ANALYSIS OF THE REAL EXCHANGE RATE MISALIGNMENT IN HONDURAS

By

CASCO ALFARO, Elvis Teodoro

THESIS

Submitted to
KDI School of Public Policy and Management
in partial fulfillment of the requirements
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Committee in charge:

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ABSTRACT

ANALYSIS OF THE REAL EXCHANGE RATE MISALIGNMENT IN HONDURAS

By Elvis Casco

In this document is discussed the real exchange rate misalignment for Honduras and the consequences of the adjustment to nominal exchange rate in inflation. Results show that the depreciation of the nominal exchange rate resulted in a very low appreciation of the real exchange rate during the last two years (less than 2%). A higher nominal exchange rate depreciation has a negative impact on inflation considering two price channels: 1) the increasing of the price of imported goods (elasticity to inflation equal to 0.059), and 2) the higher oil derivatives prices affecting food prices (elasticity to food prices of 0.208) and the total inflation rate, with elasticity of oil derivatives to inflation equal to 0.362 and elasticity of food to inflation of 0.352. Giving this situation, the actual adjustment in the nominal exchange rate applied until now is close to the equilibrium values of its fundamentals. However, it is convenient to continue observing the behavior of these variables, considering the application of monetary policy adjustments in case of a high misalignment in the future. This document uses the Error Correction Model to estimate the real exchange misalignment, and Structural Vector Autoregression methodology to evaluate the impact of prices on inflation.

Keywords: Exchange Rate Misalignment, Error Correction Model, Structural Vector Autoregression, Impulse Response Analysis.

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I. INTRODUCTION

In a small and open economy like Honduras, producers have no influence on international prices. Increases in the nominal exchange rate depreciation[1] could help to decrease the balance of payments deficit because it reaches competitive prices to the exports in the foreign markets.

The nominal depreciation in the exchange rate can also increase inflation, especially if there is a dependency on the imports of final goods. This increasing of prices can generate a decreasing in the power purchase of the population, reversing the beneficial effects of the exchange rate depreciation. I estimate the transmission mechanism of the currency depreciation in terms of inflation rate, analysing if there is a Real Effective Exchange Rate (REER) misalignment[2] in Honduras.

The basic questions I try to answer in my research are:

i. What are the fundamental variables that helps explain the equilibrium real exchange rate for Honduras?

ii. Considering the real exchange rate misalignment, if it exists, what could be the effect in the local prices of the depreciation in the nominal exchange rate?

The literature considered for my thesis presents methodologies to estimate the exchange rate misalignment. Policymakers cannot determine or influence the real exchange rate directly, and if there is a misalignment one possible solution in the short run is the application of an adjustment in the nominal exchange rate. However, this adjustment can return the real exchange rate to its equilibrium levels only if the REER is

[1] If the government decides to depreciate the nominal exchange rate, it means that one can receive more Lempiras (the local currency) by each dollar.
[2] If the actual Real Exchange Rate (RER) differs significantly from its equilibrium value (Hinkle and Montiel (1999))

effectively overvalued, and if the adjustment is accompanied by other macroeconomic policies[3].

The nominal exchange rate depreciation has an impact in the inflation rate. In my thesis, I will evaluate the pass-through of exchange rate depreciation to inflation for Honduras, using the Structural Vector Autoregression (SVAR) methodology, estimating contemporary elasticities and duration of the shocks. The SVAR analysis has been applied by other authors to measure the propagation of inflationary shocks, especially the effect of certain groups of the Consumer Price Index in the rest of the groups.

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[3] Edwards (1989).

II. LITERATURE REVIEW

The exchange rate misalignment concept is a consequence of the inobservance of the purchasing power parity (PPP). This PPP establishes that if we compare two countries, considering the nominal exchange rate convertibility, the prices of the countries must have a similar behavior, given the existence of free international trade[4]. The price relation is the price index of the local country and its trading partners, compared through the exchange rate. So, it is established the change in terms of local prices as[5]:

$$p_t = s_t + p_t^* \tag{1}$$

Where p_t is the change in the price index of the local country, s_t is the nominal exchange rate depreciation and p_t^* is the price index variation of the trading partners. This relation is not accomplished in many economies, given the existence of commercial barriers and non-tradable goods. A weaker version of the PPP, establish that the deviation from PPP measured through the REER can be obtained assuming a derivation of the PPP formula:

$$z_t \equiv s_t + p_t^* - p_t \tag{2}$$

The main idea expressed in (2) is that, even if in the short run the PPP is not applicable, one could wait that in the long-run will exist a convergence in prices (expressed in a common currency) between the countries. In other words, it could be a RER misalignment in the short run, but in the long-run the price arbitrage should have an effect. If we reject this hypothesis, the best way to evaluate the REER adjustment to its

[4] This hypothesis supposes that if in a country one good is cheaper, the possibility of arbitrage could exist, and this kind of behavior let the possibility of commerce with an additional profit until the price of the good be equal in both countries.
[5] Hayashi (2000); Hamilton (1994).

equilibrium levels is through the analysis of the behavior of the fundamentals using methodologies as the considered by Engle and Granger[6].

The methodologies that uses fundamental variables to explain the REER requires the residual from the long-term REER equation to be an I(0) process, in other words, a stationary process with zero mean and whose long-run variance is finite and positive[7]. Another aspect to observe with respect to the residuals is that its coefficient in the short run equation must be negative to ensure convergence in the long-run.

In some cases, the individual country analysis of the exchange rate misalignment presents difficulties to find a robust specification (Hosfeld, 2010). With a panel data methodology, it is allowed DOLS estimations controlled by country fixed effects and common time effects. In both cases (individual country analysis and panel data), the estimated coefficients are used to obtain forecast of the REER, comparing the difference between the observed REER and the forecast through the evaluation of the root mean square errors (RMSE).

In the document "A Panel Data Investigation of Real Exchange Rate Misalignment and Growth" (MacDonald & Vieira, 2010), it is estimated the effect of the appreciation of real exchange rate in the long-run growth, using as fundamentals the real GDP, the net foreign assets, the terms of trade and public consumption, showing that a more depreciated (appreciated) real exchange rate contributes to (harms) long-run growth; so, in this countries the long-run growth is more affected by the REER if it is compared with the same effect in the developed countries.

For the authors (MacDonald & Vieira, 2010) "one of the main empirical contributions of the paper is to test different model specifications for the long-run equilibrium exchange rate and then use these to obtain estimated real exchange rate

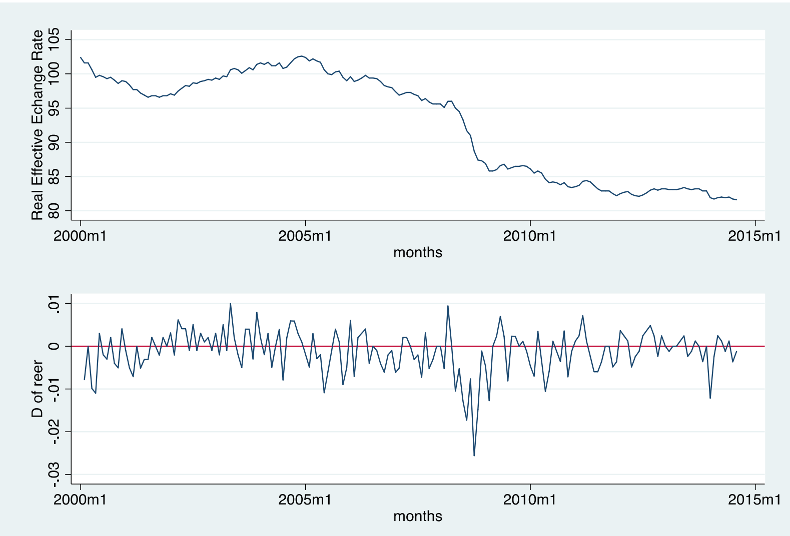
[6] Engle and Granger (1987).
[7] Hayashi (2000).

misalignment and assess how robust the results are when they are included as an explanatory variable in the panel growth model”. One of the factors that explains this situation is given in “Exchange Rate Misalignment in Developing Countries” (Edwards, 1988): the fact that a misaligned real exchange rate is related to price distortions in the tradable and non-tradable goods, and has as a consequence the inefficient allocation of resources. Also, the observed overvaluation of the real exchange rates during significant periods of time can indicate possible currency crises and a negative impact on the relative price adjustment (Frankel & Rose, 1996).

III. REER AND FUNDAMENTALS FOR HONDURAS: RECENT BEHAVIOR

In almost all the period in analysis except for the years 2001 to 2004, years in which the nominal exchange rate was depreciated at rates of more than 1% each quarter, there has been a continuous REER deterioration (growth rates below zero), caused basically by the increasing in the local prices at higher rates compared with the ones maintained by our commercial partners (see Annex 1 for the behavior of the components of the REER). After June 2011, the deterioration of the REER has been at lower rates than the observed in the period before the crisis, due principally to a higher rate of depreciation respect to our commercial partners.

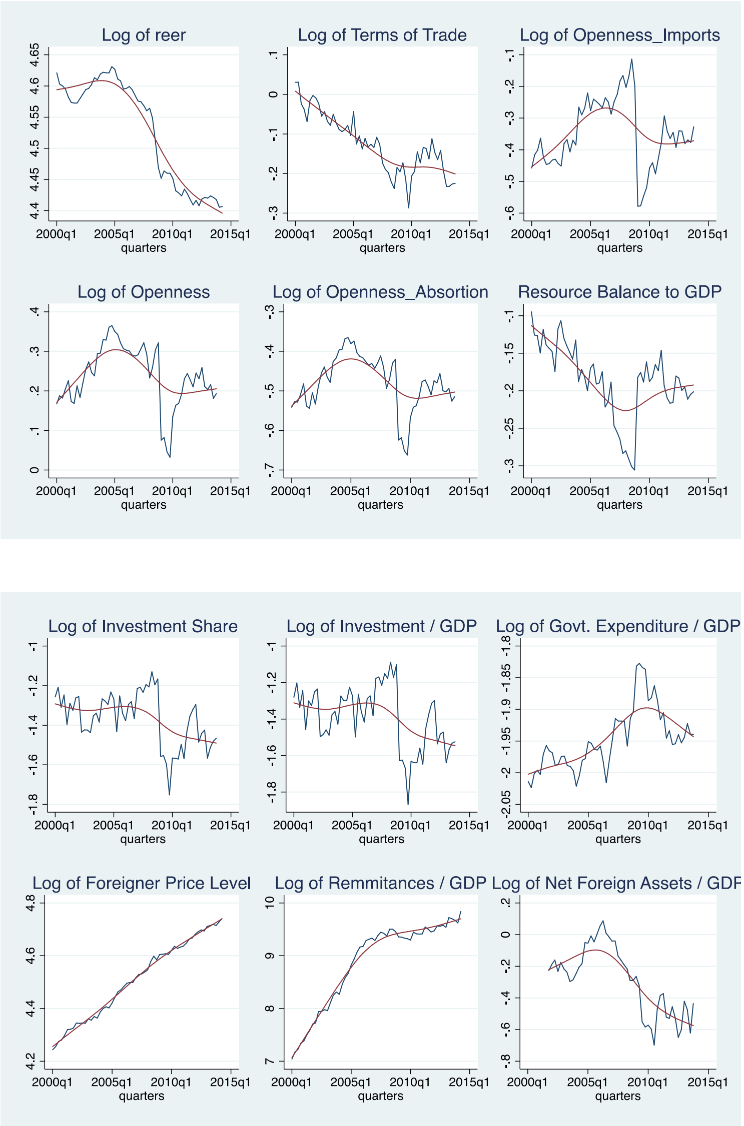
Figure 1: REER. Index and Monthly Variation



Source: SECMCA

In the period 2000-2014, the REER and its components observes a structural change after 2008, showing an increasing above the average in the CPI from Honduras and its commercial partners, and a currency appreciation for the commercial partners. Also, from November 2005 to June 2011, the Central Bank of Honduras maintained the same value for the currency (depreciation rate equal to zero), changing the way in which the reference price for the auctions from June 2011 until now. However, the most important change in the trend of the REER and its fundamentals is given by the world recession from 2008 and the political crisis in Honduras during 2009, observing a structural change in the first quarter of this last year for all the macroeconomic variables.

Figure 2: Trend and Actual Values of REER and its Fundamentals



IV. DATA AND METHODOLOGY

1. Data: REER

In general, a proxy to measure if the exchange rate depreciation results in an improvement in the competitivity of one country, is the REER. This indicator evaluates several factors, as the value of the local currency compared with our commercial partners (nominal exchange rates) and the internal prices of the goods and services with respect to the international prices, to know the position of the local country respect to our commercial partners in terms of competitiveness. In Honduras, this indicator is calculated through this formula[8]:

$$REER_t = \frac{\prod_{j=1}^{m}\left(\frac{Ej_t}{Pj_t}\right)^{w_j}}{\frac{Ei}{Pi}} \tag{3}$$

where:

REER = Real Effective Exchange Rate;

t = reference date;

m = number of commercial partners included in the sample;

Ej = exchange rate index of the commercial partners included;

Pj = consumer price index (CPI) of the commercial partners included;

Wj = weight of commerce for each commercial partner in a given year;

Pi = local CPI;

Ei = local exchange rate index;

The data available for Honduras since 1995 is the published in the SECMCA, which uses the inverse of (3). Given this composition, an easy way to see the sign of the

[8] http://www.bch.hn/download/itcer/metodologia_itcer.pdf.

variables that affect to the REER taking a simplified representation of the inverse of (3) and rearranging the components[9]:

$$\ln(REER_t) = [\ln(Pj_t) + \ln(Ei_t)] - [\ln(Ej_t) + \ln(Pi_t)] \qquad (4)$$

This formula tell us that the variables that imply a loss of competitiveness for the Honduran economy (decreasing the REER) are in the exchange rate depreciation of our commercial partners ($\Delta^+ Ej_t$) and the increase of the internal prices ($\Delta^+ Pi_t$); on the other hand, an increase in the prices of goods in our commercial partners ($\Delta^+ Pj_t$) and the depreciation of the internal exchange rate ($\Delta^+ Ei_t$) increases (improves) the REER (increasing in competitiveness), causing a real depreciation of the local currency.

In Honduras, the nominal exchange rate arrangement is a crawling band. The Central Bank of Honduras (CBH) has established a control over the buying and selling of dollars, determining the official exchange rate through daily foreign exchange auctions[10]. The buyers of US$ dollars can bid at a price that cannot be higher or lower than 7% from the base exchange rate. The CBH adjusts the base exchange rate in accordance with movements in this three variables: the anticipated inflation differentials and the changes in the exchange rates of trading partners of Honduras with respect to the U.S. dollar, and the level of the CBH's net international reserves[11].

This way of determining the exchange rate is not completely adjusted through the demand and supply equilibrium of external currency, so the concept of REER misalignment implies that in the short run can exist a deviation of the observed REER respect to its equilibrium values in the long-run, given that this equilibrium measures the price relationships that let achieve a macroeconomic balance –in other words, the Gross Domestic Product (GDP), balance of payments and the employment rate are in its optimal

[9] The operation of the weighted multiplication -the numerator in (5)- can be simplified if one considers that at the end the result of this operation is only one composite index.
[10] http://www.bch.hn/internacional/ley_indivpe.pdf.
[11] IMF Country Report No. 06/35, January 2006, in http://www.imf.org/external/pubs/ft/scr/2006/cr0635.pdf.

or tendency levels. Deviations can be originated by market rigidities like sticky prices and salaries that don't let an immediate adjustment of the production to its optimal levels[12].

In some cases, the best way to reach the REER equilibrium is the nominal exchange rate depreciation [13] (increases in Ei_t). This policy can influence the economy in the short run through at least three ways: 1) there could be an incentive to the increase of the production of exportable goods, because exporters can receive more money in terms of local currency by the selling of its merchandise in other countries; 2) it could diminish the incentive to the imports, especially of luxury goods, given that automatically the buying of goods and services from other countries will be more expensive in terms of local currency; and 3) this depreciation, assuming interest rate parity[14], could generate positive capital inflows (remittances, bank deposits, foreign direct investment), considering that it will be an increasing in the internal return to the capital.

Even if the nominal exchange rate depreciation has some advantages, if we analyze the macroeconomic effects in terms of inflation, could exist a positive exchange rate pass-through[15], increasing the general level of prices through the increasing of the importable goods prices. The impact on inflation happens by several ways: it will directly increase the price of the imported goods used in the production as raw materials (increasing in production costs), and a percentage of this increasing will be translated to the final consumers; also, the price of imported final goods will be higher, if the sellers of this goods don't want to reduce its commercial margin; this is particularly important in the case of oil derivatives, one of the goods with important weight in the commercial

[12] For example, the periodical negotiation of the minimal salary doesn't let to adjust the employment levels to an optimal production, considering that (in efficient conditions) the salary only must depend on the marginal productivity of the labor.

[13] See formula (6)

[14] Without the existence of a risk premium, $i = i^* + s^e$, where i is the local interest rate, i^* is the international interest rate and s^e represents the expected depreciation rate.

[15] This pass-through measures the elasticity of internal prices related to nominal exchange rate depreciation.

balance. The increase in the prices of final goods (especially oil derivatives) has its impact in the inflation rate, generating pressures to higher salaries and higher production costs. This analysis lets us assume that it will be a generalized increase in prices of internal final goods and a reduction of the power purchase of the consumers if one considers a high rate of nominal exchange rate depreciation.

Also, it could be a positive effect in the productivity of a country only if exist a misalignment in the REER with respect to its equilibrium values and if it is followed by effective macroeconomic policies, as the incentives to production and exports; this is because nominal exchange rate depreciations are neutral, in real terms, in the long-run[16]. Theoretically, the increasing in the GDP of a country depends fundamentally on the improvement of production factors like capital, labor and technology; the exchange rate is only a price (a nominal variable) and cannot affect the production in real terms (quantities).

The last (but not least) important consideration is the convenience of estimating (with a certain level of certainty) the degree of misalignment of the REER before the establishment of movements in nominal exchange rate. The REER (as is calculated in (3)) is only an approximation, because this variable (the real exchange rate) is unobservable and there are several ways to measure it: one of the most important is the relationship between the price of tradable and non tradable goods, but for Honduras this data is not available.

[16] Edwards (1989).

2. Data: Fundamentals

The source for the variables to explain the behavior of the dependent variable (REER) for Honduras (fundamentals[17]) are from the Central Bank of Honduras[18] and the Central American Monetary Council (SECMCA)[19] databases:

i. Terms of Trade (tot): measures the relation between Exports prices (P_X) with respect to Imports prices (P_M). Given that both variables imply a bundle composed of a variety of goods and services, I will use the implicit indexes published in the Quarterly National Accounts[20].

ii. Openness (open): through this indicator it is evaluated the weight of international trade (Exports and Imports) in the GDP. The openness is measured through three similar ways:

- $Open1 = M/GDP$, the ratio of Imports (M) over GDP, at current prices;
- $Open2 = (X + M)/GDP$, the sum of Exports (X) and Imports (M) over GDP, at constant prices (as it was finally used in equations); and
- $Open3 = M/\big(GDP - (X - M)\big)$, is the ratio of imports to domestic absorption, at constant prices.

iii. Resource Balance to GDP ratio (resgdp): is the relation of Exports (adjusted by the domestic terms of trade) minus Imports, divided by GDP, at constant prices: $RESGDP = \big((X * TOT) - M\big)/GDP$.

iv. Foreign Price Level (pfor): price index from commercial partners (P_j) divided by the local price index (P_i).

[17] Edwards (1989); Hinckle and Montiel (1999); MacDonald (2007).
[18] http://www.bch.hn/eng/index.php
[19] http://www.secmca.org/simafir.html
[20] https://see.bch.hn/portalPIBT. Given that this variables shows a strong seasonal component, it was applied a seasonal adjustment to all of them, using the program Tramo-Seats for Windows.

v. Remittances/GDP (remgdp): ration between remittances and the GDP, at current prices.

vi. Net Foreign Assets/GDP (nfagdp): this variable explains the ratio between the Net Foreign Assets (NFA) and the GDP, at current prices.

vii. Government Consumption/GDP (govgdp): expresses the relation of the government expenditure and the GDP, expressed at constant prices.

For Honduras, I define my sample from 2000q1 to 2013q4, due the data available from the Quarterly National Accounts (QNA).

3. Methodology

The exchange rate misalignment for Honduras is estimated considering as dependent variable the Real Effective Exchange Rate (REER). I use a cointegration analysis (Engle & Granger, 1987), (Hosfeld, 2010), (MacDonald & Vieira, 2010), (Hinkle & Montiel, 1999) to estimate an equation for the long-run REER. The reduced-form expression is given by the equation[21]:

$$REER_t = \beta_1' Z_{1t} + \beta_2' Z_{2t} + \tau' T_t + \varepsilon_t \qquad (5)$$

where Z_1 and Z_2 are vectors of economic fundamentals that are expected to have effects over the long-run and medium term, respectively; T is a vector of variables that affect the REER in the short run, ε_t is the error term, and β_1, β_2, τ are vectors of reduced-form coefficients.

The current equilibrium rate is the level of REER given by the current values of the two sets of fundamentals (Z_1 and Z_2), so this current equilibrium rate will be estimated through the equation:

$$REER_t' = \beta_1' Z_{1t} + \beta_2' Z_{2t} \qquad (6)$$

[21] Clarck and MacDonald (1998).

The current misalignment (cm_t) will be the difference between the actual REER and the REER considering the fundamentals:

$$cm_t = REER_t - REER_t{}' = \tau' T_t + \varepsilon_t \qquad (7)$$

To obtain the total misalignment (tm_t), we need to estimate the long-run (sustainable or desirable) values for the economic fundamentals ($\bar{Z}_1$ and $\bar{Z}_2$)[22], and using the coefficients in (6), this total misalignment is:

$$tm_t = REER - \beta_1' \bar{Z}_{1t} - \beta_2{}' \bar{Z}_{2t} \qquad (8)$$

All the fundamentals cited before were analyzed to get the most consistent equation. The sign of each variable depends in many cases on how they affect the consumption and the prices of the non-tradable goods, considering that the REER can be seen as in equation (2), where it is established a basic relationship between the price elasticity of the demand for nontradable goods, with the prices of tradable goods established internationally. With the terms of trade for example, it is expected that an improving in the price of exports increases the real income and also the demand for nontradables, so it is expected an increasing in the price of nontradables and an appreciation of the REER. A similar case can be analyzed with the increasing in the government spending, assuming that a high proportion of this spending is in nontradables. A more detailed of the expected sign of the fundamentals is widely explained in Edwards (1989) and Hinkle & Montiel (1999), in which it is emphasized that the sign of the coefficients in many cases is undetermined, and it depends also if the effect of the change in the variable to analyze is expected as temporary or permanent. This last situation implies that the coefficient could be positive in the short-run relationship and negative in the long-run representation. In this document it is included the remittances as independent variable, as an important factor that influence in the pressures to depreciation of nominal

[22] These values are estimated using the Hodrick-Prescott filter.

exchange rate in Honduras, so the expected sign of this variable could be positive (see equation (4)).

V. RESULTS

1. PPP Theory

An important fact for the REER is the related with the expected observance of the PPP theory: in Honduras, as is shown in other countries[23], the REER doesn't have the behavior of a random variable during the period, and either shows a clear trend in the long-run. To show that this variable is not I(0), two variations of an unit root test were applied to show that the variability of the index around its mean or its trend cannot be described as white noise: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Both tests shows clearly a test statistics lower (in absolute values) than the 1% critical value, causing the non rejection of the null hypothesis of unit root, concluding that the REER follows a nonstationary process.

Table 1: ADF and PP Tests, REER

Tests for Unit Root	*Levels without Time Trend*	*MacKinnon p-Value for Zt*	*Levels with Time Trend*	*MacKinnon p-Value for Zt*
ADF Test				
Log of REER	-0.266	0.930	-1.952	0.627
Dlog of REER	-4.146	0.001	-4.156	0.005
Phillips-Perron Test				
Log of REER	-0.425	0.906	-1.614	0.787
Dlog of REER	-4.889	0.000	-4.809	0.001

The rejection of the PPP theory implies that the levels and variations of prices between Honduras and its commercial partners cannot follow a similar behavior when they are expressed in a common currency; in other words, it cannot be possible to apply a shock in the nominal exchange rate to adjust the REER and maintain its equilibrium

[23] MacDonald (2007); Hinkle and Montiel (1999); Edwards (1989).

values in the long-run. In this case, it is convenient to show if the behavior of this variable can be described through the analysis of its fundamentals.

2. Misalignment: Analysis of Fundamentals

Before the estimation of the equations, the first step is to analyze the statistics of stationarity for the fundamentals, evaluating the order of integration. To achieve this purpose, I use the ADF and PP tests. Both tests let conclude strongly that all the variables are integrated of order 1 or I(1).

The Variance Ratio Test (Lo-Mackinlay Test, see Annex 1) also verifies this hypothesis, because it is expected that only the I(1) variables shows an increasing behavior. Now we have that all the variables in the model have the same level of integration (I(1)), a necessary condition to apply the Error Correction Model to analyze the dynamics of the REER based on its fundamentals.

Table 2: ADF Test, Fundamentals

ADF Tests for Unit Root	*Levels without Time Trend*	*MacKinnon p-Value for Zt*	*Levels with Time Trend*	*MacKinnon p-Value for Zt*	*Order of Integration*
Log of Terms of Trade	-1.894	0.335	-2.778	0.205	*I(1)*
Dlog of Terms of Trade	-5.912	0.000	-5.855	0.000	
Log of Openness1	-2.670	0.079	-2.640	0.262	*I(1)*
Dlog of Openness1	-5.673	0.000	-5.615	0.000	
Log of Openness2	-2.186	0.211	-2.352	0.406	*I(1)*
Dlog of Openness2	-5.650	0.000	-5.650	0.000	
Log of Openness3	-2.213	0.202	-2.380	0.390	*I(1)*
Dlog of Openness3	-5.765	0.000	-5.761	0.000	
Resource Balance to GDP	-2.140	0.229	-2.168	0.508	*I(1)*
Diff. Resource Balance to GDP	-6.444	0.000	-6.431	0.000	
Log of Gov. to GDP	-2.132	0.232	-2.129	0.530	*I(1)*
Dlog of Gov. to GDP	-4.927	0.000	-4.922	0.000	
Log of Foreign Price Level	-1.195	0.676	-2.137	0.525	*I(1)*
Dlog of Foreign Price Level	-6.387	0.000	-6.430	0.000	
Log of Remitances to GDP	-3.080	0.028	-1.449	0.846	*I(1)*
Dlog of Remitances to GDP	-4.565	0.000	-5.473	0.000	
Log of NFA to GDP	-1.332	0.614	-2.046	0.576	*I(1)*
Dlog of NFA to GDP	-6.300	0.000	-6.204	0.000	

Table 3: Phillips-Perron Test, Fundamentals

Phillips-Perron Tests for Unit Root	*Levels without Time Trend*	*MacKinnon p-Value for Zt*	*Levels with Time Trend*	*MacKinnon p-Value for Zt*	*Order of Integration*
Log of Terms of Trade	-1.920	0.323	-3.536	0.036	*I(1)*
Dlog of Terms of Trade	-11.783	0.000	-12.239	0.000	
Log of Openness1	-2.299	0.172	-2.234	0.471	*I(1)*
Dlog of Openness1	-7.131	0.000	-7.049	0.000	
Log of Openness2	-2.270	0.182	-2.259	0.457	*I(1)*
Dlog of Openness2	-7.997	0.000	-8.077	0.000	
Log of Openness3	-2.274	0.181	-2.264	0.454	*I(1)*
Dlog of Openness3	-7.792	0.000	-7.845	0.000	
Resource Balance to GDP	-2.570	0.099	-2.672	0.248	*I(1)*
Diff. Resource Balance to GDP	-10.010	0.000	-10.290	0.000	
Log of Gov. to GDP	-1.969	0.301	-2.107	0.542	*I(1)*
Dlog of Gov. to GDP	-7.387	0.000	-7.508	0.000	
Log of Foreign Price Level	-1.571	0.498	-2.576	0.291	*I(1)*
Dlog of Foreign Price Level	-9.250	0.000	-9.742	0.000	
Log of Remitances to GDP	-3.126	0.025	-1.615	0.787	*I(1)*
Dlog of Remitances to GDP	-7.847	0.000	-7.893	0.000	
Log of NFA to GDP	-1.399	0.583	-2.095	0.549	*I(1)*
Dlog of NFA to GDP	-6.359	0.000	-6.227	0.000	

To estimate the representative equation for the growth rate of the real exchange rate (short-run equation), I tried the fundamentals and the second definition of Openness in the dynamic equation. The best estimation for the error-correction model in terms of the sign and value of the coefficients, and the cointegration vector (obtained through the application of a unit root test to the residual, with the ADF and Phillips-Perron tests[24]), is presented in Table 4, where it is represented a general error-correction model similar to Hinkle & Montiel (1999):

$$\Delta lnREER_t = \alpha(lnREER_{t-1} - \beta Z_{t-1}) + \gamma \Delta Z_t + \varepsilon \qquad (9)$$

In our case, the fundamentals are assumed to have effects in the long-run (represented by βZ_{t-1}) and short-run ($\gamma \Delta Z_t$ in the equation (9)) at the same time, without any other variable interacting in the short-run. To generate a stable long-run equilibrium, the coefficient α has to be negative ($-2 < \alpha < 0$).

[24] See Annex 2 for results.

Table 4: Results of Regression, Engle-Granger Methodology

errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The adjustment speed is the speed of adjustment of the REER to its equilibrium level; it is followed from the results that more than 40% of a shock in the REER disappear in the first year; also, it can be said that to eliminate 95% of a shock, it can take around six years[25].

A comparison of the fitted values resulting from the long-run component of the equation with the observed values of the REER, shows values of the REER highly adjusted to its long-run values during the last quarters of the sample.

[25] Due the time (t) required to dissipate a percentage of a (x) percentage of a shock derived by $(1-|\alpha|)^t = 1 - x$, the time to eliminate a x% of a shock is $t = \frac{\ln(1-x)}{\ln(1-|\alpha|)}$

Figure 3: Long-Run Results, Observed and Fitted Values, with Residuals

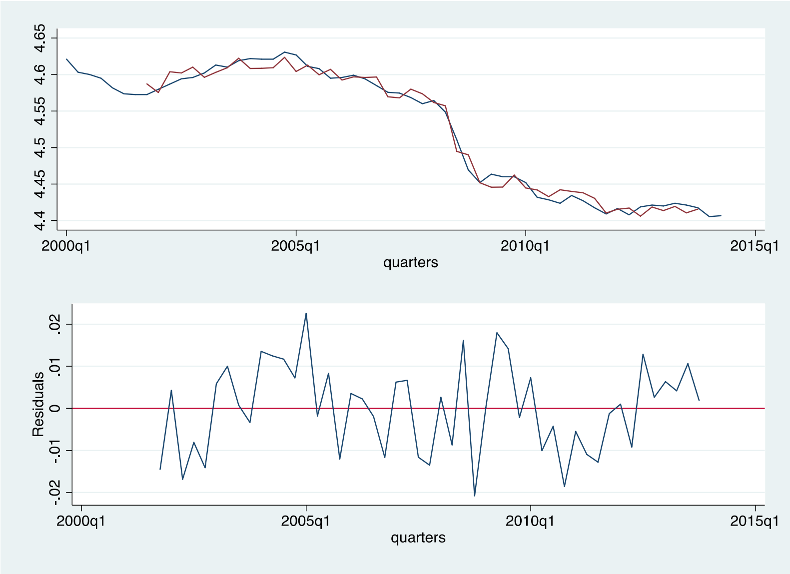
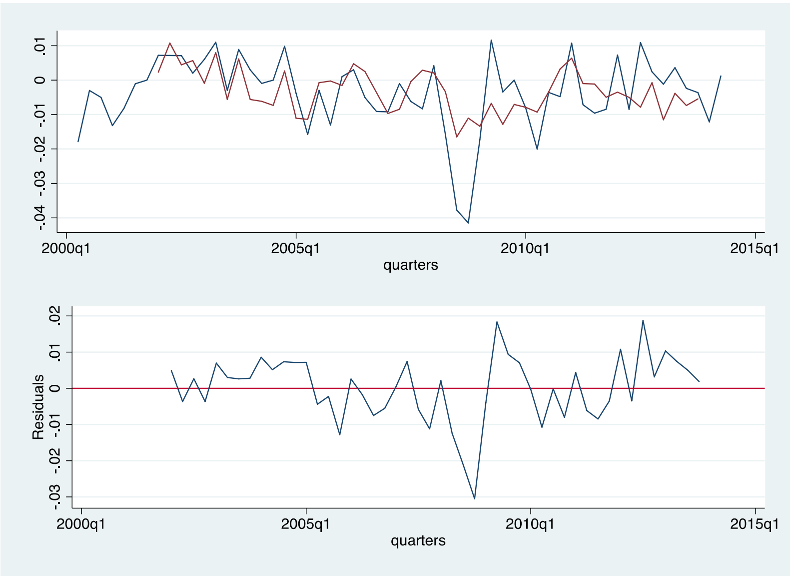


Figure 4: Short-Run Results, Observed and Fitted Values, with Residuals



To estimate the misalignment of the REER related with the long-run fundamentals (equation 8), multiply the matrix of long-run values for the fundamentals[26] and the betas from the long-run equation (equation 6). These results show that in Honduras the observed values the REER were higher than its long-run values, indicating that the REER was over appreciated in the last quarters of the sample.

[26] Obtained with the application of the Hodrick-Prescott filter.

Figure 5: REER, Observed vs. Equilibrium Values, and Misalignment from Long-Run Equilibrium (%)

In percentages, this degree of misalignment was calculated through this formula:

$$tm(\%) = \frac{\exp(\log(reer)) - \exp(\log(reer\_lr\_equil)}{\exp(\log(reer\_lr\_equil)} \qquad (10)$$

These results indicate that the exchange rate misalignment has shown a growing trend in the last quarters beginning from the third quarter of 2012, with a real appreciation of less than 2% during that period.

One way to evaluate in advance the behavior of the REER is to estimate future values of the fundamentals (using ARIMA methods, for example) and calculate the misalignment rate using the values of the betas obtained in the cointegration equation. If the actual behavior of the misalignment is maintained, an adjustment on the nominal exchange rate or a more restrictive monetary policy to lower inflation could be convenient to avoid the loss of competitiveness.

3. Depreciation of the Nominal Exchange Rates: Price Implications

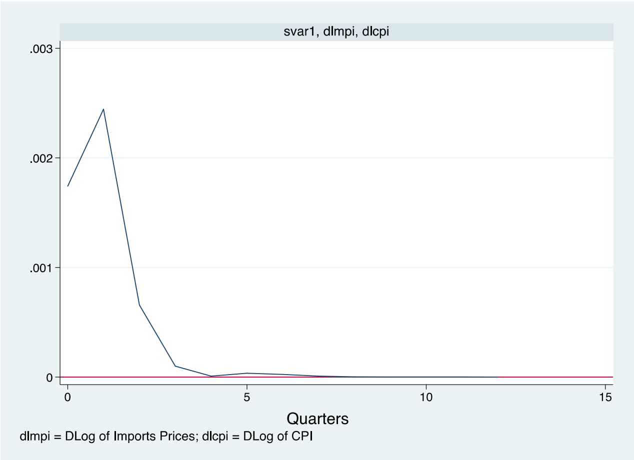
Giving that the adjustment to reach the equilibrium REER can be achieved through a nominal exchange rate depreciation, it is evaluated the impact (impulse-response analysis) of the adjustment in nominal exchange rate in terms of increasing of internal prices (inflation rate) for Honduras, using the SVAR methodology[27] considering (in order of interdependency) two variables[28]: price of imported goods (PM) and inflation, to measure the contemporary effect of an increasing in the price of imported goods as a consequence of the depreciation in nominal exchange rate, assuming that a higher value of the imports will be incorporated to the final prices in the economy.

The results of this first SVAR indicates that the contemporary elasticity of the price of imports to inflation is around 0.059, and a shock (one standard deviation) in the price of the imports has an average duration of five months, with the highest impact in the first three quarters.

Table 5: Matrix A, Price Index of Imports (dlmpi) and Inflation (dlcpi)

Variables	dlmpi	dlcpi
dlmpi	1.000	0.000
dlcpi	-0.059	1.000

Figure 6: Response to a Shock on Import Prices on CPI



Also, I consider the methodology used by other authors (Pedersen, 2011), (Rodriguez Vargas, 2012) to study the propagation of inflationary shocks, in which it is

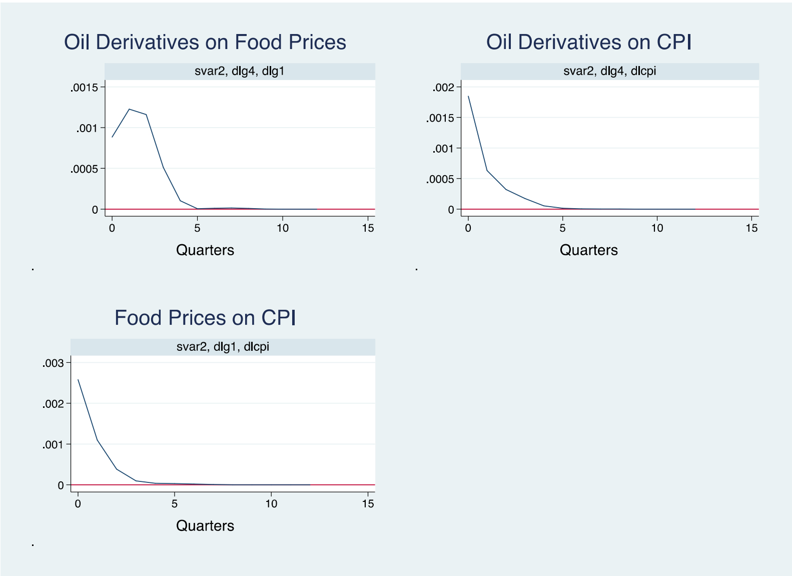
[27] Amisano and Gianini (1997), Enders (1995).
[28] See Annex 4 for a mathematical derivation of a SVAR with three variables. For the two-variables case, see Enders (1995).

evaluated the effect of an increasing in oil derivatives prices in food prices and the CPI[29], considering that the first variable has a direct impact in the price of food, and this variable is the one with the higher weight in composition of CPI groups. The respective elasticities for each variable of of oil derivatives prices in the price of food and inflation is relatively high (0.208 and 0.362, respectively), and also a 1% of increasing in the price of food can have as consequence an increasing in 0.35% in the general inflation. The response to shocks has similar behavior: its higher impact is in the first three quarters and shows a duration of approximately five quarters.

Table 6: Matrix A Cross Elasticities Oil Derivatives (dlg4), Food (dlg1) and Inflation (dlcpi)

Variables	dlg4	dlg1	dlcpi
dlg4	1.000	0.000	0.000
dlg1	-0.208	1.000	0.000
dlcpi	-0.362	-0.352	1.000

Figure 7: Impulse-Response Analysis, Shock in Oil Derivatives



The analysis of the prices of imports and oil derivatives is suggested because with the depreciation of the exchange rate, it is observed an immediate increase in the cost of this imports, and the effect on the final internal prices depend of the respective

[29] For this SVAR, I used monthly data to analyze the behavior of the SVAR with more dynamics; the results are similar to the obtained using quarterly data. In the first SVAR it is not possible to get information for monthly price index of imports.

elasticities. In this case, even when the price elasticity of imports is low, one of the mean components in Honduras is oil derivatives, so the real impact of a 10% depreciation in the nominal exchange rate on inflation could be higher than 4% on inflation, considering the dynamics of the elasticities calculated.

VI. CONCLUDING REMARKS

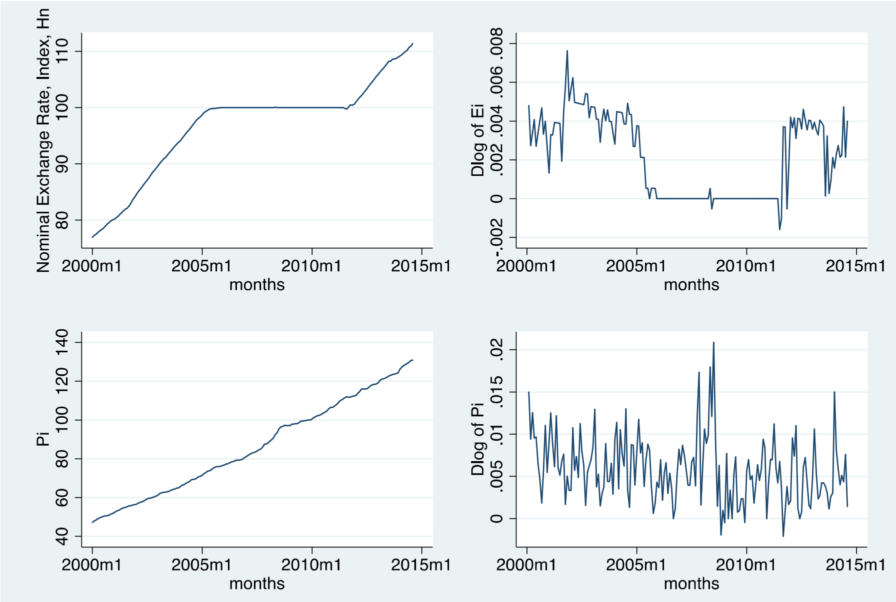
The REER for Honduras shows a low misalignment of this variable with respect to the long-run behavior of its fundamentals (less than 2%). This value could be considered as acceptable in the short run, but the behavior in the last quarters of 2013 (a trend of appreciation in the REER) indicates the convenience of adjusting the nominal exchange depreciation rate following the movements on the fundamentals in the future, analysing the possible effect of this depreciation on the inflation rate.

It is recommended to evaluate the behavior of the REER for Honduras each quarter, considering forecasting evaluations of its fundamentals, to prevent negative shocks on competitiveness in advance.

VII. ANNEX

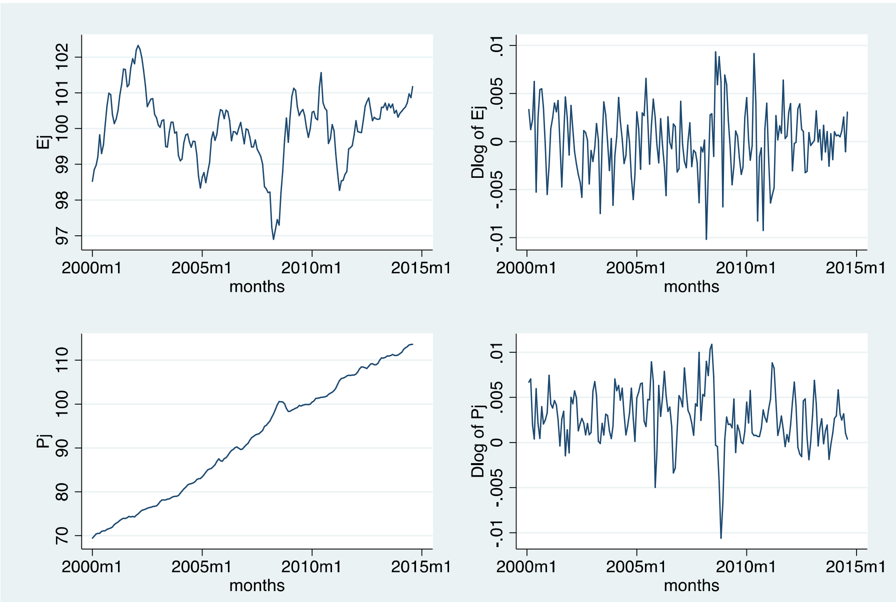
Annex 1. Graphs for the Behavior of the Variables

Figure 8: Nominal Exchange Rate and CPI for Honduras, Index and Monthly Variations



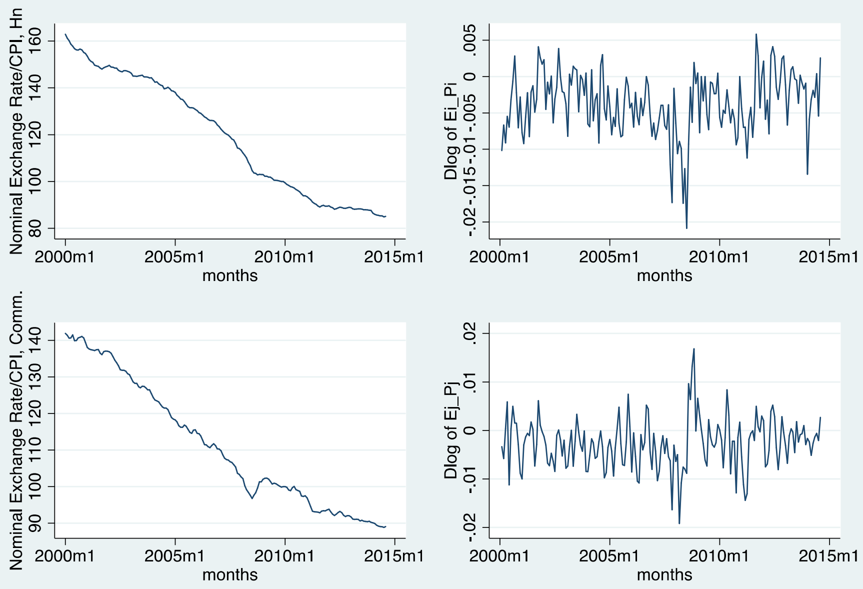
NER, Ei = Nominal Exchange Rate. CPI, Pi = Consumer Price Index. Source: Central Bank of Honduras

Figure 9: Nominal Exchange Rate and CPI for Commercial Partners, Index and Monthly Variations



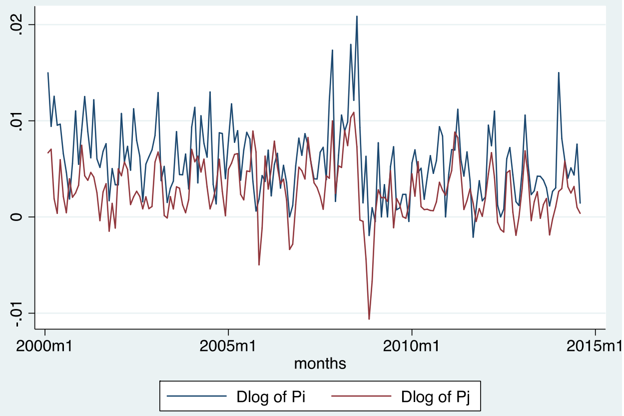
NER, Ej = Nominal Exchange Rate. CPI, Pj = Consumer Price Index. Source: Central Bank of Honduras

Figure 10: REER Components, Index and Monthly Growth



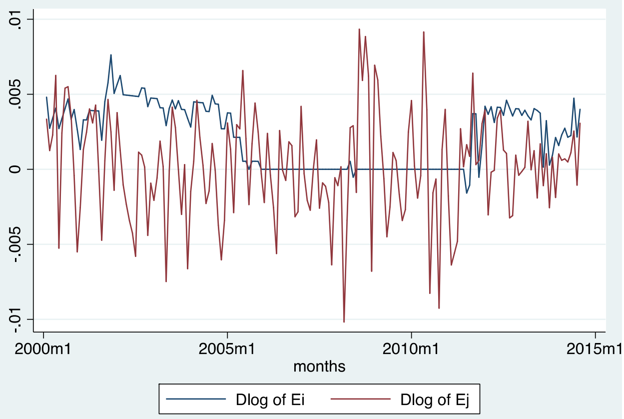
E=Exchange Rate, P=Price Index, i=Honduras, j=Commercial Partners. Source: Central Bank of Honduras

Figure 11: Monthly Growth of CPI, Honduras and Commercial Partners



P = CPI, i = Honduras, j = Commercial Partners. Source: Central Bank of Honduras

Figure 12: Monthly Growth of Nominal Exchange Rate, Honduras and Commercial Partners



E=Nominal Exchange Rate, i=Honduras, j=Commercial Partners. Source: Central Bank of Honduras

Annex 2. Cointegration Tests, Long-run and Short Run Equations

Table 7: Basic Statistics, REER and Fundamentals

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Log of REER	58	4.528	0.083	4.405	4.631
Dlog of REER	57	-0.004	0.011	-0.042	0.012
Log of Terms of Trade	56	-0.125	0.075	-0.287	0.031
Dlog of Terms of Trade	55	-0.005	0.033	-0.082	0.081
Log of Openness1	56	-0.348	0.107	-0.578	-0.114
Dlog of Openness1	55	0.002	0.066	-0.379	0.120
Log of Openness2	56	0.237	0.076	0.032	0.365
Dlog of Openness2	55	0.000	0.045	-0.246	0.103
Log of Openness3	56	-0.479	0.068	-0.662	-0.365
Dlog of Openness3	55	0.000	0.039	-0.204	0.094
Resource Balance to GDP	56	-0.186	0.049	-0.306	-0.095
Diff. Resource Balance to GDP	55	-0.002	0.028	-0.058	0.123
Log of Investment Share	56	-1.368	0.135	-1.752	-1.130
Dlog of Investment Share	55	-0.004	0.101	-0.391	0.186
Log of Investment to GDP	56	-1.392	0.172	-1.868	-1.088
Dlog of Investment to GDP	55	-0.004	0.134	-0.525	0.236
Log of Gov. to GDP	56	-1.947	0.049	-2.024	-1.827
Dlog of Gov. to GDP	55	0.001	0.022	-0.050	0.072
Log of Foreign Price Level	58	4.510	0.148	4.244	4.741
Dlog of Foreign Price Level	57	0.009	0.009	-0.013	0.031
Log of Remitances to GDP	58	8.875	0.812	7.040	9.840
Dlog of Remitances to GDP	57	0.049	0.080	-0.098	0.219
Log of NFA to GDP	49	-0.288	0.212	-0.698	0.087
Dlog of NFA to GDP	48	-0.004	0.085	-0.229	0.230

Figure 13: Variance Ratio Test for REER and its Fundamentals

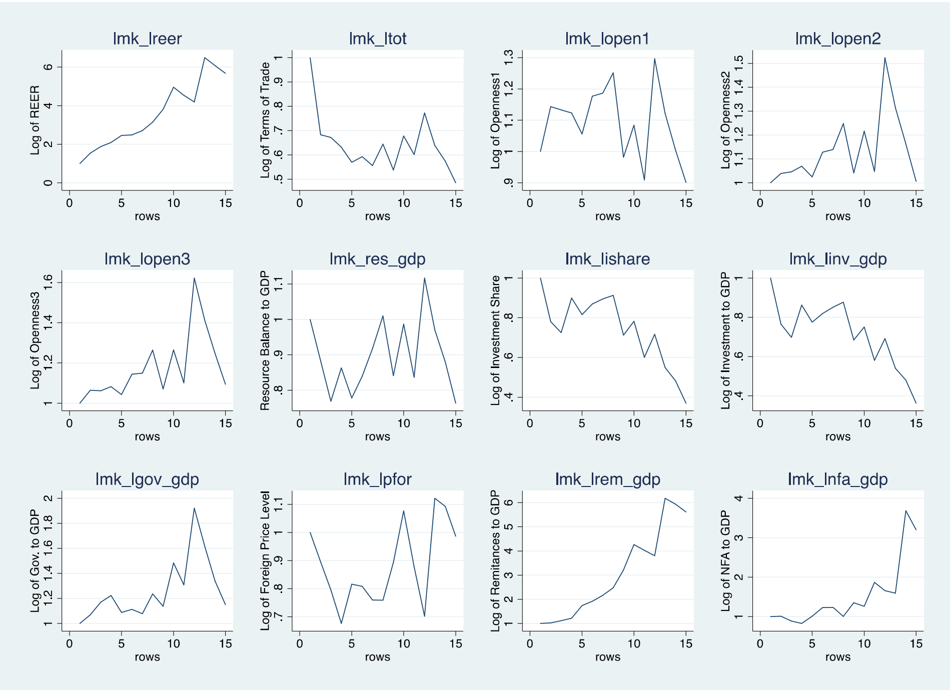


Figure 14: Autocorrelation Function, REER and Fundamentals

Figure 15: Partial Autocorrelation Function, REER and Fundamentals

Table 8: Results of Unit Root Tests, Residuals of the Long-Run and Short-Run Equations

Tests for Unit Root	*Levels without Time Trend*	*MacKinnon p-Value for Zt*	*Levels with Time Trend*	*MacKinnon p-Value for Zt*
ADF Test				
Long-Run Equation	-3.439	0.000	-3.401	0.000
Short-Run Equation	-3.540	0.000	-3.501	0.003
Phillips-Perron Test				
Long-Run Equation	-6.228	0.000	-6.168	0.000
Short-Run Equation	-4.382	0.000	-4.338	0.003

Annex 3. SVAR Statistics

1. Two Variables: Imports Price Index (dlmpi) and Inflation (dlcpi)

Figure 16: Monthly Growth of Imports Price Index and CPI

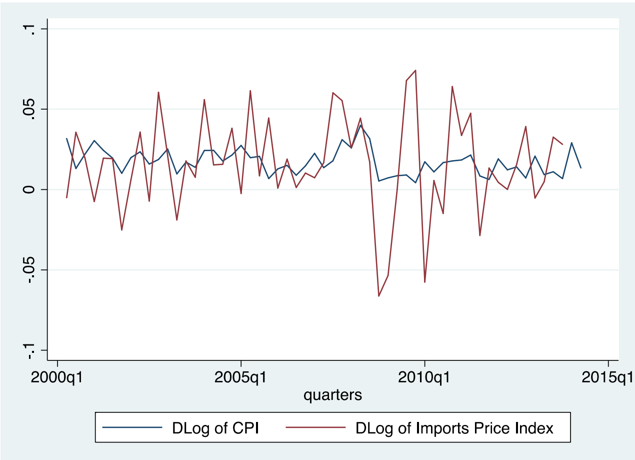


Table 9: Basic Statistics for Variables in SVAR1

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
dlmpi	55	0.016	0.030	-0.066	0.074
dlcpi	57	0.017	0.008	0.004	0.040

Table 10: : Eigenvalue Stability Condition, SVAR1

Eigenvalue	*Modulus*
0.426	0.426
0.120 + 0.361i	0.380
0.120 - 0.361i	0.380
-0.292	0.292

All the eigenvalues lie inside the unit circle.
VAR satisfies stability condition.

Table 11: Lagrange-Multiplier Test, SVAR1

lag	*chi2*	*df*	*Prob > chi2*
1	12.313	4	0.015
2	6.612	4	0.158
3	7.515	4	0.111
4	7.986	4	0.092

H0: no autocorrelation at lag order

2. Three Variables: Oil Derivatives (dlg4), Food (dlg1) and Inflation (dlcpi)

Figure 17: Monthly Growth of Food Price Index (g1) and CPI

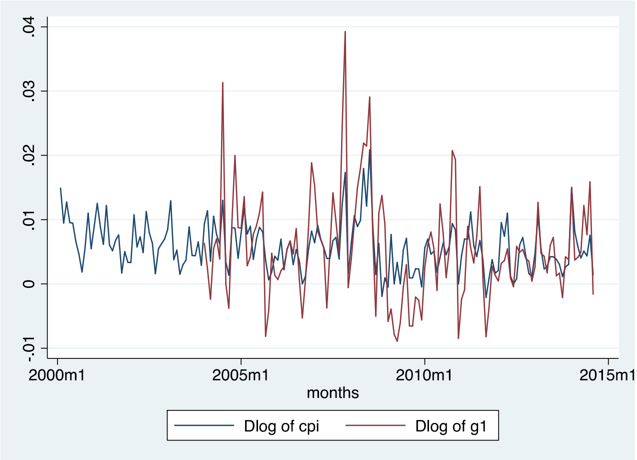


Table 12: Basic Statistics for the Variables in SVAR2

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
dlg4	128	0.006	0.004	-0.004	0.025
dlg1	128	0.005	0.008	-0.009	0.039
dlcpi	175	0.006	0.004	-0.002	0.021

Figure 18: Monthly Growth of Combustibles Price Index (g4) and CPI

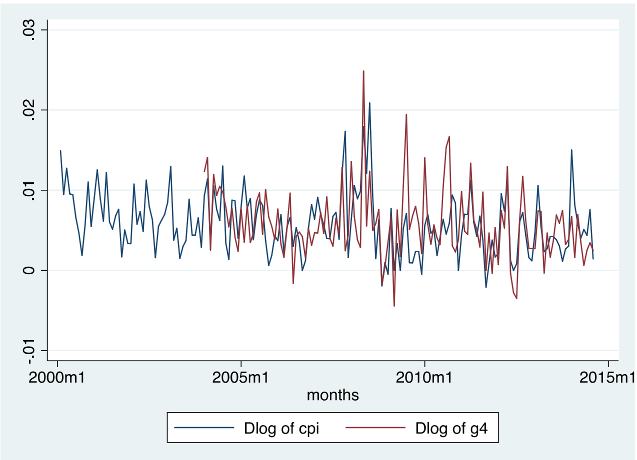


Table 13: Eigenvalue Stability Condition, SVAR2

Eigenvalue	*Modulus*
0.178 + 0.412i	0.449
0.178 - 0.412i	0.449
0.410 + 0.071i	0.416
0.410 - 0.071i	0.416
-0.157 + 0.168i	0.230
-0.157 - 0.168i	0.230

All the eigenvalues lie inside the unit circle.
VAR satisfies stability condition.

Table 14: Lagrange-Multiplier Test, SVAR2

lag	chi2	df	Prob > chi2
1	13.671	9	0.135
2	12.252	9	0.199
3	12.479	9	0.188
4	17.326	9	0.044

H0: no autocorrelation at lag order

Annex 4. SVAR identification

To identify the effect of nominal exchange rate shocks in the inflation rate, it is estimated a SVAR with three variables expressed as:

V_t, equal to price index of oil derivatives and electricity;

Y_t, as price index of food; and

Z_t, as inflation rate.

An SVAR without restrictions can be represented as:

$$V_t + a_{12}Y_t + a_{13}Z_t = c_{11} + d_{11}V_{t-1} + d_{12}Y_{t-1} + d_{13}Z_{t-1} + f_{11}V_{t-2} + f_{12}Y_{t-2} + f_{13}Z_{t-2} + \epsilon_{V_t} \quad (1A)$$

$$a_{21}V_t + Y_t + a_{23}Z_t = c_{21} + d_{21}V_{t-1} + d_{22}Y_{t-1} + d_{23}Z_{t-1} + f_{21}V_{t-2} + f_{22}Y_{t-2} + f_{23}Z_{t-2} + \epsilon_{Y_t} \quad (2A)$$

$$a_{31}V_t + a_{32}Y_t + Z_t = c_{31} + d_{31}V_{t-1} + d_{32}Y_{t-1} + d_{33}Z_{t-1} + f_{31}V_{t-2} + f_{32}Y_{t-2} + f_{33}Z_{t-2} + \epsilon_{Z_t} \quad (3A)$$

The matrix representation of the SVAR for this equations is given by:

$$\underbrace{\begin{bmatrix} 1 & a_{12} & a_{13} \\ a_{21} & 1 & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} V_t \\ Y_t \\ Z_t \end{bmatrix}}_{X_t} = \underbrace{\begin{bmatrix} c_{10} \\ c_{20} \\ c_{30} \end{bmatrix}}_{C} + \underbrace{\begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}}_{D} \underbrace{\begin{bmatrix} V_{t-1} \\ Y_{t-1} \\ Z_{t-1} \end{bmatrix}}_{X_{t-1}} + \underbrace{\begin{bmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{bmatrix}}_{F} \underbrace{\begin{bmatrix} V_{t-2} \\ Y_{t-2} \\ Z_{t-2} \end{bmatrix}}_{X_{t-2}} + \underbrace{\begin{bmatrix} \epsilon_{V_t} \\ \epsilon_{Y_t} \\ \epsilon_{Z_t} \end{bmatrix}}_{\epsilon_t} \quad (4A)$$

In a compact form, (4A) can be expressed as:

$$AX_t = C + DX_{t-1} + FX_{t-2} + \epsilon_t \quad (5A)$$

$$X_t = A^{-1}C + A^{-1}DX_{t-1} + A^{-1}FX_{t-2} + A^{-1}\epsilon_t \quad (6A)$$

In my thesis, it is analyzed two restrictions in the SVAR:

1. A shock in oil derivatives affect contemporarily to the food prices (a_{21}) and to inflation (a_{31}); also, ($a_{12} = a_{13} = 0$); and

2. Shocks in the oil derivatives affects contemporarily only the inflation (a_{32}), also ($a_{23} = 0$).

Given these restrictions, an SVAR in (4A) will be:

$$\underbrace{\begin{bmatrix} 1 & 0 & 0 \\ a_{21} & 1 & 0 \\ a_{31} & a_{32} & 1 \end{bmatrix}}_{A}\underbrace{\begin{bmatrix} V_t \\ Y_t \\ Z_t \end{bmatrix}}_{X_t} = \underbrace{\begin{bmatrix} c_{10} \\ c_{20} \\ c_{30} \end{bmatrix}}_{C} + \underbrace{\begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}}_{D}\underbrace{\begin{bmatrix} V_{t-1} \\ Y_{t-1} \\ Z_{t-1} \end{bmatrix}}_{X_{t-1}} + \underbrace{\begin{bmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{bmatrix}}_{F}\underbrace{\begin{bmatrix} V_{t-2} \\ Y_{t-2} \\ Z_{t-2} \end{bmatrix}}_{X_{t-2}} + \underbrace{\begin{bmatrix} \epsilon_{V_t} \\ \epsilon_{Y_t} \\ \epsilon_{Z_t} \end{bmatrix}}_{\epsilon_t} \quad (7A)$$

This estimation implies that there are twenty-four coefficients (included in B, C, D, F) to be estimated in the VAR (4A). The variance-covariance matrix in the SVAR[30], is equal to[31]:

$$\Sigma_\epsilon = \frac{\epsilon'\epsilon}{n-k} = \frac{1}{n-k}\begin{bmatrix} \epsilon_{V_t}'\epsilon_{V_t} & 0 & 0 \\ 0 & \epsilon_{Y_t}'\epsilon_{Y_t} & 0 \\ 0 & 0 & \epsilon_{Z_t}'\epsilon_{Z_t} \end{bmatrix} = \begin{bmatrix} Var(\epsilon_V) & Cov(\epsilon_V, \epsilon_Y) & Cov(\epsilon_V, \epsilon_Z) \\ Cov(\epsilon_Y, \epsilon_V) & Var(\epsilon_{Y_t}) & Cov(\epsilon_Y, \epsilon_Z) \\ Cov(\epsilon_Z, \epsilon_V) & Cov(\epsilon_Z, \epsilon_Y) & Cov(\epsilon_Z) \end{bmatrix} = \begin{bmatrix} \sigma_V^2 & 0 & 0 \\ 0 & \sigma_Y^2 & 0 \\ 0 & 0 & \sigma_Z^2 \end{bmatrix}$$

(8A)

The general form of equations (5A) and (6A) do not change due to these restrictions. Given (6A), the SVAR can be expressed as a VAR:

$$X_t = M + NX_{t-1} + PX_{t-2} + e_t \quad (9A)$$

Then, in (9A)

$M = A^{-1}C$

$N = A^{-1}D$

$P = A^{-1}F$

$e_t = A^{-1}\epsilon_t$.

The problem consists in use the observed values of e_t assuming restrictions to the system to recover the values of ϵ_t given that $\epsilon_t = Ae_t$. Also, the restrictions must preserve the structure of ϵ_{it}.

If we take (1A) as the original equations, the VAR equations can be expressed as:

[30] Considering that in the SVAR is supposed that the structural innovations are orthogonal (no covariance between the variables to estimate).

[31] In this case, *n* corresponds to the quarters to estimate in the VAR and *k* is the number of variables (including the constant term).

$$V_t = m_{10} + n_{11}V_{t-1} + n_{12}Y_{t-1} + n_{13}Z_{t-1} + p_{11}V_{t-2} + p_{12}Y_{t-2} + p_{13}Z_{t-2} + e_{1t} \qquad (10A)$$

$$Y_t = m_{20} + n_{21}V_{t-1} + n_{22}Y_{t-1} + n_{23}Z_{t-1} + p_{21}V_{t-2} + p_{22}Y_{t-2} + p_{23}Z_{t-2} + e_{2t} \qquad (11A)$$

$$Z_t = m_{30} + n_{31}V_{t-1} + n_{32}Y_{t-1} + n_{33}Z_{t-1} + p_{31}V_{t-2} + p_{32}Y_{t-2} + p_{33}Z_{t-2} + e_{3t} \qquad (12A)$$

In other words:

$$\underbrace{\begin{bmatrix} V_t \\ Y_t \\ Z_t \end{bmatrix}}_{X_t} = \underbrace{\begin{bmatrix} m_{10} \\ m_{20} \\ m_{30} \end{bmatrix}}_{M} + \underbrace{\begin{bmatrix} n_{11} & n_{12} & n_{13} \\ n_{21} & n_{22} & n_{23} \\ n_{31} & n_{32} & n_{33} \end{bmatrix}}_{N} \underbrace{\begin{bmatrix} V_{t-1} \\ Y_{t-1} \\ Z_{t-1} \end{bmatrix}}_{X_{t-1}} + \underbrace{\begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}}_{P} \underbrace{\begin{bmatrix} V_{t-2} \\ Y_{t-2} \\ Z_{t-2} \end{bmatrix}}_{X_{t-2}} + \underbrace{\begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{bmatrix}}_{e_t}$$

$$X_t = M + NX_{t-1} + PX_{t-2} + e_t \qquad (13A)$$

So, there are twenty-one coefficients to estimate (in M, N, P). Given the SVAR restrictions in (7A) and the VAR in (8A) and (13A), the coefficients of the VAR given the original SVAR are:

$$A^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ -a_{21} & 1 & 0 \\ a_{21}a_{32} - a_{31} & -a_{32} & 1 \end{bmatrix}$$

$$M = \begin{bmatrix} 1 & 0 & 0 \\ -a_{21} & 1 & 0 \\ a_{21}a_{32} - a_{31} & -b_{32} & 1 \end{bmatrix} \begin{bmatrix} c_{10} \\ c_{20} \\ c_{30} \end{bmatrix} = \begin{bmatrix} c_{10} \\ c_{20} - a_{21}c_{10} \\ c_{30} - a_{32}c_{20} - c_{10}(a_{31} - a_{21}a_{32}) \end{bmatrix}$$

$$N = \begin{bmatrix} 1 & 0 & 0 \\ -a_{21} & 1 & 0 \\ a_{21}a_{32} - a_{31} & -b_{32} & 1 \end{bmatrix} \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}$$

$$= \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} - a_{21}d_{11} & d_{22} - a_{21}d_{12} & d_{23} - a_{21}d_{13} \\ d_{31} - a_{32}d_{21} - d_{11}(a_{31} - a_{21}a_{32}) + & d_{32} - a_{32}d_{22} - d_{12}(a_{31} - a_{21}a_{32}) & d_{33} - a_{32}d_{23} - d_{13}(a_{31} - a_{21}a_{32}) \end{bmatrix}$$

$$P = \begin{bmatrix} 1 & 0 & 0 \\ -a_{21} & 1 & 0 \\ a_{21}a_{32} - a_{31} & -a_{32} & 1 \end{bmatrix} \begin{bmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{bmatrix}$$

$$= \begin{bmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} - b_{21}f_{11} & f_{22} - a_{21}f_{12} & f_{23} - a_{21}f_{13} \\ f_{31} - b_{32}f_{21} - f_{11}(a_{31} - a_{21}a_{32}) & f_{32} - a_{32}f_{22} - f_{12}(a_{31} - a_{21}a_{32}) & f_{33} - a_{32}f_{23} - f_{13}(a_{31} - a_{21}a_{32}) \end{bmatrix}$$

$$e_t = \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ -a_{21} & 1 & 0 \\ a_{21}a_{32} - a_{31} & -a_{32} & 1 \end{bmatrix} \begin{bmatrix} \epsilon_{V_t} \\ \epsilon_{Y_t} \\ \epsilon_{Z_t} \end{bmatrix} = \begin{bmatrix} \epsilon_{V_t} \\ \epsilon_{Y_t} - \epsilon_{V_t}a_{21} \\ \epsilon_{Z_t} - \epsilon_{Y_t}a_{32} - \epsilon_{V_t}(a_{31} - a_{21}a_{32}) \end{bmatrix}$$

The variance-covariance matrix of the unrestricted VAR will be represented by:

$$\Sigma_e = \frac{e_t{}'e_t}{n-k} = \frac{1}{n-k} \begin{bmatrix} e_{1t}{}'e_{1t} & e_{1t}{}'e_{2t} & e_{1t}{}'e_{3t} \\ e_{2t}{}'e_{1t} & e_{2t}{}'e_{2t} & e_{2t}{}'e_{3t} \\ e_{3t}{}'e_{1t} & e_{3t}{}'e_{2t} & e_{3t}{}'e_{3t} \end{bmatrix} = \begin{bmatrix} \sigma_1^2 & cov(e_1, e_2) & cov(e_1, e_3) \\ cov(e_2, e_1) & \sigma_2^2 & cov(e_2, e_3) \\ cov(e_3, e_1) & cov(e_3, e_2) & \sigma_3^2 \end{bmatrix} \qquad (14A)$$

The identification conditions of the VAR imply that must exist the same number of parameters to estimate in the VAR and the SVAR. In the SVAR (7A), it is necessary to estimate twenty-four coefficients[32] and three parameters corresponding to the variance of the SVAR error (8A); the VAR in (13A) contains twenty-one coefficients and six parameters (14A) of Σ_e[33]. Then, the system is exactly identified because in both cases we have twenty-seven parameters to estimate.

With Σ_e it can be estimated Σ_ϵ, applying the Cholesky decomposition to Σ_e. The problem to solve will be[34]:

$$\Sigma_e = \underbrace{\begin{bmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix}}_{G} \underbrace{\begin{bmatrix} b_{11} & b_{21} & b_{31} \\ 0 & b_{22} & b_{32} \\ 0 & 0 & b_{33} \end{bmatrix}}_{G\prime} = \begin{bmatrix} b_{11}^2 & b_{11}b_{21} & b_{11}b_{31} \\ b_{11}b_{21} & b_{21}^2 + b_{22}^2 & b_{21}b_{31} + b_{22}b_{32} \\ b_{11}b_{31} & b_{21}b_{31} + b_{22}b_{32} & b_{31}^2 + b_{32}^2 + b_{33}^2 \end{bmatrix} \quad (15A)$$

The algorithm used in the Cholesky decomposition can be estimated due that a symmetric matrix (as the variance-covariance) can be expressed as $\Sigma_e = GG'$. The recursive estimation[35] of the coefficients of G will be derived through (15A); for the coefficients of G, row k:

$$g_{ki} = \frac{\Sigma_{e_{ki}} - \sum_{j=1}^{i-1} g_{ij} g_{kj}}{g_{ii}}, for\ i = 1,2,\dots,k-1; \text{ with } k > j.$$

The values of the diagonal are:

$$g_{kk} = \sqrt{\Sigma_{e_{kk}} - \sum_{j=1}^{k-1} g_{kj}^2} \quad (16A)$$

The coefficients expressed in terms of the elements of Σ_e are:

32 The elements of the diagonal in A are equal to 1 and the values upper-diagonal are zero, A contains $(n^2 - 2n)$ unknown values, being n the number of equations (three, in this case). The restrictions to solve the identification problem are $(\frac{n^2-n}{2})$.

33 The variance-covariance matrix is symmetrical, so $cov(e_2, e_1) = cov(e_1, e_2)$; $cov(e_3, e_1) = cov(e_1, e_3)$; $cov(e_3, e_2) = cov(e_2, e_3)$. Given the simmetry in Σ_e , the number of restrictions for this matrix is equal to $(\frac{n^2+n}{2})$.

34 Cameron and Trivedi, 2005; Chapra and Canale, 2006.

35 First it is estimated b_{11}, and then it is calculated b_{21} and b_{31}, and after b_{22}. With this values one can estimate b_{32} and finally b_{33}.

$$\begin{bmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix} =$$

$$\begin{bmatrix} \sqrt{\sigma_1^2} & 0 & 0 \\ \frac{cov(e_2,e_1)}{\sqrt{\sigma_1^2}} & \sqrt{\sigma_2^2 - \left(\frac{cov(e_2,e_1)}{\sqrt{\sigma_1^2}}\right)^2} & 0 \\ \frac{cov(e_3,e_1)}{\sqrt{\sigma_1^2}} & \frac{cov(e_3,e_2) - \frac{cov(e_2,e_1) * cov(e_3,e_1)}{\sigma_1^2}}{\sqrt{\sigma_1^2 - \left(\frac{cov(e_2,e_1)}{\sqrt{\sigma_1^2}}\right)^2}} & \sqrt{\sigma_3^2 - \frac{cov(e_3,e_1)}{\sqrt{\sigma_1^2}} - \frac{cov(e_3,e_2) - \frac{cov(e_2,e_1) * cov(e_3,e_1)}{\sigma_1^2}}{\sqrt{\sigma_1^2 - \left(\frac{cov(e_2,e_1)}{\sqrt{\sigma_1^2}}\right)^2}}} \end{bmatrix}$$

$$= \begin{bmatrix} \sqrt{\sigma_1^2} & 0 & 0 \\ \frac{cov(e_2,e_1)}{b_{11}} & \sqrt{\sigma_2^2 - (b_{21})^2} & 0 \\ \frac{cov(e_3,e_1)}{b_{11}} & \frac{cov(e_3,e_2) - b_{21}b_{31}}{b_{22}} & \sqrt{\sigma_3^2 - (b_{31})^2 - (b_{32})^2} \end{bmatrix}$$

The elements of the square of Choleski are Σ_ϵ, the components of the of the SVAR. These elements can be represented in a matrix *B*, that lets calculate $\Sigma_\epsilon = BB'$:

$$\Sigma_\epsilon = \underbrace{\begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix}}_{B} \underbrace{\begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix}}_{B\prime} = \begin{bmatrix} b_{11}^2 & 0 & 0 \\ 0 & b_{22}^2 & 0 \\ 0 & 0 & b_{33}^2 \end{bmatrix} \qquad \text{(16A)}$$

If we want to recover the contemporary effects (*A*), we can use $\Sigma_e = A^{-1}\Sigma_\epsilon(A^{-1})'$ and the results of the Choleski decomposition:

$$\begin{bmatrix} b_{11}^2 & b_{11}b_{21} & b_{11}b_{31} \\ b_{11}b_{21} & b_{21}^2 + b_{22}^2 & b_{21}b_{31} + b_{22}b_{32} \\ b_{11}b_{31} & b_{21}b_{31} + b_{22}b_{32} & b_{31}^2 + b_{32}^2 + b_{33}^2 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ -a_{21} & 1 & 0 \\ a_{21}a_{32} - a_{31} & -a_{32} & 1 \end{bmatrix} \begin{bmatrix} b_{11}^2 & 0 & 0 \\ 0 & b_{22}^2 & 0 \\ 0 & 0 & b_{33}^2 \end{bmatrix} \begin{bmatrix} 1 & -a_{21} & a_{21}a_{32} - a_{31} \\ 0 & 1 & -a_{32} \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} b_{11}^2 & -a_{21}b_{11}^2 & b_{11}^2(a_{21}a_{32} - a_{31}) \\ -a_{21}b_{11}^2 & a_{21}^2b_{11}^2 + b_{22}^2 & -a_{21}b_{11}^2(a_{21}a_{32} - a_{31}) - a_{32}b_{22}^2 \\ b_{11}^2(a_{21}a_{32} - a_{31}) & -a_{21}b_{11}^2(a_{21}a_{32} - a_{31}) - a_{32}b_{22}^2 & -b_{11}^2(a_{21}a_{32} - a_{31})^2 + b_{33}^2 + {a_{32}}^2 b_{22}^2 \end{bmatrix}$$

This situation let us estimate the coefficients of A^{-1}, considering the numerical values of the Choleski decomposition:

$$b_{11}b_{21} = -a_{21}b_{11}^2 \rightarrow -a_{21} = \frac{b_{21}}{b_{11}}$$

$$b_{11}b_{31} = b_{11}^2(a_{21}a_{32} - a_{31}) \rightarrow (a_{21}a_{32} - a_{31}) = \frac{b_{31}}{b_{11}}$$

$$b_{21}b_{31} + b_{22}b_{32} = -a_{21}b_{11}^2(a_{21}a_{32} - a_{31}) - a_{32}b_{22}^2 \rightarrow -a_{32} = \frac{b_{32}}{b_{22}}$$

$$A^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ b_{21}/b_{11} & 1 & 0 \\ b_{31}/b_{11} & b_{32}/b_{22} & 1 \end{bmatrix} \rightarrow A = (A^{-1})^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ -b_{21}/b_{11} & 1 & 0 \\ (b_{21}b_{32} - b_{22}b_{31})/(b_{11}b_{22}) & -b_{32}/b_{22} & 1 \end{bmatrix}$$

$$C = AM =$$

$$\begin{bmatrix} 1 & 0 & 0 \\ -b_{21}/b_{11} & 1 & 0 \\ (b_{21}b_{32} - b_{22}b_{31})/(b_{11}b_{22}) & -b_{32}/b_{22} & 1 \end{bmatrix} \begin{bmatrix} m_{10} \\ m_{20} \\ m_{30} \end{bmatrix} = \begin{bmatrix} m_{10} \\ m_{20} - \left(b_{21}m_{10}/b_{11} \right) \\ m_{30} - \left(b_{32}m_{20}/b_{22} \right) + m_{10}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) \end{bmatrix}$$

$$D = AN = \begin{bmatrix} 1 & 0 & 0 \\ -b_{21}/b_{11} & 1 & 0 \\ (b_{21}b_{32} - b_{22}b_{31})/(b_{11}b_{22}) & -b_{32}/b_{22} & 1 \end{bmatrix} \begin{bmatrix} n_{11} & n_{12} & n_{13} \\ n_{21} & n_{22} & n_{23} \\ n_{31} & n_{32} & n_{33} \end{bmatrix}$$

$$= \begin{bmatrix} n_{11} & n_{12} & n_{13} \\ n_{21} - \left(b_{22}n_{11}/b_{11} \right) & n_{22} - \left(b_{21}n_{12}/b_{11} \right) & n_{23} - \left(b_{21}n_{13}/b_{11} \right) \\ n_{31} - \left(b_{32}n_{21}/b_{22} \right) + n_{11}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) & n_{32} - \left(b_{32}n_{22}/b_{22} \right) + n_{12}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) & n_{33} - \left(b_{32}n_{23}/b_{22} \right) + n_{13}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) \end{bmatrix}$$

$$F = AP = \begin{bmatrix} 1 & 0 & 0 \\ -b_{21}/b_{11} & 1 & 0 \\ (b_{21}b_{32} - b_{22}b_{31})/(b_{11}b_{22}) & -b_{32}/b_{22} & 1 \end{bmatrix} \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}$$

$$= \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} - \left(b_{22}p_{11}/b_{11} \right) & p_{22} - \left(b_{21}p_{12}/b_{11} \right) & p_{23} - \left(b_{21}p_{13}/b_{11} \right) \\ p_{31} - \left(b_{32}p_{21}/b_{22} \right) + p_{11}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) & p_{32} - \left(b_{32}p_{22}/b_{22} \right) + p_{12}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) & p_{33} - \left(b_{32}p_{23}/b_{22} \right) + p_{13}\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) \end{bmatrix}$$

$$\epsilon_t = Ae_t = \begin{bmatrix} 1 & 0 & 0 \\ -b_{21}/b_{11} & 1 & 0 \\ (b_{21}b_{32} - b_{22}b_{31})/(b_{11}b_{22}) & -b_{32}/b_{22} & 1 \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} e_1 \\ e_2 - \left(b_{21}e_1/b_{11} \right) \\ e_3 - \left(b_{32}e_2/b_{22} \right) + e_1\left(b_{21}b_{32} - b_{22}b_{31}/b_{11}b_{22} \right) \end{bmatrix}$$

The stability of the system is achieved if al the variables has weak stationarity; in other words, if with the initial conditions all the roots of the characteristic equation of the lag polynomial are outside of the unitary circle[36]. In our case, the VAR equation is given by 13A, so $\det(I_k - Nz - Pz^2) \neq 0$ for $|z| \leq 1$.

With the condition explained before, the VAR transformation in a MA(∞) process it can be obtained the impulse-response function[37].

$$X_t = M + (N + LP)X_{t-1} + e_t$$

$$\underbrace{(I_k - LN - L^2P)}_{R} X_t = M + e_t$$

[36] Kirchgässner and Wolters, 2007.

[37] To ease the mathematical operations, the lag operator is used, so $X_{t-i} = L^i X_t$. Then, $X_t = M + NX_{t-1} + PX_{t-2} + e_t = M + NX_{t-1} + PLX_{t-1} + e_t = M + (N + LP)X_{t-1} + e_t$.

$$X_t = \underbrace{R^{-1}M}_{\mu} + R^{-1}e_t = \mu + e_t - h_1e_{t-1} - h_2e_{t-2} - h_3e_{t-3} - \cdots$$ [38]

The same process can be described as a realization of consecutive iterations in the model, given (9A):

$$X_t = M + (N + LP)X_{t-1} + e_t \qquad (17A)$$

$$X_{t-1} = M + (N + LP)LX_{t-1} + Le_t \quad (18A)$$

The first iteration is[39]:

$$X_t = M + (N + LP)[M + (N + LP)LX_{t-1} + Le_t] + e_t$$

$$X_t = [I_k + (N + LP)]M + L(N + LP)^2X_{t-1} + [L(N + PL) + 1]e_t$$

In the second iteration we obtain:

$$X_t = [I_k + (N + LP)]M + L(N + LP)^2[M + L(N + LP)X_{t-1} + Le_t] + [L(N + PL) + 1]e_t$$

$$X_t = [I_k + (N + LP) + L(N + LP)^2]M + L^2(N + LP)^3X_{t-1} + [L^2(N + LP)^2 + L(N + LP) + 1]e_t$$

Then, to estimate the *nth* iteration, it is convenient to express the process with:

$$X_t = M\sum_{i=0}^{n}[L(N + LP)]^i + [L(N + LP)]^{n+1}X_t + \sum_{i=0}^{n}[L(N + LP)]^i e_t$$

$$\left[I_k - \left(L(N + LP)\right)^{n+1}\right]X_t = M\sum_{i=0}^{n}[L(N + LP)]^i + \sum_{i=0}^{n}[L(N + LP)]^i e_t$$

$$X_t = \underbrace{\left[I_k - \left(L(N + LP)\right)^{n+1}\right]^{-1} M\sum_{i=0}^{n}[L(N + LP)]^i}_{\delta} + \underbrace{\left[I_k - \left(L(N + LP)\right)^{n+1}\right]^{-1} \sum_{i=0}^{n}[L(N + LP)]^i}_{\varphi} e_t$$

(19A)

The convergence of the process in (19A) requires reducing $(N + P)^n$ as n is near to infinity[40]; if this stability is observed, one can write the solution for X_t as:

$$X_t = \delta + \varphi e_t = \delta + e_t - \mu_1e_{t-1} - \mu_2e_{t-2} - \mu_3e_{t-3} \ldots \qquad (20A)$$

[38] $R = I_k - NL - L^2P$
[39] I_k is a identity matrix with dimension *k*x*k*, with k equal to the number of variables to include in the VAR.
[40] Given that $M\sum_{i=0}^{n}[L(N + LP)]^i$, has only constant terms (the VAR coefficients), it is supposed that the lag term is equal to 1, because a constant has no lags.

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