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ASYMMETRIC EXCHANGE RATE PASS-THROUGH: EVIDENCE FROM COLOMBIA BASED IN A TVAR MODEL

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ASYMMETRIC EXCHANGE RATE PASS-THROUGH: EVIDENCE FROM COLOMBIA BASED IN A TVAR MODEL*

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Abstract

In this paper we assess the asymmetric responses of the inflation rate to nominal exchange rate shocks in Colombia. To this end, we estimate a Threshold VAR (TVAR) along with a Generalized Impulse Response Function (GIRF) framework. The empirical evidence illustrates the existence of two regimes (low and high nominal exchange rate levels) and that nominal exchange rate shocks have different effects on the inflation rate depending from the regime which the shock departs.

Keywords: asymmetries, pass-through, exchange rate, inflation, TVAR, nonlinearities, Colombia; JEL: C32, E31, E40.

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Resumen

En el presente artículo se estudian las respuestas asimétricas de la inflación ante choques en la tasa de cambio nominal en Colombia. Para este fin, se estima un modelo VAR por Umbrales (TVAR) junto con un marco de Funciones de Impulso Respuesta Generalizadas (GIRF). La evidencia empírica sugiere la existencia de dos regímenes (niveles alto y bajo de la tasa de cambio nominal) y la existencia de respuestas distintas de la inflación a choques en la tasa de cambio nominal, dependiendo del régimen de donde parte el choque.

Palabras clave: asimetrías, pass-through, tasa de cambio, inflación, TVAR, no linealidades, Colombia; JEL: C32, E31, E40.

1. INTRODUCTION

The Exchange Rate Pass-Trough (ERPT) is the degree to which exchange rate changes are passed on into aggregate prices. It is a topic of interest for many economists and policymakers. The study of the degree and timing of ERPT is important because, it helps to understand the inflation dynamics, which is a key issue for modern central banks as well as for firms and households (An & Wang, 2012).

However, as it is shown in Aleem and Lahiani (2014), the ERPT literature has seen the use of mainly three econometric techniques, the single equation regression, stationary vector autoregression (VAR) and cointegration. In the univariate process, the domestic prices are assumed to be exogenously determined by the exchange rate shocks, while, the VAR methodology has the advantage of measuring simultaneous relationships between exchange rate and other variables. Thus, this methodology (VAR) has been widely used to examine the exchange rate pass-through (PT). Nevertheless, conventional linear VAR models fail when the underlying data generative process follows nonlinear dynamics and this is often the case in macroeconomics (Cárdenas-Hurtado et al., 2018). Given the presence of nonlinearities in the exchange rate PT, linear modeling techniques may give imprecise exchange rate PT coefficients (Aleem & Lahiani, 2014). In consequence, a Threshold Vector

Autoregression (TVAR) model (which is able to capture nonlinearities in the data set) was estimated, using Colombian data from 1999-Q1 to 2018-Q2. The threshold variable is set to be the detrended nominal exchange rate (NER), mostly because Colombia is a small, open, commodities-exporter country, so the exchange rate is determined mainly by exogenous factors. The value of this variable determines the switches between regimes.

The study of the ERPT dynamics in commodity-exporter countries, such as Colombia, is very important, because, the price of imported tradeable goods can respond much more to a devaluation than in non-commodity-exporter country, and consequently total inflation increases more. For example, Colombian imported goods correspond to 30% of the producer price index, the main imported consumer goods represent 9% of the consumer price index (CPI) and total tradeable goods constitute 38% of the CPI (Rincón-Castro & Rodríguez-Niño, 2016).

That is why it is important to study the possible asymmetric ERPT dynamics in the Colombian economy, in order to asses, in a much more realistic way, the inflationary pressures derived from a nominal exchange rate devaluation. Symmetric ERPT implies that a shock of sizeon the exchange rate has exactly the opposite effect on inflation ofbut, usually this does not happen. Rincón-Castro and Rodríguez-Niño (2016) show that most of the international and Colombian empirical literature has concluded almost unanimously that the PT is incomplete, and recently that it is endogenous, nonlinear and asymmetric in both the short and the long terms, as shown by González et al. (2008) for Colombia and Donayre and Panovska (2016) for Canada and Mexico. Moreover, Rincón-Castro and Rodríguez-Niño (2016) present at least three transmission channels of exchange rate shocks on inflation, two of them direct and one indirect, which can lead to possible asymmetries in the PT. The first (direct) channel acts through the direct effect of the exchange rate fluctuations on import prices and then on producer prices. The second channel is the direct effect on prices of imported consumer goods, and which directly impacts the CPI (i,e. imported consumption channel). The indirect channel works through disturbances that impact the aggregate demand and the CPI (through the Phillips' curve).

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The empirical results suggest the existence of two regimes —low and high nominal exchange rate levels—. The results also suggest that there are asymmetric responses of the inflation rate to nominal exchange rate shocks, depending in the direction of the shock and the regime where it happens.

This paper is structured as follows: Section 1 which is the present introduction. Section 2 presents the literature review. Section 3 describe the data and the empirical strategy. Results and conclusions are presented in sections 4 and 5, respectively.

2. LITERATURE REVIEW

This section explores some of the existing literature about the ERPT dynamics both in Colombia and in other countries. A first example can be found in An and Wang (2012), who estimate ERPT into import, producer and consumer price indexes for nine OECD countries, using a Vector Autoregression with sign restrictions. The authors find that ERPT is less than one at both short and long horizons. They also present that ERPT is greatest for import price index and smallest for consumer price index. Finally, the authors find that the ERPT is greater in small economies with high import share, persistent exchange rate, volatile monetary policy and a high inflation rate. The above mentioned is consistent with three episodes of devaluation in Korea (1997), Uruguay (2002), and the U.K. (1992) presented by Burstein et al. (2005). Korea and Uruguay experienced large devaluations that were followed by contractions in aggregate economic activity. In Korea, inflation remained stable after the devaluation. In contrast, in Uruguay, inflation rose substantially after the devaluation. The UK devaluation was relatively small and was followed by a mild expansion and stable inflation (Burstein et al., 2005).

The empirical evidence for Colombia shows the existence of a nonlinear, state-dependent and shock-dependent PT. Rincón-Castro and Rodríguez-Niño (2016), using a Logistic Smooth Transition VAR (LST-VAR) estimated by Bayesian methods, find that PT is incomplete, endogenous, nonlinear and asymmetric in the short and long terms to exchange rate shocks and to the state of the economy. Moreover, Rincón-Castro et al. (2017) using a linear structural VAR shows that the transmission of the exchange rate to the aggregate prices (ERPT) is shock-dependent, this means that the size of the ERPT depends on the type of disturbances over the exchange rate. The authors also show that the disturbances of the oil price explain, to a large extent, the behavior of the NER (Rincón-Castro et al., 2018).

Other studies of the PT dynamics, specifically in Colombia, can be found in Rincón (2000) and Rincón et al., (2007). In Rincón (2000) the author studies the PT effects on export and import prices as well as in the aggregate price level of the Colombian economy. He found that the long run effects are incomplete for export and import prices and that the absolute purchase parity hypothesis is not true. The author also presents that a devaluation increases the import and export prices in an estimate value of 7.0% y 63.0% respectively. On the other hand, Rincón et al., (2007) quantifies the exchange rate PT effects on import prices within a sample of manufactured imports. They also evaluate the effects of the exchange rate and inflation regimes on the PT degree. They find evidence of the variability and different degrees of PT among manufacturing sectors, which leads to think that there are asymmetrical responses of inflation to shocks on the nominal exchange rate.

Meanwhile, Parra-Alvarez (2008) performs an approximation of the ERPT over the CPI of Colombia. He founds that a nominal devaluation of 10% imply an approximate increase in the CPI of 2.82%, and as it is shown in Parra-Alvarez (2008) and Miller et al. (2003) there are different transmission channels from a shock in the nominal exchange rate to inflation.

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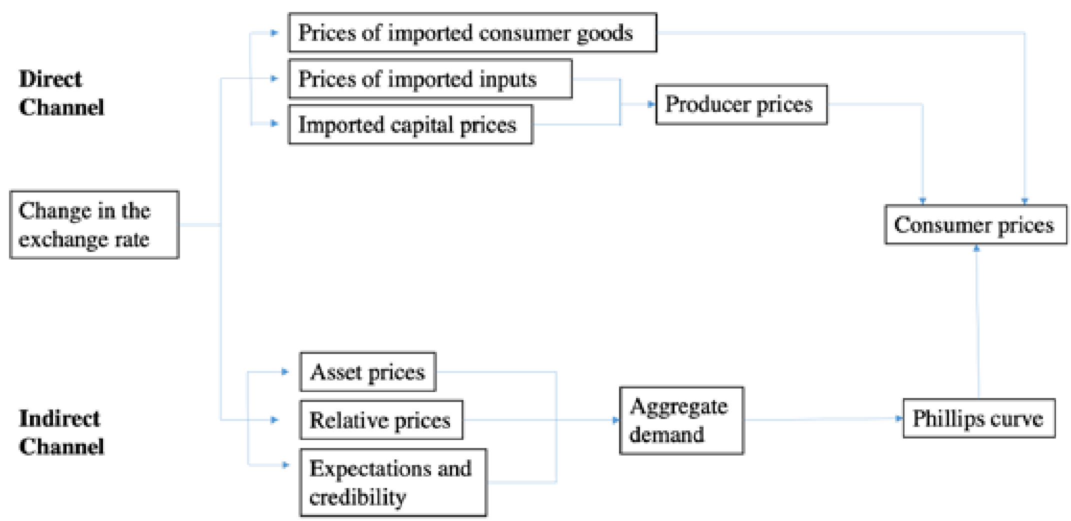
FIGURE 1: *Transmission Channels of a Shock in the Exchange Rate*



Source: Parra-Alvarez (2008) and Miller et al. (2003).

Figure 1 shows the existence of different Transmission channels from a shock in the exchange rate to the CPI, that can generate asymmetrical responses of the PT.

3. EMPIRICAL FRAMEWORK

This section describes the data used in the empirical exercise, the unit root and non-linearity tests, the econometric framework, the estimation procedures, and the computation of nonlinear impulse response functions.

3.1. Data Description

Quarterly data from 1999-Q1 to 2018-Q2 was used and consists of the inflation rate (π), the output gap (GAP) to capture demand shocks and is measured by the industrial production index detrended by quadratic time trends as in An and Wang (2012), the Nominal Exchange Rate (NER) detrended by quadratic time trends which captures deviations of the exchange rate from its trend, the oil price (Oil) measured by the price in dollars per barrel of Brent crude oil detrended by quadratic time trends, the detrended terms of trade (ToT), and the policy interest rate (i). The inflation rate, the nominal exchange rate, the industrial production index, the terms of trade and the policy interest rate are taken from Banco de la República (Central Bank of Colombia). The Brent price is taken from the Federal Reserve Economic Data (FRED) of the Federal Reserve Bank of St. Louis.

As in An and Wang (2012) output gap acts as a proxy for demand fluctuations over business cycles and it indicates if the economy is growing faster or slower than the trend. The oil price is a very important variable and it is included because, as it is shown in Gómez-González et al. (2017) there is a bidirectional causality between oil prices and exchange rates, moreover, causality is identified for longer periods of time from oil prices to exchange rates, also, there is evidence that in oil producing countries the fiscal policy has been pro-cyclical and has hence exacerbated the fluctuations in economic activity and that a small reduction in oil prices could lead to very large financing needs in the near future (Lopez-Murphy and Villafuerte 2010). Similarly, the terms of trade drive the business cycle and have a direct impact on the macroeconomic conditions in commodity-exporter countries such as Colombia (Cárdenas-Hurtado et al., 2018) and, the policy interest rate is included because some central banks adjust its policy rate in response to exchange rate movements (Clarida et al., 1998). Some descriptive statistics of the series are presented in the next section. A graph of the (detrended) series used is presented in the Appendix section (Figure A.1).

3.2. Unit Roots Tests

An augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979; 1981) was conducted for each one of the series, where the null hypothesis is the presence of unit root, with the purpose of testing for non-stationary series in the dataset. The ADF test is written as follows:

$$\Delta y_t = \rho y_{t-1} + \sum_{i=1}^{P} \gamma_i \Delta y_{t-i} + e_t$$

Where, (ρ) is the unit root parameter and (γ_i) are the autoregressive coefficients.

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The lag length P is set to be compatible with the Akaike Information Criterion (AIC) (Akaike, 1981), which is the most widely used information criterion in the empirical literature of model selection. The results for the unit root estimated test statistics and p-values are presented in the next section.

3.3. Non-linearity Tests

A multivariate non-linearity test was also conducted following the approach proposed by Lo and Zivot (2001), which is a multivariate extension of the tests proposed by Hansen (1997; 1999). The authors test the following statistic under the null hypothesis of linearity, against the alternative of a TVAR(m):

$$LR_{1,m} = T \times \left[\ln\left(|\hat{\Sigma}|\right) - \ln\left(|\hat{\Sigma}_m(\hat{\gamma}, \hat{d})|\right)\right]$$

Where $\hat{\Sigma}$, and $\hat{\Sigma}_m(\hat{\gamma}, \hat{d})$ are the estimated residual covariance matrices from the linear $\mathbf{VAR}(m)$ and the nonlinear $\mathbf{TVAR}(m)$, respectively. The asymptotic distribution for $LR_{1,m}$ is approximated using bootstrap methods (Hansen, 1996).

TVAR models are regime dependent linear VAR models with different autoregressive coefficient matrices for each regime. Switching between regimes depends on the value of a (lagged) stationary and continuous transition variable; z_{t-d} (Cárdenas-Hurtado et al., 2018). In this paper z_{t-d} is set to be the (detrended) nominal exchange rate (NER), mostly because Colombia is a small, open, commodities-exporter country, so the exchange rate is determined mainly by exogenous factors.

The number of lags in the linear VAR is set at the shortest lag length that can produce white noise residuals, which turns out to be $P = 2$. Since $d \leq P, d$ is also set as $d = 2$. Moreover, 1000 simulations were run for the bootstrap exercise in order to approximate the asymptotic distribution for $LR_{1,m}$. The results for the non-linearity test are shown in the next section.

3.4. The Threshold Vector Autoregression (TVAR) Model

Since the objective of this paper is to explore the asymmetric responses of the inflation rate to nominal exchange rate shocks, a nonlinear multivariate time series model that captures those features, such as the threshold vector autoregressive (TVAR) model, was considered.

Conventional linear VAR models fail when the underlying data generative process follows nonlinear dynamics, and this is often the case in macroeconomics. The responses of some macroeconomic variables to specific shocks are state dependent and asymmetric (Cárdenas-Hurtado et al., 2018). That is why a TVAR model as in Tsay (1998) was estimated. The TVAR model is a multivariate extension of the threshold autoregressive (TAR) model developed by Tong and Lim (1980); Tong (1983) and Tong (1990).

Said that, the nonlinear TVAR() can be defined as in Cárdenas-Hurtado et al., (2018) in the form

$$y_t = c^{(i)} + \sum_{p=1}^{P} \Gamma_p^{(i)} y_{t-i} + e_t, \text{ whenever } \gamma_{i-1} < z_{t-d} \leq \gamma_i, \text{ for each } i = 1, \dots, I, \quad (1)$$

where y_t is an 6×1 vector of variables $[\text{Oil}, \text{NER}, \text{ToT}, \text{GAP}, \pi, \text{i}]'$, $c^{(i)}$ is a vector of $K \times 1$ constants and $\Gamma_p^{(i)}$ is a matrix of $K \times K$ coefficients, both orresponding to regime $i \in I$. Finally, e_t is a $K \times 1$ vector of innovations with zero mean and co-variance matrix equal to Σ_e. An aggregate representation of the nonlinear TVAR can be written as

$$y_t = \sum_{i=1}^{I} \left[\left(c^{(i)} + \sum_{p=1}^{P} \Gamma_p^{(i)} y_{t-i} + e_t \right) \times \mathbb{I}_{\gamma_{i-1},\gamma_i}(z_{t-d}) \right], \quad (2)$$

where $\mathbb{I}_{\gamma_{i-1},\gamma_i}(z_{t-d})$ is the indicator function that takes value of 1 whenever z_{t-d} falls in the interval $(\gamma_{i-1}, \gamma_i]$ along the real line (Cárdenas-Hurtado et al., 2018).

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However, in equation (2) the contemporaneous error terms are allowed to be correlated(i,e. Σ_e is not necessarily assumed to be diagonal), affecting the inferences and conclusions derived form the model estimation. That is why, the structural shocks are identified using a Cholesky decomposition for structural identification in the error covariance matrix. Thus, the structural TVAR representation is now

$$(P^{(i)})^{-1}y_t = \sum_{i=1}^{I}\left[\left(c_0^{(i)} + \sum_{p=1}^{P} B_p^{(i)} y_{t-i} + \epsilon_t\right) \times \mathbb{I}_{\gamma_{i-1},\gamma_i}(z_{t-d})\right], \quad (3)$$

where ϵ_t is a $K \times 1$ vector of structural errors, $P^{(i)}$ is an inferior triangular matrix, $c_0^{(i)} = (P^{(i)})^{-1}c_i,\ B_p^{(i)} = (P^{(i)})^{-1}\Gamma_p^{(i)}$, and $\epsilon_t = (P^{(i)})^{-1}e_t$. The results for the estimated TVAR are presented in the next section.

3.5. *The Generalized Impulse Response Function* (GIRF)

As it is shown in (Cárdenas-Hurtado et al., (2018), traditional linear impulse response functions (IRF) are not valid for nonlinear models and might provide results that lead to misleading inferences about the responses of the model in the presence of structural shocks. Indeed, for the estimated TVAR the effects of these shocks on the future path of the random variables vector depend on numerous specific initial regime/shock characteristics, such as the complete history of the vector series, the periodwhen the shock occurs, and the sign, direction, and composition of the (nonstructural) shock (Gallant et al., 1993; Koop, 1996; Koop et al., 1996; Cárdenas-Hurtado et al., 2018).

That is why a generalized impulse response function (GIRF), proposed by Koop et al. (1996) which can be applied to both linear and nonlinear models, was selected. As in Cárdenas-Hurtado et al. (2018) $\epsilon_t^{(i_t)}$ was defined as a structural shock of a specific size δ occurring under the regime i at the time t, h is the horizon, and Ω_{t-1} is the information set at the time $t-1$. The GIRF is defined such that

$$\mathrm{GIRF}\left(h, \epsilon_{t+h}^{(i_{t+h})}, \Omega_{t-1}, \hat{\theta}\right)$$

$$= \mathbb{E}\left(y_{t+h}^{\delta} \middle| \epsilon_t^{(i_t)} = \delta, \epsilon_{t+1}^{(i_{t+1})} = 0, \dots, \epsilon_{t+h}^{(i_{t+h})} = 0, \Omega_{t-1}, \hat{\theta}\right)$$

$$- \mathbb{E}\left(y_{t+h}^{\delta} \middle| \epsilon_t^{(i_t)} = 0, \epsilon_{t+1}^{(i_{t+1})} = 0, \dots, \epsilon_{t+h}^{(i_{t+h})} = 0, \Omega_{t-1}, \hat{\theta}\right), \quad (4)$$

where the initial regime i_t is determined by ω_{t-1},, and i_t is not necessarily the same as $i_{t+1}, \dots, i_{t+h}$. Since the ERPT may be strongly associated with other variables in the system such as the oil price, the policy interest rate or the output gap, other Generalized Impulse Response Functions (GIRFs) were conducted, in order to assess the possible responses of those other variables to different shocks. The results of the GIRFs are presented in the next section.

4. RESULTS

As already mentioned, this section displays the main results of the empirical exercise.

4.1. Descriptive Statistics

Some descriptive statistics of the series used are presented in Table 1. The mean of the inflation, the nominal exchange rate, the Oil price, the output gap, the terms of trade and the policy interest rate is 0.05, -0.33, -0.08, -0.03, 0.01 and 0.07, respectively. On the other hand, the standard deviations of the series are: 0.02, 386.49, 19.75, 6.86, 11.22, 0.04. Some descriptive statistics graphs are presented in the Appendix section (Figure A.2).

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TABLE 1: *Descriptive statistics*

	Mean	Median	S.D
π	0.0543	0.0517	0.0248
NER	-0.3283	32.8117	386.4949
Oil	-0.0755	-4.5514	19.7488
GAP	-0.0276	-0.8074	6.8612
ToT	0.0056	-1.4323	11.2199
i	0.0701	0.0629	0.0362

Source: Author's estimation.

4.2. Unit Roots Tests

Table 2 displays the results for the unit root estimated test statistics and p-values. For each one of the series the null hypothesis of unit root is rejected at a 10% significance level, which means that the series in the dataset are stationary.

TABLE 2: *Unit Roots tests*

	t-stat.	p-value
π	-1.6842	0.0870
NER	-2.6797	0.0079
Oil	-3.3099	0.0012
GAP	-1.9469	0.0499
ToT	-2.2366	0.0253
i	-1.7109	0.0824

Source: Author's estimation.

4.3. Non-linearity Tests

Table 3 displays that in the case of a linear VAR against a two-regime TVAR, the null hypothesis is rejected at a 10% significance level but, in the case of a linear VAR against a three-regime TVAR the null is not rejected. Therefore, it can be concluded that the appropriate model is a two-regime TVAR. However, a test of a two-regime TVAR against a three-regime TVAR was also conducted, which supports the estimation of a two-regime TVAR.

TABLE 3: Non-Linearity test results

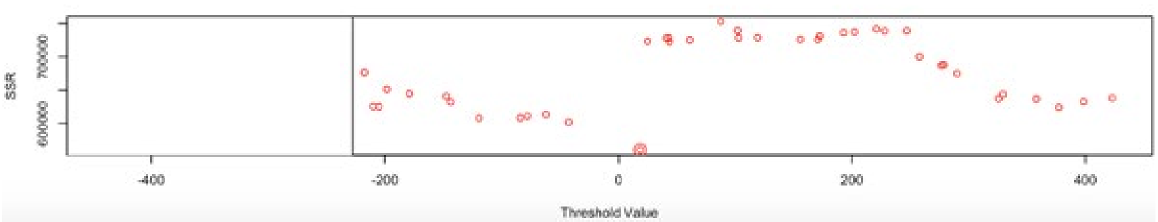
	t-stat.	p-value
VAR (1 reg.) vs TVAR (2 reg.)	166.1259	0.0960
VAR (1 reg.) vs TVAR (3 reg.)	345.6606	0.1870
TVAR (2 reg.) vs TVAR (3 reg.)	179.5348	0.5480

Source: Author's estimation.

4.4. The Threshold Vector Autoregression (TVAR) Model

For the estimation of the TVAR model, the grid search suggests that the threshold value that minimizes the SSR in the TVAR is $\hat{\gamma} = 18.607$. Figure 2 presents the SSR for each possible threshold values. As it can be seen in the figure, the threshold that minimizes the SSR is 18.607.

FIGURE 2: SSR and Possible Threshold Values, $\boldsymbol{\gamma}$



Source: Author's estimation.

Thus, Figure 3 shows the threshold variable which is the detrended nominal exchange rate and the estimated threshold value, $\hat{\gamma}$. As the threshold variable was detrended by quadratic time trends, the vertical axis represents the log-deviations from the nominal exchange rate trend. The horizontal axis represents the time.

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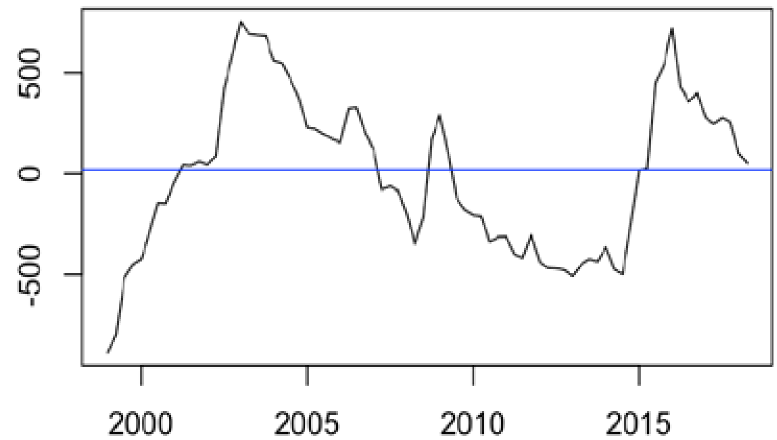
FIGURE 3: *Threshold Variable (Detrended NER) and Estimated Threshold Value*



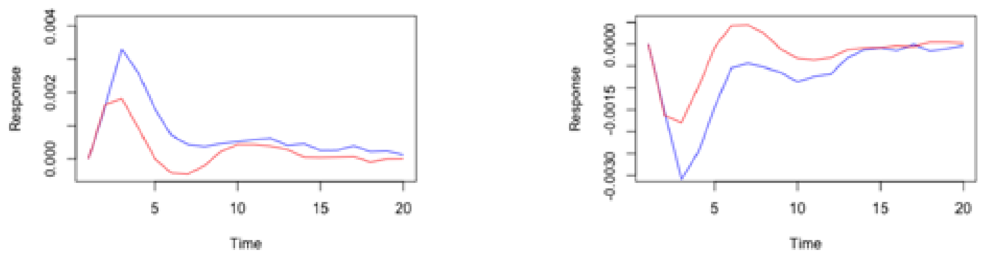
Source: Author's estimation.

In that order of ideas, the values above the blue line belong to an upper regime and values under the blue line belongs to a lower regime. The TVAR estimation results are presented in the Appendix section (Tables A.1 and A.2 for the lower and upper regimes, respectively).

4.5. The Generalized Impulse Response Function (GIRF)

Figure 4 displays the response of the inflation rate to a one standard deviation temporary (one time) shock in the detrended nominal exchange rate. Specifically, Figure 4a display the responses of π to $\mathbf{a}+1$ standard deviation shock on NER, depending if the shock occurs at an upper regime (i,e. high NER) or at a lower regime (i,e. low NER). On the other hand, Figure 4b display the response of π to $\mathbf{a}-1$ standard deviation shock on NER.

FIGURE 4: Responses of Inflation to a Nominal Exchange Rate Shock



(a) π response to a positive NER shock (b) π response to a negative NER shock

— Lower Regime — Upper Regime

Source: Author's estimation.

Results suggest that the responses of the inflation to shocks on the detrended nominal exchange rate differ between regimes but, in both regimes a positive NER shock —a devaluation of the Colombian currency— causes, as expected, an increase in the inflation rate, particularly, in the first periods after the shock. However, when the temporary shock occurs in the upper regime (the blue line), the increase in the inflation is greater than when the shock occurs in a lower regime —the red line—. On the other hand, a negative NER shock —an appreciation of the Colombian currency—, results in a decrease of the inflation rate, with asymmetric responses between regimes.

Nevertheless, as already mentioned, the ERPT may be strongly associated with other variables in the system such as the oil price, the policy interest rate or the output gap. That is why other Generalized Impulse Response Functions (GIRFs) were conducted, in order to assess the possible responses of those other variables to different shocks. Figures 5a and 5b shows the responses of the inflation to an oil price shock. Figures 5c and 5d shows the responses of the policy interest rate to a nominal exchange rate shock and finally, Figures 5e and 5f shows the response of the output gap to a nominal exchange rate shock.

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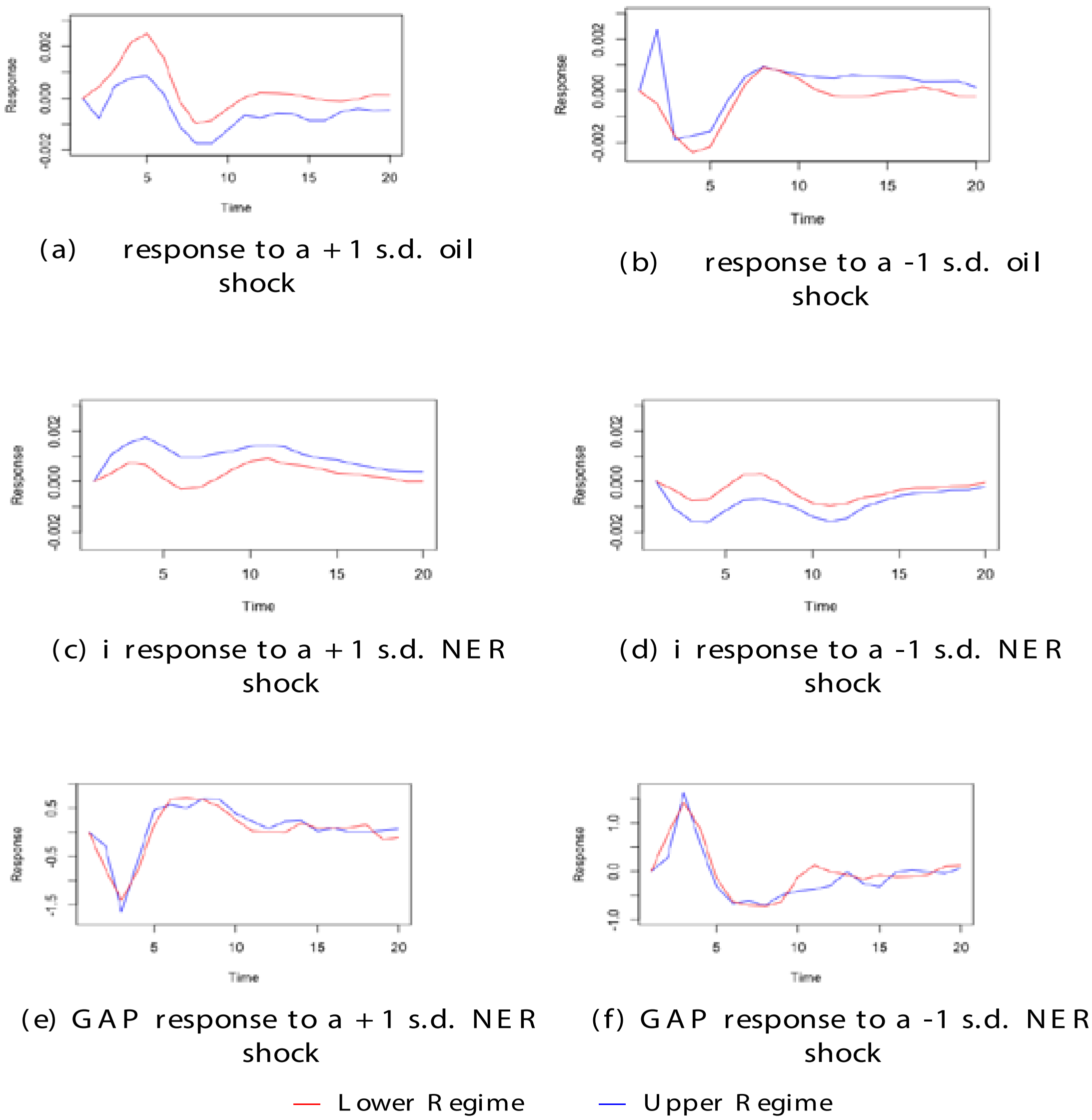
FIGURE 5: Responses of Inflation, Policy Interest Rate and Output Gap to Different Shocks



(a) response to a +1 s.d. oil shock

(b) response to a -1 s.d. oil shock

(c) i response to a +1 s.d. NER shock

(d) i response to a -1 s.d. NER shock

(e) GAP response to a +1 s.d. NER shock

(f) GAP response to a -1 s.d. NER shock

— Lower Regime — Upper Regime

Source: Author's estimation.

The results presented in Figure 5, show that the policy interest rate, , tend to increase with a positive shock in the (detrended) nominal exchange rate, NER, but it increases less than inflation because the monetary authority knows that it is a temporary shock that will disappear with time. Something similar happens with a negative NER shock, where, the policy interest ratetend to decrease, but not so much, and then it stabilizes. With respect to the output GAP, when a devaluation of the Colombian currency occurs, the immediate response is that the GAP decreases but later, it increases and ends up stabilizing. On the other hand, when an appreciation of the Colombian currency occurs, the output GAP increases, then it decreases and ends up stabilizing. Finally, the results show that a positive shock on the oil price generates inflationary pressures, while a negative shock on the oil price, in the first moments after the shock reduce the inflation for the lower regime but increase the inflation for the upper regime.

5. CONCLUSIONS

Throughout this paper, the ERPT dynamics in Colombia were explored. Specifically, we assess the asymmetric responses of the inflation to nominal exchange rate shocks. For that reason, a Threshold VAR (TVAR) model, that allows to capture the non-linearities in the data and for modeling the asymmetric effects of nominal exchange rate shocks, was employed.

The results obtained for the Colombian case suggest the existence of two regimes for the detrended nominal exchange rate. Thus, the start point of the NER shock (if it occurs during an upper regime or at a lower regime) leads to asymmetrical responses of the inflation rate. The econometric results are consistent with the expected results, since a positive NER shock increases the inflation and the policy interest rate. While a negative NER shock reduces inflation and the policy interest rate.

REFERENCES

1. Akaike, H. (1981). Likelihood of a model and information criteria. *Journal of econometrics*, 16(1), 3-14.
2. Aleem, A. & Lahiani, A. (2014). A Threshold Vector Autoregression Model of Exchange Rate PT in Mexico. *Research in International Business and Finance*, 30, 24-33.
3. An, L. & Wang, J. (2012). Exchange Rate PT: Evidence Based on Vector Autoregression with Sign Restrictions. *Open Economies Review*, 23(2), 359-380.

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Medellín, enero-diciembre 2019, 228 pp. E-ISSN 2619-6131, pp. 73-95

4. Burstein, A., Eichenbaum, M. & Rebelo, S. (2005). *Modeling exchange- rate passthrough after large devaluations*. Working Paper 11638, National Bureau of Economic Research.
5. Cárdenas-Hurtado, C. A., Garavito-Acosta, A. L. & Toro-Córdoba, J. H. (2018). *Asymmetric effects of terms of trade shocks on tradable and non- tradable investment rates: The Colombian case*. Borradores de Economía, Banco de la República Working Paper Series, 1043.
6. Clarida, R., Galí, J. & Gertler, M. (1998). Monetary Policy Rules in Practice: Some International Evidence. *European Economic Review*, 42(6), 1033-1067.
7. Dickey, D. A. and Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association*, 74(366a):427-431.
8. Dickey, D. A. &Fuller, W. A. (1981). Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica: Journal of the Econometric Society*, 49(4),1057-1072.
9. Donayre, L. & Panovska, I. (2016). State-Dependent Exchange Rate Pass-Through Behavior. *Journal of International Money and Finance*, 64, 170-195.
10. Gallant, A. R., Rossi, P. E. & Tauchen, G. (1993). Nonlinear dynamic structures. *Econometrica: Journal of the Econometric Society*, 61(4), 871-907.
11. Gómez-González, J. E., Hirs-Garzon, J. & Uribe-Gil, J. M. (2017). *Dynamic Connectedness and Causality between oil Prices and Exchange Rates*. Borradores de Economía, Banco de la República Working Paper Series, 1025.
12. González, A., Rincón, H. & Rodríguez, N. (2008). *La transmisión de los choques a la tasa de cambio sobre la inflación de los bienes importados en presencia de asimetrías*. Borradores de Economía, Banco de la República Working Paper Series, 532.
13. Hansen, B. E. (1996). Inference when a Nuisance Parameter is not Identified under the Null Hypothesis. *Econometrica: Journal of the econometric society*, 64(2), 413-430.
14. Hansen, B. E. (1997). Inference in Tar Models. *Studies in Nonlinear Dynamics and Econometrics*, 2(1), 1-14.
15. Hansen, B. E. (1999). Testing for Linearity. *Journal of Economic Surveys*, 13(5), 551-576.
16. Koop, G. (1996). Parameter Uncertainty and Impulse Response Analysis. *Journal of Econometrics*, 72(1/2),135-149.

17. Koop, G., Pesaran, M. H. & Potter, S. M. (1996). Impulse Response Analysis in Nonlinear Multivariate Models. *Journal of Econometrics*, 74(1), 119-147.
18. Lo, M. C. & Zivot, E. (2001). Threshold Cointegration and Nonlinear Adjustment to the Law of One Price. *Macroeconomic Dynamics*, 5(4), 533-576.
19. Lopez-Murphy, P. & Villafuerte, M. (2010). Fiscal Policy in Oil Producing Countries during the Recent Oil Price Cycle. IMF Working Papers.
20. Miller, S. et al. (2003). Estimación del PT del tipo de cambio a precios: 1995-2002. *Estudios Económicos*, 10.
21. Parra-Álvarez, J. C. (2008). *Sensibilidad del ipc a la tasa de cambio en Colombia: una medición de largo plazo*. Borradores de Economía; No. 542.
22. Rincón, H. (2000). Devaluación y precios agregados en Colombia, 1980-1998. *Revista Desarrollo y Sociedad*, 46,109-144. https://doi.org/10.13043/dys.46.3
23. Rincón-Castro, H. & Rodríguez-Niño, N. (2016). *Pass-Through of Exchange Rate Shocks on Inflation: A Bayesian Smooth Transition VAR Approach*. Borradores de Economía, Banco de la República Working Paper Series, 930.
24. Rincón, H., Caicedo, E. & Rodríguez, N. (2007). Exchange Rate PT Effects: A Disaggregate Analysis of Colombian Imports of Manufactured Goods. *Ensayos Sobre Política Económica*, 25(54), 90-121.
25. Rincón-Castro, H., Rodríguez-Niño, N. & Castro-Pantoja, J. (2017). *Perturbaciones macroeconómicas, tasa de cambio y pass-through sobre precios*. Borradores de Economía, Banco de la República Working Paper Series, 982.
26. Tong, H. (1983). *Threshold Models in Non-linear Time Series Analysis. Number 21 in Lecture Notes in Statistics*. New York: Springer-Verlag.
27. Tong, H. (1990). Non-linear Time Series: A Dynamical System Approach. Oxford: Oxford University Press, .
28. Tong, H. & Lim, K. S. (1980). Threshold Autoregression, Limit Cycles and Cyclical Data. *Journal of the Royal Statistical Society*. *Series B (Methodological)*, 42(3), 245-292.
29. Tsay, R. S. (1998). Testing and Modeling Multivariate Threshold Models. *Journal of the American statistical association*, 93(443), 1188-1202.

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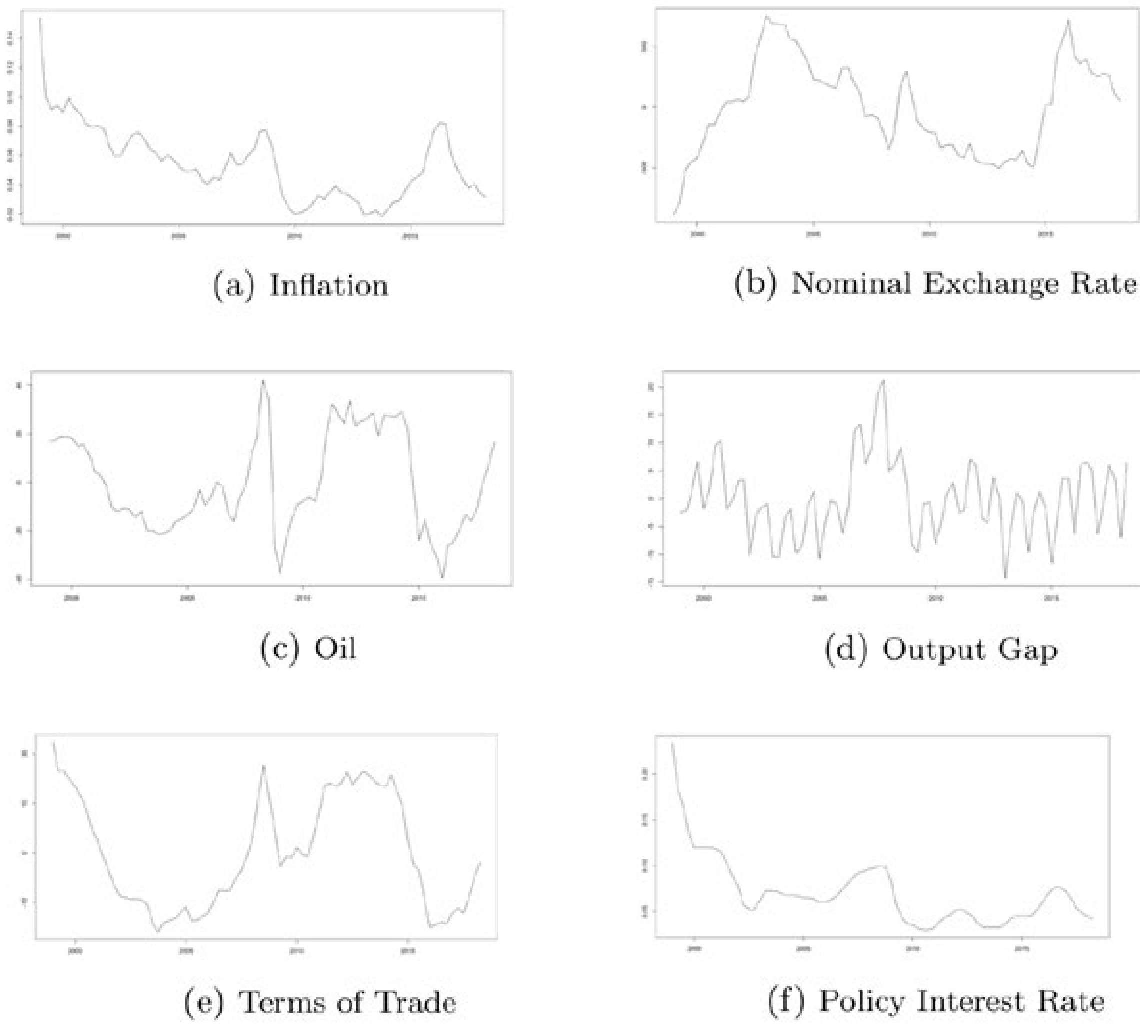
APPENDIX

FIGURE A.1: *Series*



(a) Inflation

(b) Nominal Exchange Rate

(c) Oil

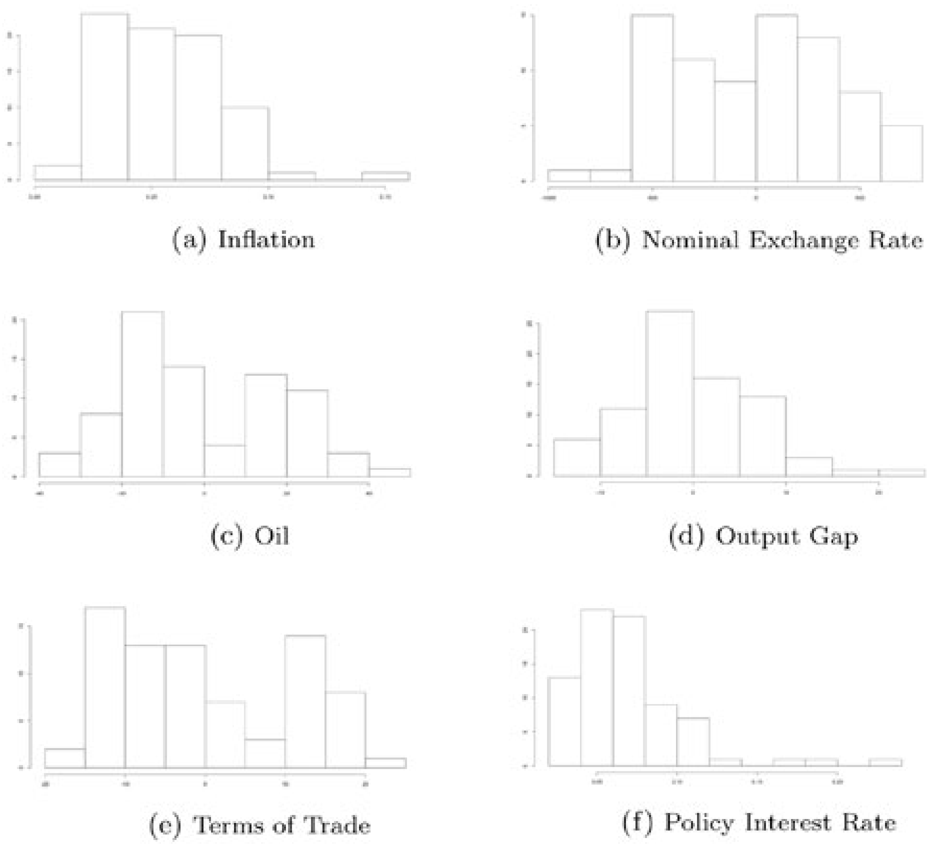
(d) Output Gap

(e) Terms of Trade

(f) Policy Interest Rate

Source: Banco de la República and Federal Reserve Bank of St. Louis.

FIGURE A.2: Descriptive Statistics Graphs



(a) Inflation
(b) Nominal Exchange Rate
(c) Oil
(d) Output Gap
(e) Terms of Trade
(f) Policy Interest Rate

Source: Author's estimation.

TABLE A.1: TVAR Estimation Results for the Lower Regime

	Intercept	Oil (-1)	NER (-1)	ToT (-1)	GAP (-1)	π (-1)	i (-1)	Oil (-2)	NER (-2)	ToT (-2)	GAP (-2)	π (-2)	i (-2)
Oil	1.158	1.499	−0.018	−1.737	−0.122	64.647	157.672	−1.102	−0.012	1.817	0.569	−287.525	−69.184
NER	−147.916	−8.095	0.664	6.238	0.951	1,578.414	−993.761	11.986	−0.129	−20.828	−3.690	4,719.121	−1,690.311
ToT	1.048	0.308	−0.007	0.290	−0.035	76.245	−146.346	−0.144	−0.007	−0.007	0.139	−68.331	111.340
GAP	−7.277	0.150	−0.009	−0.373	0.130	−50.047	696.818	−0.021	0.001	−0.387	−0.660	−32.104	−457.159
π	0.001	0.0002	0.00001	−0.001	−0.0002	1.089	0.001	0.0003	−0.00003	−0.001	−0.00002	−0.151	0.029
i	0.005	0.0003	−0.00001	−0.001	−0.00001	0.383	0.682	0.0002	−0.00000	−0.00003	0.00004	0.161	−0.120

Source: Author's estimation.

TABLE A.2:TVAR Estimation Results for the Upper Regime

	Intercept	Oil (-1)	NER (-1)	ToT (-1)	GAP (-1)	π (-1)	i (-1)	Oil (-2)	NER (-2)	ToT (-2)	GAP (-2)	π (-2)	i (-2)
Oil	−1.949	0.818	−0.002	−0.123	−0.281	−161.914	−157.290	−0.143	0.001	−0.206	0.369	5.827	224.174
NER	279.297	−2.200	0.716	1.473	0.944	2,920.731	−1,661.014	4.282	−0.278	−3.489	−9.770	4,340.085	−6,174.029
ToT	1.762	0.131	−0.001	0.732	0.027	−62.616	−69.073	−0.043	0.003	0.053	0.113	27.631	50.457
GAP	2.816	0.013	−0.007	0.572	0.249	−39.278	528.501	−0.246	−0.007	−0.457	−0.342	−204.705	−316.584
π	0.008	0.0002	0.00002	−0.001	0.00002	1.293	0.253	−0.0002	−0.00002	0.001	−0.0001	−0.589	−0.164
i	0.012	0.0001	0.00000	−0.0003	0.0002	0.267	1.258	0.00001	−0.00000	0.0001	−0.00002	−0.246	−0.486

Source: Author's estimation.