Brazil Through the Eyes of CHORINHO

Fabio Kanczuk**

Abstract

CHORINHO, a medium scale DSGE model used in the financial sector to inform investment decisions, consists of a small open economy version of Smets and Wouters (2007) with a financial accelerator mechanism, adapted for estimation with Brazilian data. Marginal likelihood comparisons indicate that the model compares favorably to Bayesian Vector Autoregressions that use Sims and Zha (1998) priors. The model is used to

(i) identify the reasons behind recent deceleration episodes,
(ii) study the effects of currency depreciation, and
(iii) investigate whether monetary policy has recently become more powerful.

Keywords: DSGE, Emerging markets.

JEL Codes: E32, E52, F41.
1. Introduction

Suppose you are asked the question, “How much will inflation rise one year from now if the Central Bank raises the interest rate by 25bps?” And suppose your circumstance is such that you cannot avoid the question, take recourse to “it depends...” or offer multiple answers. No “buts” or excuses, you must reply with a single number. On the quality of your answer hangs not only reputation, but money. Future movements of the nominal and real interest rate curves will prove your answer wrong or right.

One approach to formulating an answer would be to estimate a simple Vector Autoregression (VAR), using, for example, data on GDP, exchange rate, inflation, and interest rate, and obtain the impulse response. The problem with this approach is that you do not know how to identify the VAR, on which you know the impulse response to depend. Resorting to a Cholesky identification, and assuming an arbitrary order for the variables, is one route to an, albeit fragile, answer. But you end up a victim of the Price Puzzle (Sims, 1992), obtain an absurd result, and the model collapses.

Abandoning the VAR, you decide to imitate the Central Bank structural model and estimate the simple set of New Keynesian equations. You succeed in the IS curve, which relates GDP to real interest rate, but fail in the Phillips curve. The output gap, obtained by HP filtering, is for some reason not a relevant factor with respect to explaining inflation.

Casting about for an alternative, you settle on the admittedly more complicated Dynamic Stochastic General Equilibrium (DSGE) models. DSGE models are, in fact, a structural VAR that use dynamic macroeconomic theory to provide the needed identification. Their data fitting is comparable to the best VARs available, and they provide reasonable answers to the questions practitioners are forced to answer.

I present in this paper CHORINHO, the DSGE model I have used during the past ten years to answer questions about the Brazilian economy. CHORINHO is not an anagram, but a reference to SAMBA, the Brazilian Central Bank DSGE model. CHORINHO (“little lament”) is also a Brazilian musical genre, less renowned, but more introspective, shrewd, and refined than SAMBA.

CHORINHO is a version of Smets and Wouters (2007) adapted to a small open economy. Preferences exhibit habit persistence, prices adjust sluggishly, and capital adjustment costs depend on lagged investments. I assume a fraction of the continent of consumption goods to be tradeables, the prices of which are determined by the real exchange rate and international commodity prices. A subset of these tradeable goods can be imported and exported, a decision influenced by, among other things, world output. I extend the model to add an explicit financial sector. As in Bernanke et al. (1999), investments are affected by a finance risk premium dependent on entrepreneurs’ leverage.

To take the model to Brazilian data, I conduct a Bayesian estimation. As
with Smets and Wouters (2007), the many frictions incorporated in the model guarantee a surprisingly good fit. Marginal likelihood comparisons indicate that the model compares favorably to Bayesian Vector Autoregressions that use Sims and Zha (1998) priors.

I use the model to extract the shocks that explain several episodes of growth deceleration. I find that

(i) the energy rationing crisis of 2001 is explained by a productivity drop,

(ii) the slowdown in 2003 was due to lagged effects of the exchange rate depreciation that occurred during the 2002 elections,

(iii) the U.S. subprime crisis of 2008 hit Brazil through the credit (financial) sector, and

(iv) the deceleration during Dilma’s mandate was again explained by a negative credit shock.

I then obtain the economic impacts of a hypothetical currency depreciation. According to CHORINHO, the contraction in investment more than offsets the improvement in net exports. Depreciation thus occasions less output growth. I calculate as well the exchange rate pass-through, and indicate how it depends on monetary policy.

Ultimately, I use CHORINHO to investigate the hypothesis that monetary policy has become more powerful over time, a common intuition derived from the enormous credit deepening observed in Brazil over the past decade. In fact, monetary policy effects on output have strengthened, and seem to be transmitted by the financial accelerator mechanism, yet the impact of monetary policy over inflation has decreased over time. Due to a Phillips curve flattening, the sacrifice ratio increased considerably, a phenomenon observed in many other economies.

The rest of the paper is organized as follows. In section 2, I describe the model, in section 3, discuss the estimation results. I identify the shocks behind recent crisis episodes in section 4, and examine the effects of a currency depreciation in section 5. In section 6, I offer conclusions about whether monetary policy has become more powerful.

2. Model

The economic environment is a small open economy version of the model developed by Smets and Wouters (2007) (hereafter SW), augmented to include financial sector frictions and a simple specification of external sector and fiscal policy. I focus on the peculiarities of the estimated model and present its linearized form. The reader is referred to the original paper for details.

The consumption good $c$ is assumed to be a composite good produced with a continuum of differentiated goods $c(i)$, aggregated in a constant elasticity of
substitution fashion as

\[ c = \left( \sum_i c(i)^{1-1/\sigma_i} \right)^{1/\sigma_c} \]

For any given level of consumption of the composite good, purchase of each variety of the differentiated good must solve the dual problem of minimizing expenditure \( p = \sum_i p(i)c(i) \) subject to the aggregation constraint.

From households' utility maximization, the consumption Euler equation implies

\[ c_t = \frac{\sigma_h}{1 + \sigma_h} c_{t-1} + \frac{1}{1 + \sigma_h} c_{t+1} + \frac{w^{steady}}{c^{steady}} (\sigma_c - 1) (l_t - l_{t+1}) - \frac{(1 - \sigma_h)}{\sigma_c (1 + \sigma_h)} (r_t - \pi_{t+1} + \varepsilon_t^b) \quad (1) \]

where \( c_t \) is aggregate consumption, \( l_t \) is labor, \( r_t \) is nominal interest rate, \( \pi_t \) is inflation, and \( \varepsilon_t \), because it affects the effective interest rate (for details and some micro-foundations, see Kanczuk, 2013), can be thought of a credit shock over households. The parameter \( \sigma_h \) measures habit persistency, \( \sigma_c \) governs intertemporal substitution elasticity, and \( w^{steady} \), \( l^{steady} \), and \( c^{steady} \) are steady state values of wage, labor, and consumption, respectively.

I assume a fraction \( (\theta_{int} + \theta_{comm}) \) of the differentiated goods to be tradeable and their prices to be exogenously determined. The fraction \( \theta_{int} \) corresponds to "typical" international goods, the international prices of which are determined by some international consumer price index. When expressed in domestic currency, the prices are equal to \( p_t e_t \), where \( p_t \) is the aggregate price level and \( e_t \) the real exchange rate. The fraction \( \theta_{comm} \) corresponds to commodities goods, the prices of which are governed by an international commodity price index. In domestic currency, the prices are equal to \( p_t c y_{t} \), where \( c y_t \) is the price of commodities (in dollars). The remaining \( (1 - \theta_{int} - \theta_{comm}) \) goods are produced by monopolistic firms.

A subset of these tradeable goods is imported. Euler equations imply that imports of (typical) consumption goods and commodity goods are proportional to \( [c_t - \sigma_c e_t] \) and \( [c_t - \sigma_i (e_t + c y_t)] \), respectively. But one must consider as well imports of investment goods, which are subject to an equivalent dual problem of expenditure minimization subject to the aggregation constraint. Taking into account these considerations, total imports \( m_t \) are given by

\[ m_t = \mu c_t + \mu_i l_t - \mu_c e_t - \mu c y c y_t + \varepsilon_t^m \quad (2) \]

Due to price stickiness, a mass \( \theta_{fix} \) of the monopolistic firms cannot optimize prices in each period, occasioning partial indexation. Prices thus adjust only sluggishly to their desired mark-up and, under the usual simplifying assumptions,
firms’ price setting optimization problem gives rise to the following New-Keynesian Phillips curve (see the appendix for details),

\[
\pi_t = \frac{1}{1 + \beta \theta_{\text{lag}}} \left[ \beta \pi_{t+1} + \theta_{\text{lag}} \pi_{t-1} + \theta_{mc} mc_t + \theta_{\epsilon} (\epsilon_t - \beta \epsilon_{t+1}) + \theta_{\text{cry}} (\text{cry}_t - \beta \text{cry}_{t+1}) \right] + \epsilon_t
\]  

where \( \pi_t \) denotes inflation, \( \epsilon_t \) is the real exchange rate, \( \text{cry}_t \) is a commodity price index (prices of the commodities in dollars), \( \beta \) is the intertemporal discount factor, \( \theta_{\text{lag}} \) is the partial indexation coefficient, \( mc_t \) is the real marginal cost of production, and \( \epsilon_t \) is a cost push shock.

The output of each differentiated good is produced using capital and labor services according to a Cobb-Douglas technology. To produce, firms rent capital and labor services from a centralized market that requires this factor of production to be readily reallocatable across industries. Because all firms face the same factor prices, and all have access to the same production technology with constant returns to scale, the capital-labor ratio and marginal cost are identical across firms, and given respectively by

\[
k_t + v_t = l_t + w_t
\]  

and

\[
mc_t = \alpha v_t + (1 - \alpha) w_t - \epsilon_a
\]  

where \( k_t \) denotes (aggregate) capital and \( l_t \) (aggregate) labor, and \( v_t \) is the capital marginal product, \( w_t \) the labor marginal product (wage rate), \( \epsilon_a \) the productivity, and \( \alpha \) the capital share parameter. Assuming distortions due to price dispersion to play a negligible role, aggregate production is given by

\[
y_t = \epsilon_a t + \alpha k_t + (1 - \alpha) l_t
\]  

Returning to the households’ problem, the Euler equation for labor implies

\[
w_t - \frac{1}{1 - \tau_{\text{steady}}} \tau_t = \sigma I_t + \frac{1}{1 - \sigma_h} c_t - \frac{\sigma_h}{1 - \sigma_h} c_{t-1}
\]  

where \( \tau_t \) is the tax rate over labor. I assume taxes are levied on the households, both on labor and capital, at the same rate.

To specify the dynamics of investments, I follow De Graeve (2008) in using the financial accelerator formulation of Bernanke et al. (1999) to append financial frictions to the model. As in these models, the capital adjustment cost depends on the flow of investment, and the investment Euler equation is given by

\[
i_t = \frac{1}{1 + \beta} i_{t-1} + \frac{\beta}{1 + \beta} i_{t+1} + \frac{1}{(1 + \beta) \varphi} q_t
\]
where $i_t$ denotes investment, $\varphi$ is a capital adjustment cost parameter, and $q_t$ is the price of capital. The capital law formation is given by

$$k_{t+1} = (1 - \delta) k_t + \delta i_t$$  \hspace{1cm} (9)$$

where $\delta$ denotes the depreciation rate. As in Bernanke et al. (1999), there is an entrepreneurial sector that buys capital at price $q_t$ and uses it in production in the following period, receives the proceeds (the marginal product of capital) from operating the capital, and resells at price $q_{t+1}$. The capital arbitrage equation that describes the entrepreneur problem is given by

$$r_{t+1}^k = \frac{1 - \delta}{r_{k, steady}^k + 1 - \delta} q_{t+1} + \frac{1 - r_{k, steady}^k}{r_{k, steady}^k + 1 - \delta} \left[ \psi_{t+1} - \frac{1}{1 - \tau_{steady} \tau_{t+1}} \right] - q_t$$ \hspace{1cm} (10)$$

where $r^k$ denotes return to capital and $r_{k, steady}^k$ is its steady state value. In each period, entrepreneurs have net worth given by $n_t$, which they use to partly finance their capital expenditures. The existence of a costly state verification problem between them and the financial intermediaries gives rise to an external finance premium, a wedge between the expected return of capital and expected return demanded by households $\psi_t$, given by

$$\psi_t = r_{t+1}^k - (r_t - \pi_t)$$ \hspace{1cm} (11)$$

The presence of financial frictions implies that the size of this premium is positively related to the entrepreneur’s leverage,

$$\psi_t = -\chi_s (n_t - q_t - k_t)$$ \hspace{1cm} (12)$$

where $\chi_s$ is a coefficient that measures the elasticity of the premium to leverage. The evolution of the entrepreneurs’ net worth is given by

$$n_t = \frac{k_{steady}^k}{n_{steady}^k} \left( \frac{k_{steady}^k - 1}{n_{steady}^k} \right) \left( \psi_{t-1} + \pi_{t-1} - r_t \right) + \chi_n n_{t-1} - \varepsilon_n$$ \hspace{1cm} (13)$$

where $\chi_n$ is the survivorship rate and $\varepsilon_n$ a financial sector shock.

Firms sell a portion of the goods abroad. By symmetry, the demand for the home country’s exports is given by the imports of the other countries. As a consequence, exports $x_t$ are given by

$$x_t = \kappa_{world} world_t + \kappa_e e_t + \kappa_{cry} cry_t + \varepsilon_x^t$$ \hspace{1cm} (14)$$

where $\kappa_1$, $\kappa_2$, and $\kappa_3$ are determined by steady states and consumption shares of the importer country consumers and commodity content of the home good output, $world_t$ is a measure of the importers’ output, and $\varepsilon_x$ is a shock.
Government chooses nominal interest rate \( r_t \) according to a Taylor rule,

\[
    r_t = \gamma_r r_{t-1} + \gamma_\pi \pi_t + \gamma_{expect} \pi_{t+1} + \gamma_y y_t + \varepsilon^r_t
\]  

(15)

where \( \gamma \)'s are parameters and \( \varepsilon^r \) is a monetary shock. Government budget constraint determines the amount of transfers \( T_t \), as a fraction of output, according to

\[
    T_t = \tau_t - s_t - g^{steady} (g_t - y_t)
\]  

(16)

where \( s_t \) is government primary surplus expressed as a fraction of output and \( g_t \) government spending. The standard goods market equilibrium condition is

\[
    y_t = c^{steady} c_t + i^{steady} i_t + x^{steady} x_t - m^{steady} m_t + g^{steady} g_t
\]  

(17)

where entrepreneurs’ consumption is implicitly assumed to be negligible. To close the model, I specify the stochastic processes of the exogenous disturbances as:

\[
    \epsilon^b_{t+1} = \rho_b \epsilon^b_t + \xi_{t+1}^b
\]  

(18)

\[
    \epsilon^a_{t+1} = \rho_a \epsilon^a_t + \xi_{t+1}^a
\]  

(19)

\[
    \epsilon^g_{t+1} = \rho_g \epsilon^g_t + \xi_{t+1}^g
\]  

(20)

\[
    \epsilon^r_{t+1} = \rho_r \epsilon^r_t + \xi_{t+1}^r
\]  

(21)

\[
    \epsilon^\pi_{t+1} = \rho_1 \epsilon^\pi_t + \xi_{t+1}^\pi - \rho_2 \epsilon^\pi_{t+1}
\]  

(22)

\[
    \epsilon^n_{t+1} = \rho_n \epsilon^n_t + \xi_{t+1}^n
\]  

(23)

\[
    \epsilon^e_{t+1} = \rho_e \epsilon^e_t + \xi_{t+1}^e
\]  

(24)

\[
    \epsilon^m_{t+1} = \rho_m \epsilon^m_t + \xi_{t+1}^m
\]  

(25)

\[
    \epsilon^{cry}_{t+1} = \rho^{cry} \epsilon^{cry} t + \xi_{t+1}^{cry}
\]  

(26)

\[
    \epsilon^{world}_{t+1} = \rho^{world} \epsilon^{world} t + \xi_{t+1}^{world}
\]  

(27)

\[
    \tau_{t+1} = \rho_\tau \tau_t + \xi_{t+1}^\tau
\]  

(29)

\[
    s_{t+1} = \rho_s s_t + \xi_{t+1}^s
\]  

(30)

where all \( \xi \) are i.i.d. normal error terms with zero mean and well defined variances. Note that all but two are simple autoregressive processes. For the cost push, as in SW, I add a moving average component, and for the exchange rate add a term that captures the effect of the commodity price disturbances, a stylized fact that is well documented (e.g., Rogoff et al., 2008). I tried many other specifications of shocks, among them, postulating commodity prices to be a function of world GDP, government expenditures to depend on productivity, and productivity to depend on world output. All turned out to have a poor fit.

A more substantive point, implicit in the shocks specification, concerns the exogenous process for the real exchange rate. In small open economy models,
which typically have an international debt level equation and are “closed” using an assumption such as an international interest rate elastic to debt (see Schmitt-Grohe and Uribe, 2003), the real exchange rate can be exogenously determined through an interest parity condition. Our model directly specifies the exchange rate as an exogenous variable, a modeling choice that reflects the fact that the interest parity condition is known to perform poorly in determining exchange rate.

3. Estimation

I use quarterly data from 1999:2 to 2013:4 obtained from the Brazilian Central Bank (bcb.gov.br) and Brazilian Institute of Geography and Statistics (ibge.gov.br), from which detailed information is available. I restrict the dataset to this period because the Brazilian exchange rate devaluated sharply at the beginning of 1999 due to a balance of payment crisis. In the wake of this episode, Brazilian macroeconomic policies became reasonably stable and followed an Inflation Targeting regime, making the estimation more reliable (as quarterly data is available only after 1996, this assumption entails no important loss of information).

I estimate the model using 14 series: Output, Consumption, Investment, Employment, Overnight Interest Rates (Selic), Inflation (IPCA), Exports, Imports, Real Exchange Rate (calculated using the Brazilian and U.S. CPIs), cry (from Bloomberg), Inflation Expectations, Government primary surplus, Government revenues, and U.S. GDP (which plays the role of “world”).

Relative to SW, differences in data availability call for some adaptation of the estimation. There being, for example, no series on hours worked in Brazil, I use employment data, relating hours worked to employment by means of the equation

\[ l_t = \sigma_{employ}employment \]

where \( \sigma_{employ} \) is a parameter to be estimated. Similarly, because Brazilian data on wages covers only the post-2004 period and seems extremely volatile, I opted not to use it, as a consequence of which I find that it is not necessary to assume wage stickiness to improve fit. I also find choice of capital utilization to not be an important device for improving model fit, a result already obtained by SW, and because Brazil lacks data on durables consumption, and I cannot follow the procedure of adding those to the investment series, I instead postulate the observed consumption to be a weighted average of durables and nondurables, the latter to be proxied by investments. In practice, I posit the observed consumption series to be given by

\[ c_t^{\text{observable}} = (1 - \sigma_{durable}) c_t + \sigma_{durable} i_t \]

where \( \sigma_{durable} \) is a parameter to be estimated. Because Brazil does have very good data on inflation expectations (collected by the Central Bank, “Focus”), I use it in place of \( \pi_{t+1} \) whenever it appears in the model equations. I add for these
expectations and their disturbance the following respective equations,

\[ \pi^\text{expect}_t = \theta_{\text{backward}} \pi_t + \theta_{\text{forward}} \pi_{t+1} + \varepsilon^\text{exp}_t \]  
and  
\[ \varepsilon_{t+1} = \rho \pi^\text{exp}_t + \delta_{t+1} \]  

Not surprisingly, I find this specification choice to improve the estimation.

Six of the estimation parameters are fixed because they are either difficult to estimate with available data or unidentified. The depreciation rate is fixed at \( \delta = 0.025 \), the GDP ratio that corresponds to government expenditures, and exports and imports are set to \( g_{\text{steady}} = 0.20 \), \( x_{\text{steady}} = 0.14 \), and \( m_{\text{steady}} = 0.13 \), based on the averages of the corresponding data. The leverage and entrepreneur survivor rate are set at \( k_{\text{steady}}/n_{\text{steady}} = 1.2 \) and \( \chi_s = 0.99 \). The definition of the priors and results of the estimation for the main parameters are reported in Table 1.

Table 1
Estimation Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Mean</th>
<th>Posterior Mean</th>
<th>Confidence Interval</th>
<th>Prior Shape</th>
<th>Prior S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_c )</td>
<td>1.5</td>
<td>.92</td>
<td>.82</td>
<td>1.05</td>
<td>Normal</td>
</tr>
<tr>
<td>( \sigma_h )</td>
<td>0.7</td>
<td>0.76</td>
<td>0.65</td>
<td>0.88</td>
<td>Beta</td>
</tr>
<tr>
<td>( \sigma_d )</td>
<td>2.0</td>
<td>1.1</td>
<td>0.9</td>
<td>2.0</td>
<td>Normal</td>
</tr>
<tr>
<td>( \sigma_{\text{durable}} )</td>
<td>0.2</td>
<td>0.05</td>
<td>-0.4</td>
<td>0.14</td>
<td>Normal</td>
</tr>
<tr>
<td>( \sigma_{\text{employ}} )</td>
<td>1.5</td>
<td>2.6</td>
<td>2.1</td>
<td>3.1</td>
<td>Normal</td>
</tr>
<tr>
<td>( 100/(1/\beta - 1) )</td>
<td>0.25</td>
<td>0.25</td>
<td>0.10</td>
<td>0.40</td>
<td>Gamma</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.30</td>
<td>0.29</td>
<td>0.23</td>
<td>0.35</td>
<td>Normal</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>4.0</td>
<td>3.6</td>
<td>1.9</td>
<td>4.9</td>
<td>Normal</td>
</tr>
<tr>
<td>( \theta_{\text{lag}} )</td>
<td>0.50</td>
<td>0.71</td>
<td>0.55</td>
<td>0.88</td>
<td>Beta</td>
</tr>
<tr>
<td>( \theta_{\text{mc}} )</td>
<td>0.10</td>
<td>0.015</td>
<td>0.004</td>
<td>0.027</td>
<td>Normal</td>
</tr>
<tr>
<td>( \theta_{\text{e}} )</td>
<td>0.10</td>
<td>0.054</td>
<td>0.033</td>
<td>0.074</td>
<td>Normal</td>
</tr>
<tr>
<td>( \theta_{\text{cry}} )</td>
<td>0.10</td>
<td>0.054</td>
<td>0.033</td>
<td>0.085</td>
<td>Normal</td>
</tr>
<tr>
<td>( \theta_{\text{employ}} )</td>
<td>0.10</td>
<td>0.14</td>
<td>0.10</td>
<td>0.19</td>
<td>Normal</td>
</tr>
<tr>
<td>( \theta_{\text{forward}} )</td>
<td>0.10</td>
<td>0.14</td>
<td>0.03</td>
<td>0.26</td>
<td>Normal</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0.10</td>
<td>0.34</td>
<td>0.13</td>
<td>0.54</td>
<td>Normal</td>
</tr>
<tr>
<td>( \mu_i )</td>
<td>0.10</td>
<td>0.80</td>
<td>0.65</td>
<td>0.98</td>
<td>Normal</td>
</tr>
<tr>
<td>( \mu_e )</td>
<td>0.10</td>
<td>0.17</td>
<td>0.08</td>
<td>0.27</td>
<td>Normal</td>
</tr>
<tr>
<td>( \kappa_{\text{world}} )</td>
<td>1.0</td>
<td>1.4</td>
<td>0.8</td>
<td>1.9</td>
<td>Normal</td>
</tr>
<tr>
<td>( \kappa_e )</td>
<td>0.10</td>
<td>0.10</td>
<td>0.01</td>
<td>0.18</td>
<td>Normal</td>
</tr>
<tr>
<td>( \kappa_{\text{cry}} )</td>
<td>0.10</td>
<td>0.24</td>
<td>0.12</td>
<td>0.35</td>
<td>Normal</td>
</tr>
<tr>
<td>( \gamma_r )</td>
<td>0.75</td>
<td>0.79</td>
<td>0.67</td>
<td>0.89</td>
<td>Beta</td>
</tr>
<tr>
<td>( \gamma_\pi )</td>
<td>1.50</td>
<td>0.77</td>
<td>0.10</td>
<td>1.22</td>
<td>Normal</td>
</tr>
<tr>
<td>( \gamma_{\text{exp}} )</td>
<td>5.0</td>
<td>3.3</td>
<td>1.4</td>
<td>5.2</td>
<td>Normal</td>
</tr>
<tr>
<td>( \gamma_y )</td>
<td>0.125</td>
<td>0.15</td>
<td>0.07</td>
<td>0.22</td>
<td>Normal</td>
</tr>
</tbody>
</table>
In order to evaluate CHORINHO performance I compare the marginal likelihood of CHORINHO with those of BVARs which uses the Sims and Zha (1998) priors, estimated with the same 14 variables over the full sample. I refrain from performing the traditional out-of-sample forecast comparison as, given the small data size, it leads to fairly arbitrary results. More importantly, as Schorfheide and Wolpin (2012) show, from a Bayesian perspective, the use of holdout samples is suboptimal. The marginal likelihood embodies a measure of recursive out-of-sample fit, which pertains to the entire sample, and automatically penalizes over-fitting.

Notice, from Table 2, that the BVAR with 6 lags performs slightly better than the other BVARs, but that its marginal likelihood is substantially greater than CHORINHO’s. The results thus suggest that CHORINHO’s prediction performance compares favorably with that of BVARs.

### Table 2

<table>
<thead>
<tr>
<th>Order of BVAR</th>
<th>Marginal Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVAR(1)</td>
<td>−2136.5</td>
</tr>
<tr>
<td>BVAR(2)</td>
<td>−1915.7</td>
</tr>
<tr>
<td>BVAR(3)</td>
<td>−1646.5</td>
</tr>
<tr>
<td>BVAR(4)</td>
<td>−1586.1</td>
</tr>
<tr>
<td>BVAR(5)</td>
<td>−1585.3</td>
</tr>
<tr>
<td>BVAR(6)</td>
<td>−1583.3</td>
</tr>
<tr>
<td>BVAR(7)</td>
<td>−1585.7</td>
</tr>
<tr>
<td>BVAR(8)</td>
<td>−1586.0</td>
</tr>
<tr>
<td>CHORINHO</td>
<td>−1481.7</td>
</tr>
</tbody>
</table>

### 4. Identifying Crisis Episodes

I use the model to extract, by calculating the output when only one of the estimated shocks is present, the determinants of the five Brazilian crises that occurred over the course of the past decade. The twelve shocks in CHORINHO appear in equations (17) to (27) and (29), and are related to disturbances that occur in

(i) households’ credit,

(ii) technology (Solow residual),

(iii) government expenditure,

(iv) monetary policy (departure from Taylor rule),
(v) inflation (cost-push),
(vi) firms’ credit (net worth),
(vii) exports,
(viii) imports,
(ix) exchange rate,
(x) commodities,
(xi) world economy (U.S. GDP),
(xii) inflation expectations,
(xiii) surplus, and
(xiv) taxes.

Figure 1 displays Brazilian GDP growth, calculated as quarter over same quarter of the previous year. Over the horizon studied, Brazilian GDP had five important drops. I associate each episode with its causes, and report the shocks that were most important according to the model.

![Figure 1](image_url)

Crisis Episodes
The first episode, from 2000:Q4 to 2001:Q4 is readily associated with the electrical energy rationing that occurred during the second half of 2001. Lack of water in the hydroelectric reservoirs found households and firms restricted in the use of energy or heavily taxed. According to the model, about 2% of the 3% GDP drop during that period was due to a productivity shock, that is, 65% of what happened can be explained by productivity. This is somewhat comforting, lack of energy being, in fact, akin to a productivity drop.

The second episode is also readily associated with an historical fact. During 2002, investors considered the possibility that Lula, the Workers’ Party candidate who had once argued in favor of defaulting on the external debt, would win the presidential election. When this scenario became most likely (at the beginning of August), fear of default dominated the markets and the exchange rate depreciated by about 60%. Interestingly, GDP dropped only later, during the first half of 2003, when the exchange rate was already appreciating and returning to its previous value. According to the model, 75% of the 2.7% decline in GDP was due to an exchange rate shock. Depreciation of the exchange rate boosts inflation and expectations thereof, in response to which the Central Bank elevates interest rates, all of which has the collateral effect of causing a contraction in GDP. This process takes time, which explains why the effects of the depreciation peak with a lag of four quarters.

The third episode, in 2005, can be associated with an extraordinary monetary tightening in the sense that interest rates were much higher than dictated by the estimated Taylor rule. At the time, Central Bank Director Bevilaqua decided to “break the spine of inflation” by raising the Selic rate to 19.75%, which reduced twelve month inflation from 8% to 3%. CHORINHO suggests that 100% of the 1.7% GDP drop can be fully attributed to a monetary shock.

The 7.4% GDP drop in the fourth episode, the subprime crisis, was larger and more acute than the drops observed in the other episodes. According to the model, 42% of it was due to a credit shock that hit firms. Also relevant were drops in exports, which accounted for 15% of the total drop. CHORINHO suggests, however, that the transmission mechanism of the crisis was more finance than trade, and thus corroborates Eaton at al.’s (2011) discussion of the great recession.

That CHORINHO’s identification of these four episodes largely coincides with the results of other models (Kanczuk, 2013) is comforting, but perhaps makes the findings less interesting. The final and most recent episode of deceleration, discussed below, has to my knowledge not been the object of formal investigation thus far.

The Brazilian economy suffered a fairly large and protracted deceleration from the middle of 2010 to the middle of 2012, the reasons for which are still very much a topic of debate. Many alternative explanations have been advanced, among them,

(i) Dilma’s micro-management of economic policy (i.e., subsidies and taxes to
help particular firms and sectors, manipulation of prices to control inflation, etc.),

(ii) the end of the commodity boom, and

(iii) a reduction in labor supply, as evidenced by the reduction in unemployment.

Figure 2 depicts the decomposition of the output fluctuation, that is, which shocks caused the observed output level. Output level being reported as the deviation from the HP filter trend, it corresponds to the high frequency (or real business cycle) component of the series. According to CHORINHO, the main factors behind this crisis are related to households’ credit and firms’ credit. Monetary policy stands out as the factor in the other direction; growth would be much worse without the monetary stimulus.

Productivity and commodities, the usual suspects implicated in growth deceleration, turn out to be almost irrelevant during this period. The other suspect, reduction of the labor force, is a low frequency phenomenon that should disappear once data is filtered.

This surprising result warrants further investigation. Validating the conclusions by looking at credit information, as in Kanczuk (2013), would not be an
easy task because information began to be artificially affected by government policy as private banks were forced to reduce spreads. Data on the volume of credit tends to be greatly lagging with respect to GDP, and suffered a recent methodology break. A quick look suggests that, whereas total credit performed reasonably well, credit provided by privately owned banks collapsed during this period. But it is not obvious why one type of credit should be much more relevant than the other. I leave it to further research to shed more light on why Brazil suffered such strong deceleration during Dilma’s Government.

5. Effects of a Currency Depreciation

The impact of the exchange rate on the Brazilian economy is often a source of heated debate among government officials, industry representatives, and market economists. Currency depreciation is argued to be good for the economy because it helps to increase exports and decrease imports. This simple trade argument often underlies the “currency war” discussion and need to protect national industry. Many economists counter that because the Brazilian production system is heavily based on imported machinery, depreciation may be bad for growth. The argument that currency depreciation makes machinery expensive, which ends up reducing investments, is commonly known as the Pastore effect (after economist Affonso Celso Pastore).

Another debate related to currency depreciation concerns its effects on inflation and interest rates, in financial market and Central Bank parlance, the “pass-through” and “appropriate monetary response to avoid second order inflation effects.” Understanding the impacts of depreciation better than the rest of the market is the basis for the design of profitable trading strategies.

In this section, I use CHORINHO to evaluate these arguments. I examine in particular the impulse response of a currency depreciation over many macro variables, and attempt to quantitatively evaluate the merits of the arguments. I mention as a caveat that, as noted above, the use of an exogenous stochastic process to determine the nominal exchange rate in CHORINHO precludes an interpretation of what caused the depreciation.

Figure 3 shows the impact of a 10% currency depreciation over several macro variables. Note that, as expected, exports react positively and imports negatively to the currency depreciation. Thus, the trade argument, usually advanced by FIESP (an industry association), potentially has some validity.

Depreciation also, however, affects the price of capital and reduces investment, but for reasons different from those proposed by Pastore. In CHORINHO, depreciation creates inflation, which calls for higher interest rates. This, in turn, reduces the price of capital, which is why investment falls.
According to CHORINHO, the drop in investment more than offsets the gain in net exports, and the total effect of depreciation on output is negative; 10% depreciation reduces output by about 0.3%. In this sense, in this model, depreciation is bad for the economy.

I next use CHORINHO to calculate the exchange rate pass-through on inflation. Figures 4a and 4b show the impact of 10% depreciation on interest (Selic) and inflation (IPCA). In figure 3b, I used instead of the estimated CHORINHO a model in which the Taylor rule is arbitrarily calibrated. That is, figure 3b corresponds to a model in which all equations are exactly equal to CHORINHO equations, save (15), the parameters of which are exogenously chosen and equal to $\gamma_\pi = 1.5$ and $\gamma_r = \gamma_{expect} = \gamma_y = 0$.

The rationale for this experiment is to show pass-through to be heavily dependent on Central Bank policy, a reincarnation of the infamous Lucas Critique. In other words, pass-through is not a “deep parameter” and cannot really be estimated. In figure 3a, in which the Central Bank reacts to the depreciation by raising Selic by about 100bps, the “pass-through” is about 8% (i.e., inflation goes up by 0.8%). Were the Central Bank to react differently, say, by raising the Selic by 55bps, the “pass-through” would become 10%.
Figure 4a
Pass-through and Monetary Policy
Figure 4b
Pass-through with Alternative Taylor Rule
A curious point about figure 4b is that the real interest rate is always negative and inflation nevertheless converges to zero. This apparent contradiction is possible because the model was solved by assuming that the Central Bank reacts aggressively to inflation (the inflation coefficient in the Taylor rule is greater than 1). Thus, insofar as the Central Bank’s reaction is deemed sufficiently tough, agents’ inflation expectations will bring inflation back to the equilibrium regardless of the actual real interest rate.

6. Changes in Monetary Policy Power

That credit as a percentage of GDP grew from 24.7% to 55.2% from 2003 to 2013 is perhaps the most important transformation in the Brazilian economy during the past decade. Little is known about the macroeconomic impact of this change, but it is reasonable to suppose that it has quantitatively affected the transmission mechanism of many shocks. In particular, it is often argued that it affected the power of monetary policy.

I use CHORINHO to investigate this claim, using exactly the same specification as before, but estimating the model using only a subset of the data consisting of the first half of the horizon. That is, I estimate the model using only data from 1999:3 to 2006:3 and contrast the results with the previous results.

Note that I do not propose using the estimation exclusively of the latter part of the sample (from 2006 to 2013). This is because, after many attempts, I found this estimation to be extremely problematic. It usually resulted in the non-convergence of the computational procedures or in solutions that did not correspond to the maximum of the likelihood function. A possible reason for this was the intensity of the great recession, which dominated the years 2008 to 2009, generating extreme outcomes. The difficulty of estimating the model over short periods of time is a reason to view the results with some skepticism.

Figures 5a to 5e show the impact of raising the nominal interest rate (Selic) by 100bps during one year. Each figure plots two curves obtained by the model, the blue estimated with the full sample, the red with the first part of the sample.

Figure 5a shows GDP level. Note that, as argued, the output impact of monetary policy became more powerful over time. Figure 5b, however, which depicts inflation, indicates that this additional power was not relevant where it really matters. That is, monetary policy became more destructive to growth, but its power to affect inflation, its main objective, diminished.
Before investigating further what is behind this result, it is useful to obtain the sacrifice ratio implied by figures 5a and 5b. For that I calculate the ratio of total output lost in the period consequent to the reduction in inflation. I find the sacrifice ratio of monetary policy in the first years to be 0.8, and when the entire sample is used to be much higher at 2.8. These numbers can be compared to their international counterparts, found by Ball (1994) to range from 0 to 3.6, with an average of 1.4. Thus, notwithstanding significant changes over time, the Brazilian numbers seem reasonably within range.

One hypothesis for the increase in the sacrifice ratio is that over time the Central Bank became more complacent with inflation. As inflation expectations are affected by Central Bank policy, and inflation is affected by inflation expectations, this would reduce the impact of an economic contraction on inflation. However, according to CHORINHO the Taylor rule parameters did not change materially over time. In other words, my estimation does not suggest that Central Bank policy changed, at least with respect to the mean. (It is possible that the mean inflation target changed, but that does not affect the estimation.)

The right answer, however, is that the Phillips (equation (3)) became flatter, the output gap parameter $\theta_{mc}$ estimation mode changing from 0.038 to 0.016. Interestingly, this phenomenon seems to be happening in many countries (see International Monetary Fund (2013) and references therein).

With respect to the effect of monetary policy on growth, figures 5c and 5d report the impact of higher interest rates on consumption and investment. Note that, whereas consumption is little affected, investment suffers a large drop when the full sample is used in the estimation. This indicates that the change did not happen in the “dynamic IS curve” (equation (1)), but somewhere in the credit transmission to firms (equation (8)).

When I investigate where the change was within the credit transmission channel, I find no specific reason that stands out. Different estimation samples imply small changes in most of the parameters in equations (8), (10), (11), (12), and (13), but nothing in particular that commands attention. It seems that the accumulation of many small changes throughout the financial accelerator mechanism exerts a large total effect on investments. As one example, in figure 5e I depict the impact on the price of capital $q_t$, which has been fairly large in recent years.
7. Conclusions

I look at the Brazilian economy cycles since 1999 through the lens of CHORINHO, a DSGE model constructed and estimated for Brazil. The model is used to provide insight to the following questions:

(1) What caused a particular deceleration?

(2) What is the inflation pass-through of the exchange rate?

(3) How effective is monetary policy?

CHORINHO, in fact, provides some quantitative answers to these questions. But perhaps more interesting than the answers are the methodology and rigor behind them. The use of DSGE forces one to think in terms of exogenous shocks and endogenous responses, and thus to ask sensible questions. It helps us identify the deep parameter and not be fooled by supposed ones that are, in fact, vulnerable to the Lucas critique. And it provides a methodology for testing quantitative hypotheses.

References


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A. Appendix: Modified Phillips Curve

The Phillips Curve equation blends firms’ price setting equations with an aggregate price equation. In the economy, firms’ price setting equations are standard, but the aggregate price equation is transformed to include indexation, international prices, and commodities. To clarify, let us consider first the case with neither indexation nor commodities. In this situation, the linearized equation for the aggregate price level is

\[ p_t = \theta_{index} p_{t-1} + \theta_{int} (p_{int}^t + E_t) + (1 - \theta_{index} - \theta_{int}) p_*^t \]

where the fraction \( \theta_{index} \) of prices cannot be changed in the period, the fraction \( \theta_{int} \) of prices is linked to international prices, and \( p \) denotes the aggregate price, which is an average of

(i) the previous period prices (those that cannot be changed in the present period),

(ii) the international prices \( p_{int}^t \) expressed in local currency using the nominal exchange rate \( E_t \), and

(iii) the prices that change during the present period \( p_*^t \).

Note that this equation substitutes for the more usual, closed economy equation, \( p_t = \theta_{index} p_{t-1} + (1 - \theta_{index}) p_*^t \). Plugging in the definition of real exchange rate, \( e_t \), which is given by \( p_{int}^t + E_t = p_t + e_t \), the equation can be transformed to

\[ \pi_t = (1 - \theta_{index} - \theta_{int}) (p_*^t - p_{t-1}) + \theta_{int} e_t \]

As noted above, firms’ price setting equations are standard, and given by

\[ p_*^t - p_{t-1} = (1 - \beta \theta_{index}) mc_t + \pi_t + \beta \theta_{index} (p_{t+1}^* - p_{t}) \]

where \( \pi \) denotes inflation and \( mc \) the marginal cost. One obtains from these two equations the following Phillips curve:

\[ \pi_t = \frac{\theta_{int}}{\theta_{fix} + \theta_{int}} (e_t - \beta e_{t+1}) + \frac{\beta \theta_{fix}}{\theta_{fix} + \theta_{int}} \pi_{t+1} + (1 - \beta \theta_{fix})(1 - \theta_{fix} - \theta_{int}) mc_t \]

To include commodities, the aggregate price equation is generalized to

\[ p_t = \theta_{index} p_{t-1} + \theta_{int} (p_{int}^t + E_t) + \theta_{cry} (p_{int}^t + E_t + cry_t) + (1 - \theta_{index} - \theta_{int} - \theta_{cry}) p_*^t \]
where \( cry \) denotes the price of commodities in dollars. Including the indexation factor \( \theta_{\text{index}} \) in firms' price setting equations yields the more general Phillips curve,

\[
\pi_t = \frac{(\theta_{\text{int}} + \theta_{\text{comm}})}{(1 + \beta \theta_{\text{index}})(\theta_{\text{fix}} + \theta_{\text{int}} + \theta_{\text{comm}})}(\epsilon_t - \beta \epsilon_{t+1}) + \\
\frac{\theta_{\text{int}}}{(1 + \beta \theta_{\text{index}})(\theta_{\text{fix}} + \theta_{\text{int}} + \theta_{\text{comm}})}(cry_t - \beta cry_{t+1}) + \\
\frac{\theta_{\text{index}}}{(1 + \beta \theta_{\text{index}})(\theta_{\text{fix}} + \theta_{\text{int}} + \theta_{\text{comm}})}(\pi_{t-1} + \beta \pi_{t+1} + m_{t+1} + \epsilon_{\pi})
\]