Commodity Prices, Financial Dollarization and FX Interventions in a Small Open Economy

Paul Castillo    David Florian    Hiroshi Toma

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\[1\] The views expressed in this paper are our own and do not necessarily reflect those of the Central Reserve Bank of Peru.
Motivation

- Empirical evidence shows foreign shocks are important for small open economies.
- The 2000s were years of almost unparalleled economic growth for the Peruvian economy.
  - What role did the foreign shocks have?
- In the same period, the Central Bank adopted an inflation targeting regime, intervened in the FX market and started a de-dollarization program.
  - The benefits of the inflation targeting regime have been widely studied.
  - What role had the FX interventions and the de-dollarization in the Peruvian economy?
- We develop a dynamic stochastic general equilibrium model for an small open economy that includes a commodity producing sector, financial dollarization, FX interventions and non-Ricardian households.
Commodity Prices, Financial Dollarization and FX Interventions in a Small Open Economy Model

Model

- Castillo, Montoro and Tuesta (2009): MEGA-D
  - New Keynesian Small Open Economy model.
  - Financial accelerator mechanism (Bernanke, Gertler and Gilchrist 1999).
  - Financial and price dollarization.
  - Interest rate is the only monetary policy tool.

- Castillo, Florian and Toma: MEGA-ACDF
  - FX interventions as an additional tool for the Central Bank with the objective to reduce the volatility of the exchange rate.
  - A commodity producing firm that serves as the vehicle through which commodity prices fluctuations impact the rest of the model economy. Investment in this sector presents adjustment costs and time to build.
  - Non-Ricardian households to control for the fact that in emerging economies many households do not have access to financial services.
Figure: Model Scheme
Financial Dollarization

- We define $\delta_{FD}$ as the part of the interests the entrepreneurs must pay that is indexed to the foreign interest rate.
- This is equivalent to saying entrepreneurs have debt in both domestic currency and dollars.
- With financial dollarization the arbitrage condition that determines the demand of (non-commodity sector related) stock of capital is

$$E_t \left[ R_{t+1}^K \right] = E_t \left\{ [1 + i_t]^{1-\delta_{FD}} \left[ (1 + i_t^*) \frac{S_{t+1}}{S_t} \right]^{\delta_{FD}} \frac{P_t}{P_{t+1}} \right\},$$

where $E_t \left[ R_{t+1}^K \right]$ is the return entrepreneurs expect to obtain for investing, $i_t$ is the nominal interest rate of the home economy, $i_t^*$ is the foreign interest rate and $P_t$ is the aggregate price level.
Endogenous Commodity Sector

- The production function is

\[ Y_t^C = Z_t^C F^C \left( K_{t-1}^C \right), \]  

(2)

where \( Y_t^C \) is the commodity production, \( Z_t^C \) is the sector specific productivity, \( K_t^C \) is the specific capital this firm uses and \( F^C(\cdot) \) is the production function.

- The productivity is modelled as

\[ Z_t^C = \rho Z_{t-1}^C + \gamma P_t^C + \varepsilon_t Z_t^C, \]  

(3)

where \( P_t^C \) are the commodity prices.

- For obtaining one new unit of investment, the firm must spend in investment projects \( X_t^C \) for \( n \) periods. This is the time to build mechanism and is represented by

\[ INV_t^C = \sum_{j=0}^{n-1} \omega_j X_{t-j}^C, \]  

(4)

where \( \omega_j = 1/n \).

- Commodity sector investment demands local and foreign goods.

- Commodity sector investment responds to commodity prices as well.

- The accumulation of the sector specific stock of capital is

\[ K_t^C = (1 - \delta_C) K_{t-1}^C + \left[ 1 - \Phi \left( X_{t-n+1}^C \right) \right] X_{t-n+1}^C, \]  

(5)

where \( \delta_C \) is the sector specific capital depreciation rate and \( \Phi(\cdot) \) is a capital adjustment cost function.
FX Interventions

- We assume the FX interventions are sterilized. In the case of a nominal appreciation, this means the monetary authority issues $\Delta D_t^{CB}$ units of Central Bank-backed bonds denominated in domestic currency in an amount equal to $S_t \Delta F_t^{CB}$.
- Thus the amount of bonds in the economy does not change and the intervention only represents a recomposition of the bond holdings of the economy.
- The balance sheet of the Central Bank is

$$S_t F_t^{*, CB} - (1 + i_{t-1}^*) \Psi_F \left( F_{t-1}^{*, CB} S_{t-1} \right) S_t F_t^{*, CB} = D_t^{CB} - (1 + i_{t-1}^*) D_{t-1}^{CB}, \quad (6)$$

where $F_t^{CB}$ are the international reserves denominated in dollars and $\Psi_F(.)$ is the cost the Central Bank assumes for handling foreign assets. We have $\Psi_F'(.) > 0$. We also assume the international reserves earn an interest rate equal to the foreign interest rate, while the Central Bank-backed bonds denominated in domestic currency $D_t^{CB}$ earn an interest rate equal to the domestic one.
- For the local investor, $D_t^{CB}$ are imperfect substitutes with the private bonds in domestic currency.
- The reaction function is

$$\frac{F_t^{*, CB}}{F^{*, CB}} = \left( \frac{F_t^{*, CB}}{F_{t-1}^{*, CB}} \right)^{\rho_F} \left[ \left( \frac{S_t - S_{t-1}}{S} \right)^{-\varphi_F} \right]^{1-\rho_F} INT_t, \quad (7)$$

where $\left( \frac{S_t - S_{t-1}}{S} \right)$ is the variation of the nominal exchange rate (also known as the depreciation rate), $\varphi_F$ represents the magnitude of the reaction of the Central Bank upon nominal exchange rate variations, $\rho_F$ is a persistence parameter for the international reserves and $INT_t$ is an AR(1) process associated to the international reserves accumulation shock.
We take a look at the log-linearized UIP equation.

\[ i_t = i_t^* + \left( \psi_B \psi_{b_t^*} + \psi_F \psi_{f_t^*}, CB \right) + E_t \Delta s_{t+1} \]  

(8)

For instance, upon a foreign interest rate shock, what would have to happen if we want to keep the nominal exchange rate constant?

\[ i_t = \uparrow i_t^* + \left( \psi_B \psi_{b_t^*} + \psi_F \psi_{f_t^*}, CB \right) + E_t \Delta s_{t+1} \]

The way the FX intervention works is by lowering the international reserves.

\[ i_t = \uparrow i_t^* + \left( \psi_B \psi_{b_t^*} + \psi_F \psi_{f_t^*}, CB \right) + E_t \Delta s_{t+1} \]

However, private agents may react through \( \uparrow b_t^* \) and undo what the Central Bank did.

The model is calibrated in such a way that the effect of the FX intervention dominates.
Commodity Prices, Financial Dollarization and FX Interventions in a Small Open Economy

Preliminary Results

Preliminary results:

1. Bayesian Estimation
2. Forecast Error Variance Decomposition
3. Theoretical Moments
4. Counterfactual Exercise: FX Intervention
5. Counterfactual Exercise: Financial Dollarization
Estimation

- We estimate the linear version of model for the Peruvian economy during the inflation targeting (IT) period.
- We use 14 quarterly series from 2002Q1 to 2017Q4.
- All the variables are expressed in real terms and in levels.

### Table: Observed Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>$Y_{t,obs}$</td>
<td>GDP</td>
</tr>
<tr>
<td>$C_{t,obs}$</td>
<td>Private Consumption</td>
</tr>
<tr>
<td>$INV_{t,TOT,obs}$</td>
<td>Private Total Investment</td>
</tr>
<tr>
<td>$G_{t,obs}$</td>
<td>Public Expenditure</td>
</tr>
<tr>
<td>$Y_{t,XTOT,obs}$</td>
<td>Total Exports</td>
</tr>
<tr>
<td>$Y_{t,MTOT,obs}$</td>
<td>Total Imports</td>
</tr>
<tr>
<td>$RER_{t,obs}$</td>
<td>Real Exchange Rate</td>
</tr>
<tr>
<td>$i_{t,obs}$</td>
<td>Nominal Interest Rate</td>
</tr>
<tr>
<td>$\pi_{t,obs}$</td>
<td>Inflation Rate (without food and energy)</td>
</tr>
<tr>
<td>$Y_{t,*},obs$</td>
<td>Trade-Weighted Foreign GDP</td>
</tr>
<tr>
<td>$i_{t,*},obs$</td>
<td>3-Month LIBOR Rate</td>
</tr>
<tr>
<td>$\pi_{t,*},obs$</td>
<td>Trade-Weighted Foreign Inflation Rate</td>
</tr>
<tr>
<td>$Y_{t,C,obs}$</td>
<td>Commodity Production</td>
</tr>
<tr>
<td>$P_{t,C,obs}$</td>
<td>Metal Price Index</td>
</tr>
</tbody>
</table>
Measurement equations for variables in levels $X_t^{obs}$:

$$X_t^{obs} = x_t + x_t^{TR}, \quad (9)$$

$$x_t^{TR} = x_{t-1}^{TR} + x_t^G, \quad (10)$$

$$x_t^G = x_{t-1}^G + \varepsilon_t^x, \quad (11)$$

where $x_t$ is the model based gap, $x_t^{TR}$ is the trend, $x_t^G$ is the trend growth rate and $\varepsilon_t^x \sim N(0,1)$.

Measurement equations for variables in rates:

$$x_t^{obs} = x_t + \bar{x} \quad (12)$$

where $x_t$ is the model based rate and $\bar{x}$ is the mean.
Forecast Error Variance Decomposition
### Theoretical Moments

#### Table: Theoretical Moments

<table>
<thead>
<tr>
<th></th>
<th>Correlations with GDP</th>
<th></th>
<th>Std. Dev. Ratio (GDP)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Model</td>
<td>Observed</td>
<td>Model</td>
</tr>
<tr>
<td>$y$</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$c$</td>
<td>0.8</td>
<td>0.8</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>$inv^{tot}$</td>
<td>0.9</td>
<td>0.4</td>
<td>5.1</td>
<td>2.3</td>
</tr>
<tr>
<td>$y^x$</td>
<td>0.1</td>
<td>0.9</td>
<td>2.2</td>
<td>1.7</td>
</tr>
<tr>
<td>$y^m$</td>
<td>0.9</td>
<td>0.5</td>
<td>3.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Correlations with Inflation Rate</th>
<th></th>
<th>Std. Dev. Ratio (Inflation Rate)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Model</td>
<td>Observed</td>
<td>Model</td>
</tr>
<tr>
<td>$\pi$</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$4 \times i$</td>
<td>0.4</td>
<td>0.7</td>
<td>2.8</td>
<td>4.0</td>
</tr>
<tr>
<td>$\Delta s$</td>
<td>0.3</td>
<td>0.1</td>
<td>6.0</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Commodity Prices, Financial Dollarization and FX Interventions in a Small Open Economy

Preliminary Results

FX Intervention

**Figure:** Impulse Response Functions, Metal Price Index Shock (1)
FX Intervention

**Figure**: Impulse Response Functions, Metal Price Index Shock (2)
## FX Intervention

**Table: Theoretical Moments, Standard Deviations**

<table>
<thead>
<tr>
<th></th>
<th>Alternative Model</th>
<th>Baseline Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($\phi_{FX} = 0$)</td>
<td>($\phi_{FX} = 8$)</td>
</tr>
<tr>
<td>$y$</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>$c$</td>
<td>0.016</td>
<td>0.014</td>
</tr>
<tr>
<td>$inv^{tot}$</td>
<td>0.051</td>
<td>0.043</td>
</tr>
<tr>
<td>$y^x$</td>
<td>0.031</td>
<td>0.032</td>
</tr>
<tr>
<td>$y^m$</td>
<td>0.026</td>
<td>0.022</td>
</tr>
<tr>
<td>$\pi$</td>
<td>0.006</td>
<td>0.005</td>
</tr>
<tr>
<td>$4 \times i$</td>
<td>0.026</td>
<td>0.022</td>
</tr>
<tr>
<td>$\Delta s$</td>
<td>0.035</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Counterfactual Exercise: FX Intervention

- Based on the estimated model:
  - We feed model with observed variables for the whole sample.
  - We filter the evolution of all of the model variables.
  - We obtain the filtered shocks conditional on the model and the data.
  - We set our initial point at 2002Q1 and perform several forecasting exercises conditional on the actual realized shocks from the complete sample.
    - One scenario is that of no FX intervention ($\phi_{FX} = 0$).
    - Other case is baseline scenario ($\phi_{FX} = 8$).
Counterfactual Exercise: FX Intervention

Figure: Counterfactual Exercise (1)
Counterfactual Exercise: FX Intervention

Figure: Counterfactual Exercise (2)
Counterfactual Exercise: FX Intervention

Figure: Counterfactual Exercise (3)
Financial Dollarization

Figure: Impulse Response Functions, Foreign Interest Rate Shock
### Financial Dollarization

**Table: Theoretical Moments, Standard Deviations**

<table>
<thead>
<tr>
<th></th>
<th>Alternative Model ($\delta_F = 0.90$)</th>
<th>Baseline Model ($\delta_F = 0.53$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y$</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>$c$</td>
<td>0.015</td>
<td>0.014</td>
</tr>
<tr>
<td>$inv^{tot}$</td>
<td>0.051</td>
<td>0.043</td>
</tr>
<tr>
<td>$y^x$</td>
<td>0.032</td>
<td>0.032</td>
</tr>
<tr>
<td>$y^m$</td>
<td>0.022</td>
<td>0.022</td>
</tr>
<tr>
<td>$\pi$</td>
<td>0.006</td>
<td>0.005</td>
</tr>
<tr>
<td>$4 \times i$</td>
<td>0.022</td>
<td>0.022</td>
</tr>
<tr>
<td>$\Delta s$</td>
<td>0.024</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Counterfactual Exercise: Financial Dollarization

- We analyze the effects of having a higher financial dollarization.
  - One scenario is that of high financial dollarization ($\delta_F = 0.90$).
  - Other case is baseline scenario ($\delta_F = 0.53$).
Counterfactual Exercise: Financial Dollarization

Figure: Counterfactual Exercise (1)
Counterfactual Exercise: Financial Dollarization

Figure: Counterfactual Exercise (2)
Counterfactual Exercise: Financial Dollarization

Figure: Counterfactual Exercise (3)
For the Peruvian economy, the commodity price index has a main role on explaining the dynamics of the macroeconomic variables.

Counterfactual exercises show:

- FX interventions reduce the volatility of the economy variables.
- Lower financial dollarization levels have the same effect.
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Appendix

Assessing the Effectiveness of the FX Intervention with No Dollarization

Counterfactual Exercise: FX Intervention with No Dollarization

- We analyze the effects of having FX interventions with zero financial dollarization.
  - One scenario is that of FX interventions and zero financial dollarization \((\phi_{FX} = 8, \delta_F = 0)\).
  - Other scenario is that of no FX interventions and zero financial dollarization \((\phi_{FX} = 0, \delta_F = 0)\).
Counterfactual Exercise: FX Intervention with No Dollarization

Figure: Counterfactual Exercise (1)
Counterfactual Exercise: FX Intervention with No Dollarization

Figure: Counterfactual Exercise (2)
Counterfactual Exercise: FX Intervention with No Dollarization

Figure: Counterfactual Exercise (3)
Commodity Prices, Financial Dollarization and FX Interventions in a Small Open Economy

Appendix

Transmission Mechanisms

Figure: Commodity Price Shock Mechanism

- $t_t^C$ → $q_t^C$
- $inv_t^C$ → $k_t^C$ → $y_t^C$ → $y_t^{X,C}$
- $b_t^C$ → $c_t$ → $y_t^{M,NC}$
- $inv_t^{C,H}$ → $y_t^{H}$ → $y_t$ → $\pi_t$
- $inv_t^{C,M}$ → $y_t^{M,C}$
- $\Delta s_t$ → $r e r_t$ → $y_t^{X,NC}$
- $\pi_t^M$ → $\pi_t^D$

Note: $ben_t^C$ refers to the commodity producing firm benefits.
Figure: Foreign Interest Rate Shock Mechanism

- $i_t^*$ increases
- $E_{t}^{r_{t+1}}$ increases
- $q_{t}^{NC}$ decreases
- $i_{t}^{NC}$ decreases
- $k_{t}^{NC}$ decreases
- $n_{t}$ decreases
- $r_{p_{t}}$ increases
- $\Delta s_{t}$ increases
- $\pi_{t}^{M}$ increases
- $\pi_{t}^{D}$ increases
- $\pi_{t}^{H}$ increases
- $\text{rer}_{t}$ increases
- $mc_{t}^{X}$ decreases
- $\pi_{t}^{X}$ decreases
- $y_{t}^{X,NC}$ increases
- $y_{t}$ decreases
- $c_{t}$ decreases
Figure: Interest Rate Shock Mechanism

1. **Real Interest Rate Channel**
   - $i_t$ rises
   - Consumption ($c_t$) falls
   - Output ($y_t$) falls
   - Labor ($l_t$) falls
   - Wages and prices ($w_p_t$) fall

2. **Financial Accelerator Channel**
   - $y_t^{M, NC}$ falls
   - Investment ($n_t$) falls
   - Interest rates ($r^K_t$) rise
   - Expected future interest rates ($E_t r^K_{t+1}$) rise

3. **Asset Price Channel**
   - Asset prices ($q_{t}^{NC}$) fall
   - Investment ($inv_{t}^{NC}$) falls
   - Capital ($k_{t}^{NC}$) falls

4. **Exchange Rate Channel**
   - $\Delta s_t$ rises
   - Real exchange rate ($rer_t$) rises
   - Capital exports ($mc_t^X$) rise
   - Capital imports ($\pi_t^X$) rise
   - Output ($y_t^{X, NC}$) falls

5. **Currency Market Channel**
   - Domestic currency ($\pi_t^D$) falls
   - Foreign currency ($\pi_t^H$) falls
Metal Price Index

This index is built taking into account the main 8 metals exported by the Peruvian economy: copper, gold, iron, lead, molybdenum, silver, tin and zinc.

1. Multiply each price of the metal exports by the United States deflator, to convert the units from current dollars to constant dollars.
2. Find the weights of the dollar exports of metal in the total amount of the 8-metal dollar export basket in each period.
3. Take the 1994-2013 sample average of each weight to have an index with constant weights.³
4. Find the 1-quarter growth rate for each of the metal price indices.
5. Find the weighted metal price index 1-quarter growth rate using the individual weights and individual price indices.
6. Set a metal price index with value of 100 in the first period considered in the sample.
7. Recover the rest of the metal price index series using the growth rate.

³ The years were chosen to match those used by Shousha (2016).
### Table: Estimated Parameters, Priors (1)

<table>
<thead>
<tr>
<th>Description</th>
<th>Distribution</th>
<th>Prior Mean</th>
<th>Prior Std. Dev.</th>
<th>Posterior Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$ Habit Formation</td>
<td>Beta</td>
<td>0.75</td>
<td>0.05</td>
<td>0.8741</td>
</tr>
<tr>
<td>$\eta$ Inverse of Labor Supply Elasticity</td>
<td>Inverse Gamma</td>
<td>2</td>
<td>0.5</td>
<td>1.2215</td>
</tr>
<tr>
<td>$\varepsilon_H$ Non-Commodity Elasticity of Substitution, Domestic and Imported Goods</td>
<td>Normal</td>
<td>0.75</td>
<td>0.2</td>
<td>1.1205</td>
</tr>
<tr>
<td>$\psi_K$ Non-Commodity Capital Adjustment Cost</td>
<td>Normal</td>
<td>3.3</td>
<td>0.1</td>
<td>3.2649</td>
</tr>
<tr>
<td>$\theta_{DC}$ Calvo Probability, Domestic Currency</td>
<td>Beta</td>
<td>0.75</td>
<td>0.05</td>
<td>0.7661</td>
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<tr>
<td>$\theta_X$ Calvo Probability, Exported Goods</td>
<td>Beta</td>
<td>0.75</td>
<td>0.05</td>
<td>0.6642</td>
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<tr>
<td>$\theta_M$ Calvo Probability, Imported Goods</td>
<td>Beta</td>
<td>0.75</td>
<td>0.05</td>
<td>0.7549</td>
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<tr>
<td>$\kappa_C$ Commodity Investment Adjustment Cost</td>
<td>Normal</td>
<td>0.5</td>
<td>0.1</td>
<td>0.6379</td>
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</table>
## Estimation

<table>
<thead>
<tr>
<th>Description</th>
<th>Distribution</th>
<th>Prior Mean</th>
<th>Prior Std. Dev.</th>
<th>Posterior Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_{PREF}$ Preference Shock Persistence</td>
<td>Beta</td>
<td>0.5</td>
<td>0.3</td>
<td>0.6071</td>
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<tr>
<td>$\rho_Z$ Technology Shock Persistence</td>
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<td>0.5</td>
<td>0.3</td>
<td>0.4086</td>
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<td>$\rho_{MON}$ Interest Rate Shock Persistence</td>
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<td>0.5</td>
<td>0.3</td>
<td>0.3433</td>
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<td>$\rho_{MUP}$ Domestic Mark-Up Shock Persistence</td>
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<td>0.5</td>
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<tr>
<td>$\rho_{UIP}$ UIP Condition Shock Persistence</td>
<td>Beta</td>
<td>0.5</td>
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<td>$\rho_{DP}$ Inflation Shock Persistence</td>
<td>Beta</td>
<td>0.5</td>
<td>0.3</td>
<td>0.7034</td>
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<tr>
<td>$\rho_{INV}$ Non-Commodity Private Investment Shock Persistence</td>
<td>Beta</td>
<td>0.5</td>
<td>0.3</td>
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<tr>
<td>$\rho_{ZC}$ Commodity Sector Technology Shock Persistence</td>
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<td>0.5</td>
<td>0.3</td>
<td>0.4264</td>
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<td>$\rho_{y^*}$ Foreign GDP Persistence</td>
<td>Beta</td>
<td>0.8983</td>
<td>0.01</td>
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<td>$\rho_{i^*}$ Foreign Interest Rate Persistence</td>
<td>Beta</td>
<td>0.9817</td>
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<td>$\rho_{\pi^*}$ Foreign Inflation Rate Persistence</td>
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</table>
## Estimation

Table: Estimated Standard Deviations, Priors

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<th>Related Shock</th>
<th>Distribution</th>
<th>Prior Mean</th>
<th>Prior Std. Dev.</th>
<th>Posterior Mode</th>
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<tr>
<td>$\sigma_{PREF}$</td>
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<tr>
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<tr>
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<td>Foreign Inflation Rate</td>
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<td>Commodity Prices</td>
<td>Inverse Gamma</td>
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## Estimation

**Table**: Measurement Equations Estimated Standard Deviations

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Prior Mean</th>
<th>Prior Std. Dev.</th>
<th>Posterior Mode</th>
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<td>$\sigma_{y^x,obs}$</td>
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<td>$\sigma_{y^m,obs}$</td>
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<td>$\sigma_{r^e,obs}$</td>
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<td>$\sigma_{y^*,obs}$</td>
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<td>$\sigma_{c,obs}$</td>
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<td>$\sigma_{inv,obs}$</td>
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</tr>
<tr>
<td>$\sigma_{\pi^*,obs}$</td>
<td>Inverse Gamma</td>
<td>0.01</td>
<td>0.01</td>
</tr>
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</table>
We assume a share $\delta^{PD}$ of the firms set their prices in dollars, while a share $(1 - \delta^{PD})$ does so in domestic currency.

The aggregate price level of goods produced in the home economy is

$$P^H_t = \left[(1 - \delta^{PD}) \left( P^{DC}_t \right)^\varepsilon + \delta^{PD} \left( S_t P^D_t \right)^{1-\varepsilon}\right]^\frac{1}{1-\varepsilon},$$

where $P^H_t$ is the aggregate price level of goods produced in the home economy expressed in terms of the domestic currency, $P^{DC}_t$ is the price level of goods produced in the home economy with prices set in domestic currency, $P^D_t$ is the price level of goods produced in the home economy with prices set in dollars, $S_t$ is the nominal exchange rate and $\varepsilon$ is the elasticity of substitution.

Having firms that set prices in different currencies also means there will be two different Philips Curves, one for each currency.

---

4 The nominal exchange rate is expressed as local currency for 1 dollar. This way, an increase in the nominal exchange rate means a local currency depreciation with respect to the dollar, while a decrease in the nominal exchange rate means a local currency appreciation with respect to the dollar.
Financial Dollarization

We define $\delta_{FD}$ as the part of the interests the entrepreneurs must pay that is indexed to the foreign interest rate.

This is equivalent to saying entrepreneurs have debt in both domestic currency and dollars.

With financial dollarization the arbitrage condition that determines the demand of (non-commodity sector related) stock of capital is

$$E_t \left[ R_{t+1}^K \right] = E_t \left\{ [1 + i_t]^{1 - \delta_{FD}} \left[ (1 + i_t^*) \frac{S_{t+1}}{S_t} \right]^{\delta_{FD}} \frac{P_t}{P_{t+1}} \right\}, \quad (14)$$

where $E_t \left[ R_{t+1}^K \right]$ is the return entrepreneurs expect to obtain for investing, $i_t$ is the nominal interest rate of the home economy, $i_t^*$ is the foreign interest rate and $P_t$ is the aggregate price level.
Endogenous Commodity Sector

- For this extension we follow Fornero, Kirchner and Yany (2016).
- We assume the existence of a commodity goods producing firm within the modelled small open economy.
- This firm spends in sector specific investment goods to accumulate its own sector specific stock of capital. This investment has domestic and foreign shares.
- The accumulation of capital by this firm faces capital adjustment costs and time to build.
- The firm produces its commodity goods using this specific type of capital and exports the total of its production.
- Commodity producing firm does not require labor inputs to produce.
- Firm sells its output to foreign sector, it has its accounting denominated in domestic currency.
- We further assume that foreigners hold a share of the ownership of the firm equal to \((1 - \chi)\).
The production function is

$$Y_t^C = Z_t^C \cdot F^C (K_{t-1}^C),$$

where $Y_t^C$ is the commodity production, $Z_t^C$ is the sector-specific productivity, $K_t^C$ is the specific capital this firm uses and $F^C(.)$ is the production function.

The cash flow of the firm is

$$CF_t^C = P_t^C \cdot Y_t^C - P_t^{INV^C} \cdot INV_t^C,$$

where $CF_t^C$ is the cash flow expressed in dollars, $P_t^C$ is the international price of the produced commodity good expressed in dollars, $P_t^{INV^C}$ is the price of the investment goods expressed in dollars and $INV_t^C$ is the investment of the firm.

For obtaining one new unit of investment, the firm must spend in investment projects $X_t^C$ for $n$ periods. This is the time to build mechanism and is represented by

$$INV_t^C = \sum_{j=0}^{n-1} \omega_j X_{t-j}^C,$$

where $\omega_j = 1/n$.

The accumulation of the sector specific stock of capital is

$$K_t^C = (1 - \delta_C) K_{t-1}^C + \left[ 1 - \Phi \left( X_{t-n+1}^C \right) \right] X_{t-n+1}^C,$$

where $\delta_C$ is the sector specific capital depreciation rate and $\Phi(.)$ is a capital adjustment cost function.
The first problem the commodity producing firm solves is the maximization of its cash flow by choosing optimal levels of current stock of capital and investment. The problem is

\[
\max_{K_t^C, X_t^C} E_t \left[ \sum_{i=0}^{\infty} \beta^i CF_{t+i}^C \right] = E_t \left[ \sum_{i=0}^{\infty} \beta^i \left( P_{t+i}^C Y_{t+i}^C - P_{t+i}^{INV}^C Inv_{t+i}^C \right) \right],
\]

subject to

\[
Y_t^C = F^C \left( K_{t-1}^C \right),
\]

\[
K_t^C = (1 - \delta_C) K_{t-1}^C + \left[ 1 - \Phi \left( X_{t-n+1}^C \right) \right] X_{t-n+1}^C,
\]

\[
Inv_t^C = \sum_{j=0}^{n-1} \omega_j X_{t-j}^C,
\]

where \( \beta \) is the discount rate.

The first order conditions are

\[
\frac{\partial L}{\partial K_t^C} = -\beta^t Q_t^C + \beta^{t+1} \left[ P_{t+1}^C A_{t+1}^C \frac{\partial F^C}{\partial K_t^C} \left( K_t^C \right) + (1 - \delta_C) Q_{t+1}^C \right] = 0, \quad (15)
\]

\[
\frac{\partial L}{\partial X_t^C} = -\beta^t P_t^{INV} \omega_0 - \ldots - \beta^{t+n-1} P_{t+n-1}^{INV} \omega_{n-1} + \beta^{t+n-1} Q_{t+n-1}^C \left[ 1 - \Phi \left( \frac{X_1^C}{X_C} \right) - \Phi' \left( \frac{X_t^C}{X_C} \right) \frac{X_t^C}{X_C} \right] = 0, \quad (16)
\]

where \( Q_t^C \) is the commodity sector Tobin’s Q expressed in dollars.
The two first order conditions determine the optimal paths for the investment projects and the commodity sector Tobin’s $Q$.

For the rest of the model we assume

\[ F^C \left( K^C_{t-1} \right) = \left( K^C_{t-1} \right)^{\alpha_C}, \]  

\[ \Phi \left( \frac{X^C_t}{X^C} \right) = \frac{\kappa_C}{2} \left( \frac{X^C_t}{X^C} - 1 \right)^2, \]  

where $\alpha_C$ is the parameter associated to the stock of capital within the commodity goods production function and $\kappa_C$ is the parameter related to the capital adjustment cost for the commodity producing sector.
Commodity Sector Investment Bundle

The commodity sector investment is divided among investment on domestic goods $INV_t^{C,H}$ and foreign goods $INV_t^{C,F}$. The firm must choose the optimal composition of its investment bundle by solving the problem:

$$\max_{INV_t^{C,H},INV_t^{C,F}} \quad INV_t^{C} = \left[ (1) \gamma_C \left( INV_t^{C,H} \right) \right] ^ {\eta_{INV} - 1} + \left[ (1 - \gamma_C) \left( INV_t^{C,F} \right) \right] ^ {\eta_{INV} - 1},$$

subject to

$$P_t^{INV^{C,H}} INV_t^{C} = P_t^{INV^{C,H}} INV_t^{C,H} + P_t^{INV^{C,F}} INV_t^{C,F}.$$

Where $P_t^{INV^{C,H}}$ is the price of the domestic investment goods and $P_t^{INV^{C,F}}$ is the price of the foreign investment goods.

- Both prices are expressed in domestic currency. $\gamma_C$ is the preference of the commodity sector for spending in domestic investment goods and $\eta_{INV}$ is the degree of substitutability between domestic and foreign investment goods.
- The prices are assumed to be similar to those the domestic economy faces such that

$$P_t^{INV^{C,H}} = P_t^{H}, \quad (19)$$

$$P_t^{INV^{C,F}} = P_t^{M}, \quad (20)$$

where $P_t^{M}$ is the imported goods price level.
The aggregate price index for sector specific investment goods expressed in dollars is

\[
(P_{t}^{\text{INV}C})^{1-\eta_{\text{INV}C}} = \left[ \gamma_{C} \left( P_{t}^{\text{INV}C,H} \right)^{1-\eta_{\text{INV}C}} + (1 - \gamma_{C}) \left( P_{t}^{\text{INV}C,F} \right)^{1-\eta_{\text{INV}C}} \right].
\]  \hspace{1cm} (21)

Multiplying by the nominal exchange rate to convert the price index to domestic currency and defining the price expressed in domestic currency of the commodity investment goods as \(P_{t}^{\text{CW}} = S_{t}P_{t}^{\text{INV}C}\) gives

\[
\left( S_{t}P_{t}^{\text{INV}C} \right)^{1-\eta_{\text{INV}C}} = \left( P_{t}^{\text{CW}} \right)^{1-\eta_{\text{INV}C}} = \left[ \gamma_{C} \left( P_{t}^{H} \right)^{1-\eta_{\text{INV}C}} + (1 - \gamma_{C}) \left( P_{t}^{M} \right)^{1-\eta_{\text{INV}C}} \right].
\]

The demand functions for the sector specific investment goods expressed in domestic currency are

\[
\begin{align*}
\text{INV}_{t}^{C,H} &= \gamma_{C} \left( \frac{P_{t}^{\text{INV}C}}{P_{t}^{\text{INV}C,H}} \right)^{\eta_{\text{INV}C}} \\
\text{INV}_{t}^{C} &= \gamma_{C} \left( \frac{S_{t}P_{t}^{\text{INV}C}}{P_{t}^{H}} \right)^{\eta_{\text{INV}C}} \\
\text{INV}_{t}^{C,F} &= (1 - \gamma_{C}) \left( \frac{P_{t}^{\text{INV}C}}{P_{t}^{\text{INV}C,F}} \right)^{\eta_{\text{INV}C}}
\end{align*}
\]  \hspace{1cm} (22)

\[
\begin{align*}
\text{INV}_{t}^{C,F} &= (1 - \gamma_{C}) \left( \frac{P_{t}^{\text{INV}C}}{P_{t}^{\text{INV}C,F}} \right)^{\eta_{\text{INV}C}} \\
\text{INV}_{t}^{C} &= (1 - \gamma_{C}) \left( \frac{S_{t}P_{t}^{\text{INV}C}}{P_{t}^{M}} \right)^{\eta_{\text{INV}C}}
\end{align*}
\]  \hspace{1cm} (23)
Foreign Ownership

- We assume foreigners own a share equal to \((1 - \chi)\) of the firm. Thus, the capital flow related to the firm is

\[
S_t B_t^*, C - (1 + i_{t-1}^*) \Psi_B \left( B_{t-1}^*, \frac{S_{t-1}^*}{P_{t-1}}, F_{t-1}^*, CB_t \right) S_{t-1} B_{t-1}^*, C = (1 - \chi) S_t CF_t,
\]

(24)

where \(B_t^*, C\) are the dollar-denominated asset holdings of the foreign owners in the domestic economy.

- This means part of the cash flow is considered as a liability for the domestic economy. \(\Psi_B (.\)\) is the cost the private sector of the economy assumes for handling foreign assets. It depends on the total holdings of foreign assets by the private sector \(B_t^*\) and also the foreign holdings of the public sector \(F_t^*, CB\), which we discuss in the following section. This function is increasing in the holdings, such that \(\Psi'_B (.\) > 0.\(^5\)

\(^5\) Also, \(\Psi_B (0) = 1.\)
FX Interventions

In the fashion of Benes, Berg, Portillo and Vavra (2015) and Faltermeier, Lama and Medina (2017) we consider a Central Bank that intervenes in the money market to minimize the volatility of the nominal exchange rate.

To do so the Central Bank increases its holdings of dollar-denominated international reserves when facing a nominal appreciation (i.e. in a real economy this would mean the Central Bank buys dollars from the market) and decreases its holdings of dollar-denominated international reserves when facing a nominal depreciation (i.e. in a real economy this would mean the Central Bank sells dollars to the market).

We assume the FX interventions are sterilized. In the case of a nominal appreciation, this means the monetary authority issues $\Delta D_t^{CB}$ units of Central Bank-backed bonds denominated in domestic currency in an amount equal to $S_t \Delta F_t^{CB}$.

Thus the amount of bonds in the economy does not change and the intervention only represents a recomposition of the bond holdings of the economy.
Sterilized Interventions

The balance sheet of the Central Bank is

\[ S_t F^*_t, CB - (1 + i^*_t) \Psi_F \left( F^*_t, CB \frac{S_{t-1}}{P_{t-1}} \right) S_t F^*_t, CB = D^*_t - (1 + i_{t-1}) D^*_{t-1}, \]

(25)

where \( F^*_t, CB \) are the international reserves denominated in dollars and \( \Psi_F (.) \) is the cost the Central Bank assumes for handling foreign assets. We have \( \Psi'_F (.) > 0 \). We also assume the international reserves earn an interest rate equal to the foreign interest rate, while the Central Bank-backed bonds denominated in domestic currency earn an interest rate equal to the domestic one.

The reaction function is

\[ \frac{F^*_t, CB}{F^*_{t-1}} = \left( \frac{F^*_t, CB}{F^*_{t-1}} \right)^{\rho_F} \left[ \frac{S_t - S_{t-1}}{S} \right]^{-\varphi_F} \]^{1-\rho_F} \]

\[ INT_t, \]

(26)

where \( \frac{S_t - S_{t-1}}{S} \) is the variation of the nominal exchange rate (also known as the depreciation rate), \( \varphi_F \) represents the magnitude of the reaction of the Central Bank upon nominal exchange rate variations, \( \rho_F \) is a persistence parameter for the international reserves and \( INT_t \) is an AR(1) process associated to the international reserves accumulation shock such that

\[ \ln \left( \frac{INT_t}{INT} \right) = \rho_{INT} \left( \frac{INT_{t-1}}{INT} \right) + \varepsilon^*_{t, INT}, \]

(27)

where \( \rho_{INT} \) is the persistence and \( \varepsilon^*_{t, INT} \) is the related shock. The variables without time subscripts denote steady state values.

---

6 Also, \( \Psi_F (0) = 1 \).
Affecting the Nominal Exchange Rate

Because the cost the private sector of the economy assumes for handling foreign assets $\Psi_B(.)$ now is affected by the spillovers of the foreign reserves policy, the UIP now becomes

$$
\frac{(1 + i_t)}{(1 + i^*_t)} = \frac{\Psi_B \left( B^*_{t-1} \frac{S_{t-1}}{P^*_t}, F^*_{t-1} \frac{CB S_{t-1}}{P^*_t} \right) E_t \left[ U_{C,t+1} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right]}{E_t \left[ U_{C,t+1} \frac{P_t}{P_{t+1}} \right]},
$$

(28)

where $U_{C,t}$ is the marginal utility of consumption. This shows how the nominal exchange rate variation is affected by the FX intervention.
Non-Ricardian Households

- We assume a share $\lambda_{NR}$ of the households are non-Ricardian.
- These households do not have access to financial markets nor can they spend on investment goods.
- They must consume all their income within the same period they receive it, without the possibility of saving for a future period.
Utility Maximization

- Non-Ricardian households solve the following maximization problem

$$\max_{C_{t}^{NR}, L_{t}^{NR}} \mathbb{E}_t \left[ \sum_{s=0}^{\infty} \beta^{t+s} U \left( C_{t+s}^{fam,NR}, L_{t+s}^{NR} \right) \right],$$

subject to

$$P_t C_{t}^{fam,NR} = W_t L_{t}^{NR},$$

where $C_{t}^{fam,NR}$ and $L_{t}^{NR}$ are the consumption and the labor supplied of the non-Ricardian households. Also, these households obtain a wage $W_t$ for their labor, which is the same wage Ricardian household receive.

- Assuming the same utility function from Castillo, Tuesta and Montoro (2009), the first order conditions of the non-Ricardian households are

$$U_{C,t}^{NR} = \text{pref}_t \left( C_{t}^{fam,NR} - h C_{t-1}^{fam,NR} \right)^{-1},$$

$$U_{L,t}^{NR} = \left( L_{t}^{NR} \right)^{\eta},$$

$$C_{t}^{fam,NR} = \frac{W_t}{P_t} L_{t}^{NR},$$

$$MRS_{t}^{NR} = -\frac{U_{L,t}^{NR}}{U_{C,t}^{NR}},$$

where $U_{C,t}^{NR}$ is the marginal utility of consumption, $U_{L,t}^{NR}$ is the marginal utility of labor and $MRS_{t}^{NR}$ is the marginal rate of substitution between consumption and labor, all related to the non-Ricardian households. $\text{pref}_t$ is a preferences shock, $h$ is a habit formation parameter and $\eta$ is the inverse of the labor supply elasticity.

- As Castillo, Montoro and Tuesta (2009), we assume the existence of frictions in the determination of the real wages represented by $\lambda_{WP}$, so they do not immediately adjust to changes in the marginal rate of substitution. This is expressed as
Given now the model has two types of households, in the in equilibrium their variables must be aggregated. The variables are aggregated as

\[ C_{fam}^t = \left( C_{fam, NR}^t \right)^{\lambda_{NR}} \left( C_{fam, R}^t \right)^{1-\lambda_{NR}}, \]  
\[ L_t = \left( L_{NR}^t \right)^{\lambda_{NR}} \left( L_R^t \right)^{1-\lambda_{NR}}, \]  
\[ U_{C,t} = \left( U_{NR}^{C,t} \right)^{\lambda_{NR}} \left( U_R^{C,t} \right)^{1-\lambda_{NR}}, \]  
\[ U_{L,t} = \left( U_{NR}^{L,t} \right)^{\lambda_{NR}} \left( U_R^{L,t} \right)^{1-\lambda_{NR}}, \]  
\[ MRS_t = \left( MRS_{NR}^t \right)^{\lambda_{NR}} \left( MRS_R^t \right)^{1-\lambda_{NR}}, \]

where the superscript \( R \) denotes Ricardian households.
Goods Market

- The exports made by the commodity producing firm \( Y_{t}^{C,X} \) are equal to its production such that
  \[ Y_{t}^{C,X} = Y_{t}^{C}. \]  
  (39)
- The imports of the commodity producing firm \( Y_{t}^{C,M} \) include the foreign investment goods it uses such that
  \[ Y_{t}^{C,M} = INV_{t}^{C,F}. \]  
  (40)
- With the commodity producing firm, the absorption of the domestic economy becomes
  \[ ABS_{t} = C_{t} + INV_{t} + G_{t} + \frac{P_{t}^{CW}}{P_{t}} INV_{t}^{C}, \]  
  (41)
  where \( ABS_{t} \) is the domestic absorption, \( C_{t} \) is the consumption, \( INV_{t} \) is the non-commodity investment and \( G_{t} \) is the public expenditure. All these variables are expressed in real terms.
- The nominal GDP is
  \[ P_{t}^{def} Y_{t} = P_{t} ABS_{t} + S_{t} P_{t}^{X} Y_{t}^{X} - P_{M}^{X} Y_{t}^{M} + S_{t} P_{t}^{C} Y_{t}^{C,X} - S_{t} P_{t}^{INV_{t}^{C,F}} Y_{t}^{C,M}, \]  
  (42)
  where \( P_{t}^{def} \) is the deflator, \( Y_{t} \) is the real GDP, \( P_{t}^{X} \) is the export price level denominated in domestic currency, \( P_{M}^{M} \) is the import price level denominated in domestic currency, \( Y_{t}^{X} \) are the non-commodity real exports and \( Y_{t}^{M} \) are the non-commodity real imports.
Asset Market

- The equilibrium for the domestic currency-denominated bond market is

\[ D_t = D_t^P + D_t^{CB} = B_t, \quad (43) \]

where \( D_t \) is the total supply of bonds denominated in domestic currency and \( B_t \) are the domestic currency-denominated bond holdings by the households.

- The equilibrium of the dollar-denominated bond market is

\[ B_t^* = B_t^{*,H} - B_t^{*,C}, \quad (44) \]

where \( B_t^{*,H} \) are the foreign bonds holdings by the households. We should notice the dollar-denominated asset holdings of the foreign owners in the domestic economy \( B_t^{*,C} \) enter the total with a negative sign because they are a liability for the domestic economy.
By aggregating the budget constraints and balance sheets of the households, firms, commodity producing firm and government we obtain the balance of payments equation, which is given by

\[
S_t B^*_t - S_t B^*_{t-1} + S_t F^*_{t-1} = S_t F^*_{t-1} = \frac{p_{t}}{P_{t-1}} Y_t - ABS_t + (1 + i^*_{t-1}) \Psi_B \left( B^*_{t-1}, F^*_{t-1}, S_{t-1}, P_{t-1} \right) S_{t-1} B^*_{t-1} \\
+ (1 + i^*_{t-1}) \Psi_F \left( F^*_{t-1}, S_{t-1}, P_{t-1} \right) S_{t-1} F^*_{t-1} - (1 - \chi) CF_t + REST_t
\]

(45)

where \( REST_t \) denotes the residual terms of the equation. The balance of payments is expressed in domestic currency.