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Nonlinear Exchange Rate Pass-Through in Mexico*

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Abstract: This paper aims to investigate if the exchange rate pass-through (ERPT) to consumer prices follows a nonlinear behavior in Mexico. To look for nonlinearities, we employ a Threshold VAR approach (TVAR). The threshold allows us to differentiate regimes of "high" or "low" depreciation and the effect of exchange rate movements onto prices in each of these regimes. Our results suggest the existence of nonlinearities in Mexico only for the merchandise inflation measure, including the food and non-food subindices, with an estimated threshold that varies from an annual depreciation rate of 7.20 to 7.30 percent. Even though we find that these ERPT coefficients differ between regimes from a statistical point of view, the effect over headline inflation is small. Our results are consistent with the consolidation of a low ERPT in Mexico.

Keywords: Exchange-Rate Pass-through, Threshold VAR, Inflation, Foreign Exchange.

JEL Classification: C32, E31, F31.

Resumen: El objetivo del documento es investigar si el traspaso de las variaciones del tipo de cambio a los precios muestra un comportamiento no lineal en México. Para analizar dicha relación, se emplea un modelo de Vectores Autorregresivos con umbral (TVAR, por sus siglas en inglés). El umbral permite diferenciar regímenes de "elevada" o "baja" depreciación y el efecto de los movimientos del tipo a los precios en cada uno de esos regímenes. Los resultados sugieren la existencia de no linealidades en México para la inflación de mercancías y sus dos subíndices, con un umbral que varía entre una tasa de depreciación anual de 7.20 a 7.30%. A pesar de que se encuentran diferencias en los coeficientes de traspaso en los dos regímenes desde un punto de vista estadístico, el efecto en la inflación general es pequeño. Los resultados son consistentes con la consolidación de un bajo traspaso cambiario en México.

Palabras Clave: Elasticidad de Traspaso, VAR con umbral, Inflación, Tipo de cambio.

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1 Introduction

The real exchange rate is one of the primary and most efficient adjustment variables in an open economy, such as the Mexican one. In particular, given shocks that tend to affect the country's external accounts, adjustments in the real exchange rate lead to changes in the relative prices of tradable goods as compared to non-tradable ones. These changes, in turn, lead to adjustments in the structure of spending and production in the economy and therefore mitigate the effects of these shocks in the economic activity.

Since the 1990s, many countries have been consolidating an environment of low inflation with lower pass-through of exchange rate movements to inflation. Low inflation by itself may have been a factor leading to reduced pass-through or lower pricing power of firms.¹ However, given the role that the exchange rate has had as a shock absorber variable, and despite lower inflation rates registered in many emerging market economies, central banks, particularly in small open economies with flexible exchange rates, need to follow the impact of the exchange rate on inflation closely. In this sense, the analysis of the relationship between the exchange rate and inflation continues to be at the forefront of monetary policy, especially under an inflation targeting regime where the exchange rate is one of the monetary policy transmission channels.

In recent years, mainly after the pronounced drop in oil prices, some emerging market economies' exchange rates severely depreciated in a short period. In particular, the Mexican peso depreciated around 39% during the drop in oil prices that took place between the end of 2014 and the beginning of 2016. Given the magnitudes of these changes, the question of potential nonlinearities in the transfer of exchange rate movements to inflation gained relevance. The literature has suggested that episodes of extreme exchange rate depreciation can lead to different degrees of pass-through, such as the findings presented in Caselli and Roitman (2016) and Bussiere (2013). For this reason, this paper aims to investigate whether the exchange rate pass-through (ERPT) to consumer prices follows a nonlinear behavior in Mexico.

Although some studies have documented that pass-through of exchange rate adjustments onto inflation in Mexico has been low since the adoption of the inflation targeting regime, to the best of our knowledge, nonlinearities have not been explored yet. For instance, Capistrán et al. (2012), Cortés (2013), and Kochen and Sámano (2016) develop linear models.

In this paper, we estimate ERPT coefficients for the Mexican economy from a nonlinear approach. The framework we focus on is the threshold VAR (TVAR) methodology, following

¹See Taylor (2000).

Afonso et al. (2018), Balke (2000) and Li and St-Amant (2010). Unlike a linear VAR, this methodology allows identifying if there are different coefficients of pass-through depending if the economy is facing an environment of “low” or “high” depreciation. What defines “low” or “high” depreciation is how inflation responds to an exchange rate shock and the size of the depreciation, i.e., when the pass-through of exchange rate to inflation changes at certain level of depreciation. In this exercise, the exchange rate’s threshold value that differentiates between regimes is estimated endogenously in the model. Even if we consider a “low” and “high” depreciation regime, the model could have selected an appreciation rate as a threshold value, which would result in “low” and “high” appreciation regimes. Another possibility could have been a zero exchange rate variation as a threshold value; in this case, we would have “appreciation” and “depreciation” regimes. We consider this feature of the methodology as an advantage given that the model could have chosen all the mentioned options.

To estimate the model, we use the standard variables that are employed when modeling small open economies, such as an indicator of economic activity, inflation, the reference interest rate, and the nominal exchange rate. To account for potential differences in ERPT coefficients among inflation subindices, we analyze not only headline inflation, but also core, merchandises, services, etc.

Our results suggest that nonlinearities are only found in the merchandise inflation measure, and its food and non-food subindices. This was expected as many traded goods are in this component. Particularly, when the economy is facing an environment of low depreciation, i.e., the depreciation rate is lower than the estimated threshold, the pass-through of an additional depreciation of 1 percent raises merchandise inflation by 0.08 percentage points 12 months after, while in the environment of high depreciation merchandise inflation increases by 0.11 percentage points. Twenty-four months after the shock, the coefficients of pass-through increase to 0.17 and 0.24 percentage points in the low and high depreciation regimes, respectively. Although, from a statistical point of view, we find that the degree of pass-through is different between the two regimes for some inflation measures, the effect over the headline inflation is small. However, it is worth noting that according to our results, changes in merchandise prices relative to other goods is greater in a high depreciation environment.

The paper is organized as follows: section 2 examines the literature on exchange rate dynamics and inflation. Further, we delve into the works that seek to explain what are the conditions that lead to nonlinearities. Section 3 develops on the exchange rate dynamics in Mexico since the adoption of the inflation targeting regime and the papers that have analyzed the ERPT for Mexico. Section 4 presents the TVAR model; we explain how to derive the

nonlinear impulse response function and the estimation of the ERPT, the threshold selection, nonlinearity test, and the main results. Finally, section 5 concludes.

2 Literature review

ERPT dynamics has been widely analyzed, and it is of particular relevance for central banks given its implication for monetary policy.² Although most of the existing literature relies on linear approaches for estimating the effect of exchange rate movements to inflation, some studies have dealt with nonlinearities.³ The importance of this subject lies in the problems that can arise when nonlinearities are present but not incorporated in the analysis. Borrowing words from Bussiere (2013), if nonlinearities are strong, inference using linear models could lead to misleading conclusions.

For nonlinearities we refer to different responses of inflation to certain exchange rate variations, as explained by Caselli and Roitman (2016), Bussiere (2013), Frankel et al. (2012), among others. We will focus on a case of nonlinearities named threshold effects, which occur when the pass-through of the exchange rate to inflation changes at a certain level of depreciation. Some studies, that will be briefly described below, have analyzed asymmetric effects of appreciation and depreciation of the exchange rate on inflation, but under the approach used in this document, asymmetries are a special case of nonlinearities, i.e., when the threshold equals zero and inflation responds differently to an appreciation or depreciation. Once this distinction has been made, the question that emerges is: Why this kind of nonlinearities or asymmetries can arise? Peltzman (2000) explains that the standard literature assumes symmetric responses of prices to cost changes, even though empirical evidence is not always supportive of this behavior. In light of this situation, some authors have cited the reasons that could be behind nonlinearities or asymmetries.

Peltzman (2000) explains that prices tend to respond faster to an input-cost increase than decrease. Thus, prices seem to be rigid downwards. Bussiere (2013), Caselli and Roitman (2016), Frankel et al. (2012) explain how export prices respond to exchange rate movements. According to them, exporters gain price competitiveness after an exchange rate depreciation. Exporters can either keep export prices unchanged and increase the number of goods offered or increase export prices. In this respect, Pollard and Coughlin (2004) add that if they are operating at full capacity, they may prefer to increase export prices. On the other hand, if the

²For more details see Campa and Goldberg (2002).

³Tunç (2017) reviews the literature on asymmetric ERPT in emerging economies.

exchange rate appreciates, exporters should decrease export prices to maintain price competitiveness and market share. However, Bussiere (2013) highlights that, when a big appreciation occurs, they cannot decrease export prices at the same pace as the exchange rate appreciates because there is one point at which the mark-up becomes negative. Therefore, pass-through to export prices is greater under depreciations than appreciations.

As for threshold effects, Bussiere (2013) and Pollard and Coughlin (2004) consider another set of assumptions that, if joined to the previous ones, can explain nonlinearities. In particular, under a menu cost setting, firms may decide to change prices when significant exchange rate variations occurred and kept them if they are small. Firms may also show this behavior if they can switch costs, i.e., change between foreign and national inputs depending on exchange rate movements. If they can perfectly change external and domestic inputs, prices might not change at all. However, this not always occurs, so that, from a certain threshold, it is expected for the firm to change its inputs to prevent the price from rising further.

Some of the authors that have analyzed the relationship between exchange rate and inflation from a nonlinear perspective have usually focused on import prices and have targeted only one country. However, until now, there seems not to be a particular approach to tackle the problem. For instance, Herzberg et al. (2003) noticed that the appreciation the sterling experienced in 1996 not fully passed through onto import prices in the United Kingdom, one of the explanations he suggested was the presence of nonlinearities. However, despite employing different methodologies—a threshold model, a spline model, and a quadratic logistic STAR model, he only found limited evidence of nonlinearities and no evidence of threshold effects. Pollard and Coughlin (2004) through a model with dummy variables tested for nonlinearities and asymmetries in ERPT to the United States import prices of 30 industries. Their results show that over half of the industries respond asymmetrically to exchange rate movements, they also find that size matters, that is, the magnitude of the exchange rate change seems to be positively correlated with pass-through. In the same vein, Yang (1997) looked for asymmetries in import prices of 98 industries in the United States. Through dummy variables, he tried to identify whether the pass-through underwent any structural change after the decline of the United States dollar in 1985. His results show mixed evidence regarding the stability of pass-through coefficients.

Other authors have also analyzed groups of countries that include advanced and developing economies. When dealing with groups of countries, the usual approach to capture nonlinearities or asymmetries is through panel estimations with either dummy variables or interaction terms. For instance, Frankel et al. (2012) are interested in pass-through to 8 commodities in 76 economies, they found evidence of thresholds effects; however, their results

come across in the opposite direction they expected. They also tested for asymmetries and, according to them, there seems to be strong evidence of it. Similarly, in a study for 124 economies Carranza et al. (2009), testing for nonlinearities, find that pass-through to consumer prices is lower when the depreciation is higher. According to them, this result could be explained by the contractionary effect that depreciations have on firms' balance-sheets and financial cost. Besides, the more dollarized the economy is, the stronger the effect seems to be. Last but not least, in a study for developing countries Burstein et al. (2005) argued that large declines of real exchange rate following big devaluations is explained to a great extent by the slow adjustment of non-tradable prices, according to their results, this relationship could change depending on the size of the devaluation.

In a more recent analysis, Bussiere (2013) through an augmented standard linear model with polynomial functions and interactive dummy variables test for nonlinearities and asymmetries in the G7. This work analyzes not only import prices, but also export prices. The author finds evidence of nonlinearities and asymmetries, although the magnitude differs across countries. For its part, Caselli and Roitman (2016) in a panel of 28 emerging economies identify threshold effects employing local projection techniques.

The standard literature assumes linearity in the response of inflation to exchange rate movements. However, some authors show that nonlinear responses can be derived under certain assumptions. Admittedly, few works on nonlinearities have been made, and there seems not to be a particular approach for analyzing this subject. Nonetheless, there is evidence that nonlinear pass-through cannot be ruled out. These analyses have target advanced economies and panels of advanced and emerging economies; less has been done on small open economies, in which exchange rate is one of the principal adjustment variables to shocks such as the Mexican case.

In the next section we review the recent dynamics of the exchange rate in Mexico and some papers that have estimated the pass-through for this country using linear approaches.

3 Exchange rate dynamics and pass-through in Mexico

In the last twenty years, the exchange and fixed income markets have developed considerably in Mexico. Indeed, the autonomy of the Central Bank⁴ and several economic policy actions implemented in the last decades such as i) the adoption of a floating exchange rate regime; ii) the adoption of an inflation targeting regime; iii) greater fiscal discipline; and iv) adequate

⁴Banco de México's autonomy was granted by a constitutional reform that came into force on April 1, 1994.

financial regulation, contributed to the strengthening of the macroeconomic framework of the country and the generation of an environment of certainty and confidence that, in turn, resulted in the development of national financial markets.⁵ In particular, the exchange rate market has gained relevance in the global arena and the Mexican peso has positioned as one of the most traded currencies worldwide, as the BIS has published.⁶ Under these circumstances, the Mexican peso has registered several episodes of high volatility and depreciation rates, associated with both internal and external factors.

From March 2002 to the beginning of 2003 the nominal exchange rate depreciated almost 20 percent. At that moment, the global economy was under high levels of uncertainty around the geopolitical scenario that eventually led to the Iraq war. This environment reduced consumer and investor confidence around the world. Those concerns affected international financial markets. As for internal factors, during this period, some concerns regarding the country's competitiveness also put pressure on the peso, these concerns were a result of a lack of agreement on the structural reforms' agenda.

From August 2008 to March 2009, the nominal exchange rate depreciated over 30 percent. Since the beginning of the global financial crisis, the volatility in international financial markets and the uncertainty of the outlook for the global economy affected the Mexican economy, even though the Mexican banking system was not affected. A global environment of risk aversion and the associated fall in the global liquidity affected asset prices too. The low-risk perception of the United States dollar-denominated government assets led to an appreciation of the USD which contributed to the peso depreciation. For the Mexican peso, an additional depreciation came from the perception that the country could have had difficulties financing its current account deficit.⁷

During 2011 and 2012 concerns around the deterioration of Greece's situation and the possible contagion to other European economies, caused an increase of international markets volatility. Because investors were in a risk-off mood, the Mexican peso depreciated. This behavior was observed in both advanced and emerging economies.

The last episode of nominal exchange rate depreciation is also the longest one. It started in 2014 with the decline of oil prices. In Mexico, the exchange rate depreciated due to the high dependence of fiscal revenues on oil income. In particular, given that the public deficit

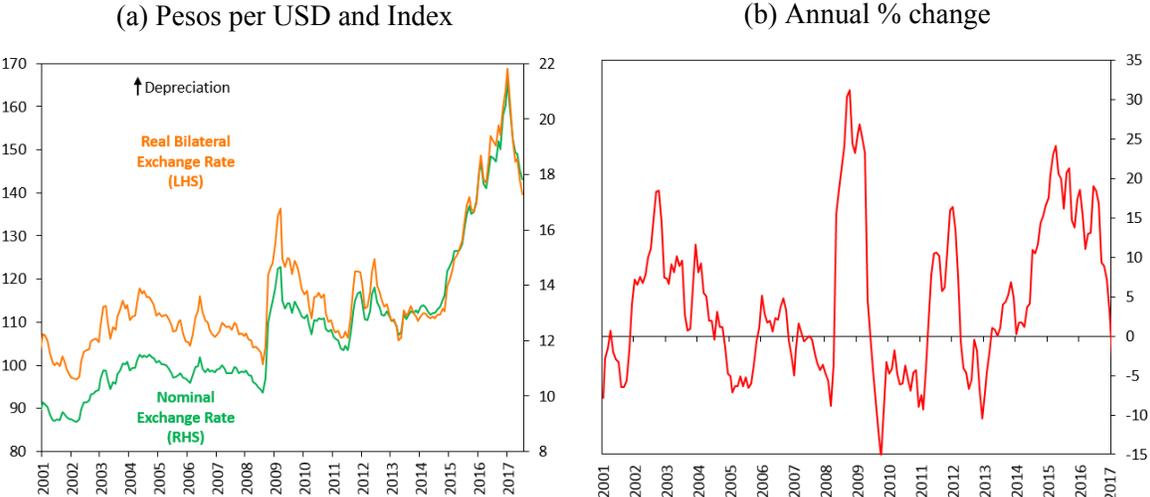
⁵See for instance Sidaoui and Ramos-Francia (2008).

⁶According to the last Triennial Central Bank Survey of foreign exchange and Over-the-counter derivatives markets published by the Bank for International Settlements (BIS) in 2019, the MXN was ranked 15th among the currencies of 35 advanced and emerging economies. Besides, the Mexican peso stood as the second most traded currency among emerging economies' currencies, only behind the Chinese renminbi.

⁷Banco de México, Quarterly Inflation Report, January-March 2009.

and public debt had increased before the oil price shock, public finances were under pressure. By the same time, the expectation of monetary policy normalization in the United States contributed to the depreciation of the currency. Afterwards, in 2016, because of the process and the outcome of the United States presidential election, the peso depreciated further and its volatility increased. In 2017, the uncertainty regarding the United States and Mexico relation contributed to the currency remaining at high levels. So, from the end of 2014 till the beginning of 2017, the annual depreciation of the peso remained above 10 percent.

Figure 1: Nominal and Real Exchange Rate against the USD



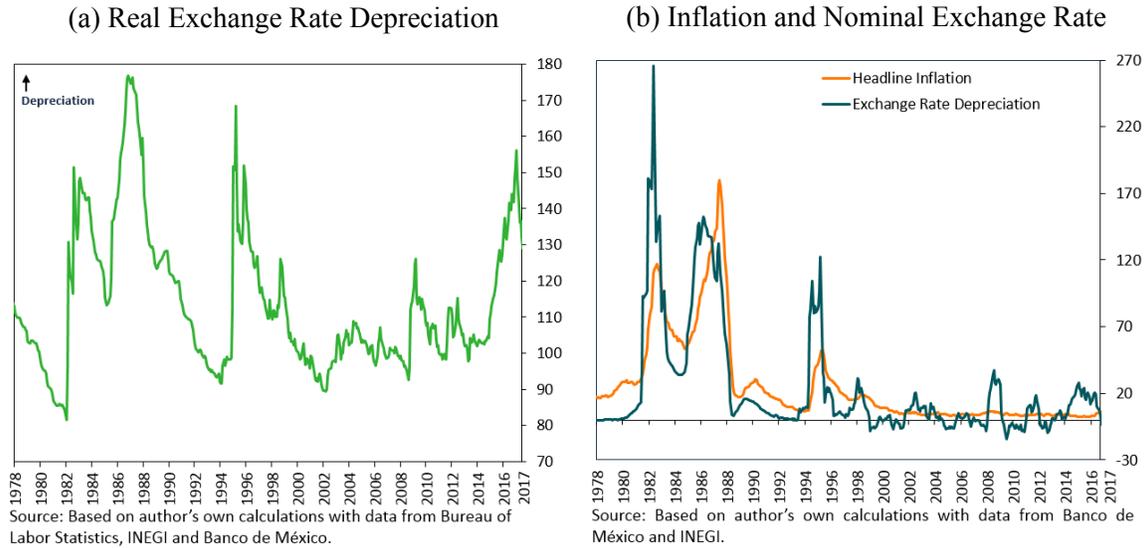
Source: Based on author's own calculations with data from Banco de México.

During these episodes and throughout the years, Banco de México has advanced in achieving a better functioning of the nominal system of the economy. According to Aguilar et al. (2014), this has allowed a reduction in the level, volatility and persistence of inflation, the anchoring of inflation expectations at levels close to the 3 percent target and a reduction in their dispersion, a decrease in the inflation risk premium (see Figure 3b), lower and transitory effects on inflation of relative price movements of certain goods, and the reduction in the pass-through from exchange rate movements onto prices (see Figure 2 and 3a). In particular, regarding ERPT, many authors have estimated it for the Mexican economy from a linear standpoint.⁸

According to Chiquiar et al. (2010), starting in 2001, inflationary dynamics in Mexico seems to have switched from a non-stationary to a stationary process. Given these findings,

⁸Capistrán et al. (2012) presents a complete review of the main papers that have estimated the ERPT before the adoption of the inflation targeting regime.

Figure 2: Exchange rate and Inflation, Annual %



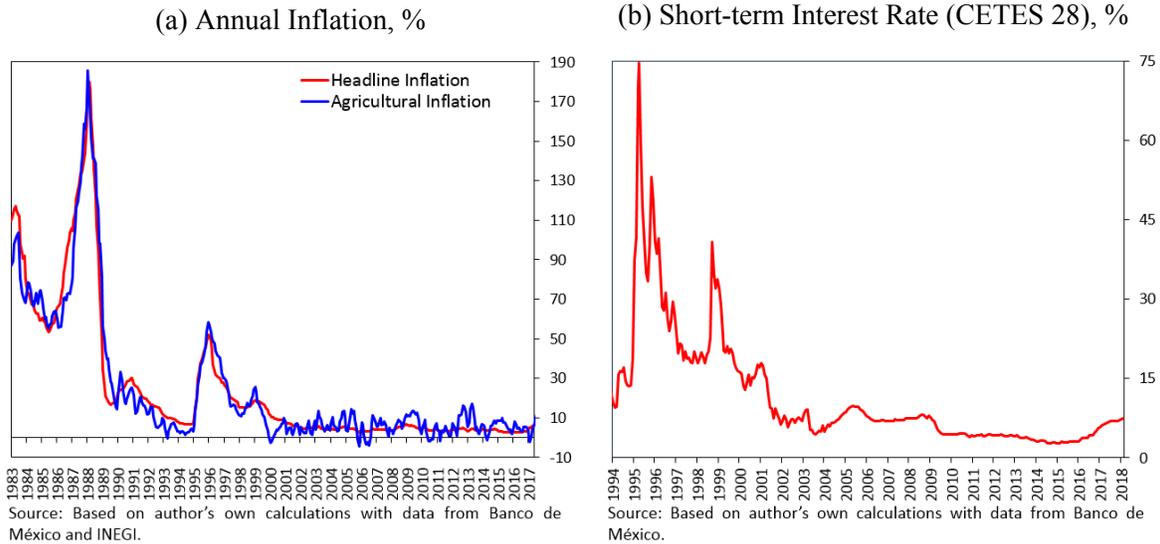
many authors that have analyzed the pass-through for Mexico use a sample starting in 2001 with elasticity estimations between 0.02 to 0.04 in a 12-month horizon.

Capistrán et al. (2012) estimate pass-through coefficients using the VAR methodology in two sub-samples, before and after the adoption of the inflation targeting regime, they find that before 2001 the exchange-rate pass-through coefficient was higher than 0.3 percentage points in a 12-month horizon and over 0.6 percentage points in a 24-month horizon for headline inflation. For the period that goes from 2001 onwards, the pass-through coefficients were near of 0.02 percentage points after a 12-month period and 0.03 percentage points after a 24-month one. However, although the coefficients are statistically significant before 2001, they seem not to be different from zero after that date.

Cortés (2013) also follows a VAR approach with data from June 2001 to August 2012. His results are very similar to those of Capistrán et al. (2012). For headline inflation, after a 1 percent exchange-rate depreciation, inflation increases by 0.039 percentage points 12 months after the shock and 0.056 after 24 months. Besides, he estimates exchange-rate pass-through coefficients for the main sixteen aggregation groups of the consumer price index.⁹ Overall, his findings indicate that pass-through is low and statistically non-significant for headline inflation, but positive and statistically significant for merchandise. This last is the result of

⁹This include four aggregation levels with the headline component at the top, then the core and non-core subindices. A third level is integrated by the merchandise and services subindices, and the agriculture and energy and government approved fares subindices. Finally, a four level of aggregation includes food, beverages and tobacco, non-food merchandise, housing, education, other services, fruit and vegetables, livestock, energy, and government approved fares.

Figure 3: Inflation and Interest Rate



the positive and statistically significant pass-through from the food index, whose prices are mainly set in the international markets.

As for other methodologies, Kochen and Sámano (2016) analyze the relation between the exchange-rate and price setting in Mexico with micro data from January 2011 to April 2016. Their sample represents the 58.6 percent of goods and services into the CPI, they estimate that after one percent change of the exchange-rate, on average, the pass-through is 0.073 percentage points.¹⁰ However, because of the sample size of goods and services, on aggregate inflation the incidence is estimated in 0.043 percentage points.

Aleem and Lahiani (2014) estimate a three-regime TVAR model for Mexico using inflation as their threshold variable, suggesting that the different degrees of pass-through are associated with different levels of inflation. They use data from January 1994 to November 2009, and their estimated thresholds are 0.167 and 0.783 for monthly inflation. They find that the exchange-rate pass-through is statistically significant only when inflation is greater than 0.783.

These results show that indeed pass-through coefficients from exchange rate movements to prices in Mexico have been low and have remained relatively stable on average during the last years. However, the question of potential nonlinearities in this context has not been explored. In the following sections we analyze this possibility.

¹⁰The authors explain that the period for the prices to respond to the exchange-rate shock is timeless, as it depends on each individual product price-setting.

In sum, all small open economies are affected by exchange rate variations and, hence, a certain degree of ERPT is present in those economies. As for the Mexican economy, the Central Bank's credibility, along with its commitment to keep low and stable inflation, have contributed to the decrease in ERPT. In particular, through his actions, the central bank has achieved an orderly adjustment of exchange rate variations onto prices mainly by containing contamination to other prices that should not necessarily be affected by exchange rate variations. In fact, a low inflation environment is often associated with a lower frequency of price adjustments by firms. In this regard, Ysusi (2013) finds a positive relationship between the frequency in which firms change price and inflation when a big shock hits inflation. Additionally, Cortés et al. (2012) explains that in Mexico a low inflation environment has allowed firms to set prices following a time-dependent strategy instead of state-dependent, under a time-dependent setting firms set prices in pre-established dates, while in a state-dependent strategy price revisions are subject to the circumstances.

4 TVAR model

The framework we focus on is the threshold VAR (TVAR) methodology, following Afonso et al. (2018), Balke (2000) and Li and St-Amant (2010). In contrast to a linear VAR, a TVAR approach allows us to identify if there are different coefficients of pass-through depending on the level of exchange rate depreciation. Thus, we try to distinguish between two regimes, one with lower depreciation rates and lower pass-through, and another regime with higher depreciation and higher pass-through. Such depreciation environments are possible when inflation responds differently to certain levels of exchange rate depreciation. Our threshold variable is the exchange rate depreciation.

The model has the following reduced-form specification:

$$Y_t = A^1 Y_t + B^1(L)Y_{t-1} + (A^2 Y_t + B^2(L)Y_{t-1}) I(NER_{t-d} > \gamma) + \varepsilon_t \quad (1)$$

Where:

$$Y_t \equiv \begin{bmatrix} Y_t^{foreign} \\ Y_t^{home} \end{bmatrix}$$

$$Y_t^{foreign} = [\Delta_{12} \ln IP_{t,US}, R_t^*, \Delta_{12} \ln PComm_t, \Delta_{12} \ln CPI_{t,US},]$$

$$Y_t^{home} = [\Delta_{12} \ln IGAE_t, R_t, \Delta_{12} \ln NER_t, \Delta_{12} \ln INPC_t]$$

We estimate the model under the assumption of a small open economy, i.e., the vector of foreign variables ($Y_t^{foreign}$) affect home variables (Y_t^{home}), but home variables do not affect foreign variables. $B^1(L)$ and $B^2(L)$ are lag polynomial matrices, which, as explained by Balke (2000) determine the regime the system is in. A^1 and A^2 are the contemporaneous relationships, and regarding the home variables, we assume a recursive structure with a causal ordering of activity, interest rate, exchange rate, and inflation as in Cortés (2013). ε_t represents the structural perturbations and d is the delay from which the threshold variable affects the system. The home variables are those usually employed in models for small open economies. In particular, home variables include the Global Indicator of Economic Activity ($IGAE$), the nominal exchange rate of the Mexican peso against the United States dollar (NER), a measure of a short-term interest rate, 28-day CETES (R), and the Consumer Price Index ($INPC$). Foreign variables are the World Bank commodity price index ($PComm$), the federal funds rate (R^*), United States industrial production (IP), and United States inflation (CPI). We employ monthly data from June 2001 to May 2017. All variables are expressed as the annual logarithmic difference, $\Delta_{12} \ln$, except for the monetary interest rate of Mexico and United States, which are included as the difference in percentage points. The term $I(NER_{t-d} > \gamma)$ is an indicative function that equals one when the exchange rate depreciation is greater than γ and zero otherwise. Thus, γ represents the threshold that distinguishes “high” and “low” depreciation regimes. As in Capistrán et al. (2012) we employed the Bayesian information criterion (BIC) to determine the lag order, we found that two lags were well suited to describe the dynamics of the system.

4.1 Nonlinear impulse response

Because of the nonlinear nature of TVAR models the analysis of impulse response functions (IRFs) is more complicated than in linear VARs. IRFs derived from linear VARs are estimated with coefficients that are constant through time, so that, linear IRFs show symmetry no matter the sign and magnitude of the shocks. Nonetheless, in a nonlinear setting, such as the TVAR case, the IRFs do not necessarily are symmetric to the sign and magnitude of the shocks. Galvao and Marcellino (2014) explains that under the exogenous threshold VAR model the responses of the shocks are regime dependent. Although a Cholesky decomposition (conditional on the regime to identify the regime-specific structural shocks) can be used

when each regime defines separate sub-samples, the assumption that follows from this identification strategy is that the response to a shock does not generate regime changes. However, under a nonlinear setting, a change of regime could result from the size of the shock as well as the realizations of future shocks. Thus, the importance of considering the history preceding the shocks or the realizations of future shocks when the dynamic responses are computed.

In order to solve the problem, Koop et al. (1996) propose the computation of generalized impulse response functions (GIRFs). Actually, the usual approach under a TVAR approach is to compute GIRF (Baum and Koester (2011), Schmidt (2013)). For that reason, we compute GIRF and we obtain IRFs for both low and high depreciation regimes. The GIRF can be represented as follows:

$$GIRF_Y(k, V_t, \Omega_{t-1}) = E[Y_{t+k}|V_t, \Omega_{t-1}] - E[Y_{t+k}|\Omega_{t-1}]$$

The GIRF for variable Y can be derived as a difference between the simulated VAR k periods ahead, conditional to certain history Ω_{t-1} and shock V_t and the simulated VAR conditional only to the history Ω_{t-1} . Baum and Koester (2011) provide a detailed algorithm for deriving GIRFs. As for the confidence bands, we follow the common approach for TVAR systems such as in Balke (2000), Afonso et al. (2018), and Schmidt (2013). For more detail on how the GIRFs and confidence bands are computed see Appendix A.

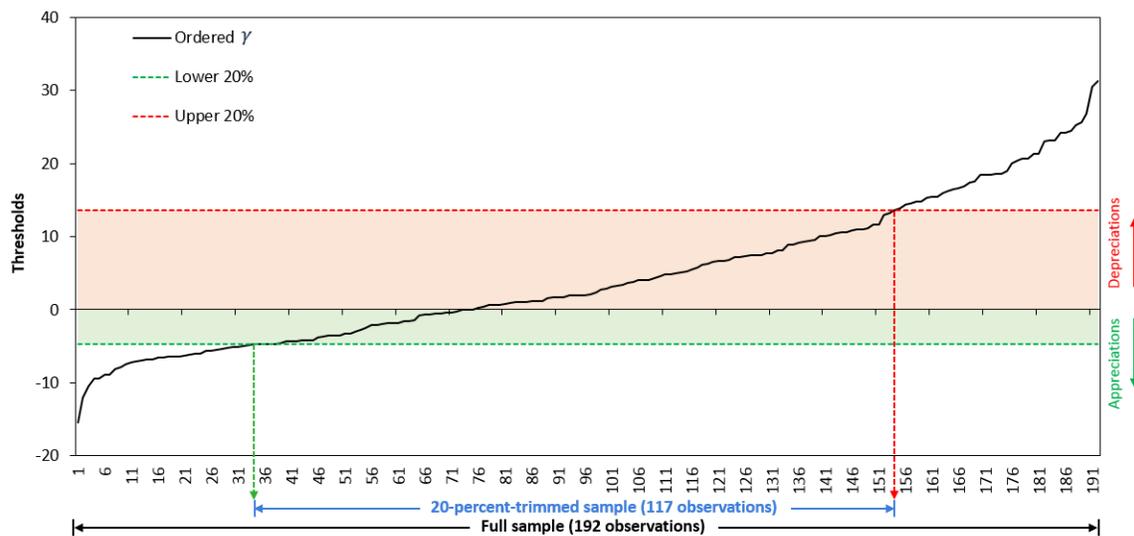
4.2 Threshold selection

To estimate the TVAR model, we need to find the rate of depreciation/appreciation that will define the threshold. In other words, the value of exchange rate variation at which we can distinguish periods of low and high depreciation/appreciation. The threshold is determined endogenously, and we proceed as follows: first, we consider all the observed values of the exchange rate depreciation as candidates. In this case, we have a set of 192 potential choices. However, for estimation purposes and statistical inference, we also need to set a minimum number of observations for each regime. Hence, we establish a trim-rate of 20 percent. After this step, we get a sub-sample with most of their elements, 69 percent, consisting of depreciation rates, and the remaining 31 percent made up of appreciation rates (see Figure 4). For each appreciation and depreciation rate within the trimmed set, we estimate a model choosing among the values of $d \in \{1, 2\}$ ¹¹ So, we estimate a total number of models that equals two times the appreciation and depreciation rates within the trimmed set, i.e., each combination

¹¹ We note that the values of d are less or equal to the lags selected from the information criterion, in this case, $d \leq 2$.

of exchange rate variation and delay. For every model, we compute its mean squared error (MSE).

Figure 4: Ordered Threshold Values (Exchange Rate Variations)



Source: Based on author's own calculations with data from Banco de México.

Finally, we select the model that provides the best fit, i.e., the one that minimizes the MSE (S_n).

$$\hat{\gamma} = \arg \min_{\gamma \in \Gamma} S_n(\gamma)$$

In Table 1, we present the estimated thresholds for merchandise, food and non-food inflation measures, with a threshold-value ranging from 7.16 to 7.30 percent. According to Durbin-Watson statistic there is no evidence of auto-correlation in the residuals. That is, when the exchange rate depreciates at any of the mentioned rates or above we might observe a different degree of pass-through.

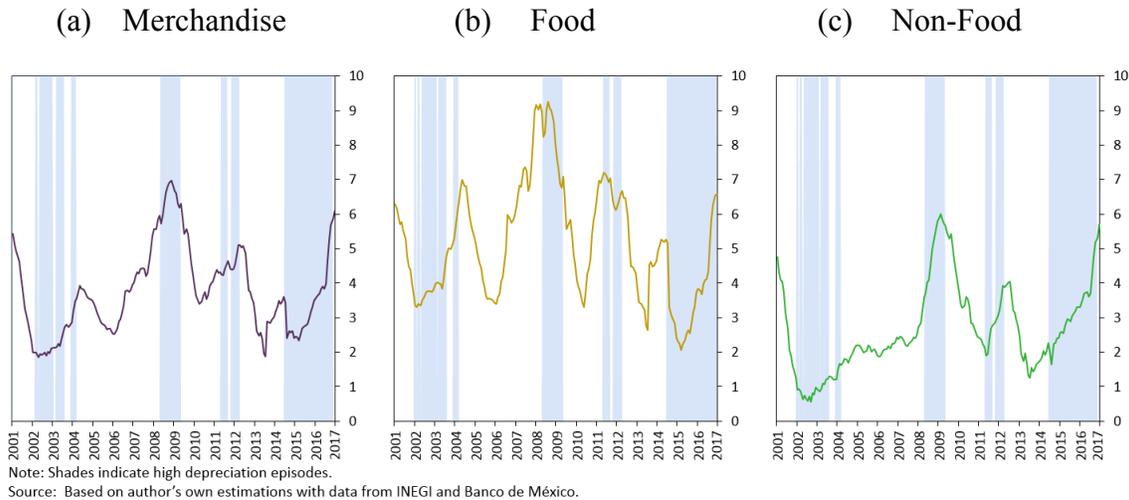
Table 1: Estimated Thresholds

Inflation	NER Threshold
Merchandise	7.30%
Food	7.16%
Non-food	7.20%

Note: Based on author's own estimations. For all the threshold values selected, the corresponding delay (d) equals 1.

For these threshold values, the number of observations in the low depreciation regime goes from 122 to 125, while in the high depreciation one the number of observations goes from 66 to 69. In Figure 5 we plot the inflation subindices for which we found evidence of a nonlinear behaviour. Shaded areas indicate those periods in which exchange rate was under a high depreciation regime according to the corresponding threshold level (see Table 1).

Figure 5: Consumer Price Index and Depreciation Regimes, Annual % change



4.3 Nonlinearity test

We are interested in knowing if the evidence of nonlinearities is statistically significant. However, through a visual inspection of the GIRFs (see Figures 6, 7, and 8) we cannot draw a conclusion because if we were to plot them on the same graph, from the values in the y-axis, we would notice that most of them would overlap. In fact, Schmidt (2013) explains that “overlapping confidence bands cannot be interpreted as an indication that the two IRFs in question are not statistically different from each other.” A common approach is to conduct nonlinearity tests.

We perform a test that compares a linear VAR *versus* the 2-regime TVAR. This is the likelihood-ratio test (LR) available in the open-source package tsDyn.¹² The test is a multivariate extension of the test proposed by Lo and Zivot (2001) to the Hansen (1999) linearity test. In particular, it compares the determinant of the estimated variance-covariance matrix of each model as shown below:

¹²We modify the test in order it can be estimated with exogenous variables.

$$LR_{12} = T(\ln(\det \hat{\Sigma}_1) - \ln(\det \hat{\Sigma}_2))$$

Where $\hat{\Sigma}_1$ is the estimated variance-covariance matrix for the linear VAR with 1 regime and $\hat{\Sigma}_2$ is the variance-covariance matrix for the TVAR with 2 regimes. The variance-covariance matrix $\hat{\Sigma}_2$ is the one that results from the model with the best fit from a grid search through all the possible threshold values, the same procedure explained in the first paragraph of section 4.2.

Given that under the null the threshold value is not identified, standard statistical inference is not possible. Hansen (1996) proposes a solution through a bootstrap procedure from which we can derive an empirical distribution for the LR-statistic and we can derive asymptotic p-values.¹³ As for the model, the test considers a 20 percent trim, which guarantees a minimum number of observations for the smallest regime. We perform 10,000 bootstrap replications.

Table 2: Likelihood Ratio Test (LR)

	Linear VAR vs Threshold VAR 2-regimes	
	Statistic	<i>p-value</i>
Headline	47.8	0.9758
Core	75.4	0.1458
Merchandise	146.2***	0.0020
Food	150.2***	0.0040
Non-food	140.3***	0.0050
Services	53.6	0.9692
Non-core	42.7	0.9920

Note: Based on author's own estimations. The stars indicate significance levels (***) < 0.01, ** < 0.05, * < 0.10).

The results for the tests and their asymptotic p-values are shown in Table 2. As can be seen, for most inflation measures we cannot reject the null of the linear model *versus* the 2-regime TVAR. Nonetheless, for the merchandise, food and non-food subindices we prefer the nonlinear model.

The likelihood ratio test compares a VAR and a TVAR model and helps us to determine which one best describes the dynamic of the system. A common approach when dealing with nonlinear settings is to present the results of the Wald-type statistics (See Balke (2000), Afonso et al. (2018), and Schmidt (2013)). To the best of our knowledge, unlike the LR test, Wald tests have to be made for each equation of the system separately. Taking this into con-

¹³The procedure consist in generating trajectories for the endogenous variables from a sampling with replacement of the errors of the lineal model and estimating the LR-statistic for the linear VAR and the 2-regime TVAR n times, then we obtain an asymptotic distribution from which we can derive the p-values.

sideration, we also performed the Wald test for the merchandise, food, and non-food inflation. We test whether the nonlinear model is preferable to the linear one for the inflation equation. For each γ , we estimated the model and calculated the Wald statistic testing for no difference between regimes. Then, we computed the maximum Wald statistic among all possible thresholds (Sup-Wald), the average Wald (avg-Wald), and the exponential Wald (exp-Wald). Finally, through the procedure of Hansen (1996) we simulated an empirical distribution for the statistics. Our results are consistent with the likelihood ratio test (See Table 3).

Table 3: Wald Test

	Ave-Wald		Sup-Wald		Exp-Wald	
	Statistic	<i>p-value</i>	Statistic	<i>p-value</i>	Statistic	<i>p-value</i>
Merchandise	21.4***	0.0024	37.9***	0.0000	15.3***	0.0000
Food	24.9***	0.0003	39.8***	0.0000	16.4***	0.0000
Non-food	15.7**	0.0421	28.4***	0.0000	11.3***	0.0009

Note: Based on author's own estimations. The stars indicate significance levels (***) < 0.01, ** < 0.05, * < 0.10).

Results from the nonlinearity tests could be associated with the fact that inflation in the merchandise subindices includes the prices of tradable goods. We would expect these type of prices to respond to a higher degree to changes in the exchange rate, compared to another set of prices, given their closest relationship with the exchange rate. Capistran et al. (2012) found a positive and statistical significant ERPT for tradable goods from an estimation for 1997 to 2010.

4.4 Pass-through estimation

The coefficient of accumulated pass-through is computed from the GIRFs for exchange rate and inflation. In particular, it is estimated using the ratio of the accumulated GIRF of inflation for a given time horizon to the accumulated GIRF of the exchange rate for the same period, as is shown in the following equation:

$$\epsilon_t = \frac{\Delta\%P_{t,t+T}}{\Delta\%NER_{t,t+T}}$$

Where $\Delta\%P_{t,t+T}$ is the percentage change of the price level T periods after the shock and $\Delta\%NER_{t,t+T}$ is the percentage change of the exchange rate in the same period. Following Cortés (2013) and Capistran et al. (2012) the accumulated pass-through elasticity (ϵ_t) can be read as the change in price in percentage points given a one percentage point exchange rate

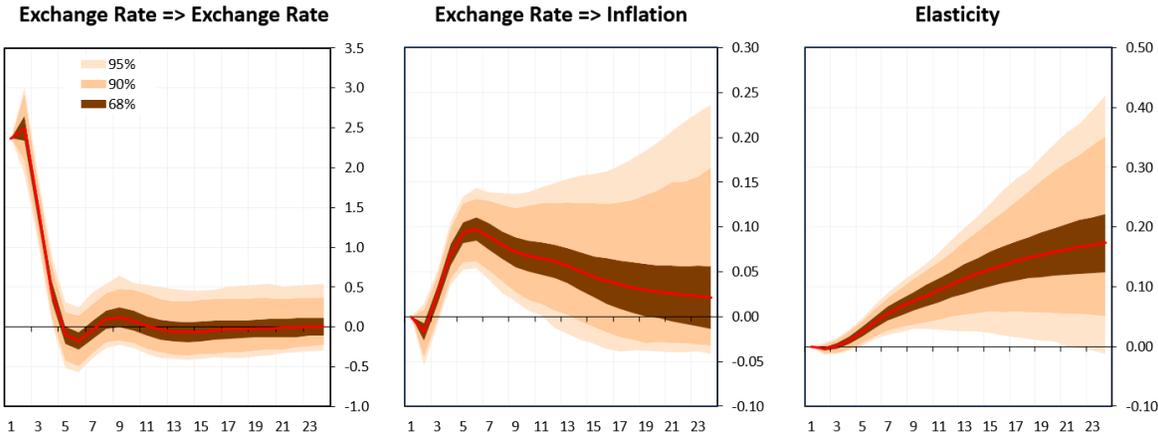
depreciation. As long as accumulated GIRF are used, elasticity refers to the average for the period.

Having pass-through coefficients for both regimes in the case of merchandise indices, we have estimated the pass-through coefficients for each measure of inflation we apply the aggregation method proposed by Hyndman et al. (2011), which was used by Capistrán et al. (2009) and Cortés (2013) for Mexican data. The aim of this procedure is for the series to respect the hierarchy of CPI's components. That is, the CPI must be a weighted average of the core and non-core indices, both of which are also weighted averages of other subindices. As explained by Cortés (2013), the Hyndman method combines the information of the aggregate indices such that the implicit hierarchy in the CPI components is fulfilled; besides, under certain assumptions, the estimator generated presents minimum variance with respect to the direct estimation. For more detail on this procedure see Appendix B. In this regard, to be able to implement the Hyndman method for each regime, we completed the system for the remaining inflation indices with estimations of ERPT from linear models such as in Cortés (2013) and Capistran et al. (2012), i.e., we repeated the ERPT coefficients for both the low and high depreciation regimes.

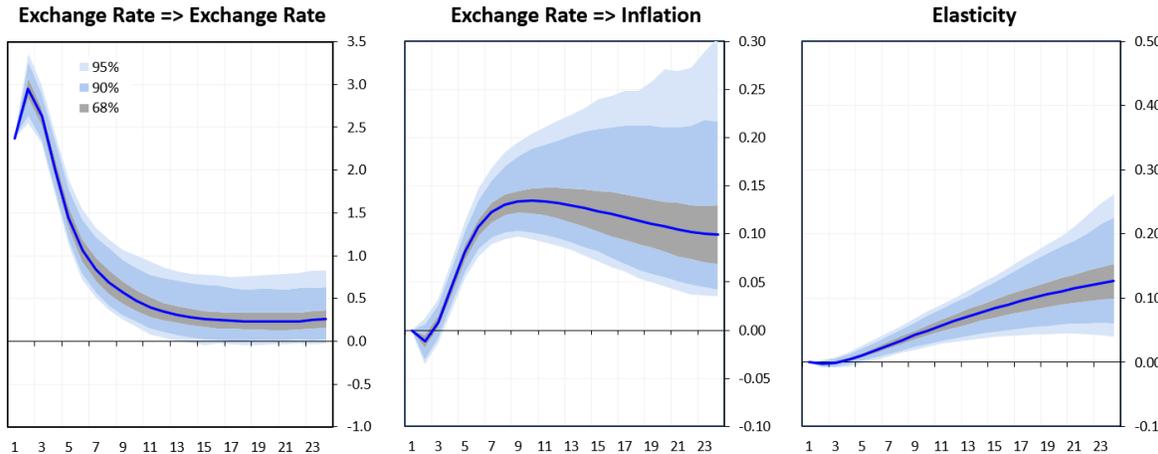
Figures 6 through 8 show pass-through estimates for merchandise, food, and non-food inflation, respectively. We present the elasticity for both the high and low depreciation regimes up to 24 months after an exchange rate shock. For merchandise and food inflation, we observe that the elasticity increases at a rapid rate a few months after the shock. Nonetheless, it decelerates at the end of the period. On the contrary, the elasticity for non-core inflation keeps accelerating 24 months after the shock. We also note a higher uncertainty in elasticity estimates for all inflation measures in the high depreciation regime. This could be related to the sample size, as the high regime includes around one quarter trimmed sample.

Figure 6: Merchandise Inflation. Effect of exchange rate depreciation on the exchange rate and inflation

(a) High depreciation regime



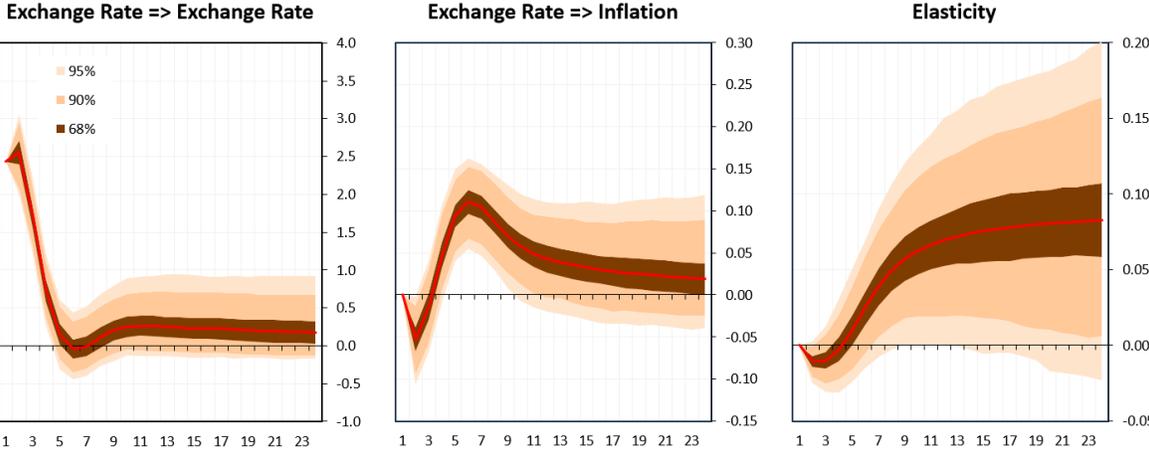
(b) Low depreciation regime



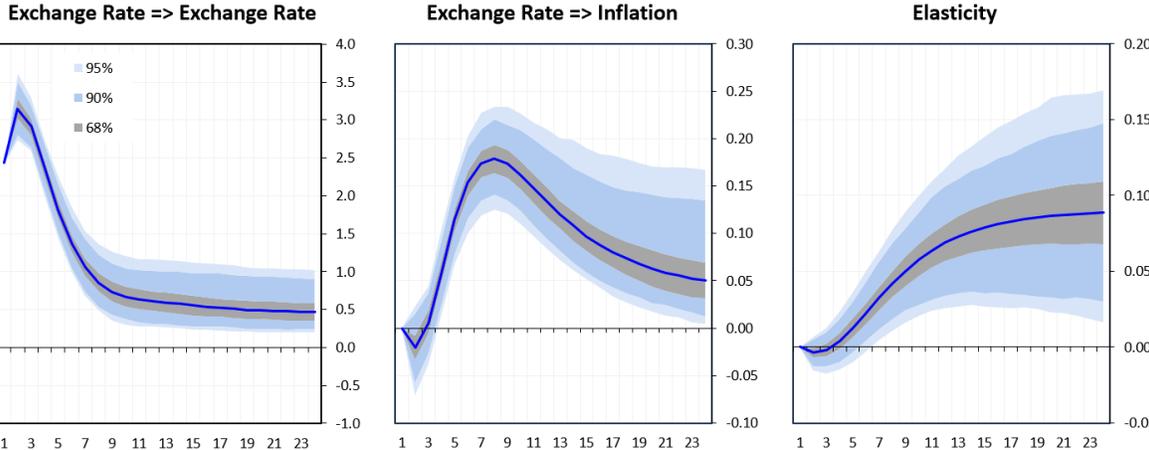
Source: Based on author's own estimations with data from Banco de México, INEGI, Federal Reserve, Bureau of Labor Statistics and World Bank.

Figure 7: Food Inflation. Effect of exchange rate depreciation on the exchange rate and inflation

(a) High depreciation regime



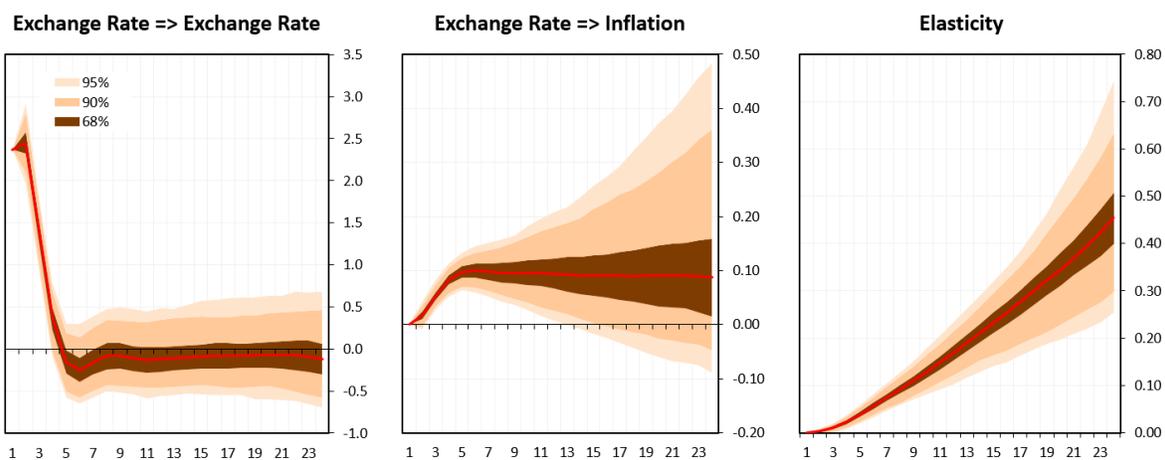
(b) Low depreciation regime



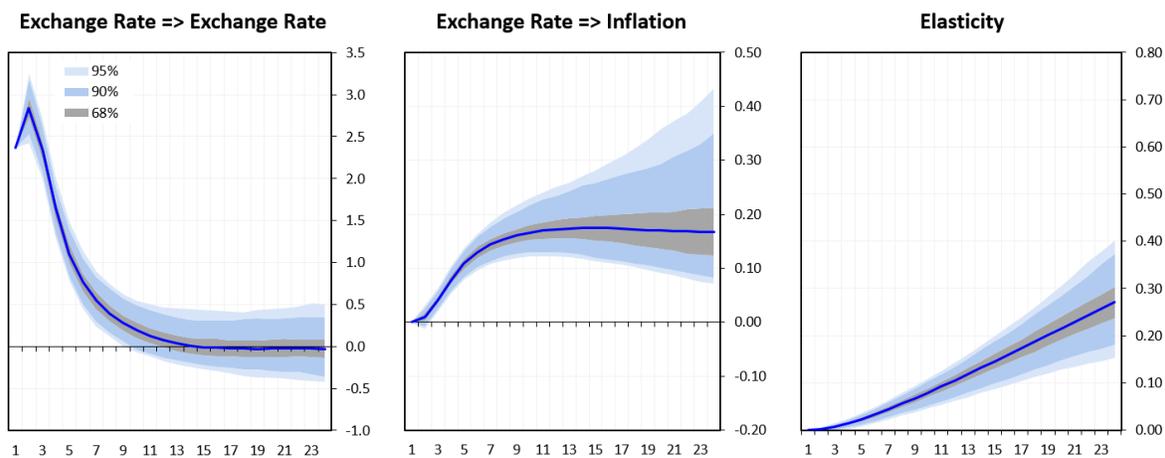
Source: Based on author's own estimations with data from Banco de México, INEGI, Federal Reserve, Bureau of Labor Statistics and World Bank.

Figure 8: Non-Food Inflation. Effect of exchange rate depreciation on the exchange rate and inflation

(a) High depreciation regime



(b) Low depreciation regime



Source: Based on author's own estimations with data from Banco de México, INEGI, Federal Reserve, Bureau of Labor Statistics and World Bank.

4.5 Results

Table 4 reports pass-through coefficients obtained through the Hyndman procedure.¹⁴ We observed more differences between the regimes of high and low depreciation in the merchandise indices. For the merchandise index, the pass-through of an additional depreciation of 1 percent increases from 0.08 percentage points in a 12-month horizon to 0.17 percentage points after 24 months in the low regime, and from 0.11 to 0.24 percentage points in the high depreciation regime. For the non-food merchandise index the pass-through increases from 0.09 percentage points in a 12-month horizon to 0.24 percentage points after 24 months in the low regime, and from 0.16 to 0.40 percentage points in the high depreciation regime, respectively. It is noteworthy that, for the food index, we did not find any differences in the ERPT coefficients between the high and low depreciation regimes in a 12-month horizon. The result holds even though the nonlinearity test suggests the presence of nonlinearities.

When the economy is facing an environment of low depreciation, the pass-through of an additional depreciation of 1 percent raises headline inflation by 0.05 percentage points 12 months after the shock. On the other hand, in the environment of high depreciation, it increases by 0.06 percentage points. It can be seen from these results that, even though nonlinearities are found in the merchandise indices, the effect over the headline inflation is small. For core inflation, when the rate of depreciation is below the threshold, inflation increases 0.04 percentage points, while it increases by 0.05 percentage points when it lies above that level. Pass-through coefficients are not statistically significant for services inflation in either of the two regimes.

Table 4: Exchange Rate Pass-Through

Inflation	12 Months		24 Months	
	Low depreciation regime	High depreciation regime	Low depreciation regime	High depreciation regime
Headline	0.05*	0.06*	0.08	0.10
Core	0.04***	0.05***	0.06**	0.09**
Merchandise	0.08***	0.11***	0.17***	0.24**
Food	0.06***	0.06**	0.07***	0.04**
Non-food	0.09***	0.16***	0.24***	0.40***
Services	-0.00	-0.01	-0.02	-0.04
Non-core	0.11*	0.11*	0.14	0.13

Source: Based on author's own estimations. The stars indicate significance levels (***) < 0.01, (**) < 0.05, (*) < 0.10). The statistical significance is determined by analyzing if confidence intervals are different from zero at the aforementioned levels of significance.

¹⁴For robustness check, we additionally estimated a model for each inflation measure, including dummy variables to test for time or seasonal fixed effects. Dummy variables were not significant in the system of equations, and the results do not change when we add these variables.

In a 24-month horizon (see Table 4), headline inflation increases by 0.08 percentage points in the low depreciation regime and 0.10 percentage points in the high depreciation one. For core inflation, the pass-through coefficient is 0.06 percentage points in the low depreciation environment and 0.09 percentage points in the high depreciation regime.

We tested for statistical significance in both the nonlinear ERPT coefficients and the linear ones. Regarding the nonlinear estimates, the significance of each ERPT coefficient is determined separately for the high and low depreciation regimes. Overall, we found that individually, each coefficient is statistically significant for most inflation measures.

As was explained in section 2, mark-up considerations, menu cost, the possibility of switching costs, among others, all could be explanations for nonlinearities. Although the TVAR methodology allows us to estimate the ERPT coefficients, it does not allow us to identify the underlying causes of nonlinearities accurately. In this regard, to go further and determine which one is explaining our results, we require another kind of analysis that escapes the scope of the document. For instance, a micro-level approach is more suitable to identify the behavior of firms.

5 Conclusion

Since the 1990s, many countries have been consolidating an environment of low inflation with lower pass-through of exchange rate movements to inflation. However, given the role that the exchange rate has had as a shock absorber variable, and despite lower inflation rates registered in many emerging market economies, central banks, particularly in small open economies with flexible exchange rates, need to follow the impact of the exchange rate on inflation closely. In this sense, the analysis of the relationship between exchange rate and inflation continues to be at the forefront of monetary policy, especially under an inflation targeting regime where the exchange rate is a monetary policy transmission channel.

Although some studies have documented that pass-through of exchange rate adjustments onto inflation in Mexico has been low since the adoption of the inflation targeting regime, to the best of our knowledge, nonlinearities have not been explored yet. In this paper, we employ a novel methodology to estimate ERPT coefficients using a TVAR model. With this methodology, we can identify if there are nonlinear responses of inflation to exchange rate movements, in particular, we can assess if coefficients of pass-through differ depending if the economy is facing an environment of “low” or “high” depreciation. “Low” and “high” depreciation regimes are defined using a certain level of exchange rate depreciation (a threshold level) that is estimated endogenously. Thus, “low” or “high” depreciation regimes occur if there are changes in how inflation responds to an exchange rate shock depending on the size of the depreciation.

Using data from 2001, when Banco de México adopted the inflation targeting regime, we look for nonlinear pass-through coefficients for headline, core, non-core, merchandise, food and non-food, and services inflation. Our results indicate that we only find a nonlinear behavior in merchandise, food, and non-food inflation measures. The threshold variable for these components, on average, is a depreciation rate of 7.2 percent (with values that range from 7.16 percent to 7.30 percent). Considering these thresholds, we find that when the economy is facing an environment of low depreciation, the pass-through of an additional depreciation of 1 percent raises merchandise inflation by 0.08 percentage points 12 months after the shock, while in the environment of high depreciation merchandise inflation increases by 0.11 percentage points. For the non-food merchandise inflation, the ERPT coefficients are 0.09 percentage points under a low depreciation environment and 0.16 under a high depreciation one. Although, from a statistical point of view, we find that the degree of pass-through is different between the two regimes, the effect over headline inflation is small. Our results are consistent with the consolidation of a low ERPT in Mexico.

This paper sought to address a concern of policymakers that has to do with the magnitude of the ERPT to inflation. In conducting this analysis, we look for an approach similar to those commonly used when estimating ERPT. However, we also tried to introduce nonlinearities to the traditional VAR settings. Concerns around this subject gained particular relevance after the episodes of high depreciation that the MXN experienced since mid-2014. One of our main results indicates that we cannot rule out nonlinear effects, although they seem to be limited to the inflation of the merchandise subindices. The latter implies that although nonlinear effects are almost imperceptible in the aggregate, at least in some subindices there are a nonlinear behavior. For these set of prices, higher rates of depreciation can lead to greater changes in relative prices. A promising area of research is to extent our analysis to identify the underlying reasons behind nonlineries from a firm-level approach.

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A GIRFs algorithm

GIRFs are computed following the algorithm in Baum and Koester (2011). This procedure has also been used for Schmidt (2013) and Ferraresi et al. (2015).

1. Pick a history Ω_{t-1}^r . A history is chosen for each regime, so we repeat the algorithm twice.
2. Through bootstrap sampling, shocks are drawn based on the matrix of variance-covariance of the residuals.
3. Use the history Ω_{t-1}^r and the shocks to simulate the evolution of the model.
4. Step 3 is repeated but we add a new shock.
5. Steps 2 to 4 are repeated B (here: B=500) times.
6. Take the average over the difference of the B estimates of the two paths.
7. Repeat steps 1 to 6 over all possible histories, i.e., all the points in the sample.
8. Compute the average GIRF, which is the difference between the simulated forecast assuming the shock and the forecast without a particular shock.

Then, the confidence bands are computed following the algorithm in Schmidt (2013).

1. Artificial data is generated recursively using the estimated coefficients and errors from the TVAR structure.
2. Using the recursive dataset, the regression coefficients as well as error terms are estimated from a TVAR assuming the threshold corresponds to the estimated value.
3. Using the original data set, but the coefficients and errors from step 2, GIRFs are estimated as described in the above algorithm for each particular combination of shocks and initial conditions.
4. Steps 1 to 3 are repeated 400 times to generate a sample distribution of the GIRFs from which confidence bands are drawn at the respective significance levels.

B Aggregation

We use four levels of aggregation,¹⁵ from level zero to level three, level zero corresponds to the headline index (I_H), level one is for the core index (I_S), level two for the merchandise index (I_{SM}), and level three for the food (I_{SMA}), non-food (I_{SMO}), services (I_{SS}), and non-core indices (I_N). For the four levels described above, following the vector representation of Capistrán et al. (2009) and Cortés (2013), $P_{i,t}$ (for $i = 0, 1, 2, 3$) will be the vector of all observations of level i at time t and $P_t = [P_{0,t}, P_{1,t}, P_{2,t}, P_{3,t}]^T$ the information at time t of the seven indices. That is, we fill vector P_t with the estimated coefficients of pass-through for t equal to 12 and 24 months. Additionally, we define a S matrix of weights, which instead of having zeros and ones as the one of Hyndman et al. (2011), it includes the weights that compose the CPI. The S matrix and the P_t vector are presented below:

$$S = \begin{bmatrix} 0.15 & 0.20 & 0.43 & 0.23 \\ 0.19 & 0.25 & 0.56 & 0 \\ 0.43 & 0.57 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad P_t = \begin{bmatrix} I_{H,t} \\ I_{S,t} \\ I_{SM,t} \\ I_{SMA,t} \\ I_{SMO,t} \\ I_{SS,t} \\ I_{N,t} \end{bmatrix}$$

Thus, using the vector of ERPT coefficients estimated separately (\hat{P}), the weighting matrix described above S , and a matrix (Q) that varies according with the aggregation method, we can compute the vector (\tilde{P}). This vector give us coefficients of pass-through that respect the CPI's hierarchy. \tilde{P} can be obtained as follows:

$$\tilde{P} = SQ\hat{P}$$

For the Hyndman method the matrix Q takes the form $(S^T S)^{-1} S^T$.

¹⁵We employ the same notation as in Capistrán et al. (2009).

C Descriptive statistics

Table 5: Descriptive Statistics¹

Variable	Mean	Std. Deviation
IGAE	1.98	2.96
Nominal Exchange Rate	4.47	9.63
Short-term Interest Rate	5.69	1.98
Inflation		
Headline	4.09	0.92
Core	3.67	0.85
Merchandise	3.75	1.24
Food	5.18	1.70
Non-food	2.67	1.27
Services	3.65	1.41
Non-core	5.50	2.18

¹ All figures but the short-term interest rate, which is presented in levels, are estimated from their annual percentage change.

Table 6: Data Sources

Variable	Source
Global Economic Activity Indicator	INEGI
Consumer Price Index	INEGI
Nominal Exchange Rate	Banco de México
Short-term Interest Rate	Banco de México
Commodity Price Index	World Bank
Federal Funds Rate	Federal Reserve
U.S. Industrial Production	Federal Reserve
U.S. Inflation (CPI)	U.S. Bureau of Labor Statistics