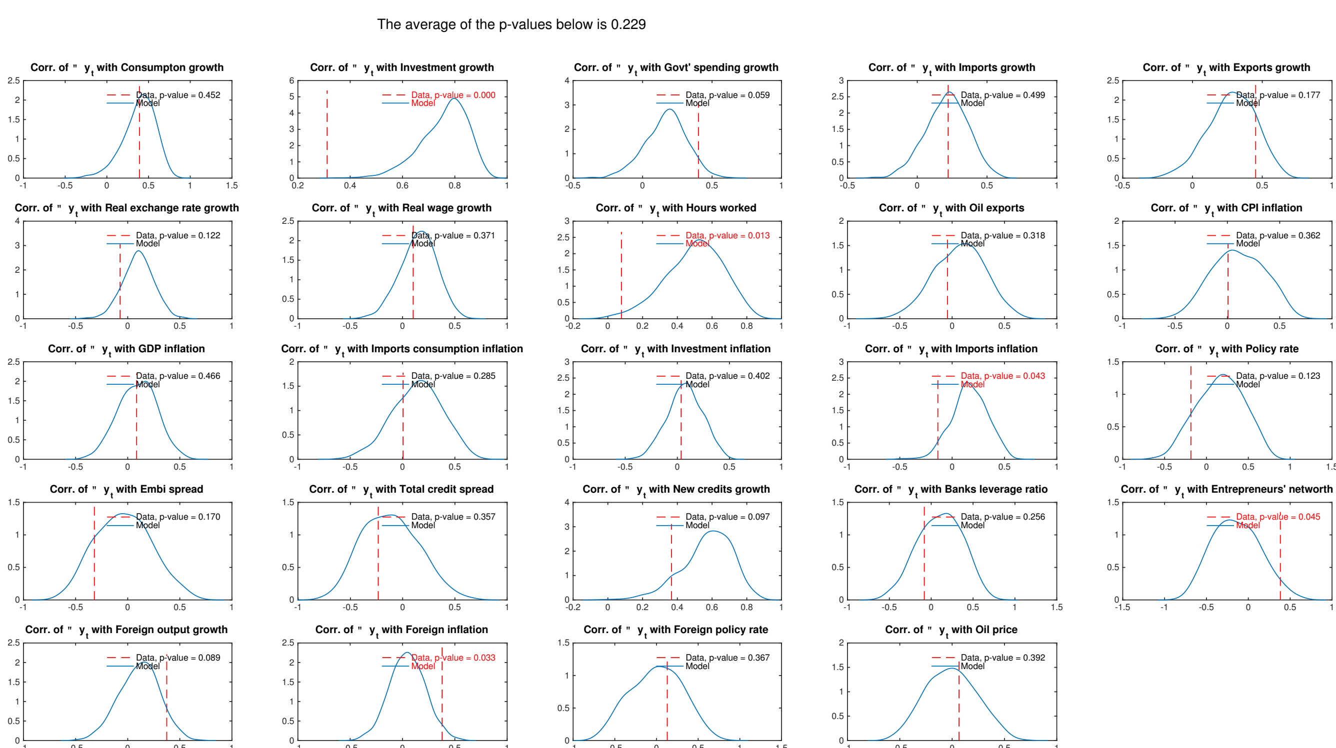
Figure 2: Posterior predictive checking for standard deviations: Colombia.



Note: This figure shows the standard deviations of the observed variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 5,000 draws of the moments from the model at the posterior mean of the estimated parameters, each draw with 44 observations, as in the original (adjusted) sample, with 200 burn-in periods. The p-values correspond to the test of equality of the standard deviations.

Figure 3: Posterior predictive checking for correlations with real GDP growth: Colombia.



Note: See Figure 2. This figure shows the correlations with real GDP growth of the observed variables and compares them to a distribution of the same moments derived from the model.

Table 4: Posterior predictive checking for std. deviations and correlations with real GDP growth: Chile.

Variable	Description	s.d.			Correl. with GDP growth		
		Data	Model mean	Model 95% CI	Data	Model mean	Model 95% CI
Δy	GDP growth	0.9	1.4	$(1.0, 2.0)$			
Δc	Priv. consumption growth	0.7	1.0	$(0.7, 1.3)^*$	0.4	0.4	$(-0.06, 0.71)^*$
Δi	Investment growth	9.1	7.8	$(5.4, 11.0)^*$	0.3	0.8	$(0.55, 0.89)$
Δg	Gov. consumption growth	1.6	1.6	$(1.2, 1.9)^*$	0.4	0.2	$(-0.14, 0.45)^*$
Δx	Exports growth	3.6	5.2	$(4.1, 6.4)$	0.2	0.2	$(-0.11, 0.49)^*$
Δm	Imports growth	4.4	4.2	$(3.2, 5.3)^*$	0.5	0.3	$(-0.08, 0.59)^*$
Δq	Real exchange rate growth	6.0	5.9	$(4.7, 7.2)^*$	-0.1	0.1	$(-0.18, 0.38)^*$
Δw	Real wage growth	1.6	1.4	$(1.1, 1.8)^*$	0.1	0.2	$(-0.20, 0.46)^*$
$\hat{h}$	Hours worked	1.1	4.6	$(2.3, 7.5)$	0.08	0.50	$(0.13, 0.78)$
y^{Co}	Commodity/mining prod.	3.0	3.3	$(2.3, 4.6)^*$	0.0	0.1	$(-0.42, 0.53)^*$
π^c	CPI inflation	2.2	2.7	$(1.9, 3.8)^*$	0.0	0.1	$(-0.37, 0.55)^*$
π^d	GDP inflation	4.3	5.3	$(4.1, 6.4)^*$	0.1	0.1	$(-0.27, 0.43)^*$
$\pi^{m,c}$	Cons. imports inflation	3.9	4.0	$(2.7, 5.7)^*$	0.0	0.1	$(-0.35, 0.58)^*$
π^i	Investment inflation	31.0	10.7	$(8.4, 13.2)$	0.0	0.1	$(-0.26, 0.40)^*$
π^m	Imports inflation	3.0	14.3	$(11.0, 17.9)$	-0.14	0.17	$(-0.17, 0.49)^*$
R	Monetary policy rate	2.2	2.8	$(1.4, 4.9)^*$	-0.2	0.2	$(-0.37, 0.66)^*$
cp	EMBI global Chile spread	1.8	1.2	$(0.7, 1.9)^*$	-0.3	0.0	$(-0.53, 0.50)^*$
$R^E - R$	Credit rate spread	1.2	3.2	$(1.6, 5.5)$	-0.2	-0.1	$(-0.58, 0.44)^*$
Δl^E	Loans growth	2.2	3.8	$(2.8, 5.1)$	0.4	0.6	$(0.24, 0.81)^*$
$\Delta capb$	Banks' networth growth	2.9	11.9	$(5.9, 20.3)$	-0.1	0.1	$(-0.45, 0.58)^*$
Δn	Entreprs.' networth growth	16.3	26.1	$(11.1, 51.3)^*$	0.4	-0.1	$(-0.65, 0.43)^*$
Δy^*	Foreign GDP growth	0.6	0.6	$(0.5, 0.7)^*$	0.4	0.1	$(-0.29, 0.48)^*$
π^*	Foreign inflation	7.9	7.1	$(5.6, 8.7)^*$	0.4	0.1	$(-0.29, 0.39)^*$
R^*	Foreign interest rate	1.8	1.6	$(0.6, 3.3)^*$	0.1	0.0	$(-0.58, 0.57)^*$
p^{Co*}	Commodity/copper price	13.6	12.2	$(8.7, 16.7)^*$	0.1	0.0	$(-0.46, 0.46)^*$

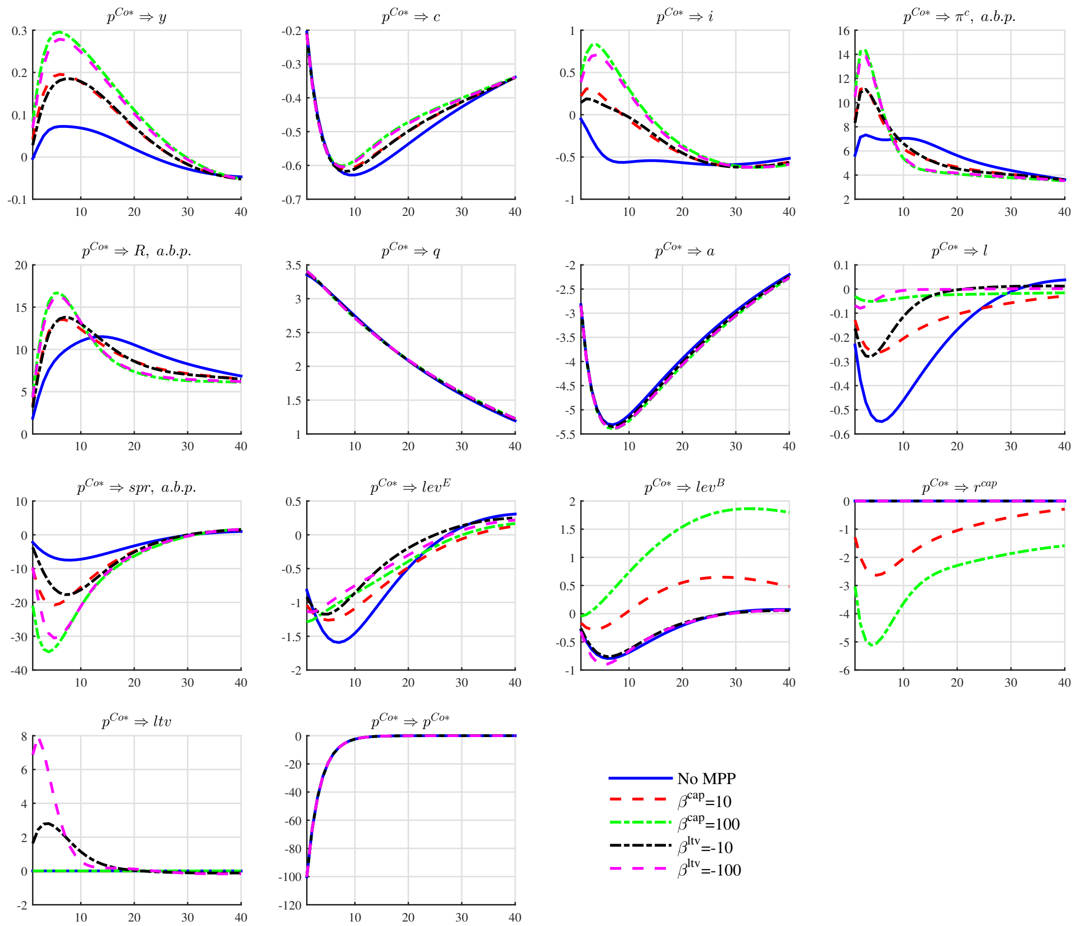
Note: This table shows the standard deviations and correlations with real GDP growth of the observed variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 5,000 draws of the moments from the model at the posterior mean of the estimated parameters, each draw with 44 observations, as in the original (adjusted) sample, with 200 burn-in periods. The * denotes those data moments that are likely to be generated by the model (i.e. those that are inside the confidence interval).

Table 5: Unconditional variance decomposition: Colombia

Shock	Description	Δy	Δc	Δi	Δq	π^c	R	a	Δl^E	Ψ
$\mu_{z,t}$	Unit-root tech.	4.07	8.62	0.09	0.83	0.44	0.42	0.64	4.35	0.47
ϵ_t	Stationary tech.	5.25	9.03	1.55	1.69	13.11	10.57	0.08	14.80	0.35
Υ_t	MEI	39.59	7.55	46.75	2.60	18.72	36.94	15.31	13.08	7.34
ζ_t^c	Consumption prefs.	6.54	41.98	0.50	1.40	2.62	4.00	0.27	1.88	0.14
ζ_t^h	Labor prefs.	9.32	12.21	3.07	2.16	24.58	16.64	0.21	13.08	0.43
$\tilde{\phi}_t$	Country risk premium	0.13	2.02	0.37	52.79	1.33	1.78	3.45	0.91	0.18
$\tilde{\phi}_{cp,t}$	Obs. country risk prem.	0.01	0.21	0.03	3.92	0.14	0.20	0.21	0.09	0.02
$\tilde{\varepsilon}_{D,t}$	Deposit spread	0.28	0.00	0.40	0.00	0.02	0.02	0.01	0.80	8.85
$\tilde{\varepsilon}_{E,t}$	Credit spread	19.78	3.40	30.72	0.52	10.13	16.27	2.58	23.02	80.45
$\varepsilon_{R,t}$	Monetary policy	1.16	1.39	0.53	0.04	1.79	4.79	0.02	1.48	0.05
g_t	Gov. expenditures	2.00	0.06	0.02	0.02	0.07	0.09	0.00	0.83	0.01
y_t^{Co}	Commod./mining prod.	2.72	0.01	0.00	0.02	0.00	0.01	0.07	0.00	0.00
p_t^{Co*}	Commod./copper price	0.09	6.97	0.09	23.81	1.47	3.22	75.15	0.77	0.34
τ_t^d	Markup, domestic	1.80	1.51	0.46	0.04	20.00	4.28	0.09	12.61	0.22
τ_t^x	Markup, exports	1.05	0.01	0.00	0.00	0.02	0.02	0.00	0.45	0.01
$\tau_t^{m,c}$	Markup, imported cons.	0.02	0.09	0.01	0.00	0.57	0.25	0.02	0.01	0.00
$\tau_t^{m,i}$	Markup, imported inv.	1.93	0.10	1.43	0.01	0.28	0.22	0.25	7.87	0.44
$\tau_t^{m,x}$	Markup, imported exp.	0.10	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00
y_t^*	Foreign GDP	0.01	0.13	0.01	0.98	0.07	0.12	0.10	0.06	0.01
π_t^*	Foreign inflation	0.10	0.24	0.01	1.67	0.07	0.14	1.52	0.12	0.02
R_t^*	Foreign interest rate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Measurement error	4.04	4.46	13.94	7.50	4.56	0.00	0.00	3.76	0.66

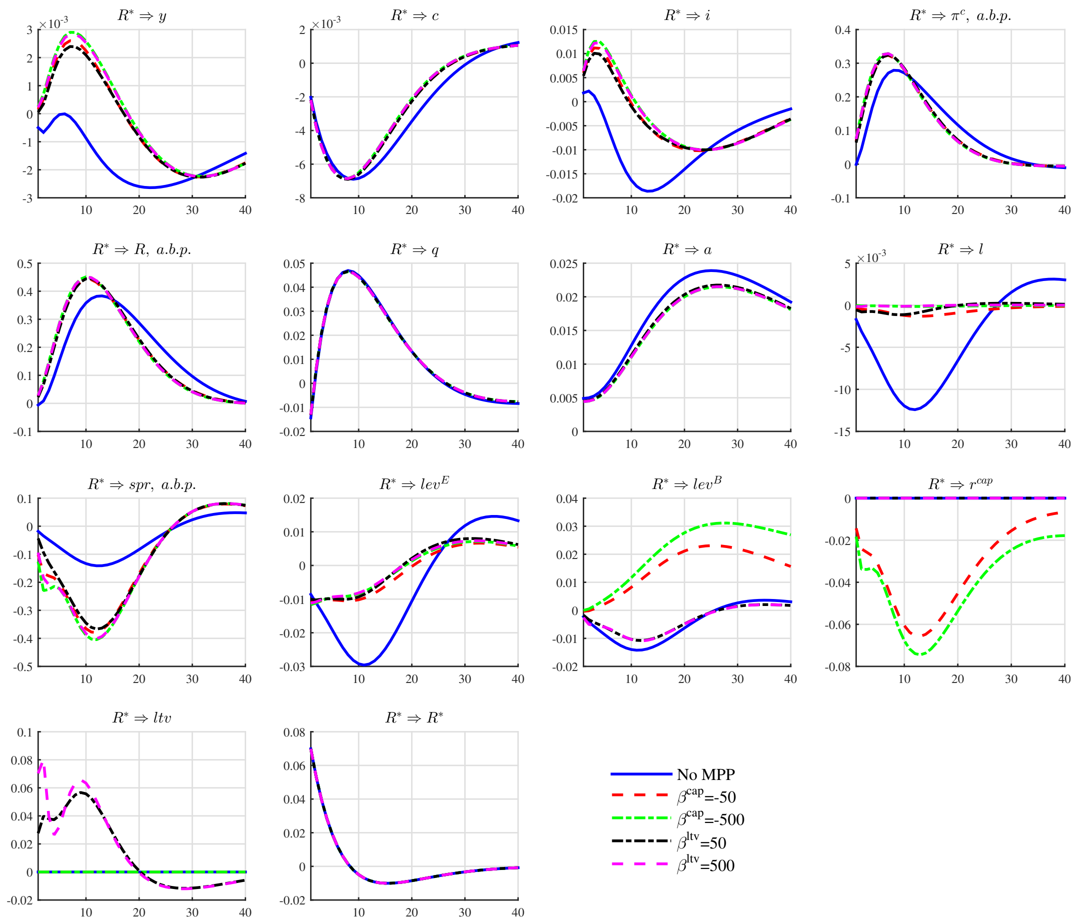
Note: This table shows the contribution of the different shocks to the unconditional variances of the respective variables in %, computed at the posterior mean of the estimated parameters. The selected variables in the columns of the table are the growth rates of real GDP (Δy), private consumption (Δc) and investment (Δy), CPI inflation (π^c), the monetary policy rate (R), real exchange rate growth (Δq), the current account (a), credit growth (Δl^E), the total spread ($\Psi = \Psi^D \Psi^E$).

Figure 4: Impulse responses to a negative commodity price shock: Colombia.



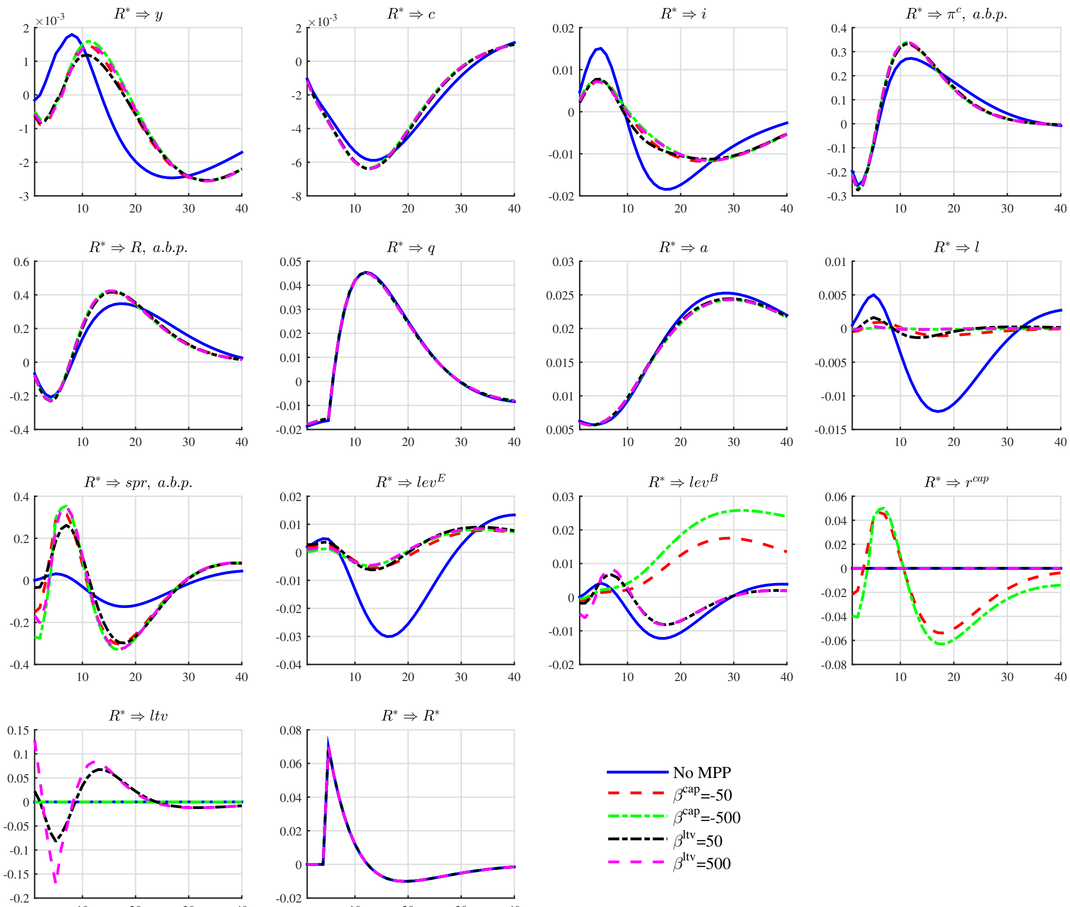
Note: This figure shows the impulse responses of selected variables to a negative one-standard deviation commodity price shock in period 1. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is real credit.

Figure 5: Impulse responses to a foreign interest rate shock: Colombia.



Note: This figure shows the impulse responses of selected variables to a 1% foreign interest rate shock in period 1. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is the total credit spread.

Figure 6: Impulse responses to an announced foreign interest rate shock: Chile.



Note: This figure shows the impulse responses of selected variables to an announced 1% foreign interest rate shock in period 3. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is the total credit spread.

Estimation and Policy Analysis for Mexico*

This version: December 22, 2014

1 Estimation of the full model

In this section, we briefly review the estimation results for Mexico, and the findings for the policy exercises. For the former, we list a few characteristics of the estimation settings, estimated parameters, the model's goodness of fit, and the variance decomposition. For the policy exercises, we report the effect of two dynamic macroprudential policies that aim to moderate the impact of a sudden decrease in the price of oil, and that of an announced increase in the foreign short-term nominal interest rate. The macroprudential policies take the form of a reaction function for both, the bank capital requirement, γ_t, and the loan-to-value ratio regulation ltv_t, in terms of the deviation of loans with respect to its steady-state value. The results of these exercises show that the macroprudential rules considered are more effective for the commodity-price shock, but not so for the shock in the foreign nominal interest rate.

1.1 Data and calibration

The sample for Mexico spans 2004Q2:2014Q2, with 23 observable variables. The short sample responds to unavailable data for the financial sector, like the interest rate of newly issued loans by banks to firms, which is only available since 2004. We believe this measure of the price of credit is closer to the model's definition than the implicit interest rate for the total amount of credit outstanding in banks balance sheets.[1] The observable variables included in estimation are the growth rates of output (y), consumption (c), investment (i), the real exchange rate (q), exports (x), imports (m), government spending (g), real wages (w), and new loans issued by banks to firms (l^E); further, we add CPI inflation (π^c), the percent change of the implicit deflators of GDP (π^d), exports (π^x), imports (π^m), and investment (π^i), the monetary policy rate (R), the lending spread defined as the interest rate of new loans minus the policy rate (Ψ), a cyclical measure of entrepreneur's networth (n), banks' capital ($capb$), and banks' leverage ratio, which is computed as the total amount of credit issued to firms divided by banks' capital ($leve^B \equiv \frac{l^E}{capb}$), the EMBI sovereign credit spread (cp), the cyclical component of total oil exports in real pesos (y^{Co}), and also that of the price of the Mexican oil mix barrel (p^{Co}).[2] We completed the sample with measures of foreign output growth ($y^\star$), foreign inflation ($\pi^\star$), and the foreign short-term nominal interest rate ($R^\star$), as computed by the BIS, taking into account the weights of the major trading partners of Mexico. The data used in estimation is shown in Figure 1 and it is listed in Table 4 in the Appendix.

[Insert Figure 1]

*Technical note for the joint project of the BIS CCA Research Network on "Incorporating financial stability considerations into central bank policy models". For questions and comments, please contact Julio Carrillo (jcarrillo@banxico.org.mx).

[1] The reason is that the interest rate of newly issued loans reflects current market conditions, while the implicit rate for total loans is a combination of the interest rates of loans issued in present and past periods.

[2] We used the standard HP filter to compute the cyclical component of a variable.

Most of the calibrated parameters, like preference and technology, are set as in CTW, except for some parameters that were specially tailored for Mexico, such as the steady-state growth rate and real interest rate, target inflation, the historical contributions of the different components of aggregate demand, and the proportions of imported goods in consumption, investment, and exports bundles, among other parameters. The complete details of the calibration for Mexico are shown in Table 5 in the Appendix. Finally, the model was estimated in Dynare, v 4.4.2, using Bayesian methods.[3]

1.2 Main results and goodness-of-fit indicators

For the sake of brevity, Table 1 shows only a selection of estimated parameters corresponding to the financial and commodity sectors of the model (the rest of estimated parameters are presented in Tables 6 and 7 the Appendix).

Table 1. Mexico: Results from Metropolis-Hastings, selection

Parameter	Description	Prior			Posterior			
		Dist.	Mean	s.d.	Mean	s.d.	5%	95%
$10\chi_{E,3}$	Elasticity credit spread	Inv-Γ	0.200	Inf	0.064	0.0167	0.0399	0.0884
$10\chi_D$	Elasticity deposit spread	Inv-Γ	0.100	Inf	0.048	0.0223	0.0215	0.0741
$\chi_{E,1}$	Persistence lending spread	β	0.500	0.0750	0.867	0.0200	0.8390	0.8905
ϑ^e	Adj. costs Entrepreneurs	Inv-Γ	0.500	Inf	0.240	0.0804	0.1253	0.3600
ϑ^b	Adj. costs Banks	Inv-Γ	0.500	Inf	0.291	0.1744	0.1069	0.4798
$\rho_{\tilde{\epsilon}_E}$	Persistence credit spread	β	0.500	0.0750	0.820	0.0388	0.7645	0.8850
$\rho_{\tilde{\epsilon}_D}$	Persistence deposit spread	β	0.500	0.0750	0.650	0.0562	0.5593	0.7433
$\sigma_{\tilde{\epsilon}_E}$	S.D. financial shock entrep.	Inv-Γ	0.150	Inf	0.110	0.0201	0.0781	0.1422
$\sigma_{\tilde{\epsilon}_D}$	S.D. financial shock depo.	Inv-Γ	0.150	Inf	0.157	0.0288	0.1099	0.2017
b_{44}	Persistence commodity price	N	0.500	0.5000	0.679	0.1176	0.4882	0.8775
σ_{pco}	S.D. commodity price shock	Inv-Γ	0.500	Inf	1.412	0.1656	1.1498	1.6797

Note : This table shows the priors and posteriors based on 500,000 draws from the Metropolis-Hastings (MH) algorithm, discarding the first 300,000 draws. The mean and covariance matrix of the proposal density for the MH algorithm were the maximum of the posterior distribution and the negative inverse Hessian around that maximum obtained with Marco Ratto's numerical optimization routine. Following CTW, the parameters were scaled to obtain the same order of magnitude of the parameters. The inverse Hessian was scaled to obtain an average acceptance rate from the MH algorithm of approximately 23.4% (see Roberts, Gelman, and Gilks, 1997). The computations were conducted using Dynare 4.4.2.

Notice that the estimated elasticity of the lending spread with respect to private leverage (i.e. $\chi_{E,3}$) implies that for an increase of 20 percent points in the latter, the lending spread rises by approximately 0.50 percent points at an annual basis (i.e., $\frac{0.064}{10} \times 20\% \times 400$). Similarly, the estimated elasticity of the deposit spread with respect to banks' capital, (i.e. χ_D) implies that an increase of 20 percent points in the latter translates into a rise of the lending spread by 0.40 percent points at an annual basis (i.e., $\frac{0.048}{10} \times 20\% \times 400$). Further, the lending spread displays an elevated intrinsic persistence, as it is denoted by the estimated value of $\chi_{E,1}$. In addition, the shocks to the lending spread and the deposit spread are also mildly persistent. When it comes to the commodity sector parameters, we observe that the cyclical component of the price of oil is also moderately persistence, but in contrast it is quite volatile (see the estimated values for $b44$ and σ_{pco}, respectively).

[3]The likelihood was maximized through a Monte-Carlo-based routine. For the Metropolis-Hastings estimation, we ran 3 chains with 500,000 draws each, where the first 300,000 were discarded. The j-scale parameter was calibrated to achieve an acceptance ratio of $\frac{1}{3}$.

To assess the goodness of fit of the model, we performed a posterior predictive checking exercise to assess the dimensions in which the model does a good job in replicating the data. In particular, we ask how likely is for the estimated model to replicate the volatility of the observable variables and their crossed correlation with respect to output growth.[4] Table 2 presents the results of the exercise. Columns 2 and 5 of the table show the standard deviation and the correlation with respect to Δy_t of the corresponding observable variable. Columns 3 and 6 present the model-based mean of the same moment drew from the Monte Carlo simulations. Finally, columns 4 and 7 display the 95 % confidence interval of the model-based moments. A value with a * appears in columns 2 and 5 if it lies inside the corresponding model-based confidence interval. In other words, the star implies that with 95 % confidence the model can reproduce the corresponding moment in the data. Figures 4 and 5 in the Appendix depict the full distribution of the model-based moments and show the p-value of the null hypothesis "H_0 : *The model predicts the corresponding moment in the data.*"

Table 2. Mexico: Posterior predictive checking.

	Standard deviation			Crossed correlation w.r.t. Δy_t		
	Data	Model mean	Model 95 % CI	Data	Model mean	Model 95 % CI
Output growth	1.1	1.5	(1.2, 1.9)	1.00	1.00	(−, −)
CPI inflation	1.3	2.5	(1.7, 3.5)	-0.39	-0.03	(−0.39, 0.36)
Policy rate	1.9*	2.5	(1.1, 4.8)	−0.17*	0.05	(−0.33, 0.44)
Consumption growth	1.5*	1.5	(1.1, 1.9)	0.87*	0.39	(0.05, 0.66)
Investment growth	1.9	3.2	(2.0, 5.0)	0.76	0.30	(−0.07, 0.62)
Real exchange rate growth	4.1*	4.0	(3.2, 5.0)	−0.25*	0.00	(−0.29, 0.31)
New credits growth	6.8*	6.0	(4.5, 8.1)	0.06*	0.07	(−0.26, 0.39)
Total credit spread	0.5	2.5	(1.1, 4.4)	-0.39	-0.09	(−0.48, 0.31)
Entrepreneurs' networth	14.0	47.8	(16.8, 99.0)	0.52	0.05	(−0.35, 0.45)
Banks leverage ratio	4.2	20.5	(8.5, 40.1)	-0.59	-0.09	(−0.47, 0.30)
Real wage growth	0.5	0.8	(0.6, 1.0)	0.26	0.02	(−0.33, 0.37)
Imports growth	4.2*	4.3	(3.3, 5.4)	0.83*	0.21	(−0.13, 0.50)
Exports growth	3.7	12.8	(9.9, 15.9)	0.70	0.54	(0.29, 0.74)
Oil exports	14.4*	13.9	(8.6, 21.0)	0.49*	0.09	(−0.30, 0.46)
Govt' spending growth	0.9*	1.0	(0.8, 1.2)	0.26*	0.19	(−0.12, 0.47)
Imports inflation	5.5*	7.2	(5.2, 10.0)	0.57*	0.10	(−0.26, 0.46)
Investment inflation	6.1*	5.9	(4.6, 7.6)	0.04*	0.13	(−0.22, 0.45)
GDP inflation	3.1*	3.7	(2.8, 4.6)	0.16*	-0.06	(−0.36, 0.27)
Oil price	18.5*	24.3	(16.0, 35.9)	0.42*	0.01	(−0.37, 0.35)
EMBI spread	0.7*	0.9	(0.5, 1.6)	−0.71*	-0.07	(−0.49, 0.33)
Foreign output growth	0.6*	0.6	(0.4, 0.8)	0.74*	0.27	(−0.08, 0.57)
Foreign inflation	4.9*	4.0	(3.1, 5.0)	0.48*	0.19	(−0.13, 0.48)
Foreign policy rate	2.0*	1.6	(0.7, 3.0)	0.04*	0.05	(−0.35, 0.48)

Note : The table shows the standard deviation of the observable variables and the correlation with respect to output growth, and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 1000 draws of the model at the posterior means, each draw with 41 observations, as in the original sample, with 200 burning periods. These simulations generate a distribution of model-based moments that can be compared to the same moment in the data. The (*) denotes those data moments that are likely to be generated by the model (i.e., those that are inside the confidence interval).

For the standard deviations, we have that the model can replicate 15 out of the 23 standard deviation of the

[4] The exercise consisted in simulating 1000 draws of the model at the posterior means of the estimated parameters, where each draw featured 41 observations, as in the original sample, with 200 burning periods. The simulations generated a distribution of model-based moments that were then compared to the same moment in the data.

observable variables. However, the model overestimates the volatility of output growth, CPI inflation, the real wage growth, among others variables. For the crossed correlations with respect to output growth, the model features a moderate success, fitting only 11 correlations out of 22. Notably, the model fails to deliver the high correlation between consumption and output growth, among others.[5]

Table 3 display the unconditional (or at infinite horizon) variance decomposition of a selection of real, nominal and financial endogenous variables, such as output, consumption, investment, the real exchange rate, CPI inflation, the nominal interest rate, the current account, loans, the lending spread, entrepreneurs' networth, banks' capital, and banks' leverage. The table thus show what shocks explain the variation of these variables in the long-run. A clear pattern emerges when looking at the table. Similar to Justiniano et al. (2010), the marginal efficiency of investment (MEI) shock explains a large part of the long-run variance of the nominal and real variables, while only a small proportion of the variance of financial variables. The long-run variance of these variables is mainly explained by the credit spread shock. These results are at odds with the evidence of Christiano et al. (2014), who find that adding financial frictions shocks decrease enormously the importance of the MEI shock reported in Justiniano et al..

Table 3. Unconditional variance decomposition: Mexico.

Shock	Description	y	c	i	q	π^c	R	a	l^E	Ψ	n_t	$capb$	lev^B
μ_z	Unit-root tech.	0.1	0.3	0.1	3.2	1.6	1.0	2.4	0.2	0.1	0.1	3.0	3.3
ϵ	Stationary tech.	0.2	0.3	0.1	0.1	4.1	1.7	0.3	1.1	0.1	0.1	0.2	3.8
Υ	MEI	97.2	94.6	96.4	78.7	55.2	79.1	64.3	9.3	0.0	6.4	21.4	4.4
ζ_c	Consumption pref.	0.2	1.5	0.2	0.6	1.1	1.1	0.3	0.2	0.0	0.0	0.1	0.8
ζ_h	Labor pref.	1.6	2.7	1.2	2.1	9.0	7.4	14.1	0.5	0.0	0.3	0.5	0.5
ϵ_R	Monetary policy	0.0	0.1	0.0	0.3	1.0	3.9	0.3	0.0	0.0	0.4	0.7	0.5
g	Govn't spending	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
τ_d	Markup, domestic	0.0	0.1	0.0	0.1	14.1	1.5	0.1	0.2	0.0	0.0	0.0	0.3
τ_x	Markup, exports	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.7
$\tau_{m,c}$	Markup, imported cons.	0.0	0.1	0.0	0.6	10.8	2.2	0.5	0.1	0.0	0.0	0.1	0.2
$\tau_{m,i}$	Markup, imported inv.	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.3
$\tau_{m,x}$	Markup, imported exp.	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.2
$\tilde{\epsilon}_D$	Deposit spread	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.8	0.6
$\tilde{\epsilon}_E$	Credit spread	0.3	0.2	1.5	0.6	0.9	0.9	8.3	87.8	93.6	92.6	71.9	83.0
ϵ_{capb}	Bank capital	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.0
y^{Co}	Commod./Oil prod.	0.0	0.1	0.1	0.4	0.1	0.1	0.6	0.0	0.0	0.0	0.0	0.0
p^{Co}	Commod./Oil price	0.1	0.1	0.1	1.0	0.2	0.1	1.6	0.0	0.0	0.0	0.0	0.1
$\tilde{\phi}$	Country risk premium	0.0	0.0	0.1	10.2	1.4	0.7	4.3	0.0	0.0	0.0	0.0	0.1
$\tilde{\phi}_{cp}$	Obs. Country risk prem.	0.0	0.0	0.0	0.6	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0
$R^\star$	Foreign interest rate	0.0	0.0	0.0	0.5	0.1	0.1	0.4	0.0	0.0	0.0	0.0	0.0
$y^\star$	Foreign output	0.0	0.0	0.0	0.7	0.2	0.1	1.6	0.0	0.0	0.0	0.0	0.0
$\pi^\star$	Foreign inflation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	All foreign	0.3	0.3	0.3	13.8	12.9	3.3	9.4	0.6	0.1	0.1	0.1	1.7

Note : This table shows the contribution of the different shocks to the unconditional variances of the respective variables in %, computed at the posterior mean of the estimated parameters. All foreign shocks are μ_z, $\tau_{m,c}$, $\tau_{m,i}$, $\tau_{m,x}$, $\tilde{\epsilon}_D$, $\tilde{\epsilon}_E$, p^{Co}, $\tilde{\phi}$, $\tilde{\phi}_{cp}$, $R^\star$, $y^\star$, $\pi^\star$. The selected variables in the columns, all of them as model-based percent deviations from the steady state, are output (y), consumption (c), investment (i), the real exchange rate (q), CPI inflation (π^c), the monetary policy rate (R), the current account (a), credit (l^E), the credit spread (Ψ), entrepreneur's networth (n), banks' capital ($capb$), and banks' leverage ratio ($leve^B$).

The controversy partly dissipates if one considers different time horizons to analyse the variance decomposi-

[5]This finding might be explained by the inclusion of measurement errors for all of the observable variables during estimation.

tion of endogenous variables. In the Appendix, Tables 8, 9, and 10 show the variance decomposition for the same variables than Table 3 at impact, 1.5 years after the shocks, and 3 years after the shocks. The tables show that, in the short-run, the credit-spread shock is an important contributor for investment, and to a lesser extent to output. However, its importance dissipates over time, which yields place for the MEI shock to become the more important shock.

2 Policy exercise

We consider two types of foreign shocks hitting the Mexican economy: *1)* A sudden and mildly persistent decrease in the price of the oil Mexican barrel of 15 percent, and *2)* An announced increase in the foreign short-term nominal interest rate of 30 basis points in 3-quarters time. We consider two scenarios for analyzing the effects of these shocks. In the benchmark scenario, the macroprudential authority leaves its instruments (the bank capital requirement, γ_t, on the one hand, and the loan-to-value ratio, ltv_t, on the other) unchanged. In the alternative scenario, one of the instruments follows a reaction function of the form

$$\ln(ins_t) = \ln(ins) + \beta_{ins} \ln\left(\frac{l_t^E}{l^E}\right),$$

where variables without a time subindex denote steady-state levels, $ins \in \{\gamma, ltv\}$, β_{ins} is the elasticity of the instrument with respect to the percent deviation of (detrended) loans,l_t^E, from its (detrended) steady-state value, l^E. For the sake of exposition, only one macroprudential policy rule will be active at a time on each of the following exercises.

2.1 A sudden fall of the price of oil

Figure 2 presents the impulse responses of selected endogenous variables, in terms of the percent deviations from the steady state levels, from a fall in the price of oil of 15 percent. The blue plain line portrays the aggregate dynamics when none of the macroprudential policy rules are active. Panel (a) of the figure displays the case when the policy rule for γ_t is active, and Panel (b) does it for the case when the policy rule for ltv_t is active. For each macroprudential rule, we consider two different values for the elasticity of the macroprudential instrument. These cases are shown by the red dashed line and black dotted line in the figure.

[Insert Figure 2]

According to the model, the decrease in the price of oil has a negative effect on output in the medium term, although such effect is relatively small. This is not surprising, as the weight of the oil-exporting-sector is only 4 percent of total GDP. However, the model does not feature re-adjustments in government spending due to a decrease of fiscal revenues. PEMEX, the state-own company that produces and exports Mexican oil, reports great part of its revenues to the Mexican government. The oil-exporting revenues represent roughly a third of all fiscal revenues of Mexico. Therefore, it might be possible that the model underestimates the spill over effects of a decrease in oil prices in the Mexican economy. With the current model configuration, the biggest effect of the oil price shock is on investment, that decreases by more of 60 basis points after 10 quarters, and the current account, that falls sharply. In turn, the real exchange rate depreciates and the banking loans decrease by 20 basis points.

Since loans have fallen bellow its steady state level, both macroprudential policy rules move the instruments to ease credit conditions. In Panel (a) we observe that the bank capital requirement diminishes about 10 or

20 percent (depending on the instrument elasticity to loans deviations), which is roughly a decrease from 8 % to 7 % and 6.5 %, respectively. Better credit conditions contain the fall of loans, and push upwards the price of capital, p^K, which in turn boost entrepreneurs networth. The mechanism operates similarly to the financial accelerator of Bernanke et al. (1999). Overall, the dynamic macroprudential policy help to contain the fall of investment, whose through effect arrives a few quarters later than the benchmark scenario (i.e., no dynamic macroprudential policy). A very similar story evolves if instead the macroprudential authority rises the loan-to-value ratio, following the policy rule, from 65 % from the steady state value to 70 % and 80 % for both values of β_{ltv} in the figure.

2.2 An announced increase of the foreign nominal interest rate

Figure 3 presents the impulse responses of selected endogenous variables to an announced increase of 30 basis points (an estimated standard deviation) in the foreign short-term nominal interest rate, which occurs 3 quarters ahead. For the case of Mexico, the model's foreign country mimics closely the U.S., as most of Mexican goods are traded with his northern neighbor (in 2012, 77.5 % of Mexican exports were sold in the U.S.). Therefore, this exercise might bring some light to what may happen to Mexico when the Federal Funds rate exits the zero lower bound in 2015 and during the U.S. monetary policy normalization period. In Figure 3, the rise in the nominal rate is also accompanied by an increase in both U.S. output and U.S. inflation, which reflects an improvement of economic conditions of Mexico's largest trading partner.

[Insert Figure 3]

An expected improvement of U.S. economic activity may bring about two type of effects for the Mexican economy. First, an increase of the fed funds rate strengthens the U.S. dollar against the peso, which entails a negative income effect for Mexican consumers and entrepreneurs. But also, the expectation of higher income in the U.S. implies that Mexican exports will boost in the future, and that brings about a positive income effect to the Mexican consumers and entrepreneurs, who are forward-looking agents. Depending on which one of the two income effects prevails, the Mexican domestic demand may increase or fall following the U.S. news shock. In Figure 3, the blue plain line depicts the model's predictions for the baseline scenario, in which consumption, investment and banking loans increases even before U.S. economic activity picks up. The reaction of these variables is so large that the real exchange rate appreciates, causing exports (x) to decrease in the short run and the current account to fall (a). As a consequences, total GDP falls on the margin. After a few quarters, when U.S. output increases, exports rise and Mexican GDP will tend to increase on the margin. Notice that the dynamic macroprudential policies considered, regardless of the instrument used, may be harmful for output for the first quarters after the shock (see both panels in the figure). The reason is that the macroprudential policy rules try to mitigate the increase of banking loans after the realization of the news shock. Therefore, the macroprudential authority tightens credit conditions to discourage banking loans, and investment. Overall, this policy worsens output dynamics in the short-run, although only marginally.

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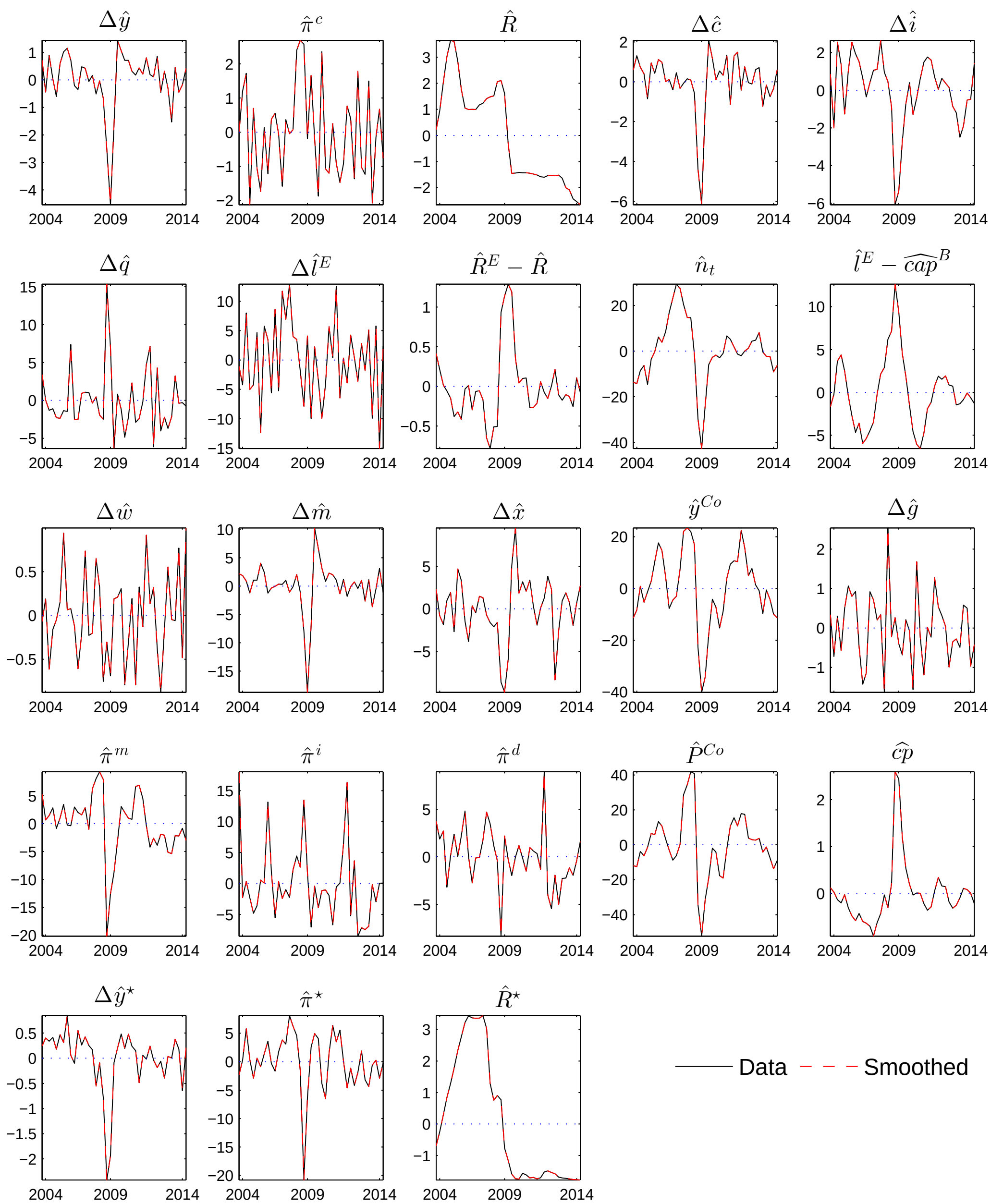
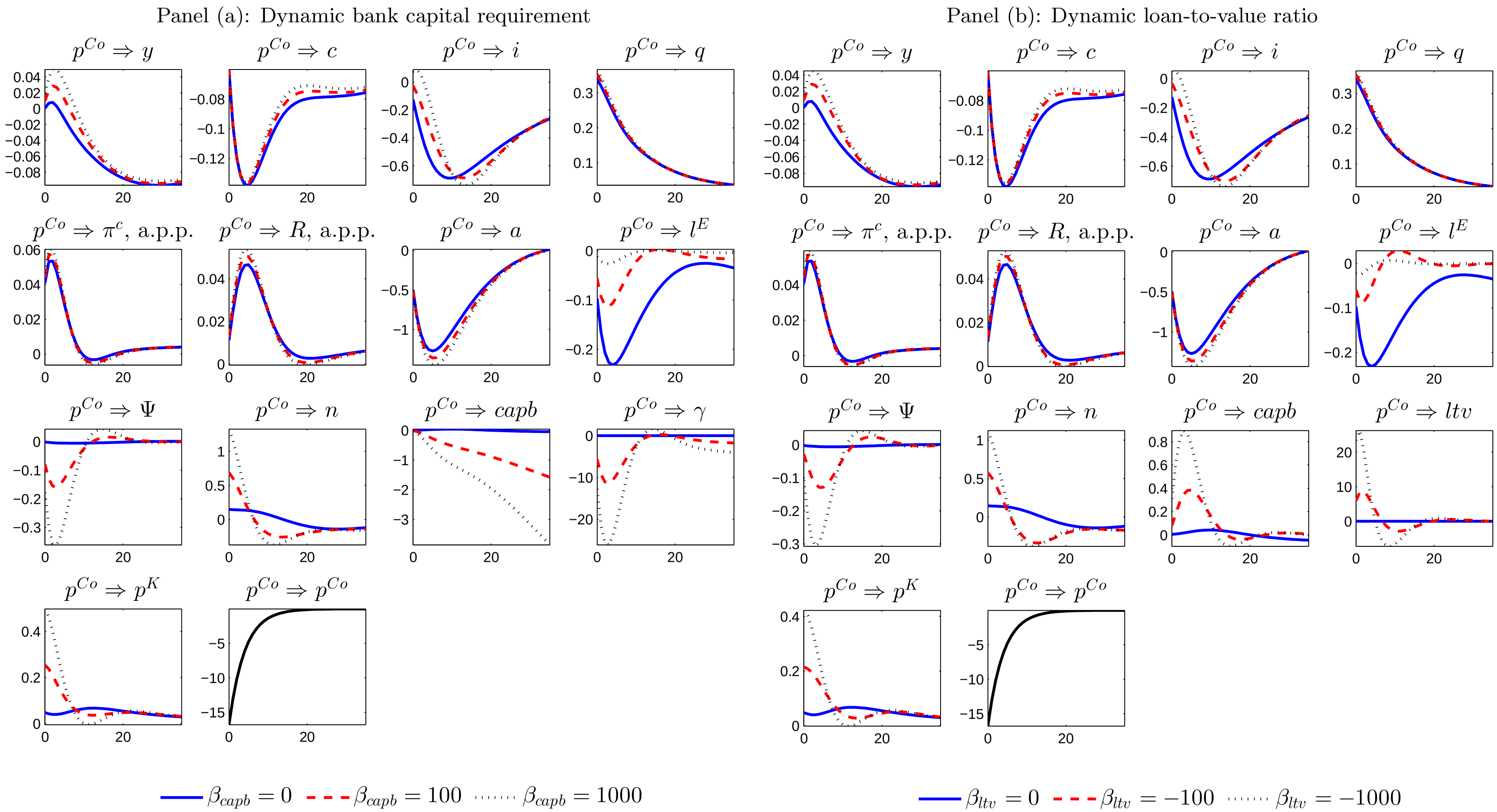
Figure 1: Mexico: Quarterly data from 2004Q2-2014Q2.



Note: The observable variables included in estimation are the growth rates of output (y), of consumption (c), of investment (i), of the real exchange rate (q), of exports (x), of imports (m), of government spending (g), of real wages (w), of new loans (l^E), CPI inflation (π^c), inflation based on the GDP deflator, (π^d), on exports (π^x), on imports (π^m), and on investment (π^i), the monetary policy rate (R), the lending spread (Ψ), entrepreneur's networth (n), banks' capital ($capb$), banks' leverage ratio ($leve^B$), the EMBI sovereign credit spread (cp), real total oil exports (y^{Co}), the price of the Mexican oil mix barrel (p^{Co}), foreign output growth ($y^\star$), foreign inflation ($\pi^\star$), and the foreign short-term nominal interest rate ($R^\star$).

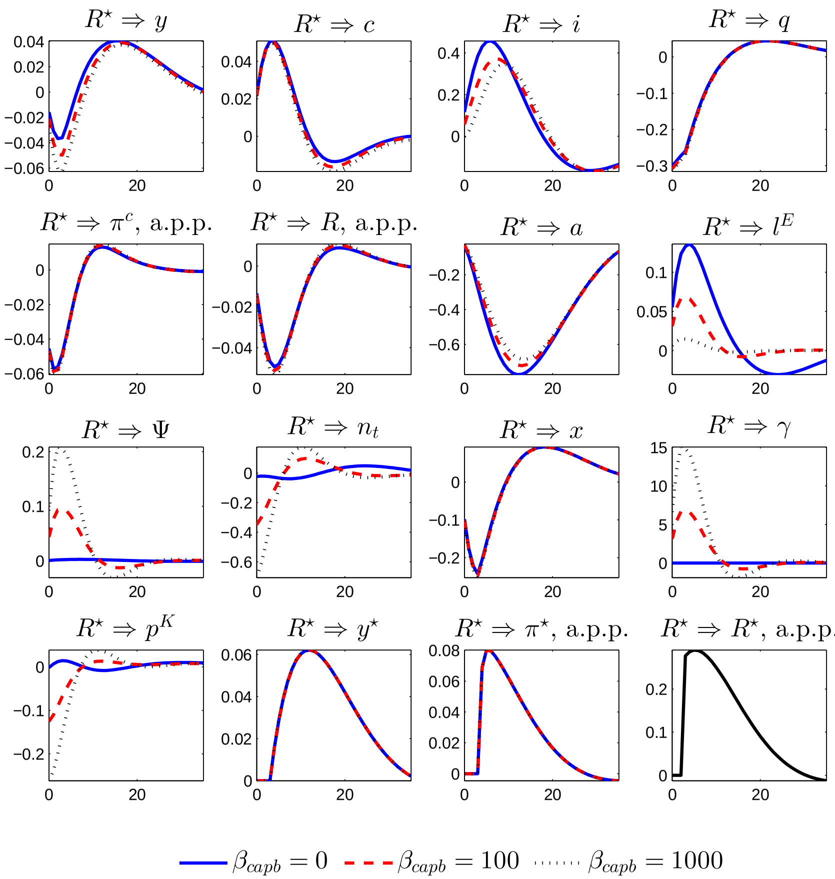
Figure 2: Mexico: A sudden fall in the price of oil.



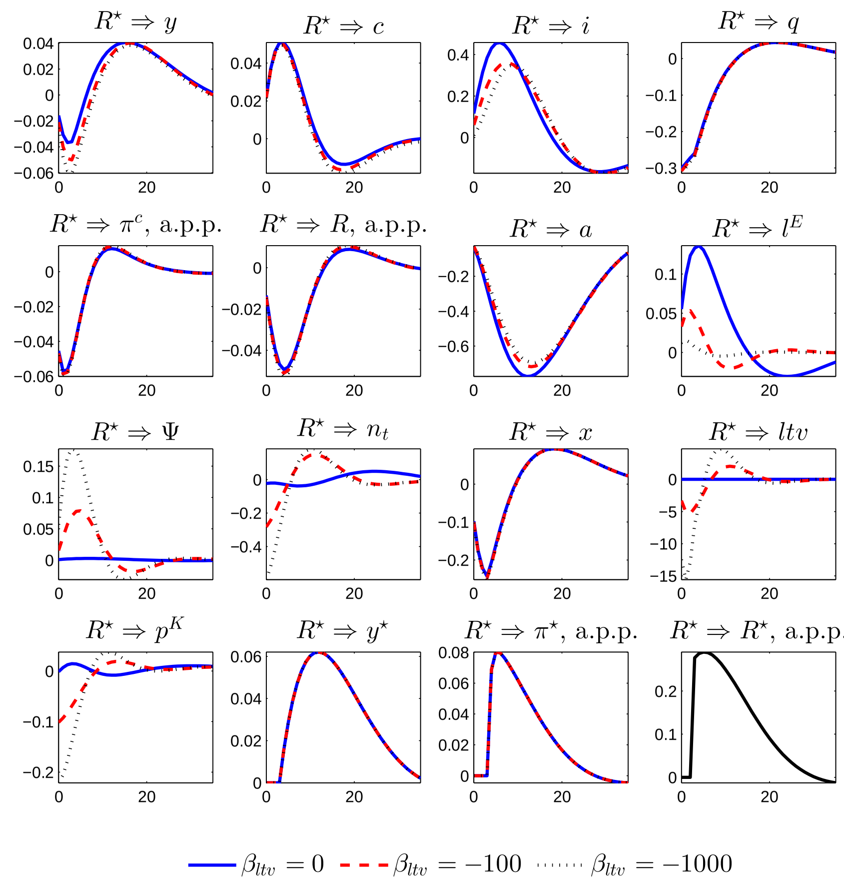
Note: The figure presents the impulse-response functions of a sudden fall of 15 % in the price of the Mexican oil barrel. In both panels, the blue plain line represents the aggregate dynamics when there is not a dynamic response of the macroprudential instrument. The red dashed line and the black dotted line display the counterfactual dynamics when the macroprudential instrument follow a rule of the form $\ln(INS_t) = \ln(INS) + \beta_{INS}\left(\ln(l_t^E/l^E)\right)$, where $INS_t \in \{\gamma_t, ltv_t\}$, i.e., the bank capital requirement (γ_t) or the loan-to-value ratio (ltv_t). The variables listed in the figure are, in order and as percent deviations from he steady state, output (y), consumption (c), investment (i), real exchange rate (q), CPI inflation (π^c) in annual percent points, nominal interest rate in annual percent point (R), current account (a), loans (l^E), lending spread (Ψ), entrepreneurs networth (n), banks' capital ($capb$), macroprudential instrument (ins), price of capital (p^K), and price of oil (p^{Co}).

Figure 3: Mexico: An announced increase in the foreign interest rate.

Panel (a): Dynamic bank capital requirement



Panel (b): Dynamic loan-to-value ratio



Note: The figure presents the impulse-response functions of an announced increased of the foreign interest rate by 30 basis points. In both panels, the blue plain line represents the aggregate dynamics when there is not a dynamic response of the macroprudential instrument. The red dashed line and the black dotted line display the counterfactual dynamics when the macroprudential instrument follow a rule of the form $\ln(INS_t) = \ln(INS) + \beta_{INS}\left(\ln(l_t^E/l^E)\right)$, where $INS_t \in \{\gamma_t, ltv_t\}$, i.e., the bank capital requirement (γ_t) or the loan-to-value ratio (ltv_t). The variables listed in the figure are, in order and as percent deviations from he steady state, output (y), consumption (c), investment (i), real exchange rate (q), CPI inflation (π^c) in annual percent points, nominal interest rate in annual percent point (R), current account (a), loans (l^E), lending spread (Ψ), entrepreneurs networth (n), exports (x), macroprudential instrument (ins), price of capital (p^K), foreign output ($y^\star$), foreign inflation ($\pi^\star$) in annual percent points, and foreign nominal interest rate ($R^\star$).

Appendix: Complementary estimation results for Mexico

Table 4. Mexico: Observable variables.

Code	Definition
R_t	Nominal interest rate, overnight interbank rate, Banxico
Δw_t	Real wage growth, the compensation of the Manufacturing sector, INEGI
Δc_t	Consumption growth, INEGI
Δy_t	GDP growth, INEGI
Δy_t^*	Foreign GDP growth, BIS
π_t^*	Foreign inflation, BIS
R_t^*	Foreign interest rate, BIS
Δm_t	Total Imports growth, INEGI
π_t^i	Investment (excluding inventories) implicit deflator, INEGI
π_t^d	GDP implicit deflator, INEGI
π_t^c	CPI inflation, INEGI
π_t^x	Exports growth, INEGI
Δq_t	Real exchange rate growth, own computation with data from Banxico, BIS, INEGI
Δi_t	Investment growth, INEGI
cp_t	EMBI rate for Mexico, Bloomberg
Δg_t	Government consumption growth, INEGI
$\pi_t^{c,m}$	Imports inflation based on CPI, INEGI
Commodity sector	
y_t^{Co}	Total Oil exports for Mexico, INEGI
P_t^{Co}	Price for Mexican oil mix, INEGI
Financial sector	
Δl_t^E	New loans growth rate, Banxico (non-public data)
n_t	Cyclical component of stock market index (proxy of networth), INEGI
$\Psi_t \equiv R_t^E - R_t$	New loans-to-policy-rate spread, Banxico (non-public data)
$l_t^E/capb_t$	Observed bank-capital-to-loans-to-firms ratio, CNBV

Table 5. Mexico: Calibration.

Parameter	Calibrated value	Definition
α	0.33	Capital share in production, Garcia-Verdu (2005)
R	1.0152	Steady State interest rate
β	0.9986	Discount factor, $\beta = \bar{\pi}\mu_z/R$
ω_i	0.1421	Import share in investment goods, Input-Output tables (INEGI; 2003)
ω_c	0.0421	Import share in consumption goods, Input-Output tables (INEGI; 2003)
ω_x	0.0535	Import share in export goods, Input-Output tables (INEGI; 2003)
$\tilde{\phi}^a$	0.01	Elasticity of country risk to net asset position, CTW
η_g	0.1126	Government expenditure share of GDP, CTW
τ_k	0.300	Capital tax rate, OECD average (2003-2013)
τ_w	0	Payroll tax rate, there are no payroll taxes in Mexico
τ_c	0.1541	Consumption tax rate, OECD average (2003-2013)
τ_y	0.098	Labour income tax rate, OECD average (2003-2013)
τ_b	0	Bond tax rate, CTW
$\bar{\pi}$	1.0075	Steady state gross inflation target, Banxico
λ_j	1.2	Price markups, $j = d; x; m, c; m, i; m, x.$, CTW
λ_w	1.5	Wage markpus, CTW
θ_w	1	Wage indexation to real growth trend, CTW
π_{breve}	1.0075	Third indexing base, CTW
μ_{z+}	1.0061	Average annual growth rate of GDP, INEGI (2003-2013)
μ_ψ	1	" growth rate of investment technology (implied), CTW
τ_d	1	" markup domestic, CTW
τ_x	1	" markup exports, CTW
τ_{mc}	1	" markup imported consumption, CTW
τ_{mi}	1	" markup imported investment, CTW
τ_{mx}	1	" markup imported exports, CTW
ϵ	1	" stationary neutral technology, CTW
Υ	1	" investment specific technology shock, CTW

(Continued on next page)

Table 5: (continued)

	Calibrated value	Definition
ζ_c	1	" preference shock - consumption, CTW
ζ_h	1	" preference shock - labour, CTW
$\bar{\phi}$	1.005	" country risk premium, CTW
$\bar{\pi}^*$	1.005	" foreign inflation, CTW
$\bar{R}^*$	1.01	" foreign nominal interest rate, CTW
u	1	" capital utilization, CTW
$\tilde{S}$	0	" Investment cost function, CTW
$\tilde{S}'$	0	" Derivative investment cost function, CTW
$\tilde{\phi}$	0	" risk adjustment - foreign asset return, CTW
AL		Scaling of disutility of work (match hours-target = 0.25)
δ	0.015	Depreciation rate of capital (match i/y = 0.18 ratio)
φ		Steady state real exchange rate (match x/y =0.44 ratio), CTW
Commodity sector		
χ	1	Proportion of oil production own by state, by PEMEX
η_{co}	0.0386	Proportion of Oil exports in GDP, own computation from INEGI's data
Financial sector		
$\chi_{E,0}$	3.09/400	*'Steady state'* loans-to-deposits spread, Banxico
$\psi_{z+,e}$	1	" Lagrange mult. of entrepreneurs
$\psi_{z+,b}$	1	" Lagrange mult. of banks
$\chi_{D,0}$	0	Deposits-to-target-rate spread
ltv	0.65	Approx. LTV regulation for Mexico, CNBV
γ	0.08	Bank capital requirement, CNBV

Table 6. Results from Metrpolis-Hastings (parameters)

Parameter	Description	Prior Dist.	Prior Mean	Prior s.d.	Posterior Mean	Posterior s.d.	5%	95%
ξ_d	Calvo, domestic	β	0.750	0.0750	0.886	0.0217	0.8513	0.9221
ξ_x	Calvo, exports	β	0.750	0.0750	0.580	0.0661	0.4731	0.6895
ξ_{mc}	Calvo, imported consumption	β	0.750	0.0750	0.814	0.0338	0.7594	0.8700
ξ_{mi}	Calvo, imported investment	β	0.750	0.0750	0.556	0.0680	0.4447	0.6678
ξ_{mx}	Calvo, imported exports	β	0.660	0.1000	0.477	0.0749	0.3521	0.5985
ϑ_b	Dividend adj. cost banks	Inv-Γ	0.500	Inf	0.291	0.1744	0.1069	0.4798
ϑ_e	Dividend adj. cost entrep.	Inv-Γ	0.500	Inf	0.240	0.0804	0.1253	0.3600
10χ	Elasticity deposit spread	Inv-Γ	0.100	Inf	0.048	0.0223	0.0215	0.0741
$\chi_{E,1}$	Persistence monit. costs B	β	0.500	0.0750	0.867	0.0200	0.8390	0.8905
$10\chi_{E,3}$	Elasticity credit spread	Inv-Γ	0.200	Inf	0.064	0.0167	0.0399	0.0884
$\rho_{\tilde{\epsilon}_E}$	Persistence credit spread	β	0.500	0.0750	0.820	0.0388	0.7645	0.8850
$\rho_{\tilde{\epsilon}_D}$	Persistence deposit spread	β	0.500	0.0750	0.650	0.0562	0.5593	0.7433
ξ_w	Calvo wages	β	0.750	0.0750	0.768	0.0477	0.6915	0.8464
κ_d	Indexation domestic	β	0.500	0.1500	0.286	0.1019	0.1191	0.4491
κ_x	Indexation exports	β	0.500	0.1500	0.522	0.1235	0.3193	0.7260
κ_{mc}	Indexation imported consumption	β	0.500	0.1500	0.648	0.1154	0.4629	0.8385
κ_{mi}	Indexation imported investment	β	0.500	0.1500	0.316	0.1246	0.1081	0.5019
κ_{mx}	Indexation imported exports	β	0.500	0.1500	0.476	0.1362	0.2478	0.7000
κ_w	Indexation wages	β	0.500	0.1500	0.317	0.1153	0.1310	0.5015
b	Habit in consumption	β	0.650	0.1500	0.519	0.0649	0.4147	0.6261
$S''/10$	Investment adj. cost	Γ	0.500	0.1500	0.749	0.1453	0.5148	0.9818
σ_a	Variable capital utilization	Γ	0.200	0.0750	0.256	0.0761	0.1344	0.3798
ρ_R	Taylor rule, lagged interest rate	β	0.800	0.1000	0.849	0.0287	0.8025	0.8961
r_π	Taylor rule, inflation	N	1.700	0.1500	1.845	0.1283	1.6328	2.0481
r_{Δ_y}	Taylor rule, output growth	N	0.125	0.0500	0.126	0.0493	0.0464	0.2099
η_x	Elasticity of subs., exports	Γ	1.500	0.2500	1.911	0.1445	1.6812	2.1447
η_i	Elasticity of subs., investment	Γ	1.500	0.2500	1.836	0.1659	1.5685	2.1049
η_f	Elasticity of subs., foreign	Γ	1.500	0.2500	1.480	0.2264	1.1087	1.8216
$\tilde{\phi}$	Country risk adj. coeff.	Γ	1.250	0.1000	1.189	0.0845	1.0509	1.3282
ρ_{μ_z}	Persistence, unit-root tech.	β	0.500	0.0750	0.525	0.0674	0.4143	0.6354
ρ_ϵ	Persistence, stationary tech.	β	0.850	0.0750	0.701	0.0598	0.6050	0.7988
ρ_Υ	Persistence, MEI	β	0.850	0.0750	0.977	0.0174	0.9590	0.9967
ρ_{ζ^c}	Persistence, consumption prefs.	β	0.850	0.0750	0.815	0.0575	0.7246	0.9074
ρ_{ζ^h}	Persistence, labor prefs.	β	0.850	0.0750	0.765	0.0829	0.6322	0.9034
$\rho_{\tilde{\phi}}$	Persistence country risk premium	β	0.850	0.0750	0.809	0.0805	0.6891	0.9409
$\rho_{\tilde{\phi}_c^p}$	Persistence, obs. country risk prem.	β	0.850	0.0750	0.844	0.0606	0.7454	0.9396
ρ_g	Persistence, gov. expenditures	β	0.850	0.0750	0.856	0.0643	0.7578	0.9569
ρ_{yco}	Persistence, commodity production	β	0.850	0.0750	0.811	0.0700	0.7030	0.9264
a_{11}	Foreign VAR parameter	N	0.500	0.5000	0.664	0.1916	0.3493	0.9505
a_{22}	Foreign VAR parameter	N	0.000	0.5000	0.220	0.1210	0.0258	0.4223
a_{33}	Foreign VAR parameter	N	0.500	0.5000	1.036	0.1552	0.7878	1.2760
b_{44}	Foreign VAR parameter	N	0.500	0.5000	0.679	0.1176	0.4882	0.8775
a_{12}	Foreign VAR parameter	N	0.000	0.5000	0.007	0.0559	-0.0824	0.0969
a_{13}	Foreign VAR parameter	N	0.000	0.5000	0.354	0.3126	-0.1537	0.8171
a_{21}	Foreign VAR parameter	N	0.000	0.5000	0.052	0.3013	-0.4382	0.5487
a_{23}	Foreign VAR parameter	N	0.000	0.5000	0.120	0.2770	-0.3360	0.5661
a_{24}	Foreign VAR parameter	N	0.000	0.5000	0.206	0.2795	-0.2399	0.6822
a_{31}	Foreign VAR parameter	N	0.000	0.5000	-0.076	0.1632	-0.3015	0.2271
a_{32}	Foreign VAR parameter	N	0.000	0.5000	0.003	0.0178	-0.0256	0.0323
a_{34}	Foreign VAR parameter	N	0.000	0.5000	0.093	0.0571	0.0092	0.1786
c_{21}	Foreign VAR parameter	N	0.000	0.5000	0.041	0.5166	-0.8301	0.8758
c_{31}	Foreign VAR parameter	N	0.000	0.5000	0.052	0.1622	-0.2144	0.3235
c_{32}	Foreign VAR parameter	N	0.000	0.5000	-0.036	0.0186	-0.0658	-0.0041
c_{24}	Foreign VAR parameter	N	0.000	0.5000	1.048	0.3728	0.4617	1.6404
c_{34}	Foreign VAR parameter	N	0.000	0.5000	0.050	0.0567	-0.0362	0.1275

Note : This table shows the priors and posteriors based on 500,000 draws from the Metropolis-Hastings (MH) algorithm, discarding the first 300,000 draws. The mean and covariance matrix of the proposal density for the MH algorithm were the maximum of the posterior distribution and the negative inverse Hessian around that maximum obtained with Marco Ratto's numerical optimization routine. Following CTW, the parameters were scaled to obtain the same order of magnitude of the parameters. The inverse Hessian was scaled to obtain an average acceptance rate from the MH algorithm of approximately 23.4% (see Roberts, Gelman, and Gilks, 1997). The computations were conducted using Dynare 4.4.2.

Table 7. Results from Metrpolis-Hastings (parameters)

Parameter	Description	Prior			Posterior			
		Dist.	Mean	s.d.	Mean	s.d.	5%	95%
$\mu_{z,\epsilon}$	Unit-root tech.	Inv-Γ	0.150	Inf	0.438	0.0705	0.3312	0.5525
ϵ_ϵ	Stationary tech.	Inv-Γ	0.500	Inf	2.444	0.3657	1.8436	3.0232
Υ_ϵ	MEI	Inv-Γ	0.150	Inf	0.285	0.0434	0.2148	0.3536
ζ^c_ϵ	Consumption prefs.	Inv-Γ	0.150	Inf	0.233	0.0465	0.1596	0.3067
ζ^h_ϵ	Labor prefs.	Inv-Γ	0.150	Inf	2.195	1.0770	0.7247	3.7517
$\tilde{\phi}_\epsilon$	Country risk premium	Inv-Γ	0.150	Inf	0.417	0.2140	0.1014	0.7159
ϵ_D	Deposit spread	Inv-Γ	0.150	Inf	0.157	0.0288	0.1099	0.2017
ϵ_E	Credit spread	Inv-Γ	0.150	Inf	0.110	0.0201	0.0781	0.1422
$capb_\epsilon$	Banks capital	Inv-Γ	0.150	Inf	0.630	0.1340	0.4105	0.8414
$\tilde{\phi}_{cp,\epsilon}$	Obs. country risk premium	Inv-Γ	0.150	Inf	0.112	0.0126	0.0919	0.1322
ϵ_R	Monetary policy	Inv-Γ	0.150	Inf	0.140	0.0174	0.1114	0.1669
g_ϵ	Goverment expenditure	Inv-Γ	0.500	Inf	0.827	0.1086	0.6509	0.9986
τ^d_ϵ	Markup domestic	Inv-Γ	0.500	Inf	2.899	1.2633	1.1661	4.7616
τ^x_ϵ	Markup exports	Inv-Γ	0.500	Inf	3.464	1.4773	1.3864	5.4261
τ^{mc}_ϵ	Markup imported consumption	Inv-Γ	0.500	Inf	3.957	1.3609	1.9440	6.0205
τ^{mi}_ϵ	Markup imported investment	Inv-Γ	0.500	Inf	0.846	0.3571	0.3403	1.3533
τ^{mx}_ϵ	Markup imported exp.	Inv-Γ	0.500	Inf	2.867	1.0750	1.3375	4.3586
y^*_ϵ	Foreign GDP	Inv-Γ	0.500	Inf	0.210	0.0589	0.1213	0.2957
π^*_ϵ	Foreign inflation	Inv-Γ	0.500	Inf	0.934	0.1331	0.7173	1.1529
R^*_ϵ	Foreign interest rate	Inv-Γ	1.500	Inf	0.693	0.1264	0.4785	0.8964
y^{Co}_ϵ	Commod./minning prod.	Inv-Γ	0.500	Inf	9.409	1.0546	7.6430	11.0516
p^{Co*}_ϵ	Commod./copper price	Inv-Γ	0.500	Inf	1.412	0.1656	1.1498	1.6797

Note : See previous Table.

Table 8. Variance decomposition at impact: Mexico.

Shock	Description	y	c	i	q	π^c	R	a	l^E	Ψ	n_t	$capb$	lev^B
μ_z	Unit-root tech.	0.7	0.0	0.3	8.0	1.2	0.6	0.8	4.0	0.1	0.1	4.1	6.5
ϵ	Stationary tech.	21.4	2.5	2.2	0.4	6.5	1.3	10.6	69.0	0.7	0.9	3.0	52.5
Υ	MEI	0.8	24.8	29.7	52.9	13.5	6.2	3.9	3.1	0.0	37.9	0.1	1.4
ζ_c	Consumption pref.	12.5	50.4	1.7	0.9	0.6	0.7	1.1	2.1	0.0	0.0	0.1	1.6
ζ_h	Labor pref.	5.8	13.2	10.1	0.8	4.7	1.3	1.2	0.1	0.0	0.9	0.1	0.0
ϵ_R	Monetary policy	1.9	5.0	2.0	0.3	0.4	58.5	0.5	0.5	0.0	9.0	0.0	0.4
g	Govn't spending	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
τ_d	Markup, domestic	1.6	1.9	0.5	0.0	46.7	18.5	0.0	4.0	0.0	0.8	1.1	1.0
τ_x	Markup, exports	37.5	0.0	0.0	0.0	0.0	0.6	0.1	8.4	0.1	0.1	0.2	6.0
$\tau_{m,c}$	Markup, imported cons.	0.6	1.1	0.0	0.1	24.7	11.0	2.5	0.1	0.0	0.7	0.0	0.1
$\tau_{m,i}$	Markup, imported inv.	2.2	0.0	1.7	0.1	0.0	0.1	4.0	3.4	0.0	0.3	0.1	2.3
$\tau_{m,x}$	Markup, imported exp.	11.4	0.1	0.1	0.1	0.0	0.1	16.1	2.8	0.0	0.0	0.1	2.0
$\tilde{\epsilon}_D$	Deposit spread	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	52.7	1.9	0.0	0.0
$\tilde{\epsilon}_E$	Credit spread	1.2	0.0	46.3	0.9	0.3	0.2	1.7	2.1	36.9	47.3	22.3	1.7
ϵ_{capb}	Bank capital	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	68.7	17.8
y^{Co}	Commod./Oil prod.	0.0	0.2	0.2	0.3	0.0	0.1	11.9	0.0	0.0	0.1	0.0	0.0
p^{Co}	Commod./Oil price	0.0	0.4	0.4	0.9	0.1	0.0	41.3	0.1	0.0	0.1	0.0	0.0
$\tilde{\phi}$	Country risk premium	1.4	0.3	3.4	30.4	1.1	0.7	3.3	0.2	0.0	0.0	0.0	0.1
$\tilde{\phi}_{cp}$	Obs. Country risk prem	0.1	0.0	0.2	1.8	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
$R^\star$	Foreign interest rate	0.0	0.0	0.3	1.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
$y^\star$	Foreign output	0.0	0.1	0.5	1.0	0.1	0.1	0.6	0.0	0.0	0.0	0.0	0.0
$\pi^\star$	Foreign inflation	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
	All foreign	53.7	2.0	6.7	35.4	26.2	12.6	68.3	15.1	0.1	1.2	0.4	10.7

Note : This table shows the contribution of the different shocks to the unconditional variances of the respective variables in %, computed at the posterior mean of the estimated parameters. All foreign shocks are μ_z, $\tau_{m,c}$, $\tau_{m,i}$, $\tau_{m,x}$, $\tilde{\epsilon}_D$, $\tilde{\epsilon}_E$, p^{Co}, $\tilde{\phi}$, $\tilde{\phi}_{cp}$, $R^\star$, $y^\star$, $\pi^\star$. The selected variables in the columns, all of them as model-based percent deviations from the steady state, are output (y), consumption (c), investment (i), the real exchange rate (q), CPI inflation (π^c), the monetary policy rate (R), the current account (a), credit (l^E), the credit spread (Ψ), entrepreneur's networth (n), banks' capital ($capb$), and banks' leverage ratio ($leve^B$).

Table 9. Variance decomposition at 1.5 years horizon: Mexico.

Shock	Description	y	c	i	q	π^c	R	a	l^E	Ψ	n_t	$capb$	lev^B
μ_z	Unit-root tech.	1.9	0.0	0.2	4.6	1.8	2.3	4.6	1.2	0.1	1.0	7.9	14.7
ϵ	Stationary tech.	10.6	3.3	2.4	0.2	5.3	4.5	1.2	12.3	0.1	1.7	1.0	28.2
Υ	MEI	15.6	41.9	34.3	67.8	44.1	52.5	29.7	12.1	0.0	42.2	0.6	14.0
ζ_c	Consumption pref.	12.9	27.3	2.4	0.9	1.4	2.0	0.8	2.3	0.0	0.1	0.1	5.1
ζ_h	Labor pref.	31.3	22.2	14.7	0.5	10.8	9.8	7.6	1.1	0.0	1.6	0.7	0.3
ϵ_R	Monetary policy	2.7	2.2	0.9	0.4	1.2	12.8	0.9	0.2	0.0	5.9	1.4	2.0
g	Govn't spending	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
τ_d	Markup, domestic	1.3	0.9	0.2	0.1	18.6	5.0	0.1	1.9	0.0	0.3	0.2	2.1
τ_x	Markup, exports	10.4	0.0	0.0	0.0	0.1	0.2	0.1	2.7	0.0	0.2	0.1	5.5
$\tau_{m,c}$	Markup, imported cons.	0.8	0.5	0.2	0.9	13.6	6.9	4.1	0.9	0.0	0.4	0.1	0.8
$\tau_{m,i}$	Markup, imported inv.	0.5	0.0	0.4	0.1	0.0	0.0	1.8	1.1	0.0	0.3	0.0	2.2
$\tau_{m,x}$	Markup, imported exp.	2.0	0.1	0.1	0.2	0.0	0.0	4.1	0.6	0.0	0.1	0.0	1.1
$\tilde{\epsilon}_D$	Deposit spread	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	8.2	0.7	1.1	0.7
$\tilde{\epsilon}_E$	Credit spread	8.3	0.0	39.0	1.0	0.7	1.2	10.4	62.5	90.6	45.4	77.5	11.9
ϵ_{capb}	Bank capital	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	7.5
y^{Co}	Commod./Oil prod.	0.0	0.3	0.3	0.5	0.1	0.1	4.6	0.1	0.0	0.1	0.0	0.2
p^{Co}	Commod./Oil price	0.0	0.7	0.8	1.2	0.2	0.2	14.0	0.2	0.0	0.1	0.0	0.4
$\tilde{\phi}$	Country risk premium	1.4	0.3	2.8	18.4	1.7	1.9	12.3	0.4	0.0	0.1	0.0	0.9
$\tilde{\phi}_{cp}$	Obs. Country risk prem	0.1	0.0	0.2	1.1	0.1	0.1	0.8	0.0	0.0	0.0	0.0	0.1
$R^\star$	Foreign interest rate	0.0	0.1	0.3	0.9	0.1	0.2	0.9	0.1	0.0	0.0	0.0	0.1
$y^\star$	Foreign output	0.0	0.1	0.7	1.0	0.3	0.3	2.1	0.1	0.0	0.0	0.0	0.2
$\pi^\star$	Foreign inflation	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	All foreign	15.3	1.8	5.4	23.9	16.1	9.8	40.1	6.2	0.1	1.1	0.3	11.3

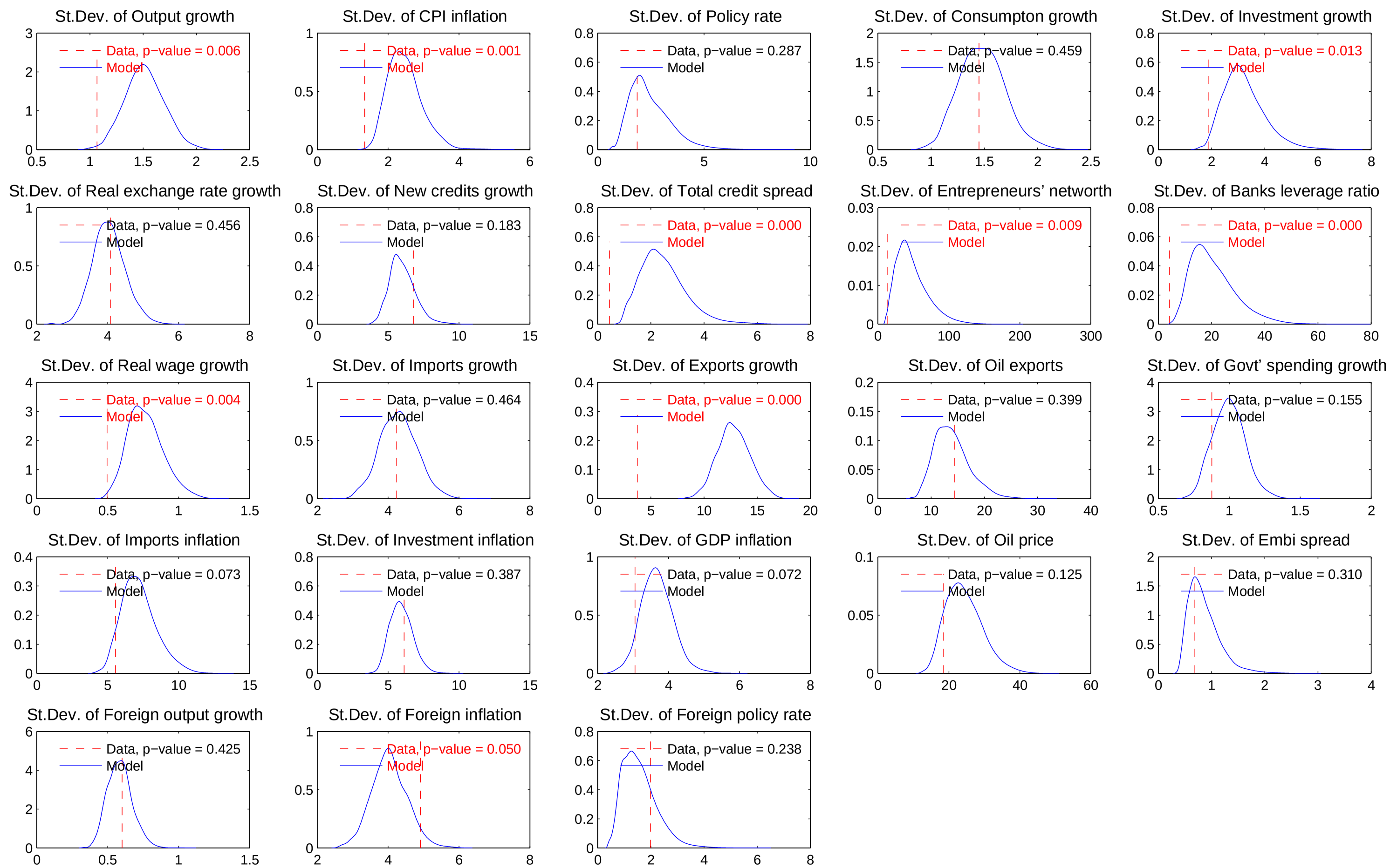
Note : This table shows the contribution of the different shocks to the unconditional variances of the respective variables in %, computed at the posterior mean of the estimated parameters. All foreign shocks are μ_z, $\tau_{m,c}$, $\tau_{m,i}$, $\tau_{m,x}$, $\tilde{\epsilon}_D$, $\tilde{\epsilon}_E$, p^{Co}, $\tilde{\phi}$, $\tilde{\phi}_{cp}$, $R^\star$, $y^\star$, $\pi^\star$. The selected variables in the columns, all of them as model-based percent deviations from the steady state, are output (y), consumption (c), investment (i), the real exchange rate (q), CPI inflation (π^c), the monetary policy rate (R), the current account (a), credit (l^E), the credit spread (Ψ), entrepreneur's networth (n), banks' capital ($capb$), and banks' leverage ratio ($leve^B$).

Table 10. Variance decomposition at 3 years horizon: Mexico.

Shock	Description	y	c	i	q	π^c	R	a	l^E	Ψ	n_t	$capb$	lev^B
μ_z	Unit-root tech.	1.3	0.4	0.1	3.9	1.7	1.5	5.0	0.3	0.1	0.3	7.4	7.6
ϵ	Stationary tech.	6.2	3.0	1.8	0.2	4.8	3.0	0.3	3.1	0.1	0.4	0.5	9.6
Υ	MEI	31.2	45.1	52.0	71.4	48.2	66.3	39.9	5.6	0.0	11.6	0.6	8.6
ζ_c	Consumption pref.	6.2	20.0	2.3	0.8	1.3	1.7	0.3	0.6	0.0	0.0	0.1	1.8
ζ_h	Labor pref.	35.8	26.8	14.4	1.4	10.5	10.9	11.8	0.8	0.0	0.5	0.6	0.6
ϵ_R	Monetary policy	1.6	1.6	0.4	0.4	1.2	7.1	0.7	0.1	0.0	1.3	1.7	1.0
g	Govn't spending	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
τ_d	Markup, domestic	0.7	0.6	0.1	0.1	16.6	2.8	0.1	0.5	0.0	0.1	0.1	0.8
τ_x	Markup, exports	4.8	0.0	0.0	0.0	0.1	0.1	0.0	0.7	0.0	0.0	0.0	1.9
$\tau_{m,c}$	Markup, imported cons.	0.5	0.5	0.3	0.8	12.6	3.9	2.0	0.4	0.0	0.1	0.2	0.4
$\tau_{m,i}$	Markup, imported inv.	0.2	0.0	0.1	0.1	0.0	0.0	0.8	0.3	0.0	0.1	0.0	0.8
$\tau_{m,x}$	Markup, imported exp.	0.9	0.1	0.1	0.2	0.0	0.0	1.4	0.1	0.0	0.0	0.0	0.4
$\tilde{\epsilon}_D$	Deposit spread	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.1	1.5	0.8
$\tilde{\epsilon}_E$	Credit spread	9.6	0.3	24.8	0.9	0.7	0.9	14.7	87.1	93.3	85.5	82.8	61.6
ϵ_{capb}	Bank capital	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	2.5
y^{Co}	Commod./Oil prod.	0.0	0.4	0.4	0.5	0.1	0.1	2.2	0.1	0.0	0.0	0.0	0.1
p^{Co}	Commod./Oil price	0.1	0.8	0.8	1.3	0.2	0.2	6.1	0.1	0.0	0.0	0.0	0.2
$\tilde{\phi}$	Country risk premium	0.7	0.2	1.4	15.3	1.7	1.1	10.5	0.1	0.0	0.0	0.0	0.3
$\tilde{\phi}_{cp}$	Obs. Country risk prem	0.0	0.0	0.1	0.9	0.1	0.1	0.7	0.0	0.0	0.0	0.0	0.0
$R^\star$	Foreign interest rate	0.0	0.0	0.2	0.8	0.1	0.1	0.9	0.0	0.0	0.0	0.0	0.1
$y^\star$	Foreign output	0.1	0.1	0.5	0.9	0.2	0.2	2.6	0.0	0.0	0.0	0.0	0.1
$\pi^\star$	Foreign inflation	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	All foreign	7.5	1.8	3.6	20.3	15.0	5.8	25.0	1.8	0.0	0.2	0.3	4.2

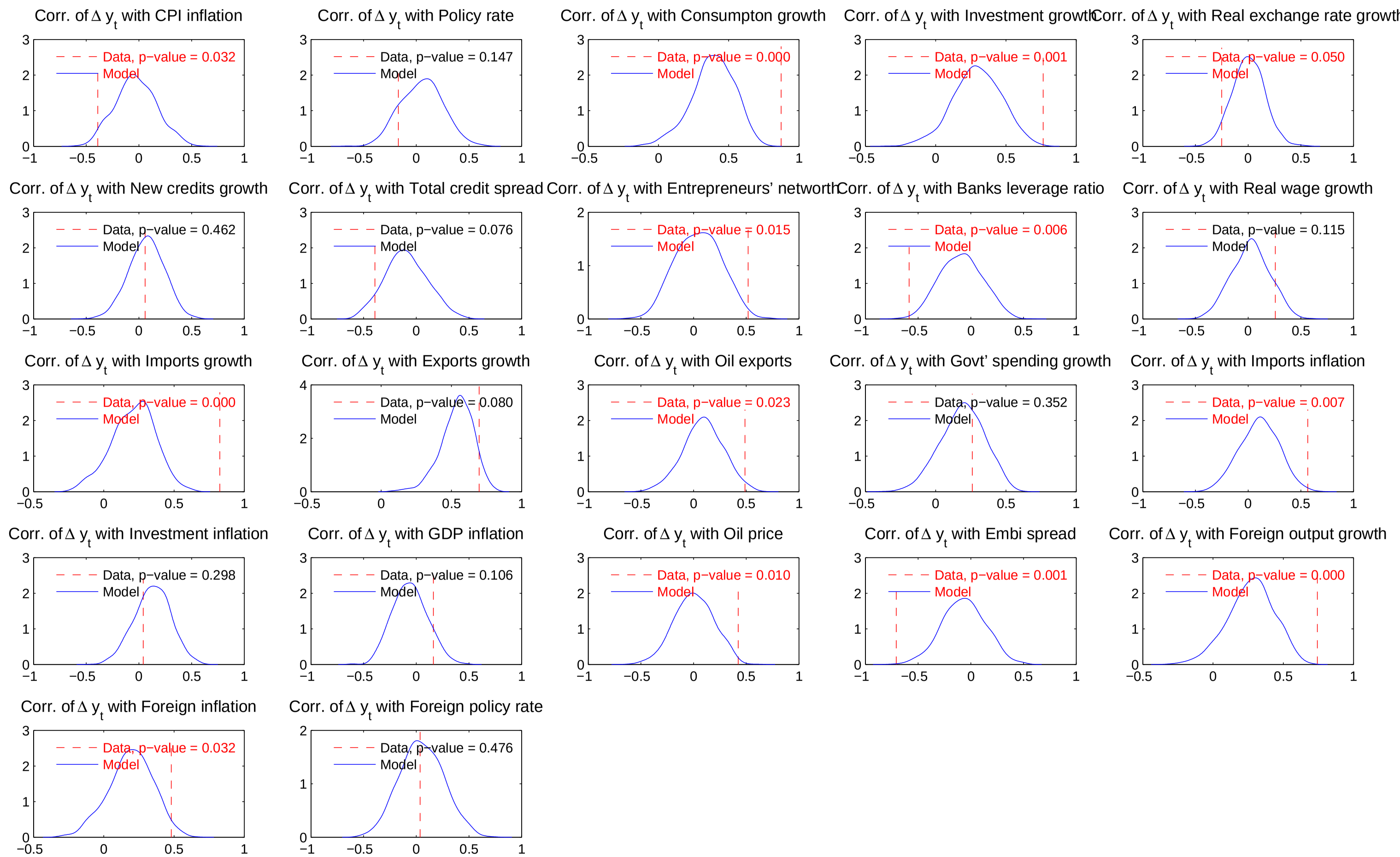
Note : This table shows the contribution of the different shocks to the unconditional variances of the respective variables in %, computed at the posterior mean of the estimated parameters. All foreign shocks are μ_z, $\tau_{m,c}$, $\tau_{m,i}$, $\tau_{m,x}$, $\tilde{\epsilon}_D$, $\tilde{\epsilon}_E$, p^{Co}, $\tilde{\phi}$, $\tilde{\phi}_{cp}$, $R^\star$, $y^\star$, $\pi^\star$. The selected variables in the columns, all of them as model-based percent deviations from the steady state, are output (y), consumption (c), investment (i), the real exchange rate (q), CPI inflation (π^c), the monetary policy rate (R), the current account (a), credit (l^E), the credit spread (Ψ), entrepreneur's networth (n), banks' capital ($capb$), and banks' leverage ratio ($leve^B$).

Figure 4: Mexico: Posterior predictive checking, volatility.



Note: The figure shows the standard deviation of the observable variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 1000 draws of the model at the posterior means, each draw with 41 observations, as in the original sample, with 200 burning periods. These simulations generate a distribution of model-based moments that can be compared to the same moment in the data. The (*) denotes those data standard deviations that are likely to be generated by the model (i.e., those that are inside the confidence interval).

Figure 5: Mexico: Posterior predictive checking, crossed correlations.



Note: The figure shows the the correlation of the observable variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 1000 draws of the model at the posterior means, each draw with 41 observations, as in the original sample, with 200 burning periods. These simulations generate a distribution of model-based moments that can be compared to the same moment in the data. The (*) denotes those data standard deviations that are likely to be generated by the model (i.e., those that are inside the confidence interval).

Estimation and Policy Analysis for Peru*

December 18, 2014

1 Estimation

1.1 Estimation strategy

1.1.1 Data

We estimate the model using Peruvian data for the period 2003Q1-2013Q4 as observables, which is the period of Inflation Targeting in Peru using the Interbank Rate as the policy instrument. More specifically, we include the quarterly growth rates of real GDP ($\Delta \log Y_t$), private consumption ($\Delta \log C_t$), investment ($\Delta \log I_t$), government expenditures ($\Delta \log G_t$), exports ($\Delta \log X_t$), imports ($\Delta \log M_t$), the multilateral real exchange rate ($\Delta \log q_t$) and real wages ($\Delta \log W_t$), average hours worked, i.e. ($\hat{h}_t$), real traditional exports as a proxy of commodity production/exports (y_t^{Co}), domestic inflation based on the GDP deflator (π_t), CPI inflation (π_t^c), tradable CPI inflation as a proxy for imported consumption price inflation ($\pi_t^{m,c}$), investment price inflation based on the investment deflator (π_t^i), the overnight interbank rate as the monetary policy rate (R_t), the EMBI global Peru spread as a proxy for the observed country premium (cp_t), the average deposit rate as a proxy for the interest rate paid on deposits (R_t^D), the average lending rate as a proxy for the interest rate paid by entrepreneurs (R_t^E), the growth rates of real bank loans ($\Delta \log L_t^E$), banks' leverage ($\Delta \log levb_t$) and the deflated growth rate of the Stock Market index of Lima as a proxy of firms' networth ($\Delta \log n_t$), the growth rate of a trade-weighted average of commercial partners' real GDP ($\Delta \log Y_t^*$) and a trade-weighted foreign inflation rate (π_t^*), both computed according to BIS methodology, the short-term LIBOR as a proxy for the foreign interest rate (R_t^*), and the price of traditional exports as a proxy for the price of the exported commodity (p_t^{Co*}).

Some transformations were applied to the time series. First of all, seasonal adjustment was performed using TRAMO-SEATS. All growth rates are quarterly log differences. The inflation and interest rates are annualized quarterly rates. To account for the trends in the data, some of which are different from the model's balanced growth path and average values, the growth rates and interest rates are demeaned. The only exceptions are hours worked, commodity production and commodity prices, which are detrended by fitting log-linear trends, since those variables exhibit pronounced trends that are not explained by the model. All transformed series are multiplied by 100.[1]

Finally, we calibrate the standard deviation of measurement errors as 10 percent of the sample variance of transformed series, including the ones from the financial block. The only exception is the group of prices, where we applied a measurement error of 25 percent.

It is worth to remark that posteriors are based on 1,000,000 draws from the Random Walk Metropolis-Hastings (MH) algorithm, discarding the first 500,000 draws. The covariance matrix of the proposal density was the negative inverse Hessian around that maximum obtained sequentially using the options 4, 8 and 6 in DYNARE, i.e. numerical optimization routines of C. Sims routine, a Simplex-based routine and a Monte-Carlo based optimization routine. Following CTW11, the parameters were scaled to obtain the same order of magnitude of the parameters. The inverse Hessian was scaled to obtain an acceptance rate of approximately 35.2%. The computations were conducted using Dynare 4.4.2.

1.1.2 Calibration and priors

Table 1 displays the calibrated parameters for Peru. Some of the calibrated values are identical to the ones used by CTW. Most of the remaining calibrated parameters are set to match the characteristics of Peruvian

*Technical note for the joint project of the BIS CCA Research Network on "Incorporating financial stability considerations into central bank policy models". For questions and comments, please contact Fernando P ´rez Forero (fernando.perez@bcrp.gob.pe).

[1]Unlike CTW, we do not express real quantities in per capita terms because quarterly population figures for Peru are not available from official sources. Instead, we assume that population growth is constant over time and demean the variables.

Parameters	Definition	Value
sigmaLScaled	Calibrated Frisch elasticity to 1 for Peru	0.2000
α	Share of Capital	0.3300
β	Discount Factor	0.9975
η^a	open economy	0.31*4
η^g	open economy	0.1100
ω^c	import share	0.2000
ω^i	import share	0.2000
ω^x	import share	0.2000
τ^c	taxes	0.1900
τ^w	taxes	0.0000
τ^y	taxes	0.1500
τ^k	taxes	0.3000
τ^b	taxes	0.0000
$spree$	steady state spread	18.92/400
$spreb$	steady state spread	0/400
$levb$	steady state leverage	4.6500

Table 1: Calibrated Parameters

economy.

The parameters that are not calibrated are estimated by Bayesian methods. The prior distributions associated with Peru are displayed in Tables 2 and 3. The selection of most of the estimated parameters and their priors is in line with CTW11.

1.2 Estimation results and goodness of fit

1.2.1 Posterior parameter values

The posterior estimates for Peru are reported in Tables **??** and 3. On the financial sector side, most of the parameters, e.g. κ_b, κ_d, $\rho_{spreadE}$ and $\rho_{spreadB}$ and also standard deviations are well identified. Regarding the parameters associated with the commodity sector, commodity price shocks have a high degree of persistence (b_{44}).

1.2.2 Data vs. smoothed variables

To assess the goodness of fit of the model, Figure 1 shows the observed data for Peru and the corresponding smoothed variables from the model. Conditional upon the calibrated measurement errors (10 percent in most of the cases), the model tracks the in-sample dynamics of most variables quite well. We have found some differences in the credit growth and the net worth of firms, as well as the inflation-associated variables.

1.2.3 Comparison of moments

We also performed a posterior predictive exercise that consisted of simulating the standard deviations and correlations with real GDP growth of the observed variables from the model. Table 4 displays the moments in the data and the simulated moments from the model (means and 95% confidence intervals) while Figures 2 and 3 show the distributions of the moments and the p-values of the test of equality of moments. The principal differences can be found in the interest rates of lending and deposit activities as well as in credit growth. Nevertheless, it is worth to mention the differences in the real exchange rate and hours. Regarding the correlations, we find a reduced number of variables that do not match with the observed data.

2 Policy analysis

2.1 Sudden decrease in commodity price

2.2 Increase in foreign interest rate

The next scenario is a sudden increase in the foreign interest rate by 1%. Figure 5 shows the impulse responses for this scenario.

Table 2: Priors and posteriors of estimated parameters: Peru.

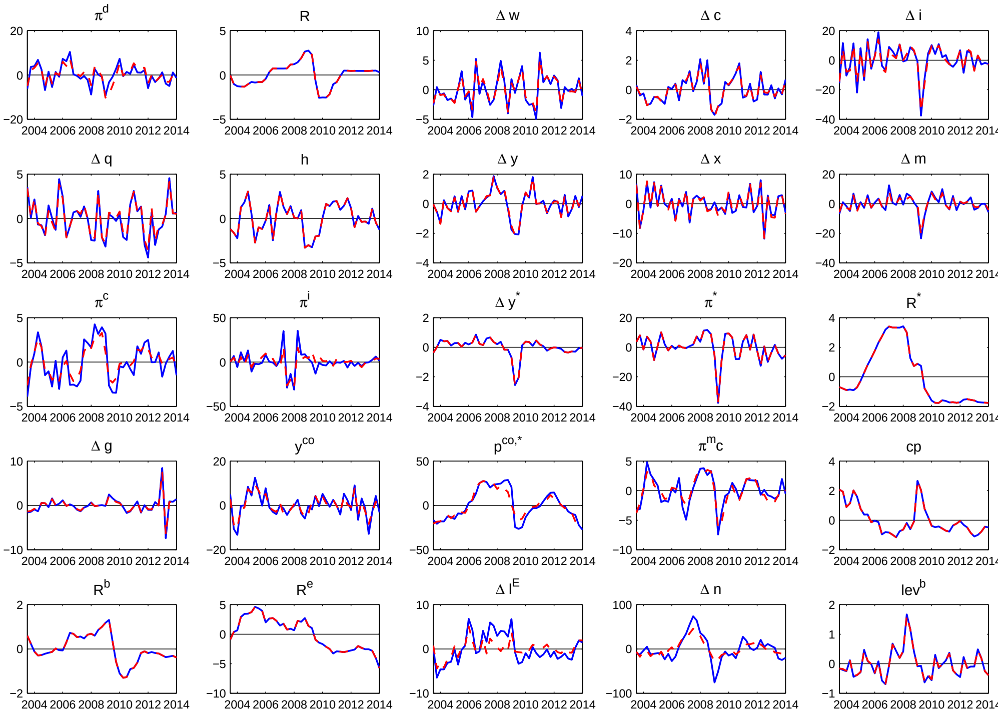
Parameters	Prior	Pr mean	Prior. Sd	Post. Mean	Post.Std	90% HPD interval	
ξ_d	β	0.750	0.075	0.9772	0.0025	0.9732	0.9814
ξ_x	β	0.750	0.075	0.6961	0.0116	0.6210	0.7593
ξ_{mc}	β	0.750	0.075	0.8051	0.0166	0.7539	0.8553
ξ_{mi}	β	0.750	0.075	0.4031	0.0137	0.3115	0.5039
ξ_{mx}	β	0.660	0.100	0.4692	0.0187	0.3584	0.5811
κ_b	Γ^{-1}	0.500	Inf	0.4874	0.1081	0.1135	1.0205
κ_e	Γ^{-1}	0.500	Inf	0.1178	0.0222	0.0795	0.1543
$\xi_{spreb_e last}$	Γ^{-1}	0.100	Inf	0.2192	0.0465	0.1293	0.3040
ξ_{spree1}	β	0.500	0.075	0.7084	0.0083	0.6243	0.7831
ξ_{spree3}	Γ^{-1}	0.200	Inf	0.0475	0.0068	0.0339	0.0607
$\rho_{spreadE}$	β	0.500	0.075	0.4872	0.0181	0.4124	0.5600
$\rho_{spreadB}$	β	0.500	0.075	0.6634	0.0132	0.5850	0.7487
ξ_w	β	0.750	0.075	0.4719	0.0133	0.3924	0.5534
κ_d	β	0.500	0.150	0.7528	0.0557	0.6073	0.9063
κ_x	β	0.500	0.150	0.4051	0.0387	0.2216	0.6399
κ_{mc}	β	0.500	0.150	0.6670	0.0398	0.5031	0.8343
κ_{mi}	β	0.500	0.150	0.4611	0.0356	0.2944	0.6361
κ_{mx}	β	0.500	0.150	0.4443	0.0578	0.2417	0.7018
κ_w	β	0.500	0.150	0.3689	0.0319	0.1697	0.6233
b	β	0.65	0.150	0.8483	0.0341	0.7835	0.9156
$S''/10$	Γ	0.50	0.150	0.0358	0.0034	0.0296	0.0464
σ_a	Γ	0.20	0.050	0.1801	0.0054	0.1426	0.2183
ρ_R	β	0.80	0.100	0.9395	0.0242	0.9152	0.9640
r_π	N	1.70	0.150	1.5440	0.0285	1.3492	1.7184
$r_{\Delta y}$	N	0.13	0.050	0.0784	0.0105	0.0244	0.1410
η_x	Γ	1.50	0.150	1.5996	0.0404	1.4192	1.7813
η_i	Γ	1.50	0.150	1.5357	0.0251	1.3614	1.7496
η_f	Γ	1.50	0.150	1.1621	0.0332	1.0333	1.2880
$\rho_{\tilde{\phi}_s}$	Γ	1.25	0.100	1.1438	0.0225	1.0305	1.2602
ρ_{μ_z}	β	0.50	0.075	0.6204	0.0072	0.5416	0.6986
ρ_ϵ	β	0.85	0.075	0.9480	0.0088	0.9282	0.9680
ρ_Υ	β	0.85	0.075	0.7914	0.0172	0.6635	0.9135
ρ_{ζ^c}	β	0.85	0.075	0.7752	0.0161	0.6667	0.8961
ρ_{ζ^h}	β	0.85	0.075	0.5094	0.0198	0.4051	0.6279
$\rho_{\tilde{\phi}}$	β	0.85	0.075	0.8590	0.0124	0.7954	0.9225
$\rho_{\tilde{\phi}_{cp}}$	β	0.85	0.075	0.7460	0.0150	0.6732	0.8229
ρ_g	β	0.85	0.075	0.8965	0.0160	0.8277	0.9638
ρ_{yco}	β	0.85	0.075	0.7236	0.0220	0.6245	0.8294
a_{11}	N	0.5	0.5	0.7661	0.0452	0.6566	0.8763
a_{22}	N	0	0.5	0.3139	0.0749	0.0496	0.5736
a_{33}	N	0.5	0.5	1.0434	0.0286	0.8964	1.1855
b_{44}	N	0.5	0.5	0.9108	0.0431	0.8393	0.9876
a_{12}	N	0	0.5	0.1384	0.0347	0.0826	0.1934
a_{13}	N	0	0.5	0.6888	0.1204	0.2647	1.1472
a_{21}	N	0	0.5	-0.1137	0.0592	-0.3276	0.0907
a_{23}	N	0	0.5	0.4650	0.1237	0.0102	0.8907
a_{24}	N	0	0.5	0.3611	0.0478	-0.0177	0.8001
a_{31}	N	0	0.5	-0.0318	0.0117	-0.0744	0.0096
a_{32}	N	0	0.5	0.0089	0.0098	-0.0071	0.0248
a_{34}	N	0	0.5	0.2059	0.1207	-0.2674	0.6915
c_{21}	N	0	0.5	0.9094	0.2043	0.4131	1.4303
c_{31}	N	0	0.5	0.0947	0.0334	-0.0108	0.2014
c_{32}	N	0	0.5	-0.0271	0.0072	-0.0450	-0.0084
c_{24}	N	0	0.5	0.0529	0.1017	-0.6325	0.7192
c_{34}	N	0	0.5	0.0847	0.0970	-0.4300	0.6546

Table 3: Priors and posteriors of estimated shock standard deviations: Peru.

Parameters	Prior	Pr mean	Prior. Sd	Post. Mean	Post. Std	90% HPD interval	
μ_{z_ϵ}	Γ^{-1}	0.15	Inf	0.1089	0.0237	0.0434	0.1727
ϵ_ϵ	Γ^{-1}	0.50	Inf	2.6395	0.2929	2.0625	3.2164
Υ_ϵ	Γ^{-1}	0.15	Inf	0.4660	0.0572	0.3518	0.5779
ζ_{c_ϵ}	Γ^{-1}	0.15	Inf	0.5589	0.1393	0.3132	0.7987
$_\epsilon$	Γ^{-1}	0.15	Inf	7.4714	0.9608	4.7968	10.4949
$\tilde{\phi}_\epsilon$	Γ^{-1}	0.15	Inf	0.3448	0.0470	0.1787	0.5055
eps$_s preb_e ps$	Γ^{-1}	0.15	Inf	0.1548	0.0197	0.1178	0.1911
eps$_s pree_e ps$	Γ^{-1}	0.15	Inf	0.2358	0.0243	0.1850	0.2834
capb$_e ps$	Γ^{-1}	0.15	Inf	0.0484	0.0087	0.0346	0.0617
$\tilde{\phi^{cp}}_\epsilon$	Γ^{-1}	0.15	Inf	0.1448	0.0151	0.1200	0.1696
ϵR_ϵ	Γ^{-1}	0.15	Inf	0.1456	0.0172	0.1200	0.1709
g_ϵ	Γ^{-1}	0.50	Inf	1.7671	0.1964	1.4095	2.0978
τ_{d_ϵ}	Γ^{-1}	0.50	Inf	62.1081	0.9012	57.9337	66.5072
τ_{x_ϵ}	Γ^{-1}	0.50	Inf	1.6237	0.4110	0.1570	2.8038
τ_{mc_ϵ}	Γ^{-1}	0.50	Inf	0.9416	0.3996	0.3710	1.5088
τ_{mi_ϵ}	Γ^{-1}	0.50	Inf	2.5359	0.3709	1.6327	3.4169
τ_{mx_ϵ}	Γ^{-1}	0.50	Inf	4.7919	0.5339	2.4011	7.0103
ystar$_e ps$	Γ^{-1}	0.50	Inf	0.4274	0.0558	0.3312	0.5260
pistar$_e ps$	Γ^{-1}	0.50	Inf	1.8525	0.2152	1.5024	2.1985
Rstar$_e ps$	Γ^{-1}	1.50	Inf	0.7083	0.1158	0.4601	0.9455
yco$_e ps$	Γ^{-1}	0.50	Inf	4.2919	0.4258	3.4783	5.0940
pcostar$_e ps$	Γ^{-1}	0.50	Inf	0.5884	0.0684	0.4682	0.7032

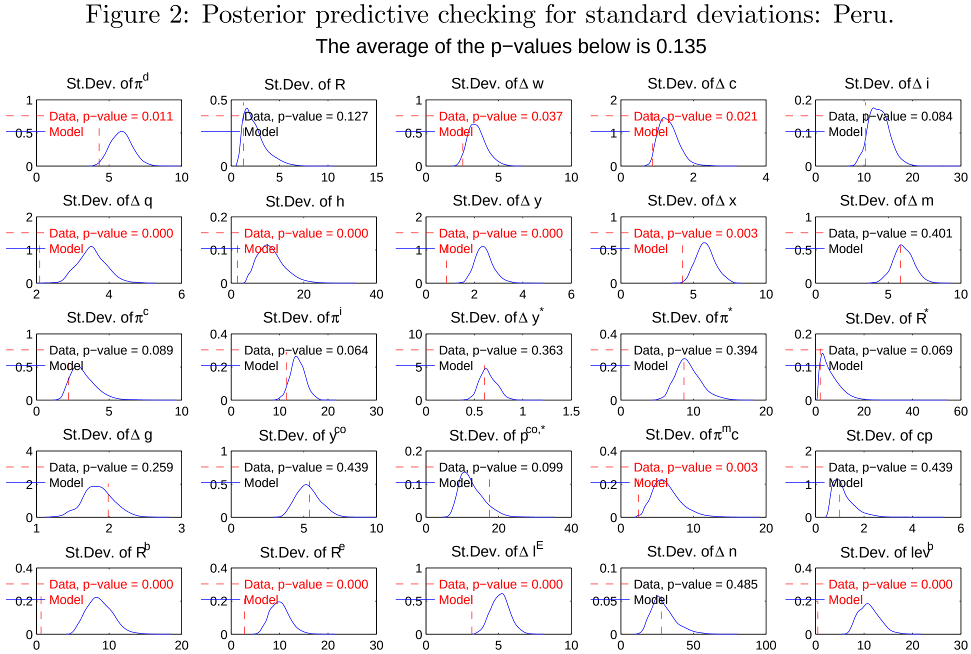
References

Figure 1: Observed data vs. smoothed variables: Peru, 2001Q3-2013Q4.



Note: This figure shows the observed data and the corresponding smoothed model variables, computed by the Kalman smoother at the posterior mean of the estimated parameters.

Figure 2: Posterior predictive checking for standard deviations: Peru.



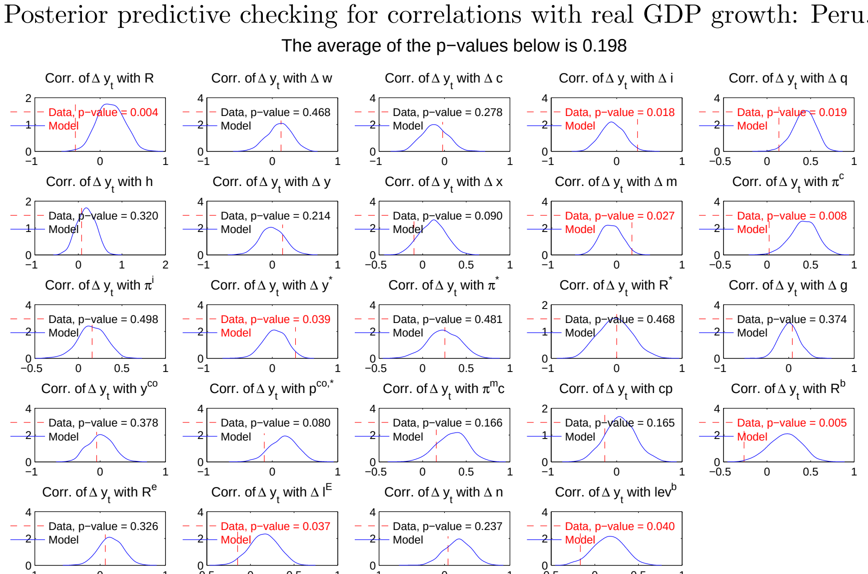
Note: This figure shows the standard deviations of the observed variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 5,000 draws of the moments from the model at the posterior mean of the estimated parameters, each draw with 43 observations, as in the original (adjusted) sample, with 200 burn-in periods. The p-values correspond to the test of equality of the standard deviations.

Table 4: Posterior predictive checking for std. deviations: Peru

Variable	Data	Model mean	Model 95 % CI
π^d	4.3	5.9	(4.5, 7.4)
R	1.3	2.4	(0.9, 5.2)*
Δw	2.5	3.5	(2.5, 5.0)*
Δc	0.9	1.3	(0.9, 2.0)
Δi	10.4	13.1	(9.3, 17.7)*
Δq	2.1	3.5	(2.8, 4.4)
h	1.7	11.0	(5.1, 19.6)
Δy	0.9	2.4	(1.7, 3.3)
Δx	4.3	5.8	(4.7, 7.2)
Δm	5.9	6.0	(4.7, 7.5)*
π^c	2.2	3.2	(1.9, 5.2)*
π^i	11.5	13.8	(10.8, 16.9)*
Δy^*	0.6	0.6	(0.5, 0.8)*
π^*	8.7	9.3	(6.4, 13.4)*
R^*	1.9	6.1	(1.3, 15.4)*
Δg	2.0	1.9	(1.4, 2.3)*
y^{co}	5.4	5.3	(3.9, 7.0)*
$p^{co,*}$	17.5	12.6	(7.8, 20.2)*
$\pi^m c$	2.5	6.4	(3.4, 10.8)
cp	1.0	1.1	(0.6, 2.3)*
R^b	0.6	8.7	(5.7, 12.3)
R^e	2.7	10.0	(6.5, 14.2)
Δl^E	3.2	5.1	(3.9, 6.4)
Δn	27.8	29.4	(17.0, 49.0)*
lev^b	0.5	11.1	(7.5, 15.7)

Note: The table shows the standard deviation of the observable variables and compares them to a distribution of the same moments derived from the model. This posterior checking exercise consists in simulating 1000 draws of the model at the posterior means, each draw with 43 observations, as in the original sample, with 200 burning periods. These simulations generate a distribution of model-based moments that can be compared to the same moment in the data. The (*) denotes those data standard deviations that are likely to be generated by the model (i.e., those that are inside the confidence interval).

Figure 3: Posterior predictive checking for correlations with real GDP growth: Peru.



Note: See Figure 2. This figure shows the correlations with real GDP growth of the observed variables and compares them to a distribution of the same moments derived from the model.

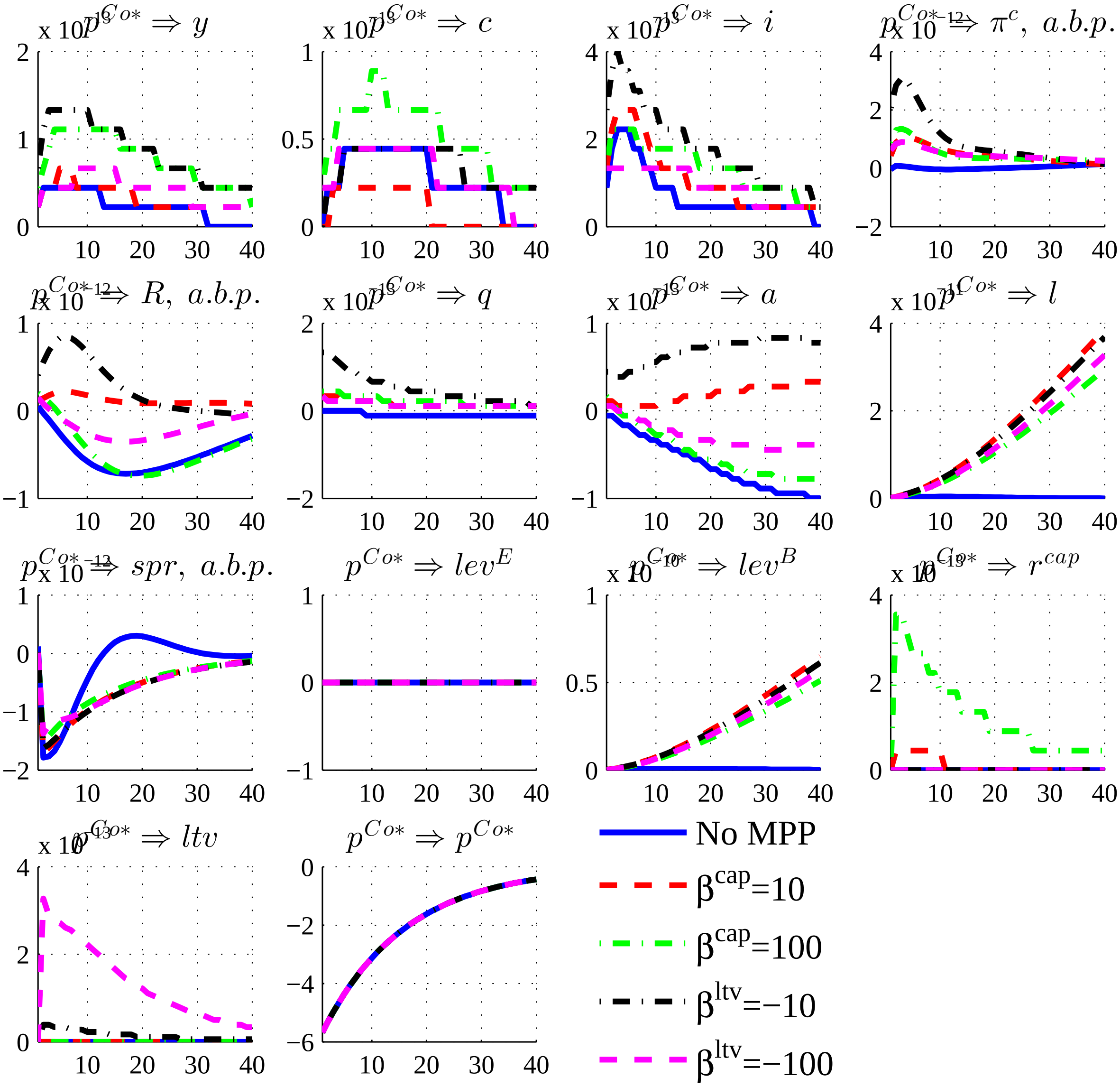
Table 5: Posterior predictive checking for correlations with real GDP growth: Peru

with respect to the corresponding variable: Peru, full model.

Variable	Data	Model mean	Model 95 % CI
R	-0.38	0.16	$(-0.22,\ 0.53)$
Δw	0.13	0.11	$(-0.26,\ 0.46)^{\star}$
Δc	-0.03	-0.15	$(-0.50,\ 0.23)^{\star}$
Δi	0.32	-0.06	$(-0.40,\ 0.28)$
Δq	0.14	0.43	$(0.16,\ 0.65)$
h	0.08	0.18	$(-0.22,\ 0.57)^{\star}$
Δy	0.16	0.00	$(-0.34,\ 0.36)^{\star}$
Δx	-0.10	0.11	$(-0.18,\ 0.39)^{\star}$
Δm	0.23	-0.09	$(-0.38,\ 0.23)$
π^c	0.02	0.42	$(0.10,\ 0.71)$
π^i	0.16	0.16	$(-0.17,\ 0.44)^{\star}$
Δy^*	0.36	0.04	$(-0.31,\ 0.37)^{\star}$
π^*	0.25	0.24	$(-0.12,\ 0.58)^{\star}$
R^*	0.00	-0.02	$(-0.49,\ 0.49)^{\star}$
Δg	0.05	0.01	$(-0.27,\ 0.30)^{\star}$
y^{co}	-0.05	0.00	$(-0.33,\ 0.36)^{\star}$
$\mathrm{p}^{co,*}$	-0.12	0.17	$(-0.24,\ 0.54)^{\star}$
$\pi^m c$	0.16	0.33	$(-0.02,\ 0.65)^{\star}$
cp	-0.18	0.05	$(-0.40,\ 0.53)^{\star}$
R^b	-0.26	0.21	$(-0.15,\ 0.53)$
R^e	0.08	0.16	$(-0.19,\ 0.51)^{\star}$
Δl^E	-0.15	0.15	$(-0.16,\ 0.45)^{\star}$
Δn	0.05	0.20	$(-0.20,\ 0.59)^{\star}$
lev^b	-0.17	0.16	$(-0.21,\ 0.49)^{\star}$

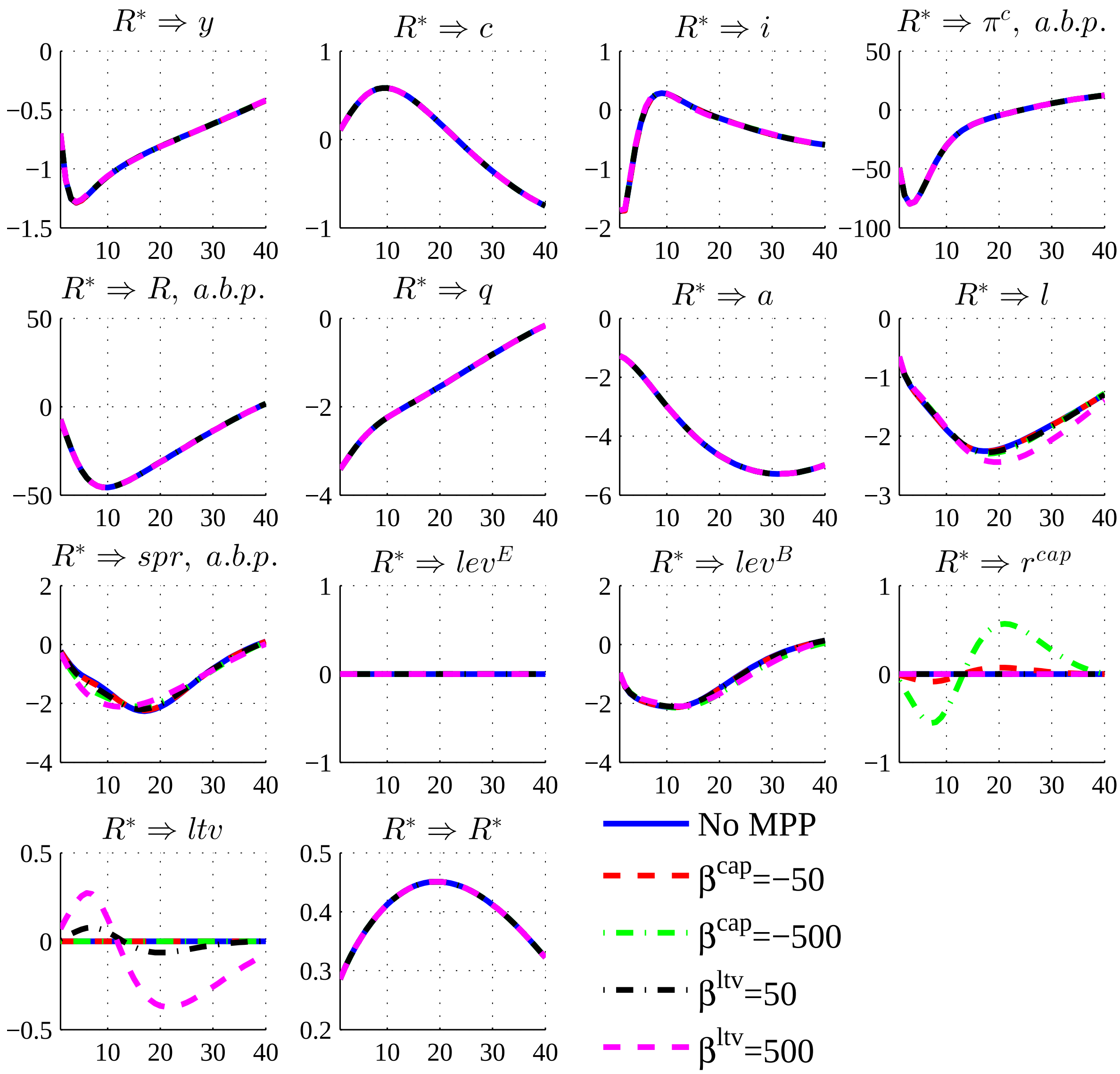
Note : The table compares the correlation between the row observable variable and output growth obtained in the data to the same correlation obtained in the model. This posterior checking exercise consists in simulating 1000 draws of the model at the posterior means, each draw with 43 observations, as in the original sample, with 200 burning periods. These simulations generate a distribution of model-based moments that can be compared to the same moment in the data. The (*) denotes those data correlations that are likely to be generated by the model (i.e., those that are inside the confidence interval).

Figure 4: Impulse responses to a negative commodity price shock: Peru.



Note: This figure shows the impulse responses of selected variables to a negative one-standard deviation commodity price shock in period 1. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is real credit.

Figure 5: Impulse responses to a foreign interest rate shock: Peru.



Note: This figure shows the impulse responses of selected variables to a 1% foreign interest rate shock in period 1. The impulse responses are computed at the posterior mean of the estimated parameters when the only policy variable at work is the short-term interest rate ("No MPP") and when in conjunction to the policy rate capital requirements and LTV limits are used (using one instrument at the time) according to the feedback rule $\text{INST}_t = \text{INST} + \beta(\text{VAR}_t - \text{VAR})$, where INST_t and VAR_t are the alternative policy instruments and the variable to react, respectively, in logs. In this case, VAR_t is the total credit spread.