

López Marmolejo, Arnoldo; Ventosa-Santaulària, Daniel

Working Paper

Why does the Mexican peso depreciate against the dollar? The role of productivity differentials

IDB Working Paper Series, No. IDB-WP-957

Provided in Cooperation with:

Inter-American Development Bank (IDB), Washington, DC

Suggested Citation: López Marmolejo, Arnoldo; Ventosa-Santaulària, Daniel (2018) : Why does the Mexican peso depreciate against the dollar? The role of productivity differentials, IDB Working Paper Series, No. IDB-WP-957, Inter-American Development Bank (IDB), Washington, DC, <https://doi.org/10.18235/0001370>

This Version is available at:

<https://hdl.handle.net/10419/208152>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/3.0/igo/legalcode>

IDB WORKING PAPER SERIES N° IDB-WP-957

Why Does the Mexican Peso Depreciate against the Dollar? The Role of Productivity Differentials

Arnoldo López Marmolejo
Daniel Ventosa-Santaulària

Inter-American Development Bank
Country Department Central America, Haiti, Mexico, Panama
and the Dominican Republic

October 2018

Why Does the Mexican Peso Depreciate against the Dollar? The Role of Productivity Differentials

Arnoldo López Marmolejo
Daniel Ventosa-Santaulària

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
López-Marmolejo, Arnoldo.

Why does the Mexican peso depreciate against the dollar?: the role of productivity differentials / Arnoldo López-Marmolejo, Daniel Ventosa-Santaulària.

p. cm. — (IDB Working Paper Series ; 957)

Includes bibliographic references.

1. Foreign exchange rates-Mexico-Econometric models. 2. Industrial productivity-Mexico-Econometric models. 3. Peso, Mexican. 4. Dollar, American. I. Ventosa Santaulària, Daniel. II. Inter-American Development Bank. Country Department Central America, Haiti, Mexico, Panama and the Dominican Republic. III. Title. IV. Series. IDB-WP-957

<http://www.iadb.org>

Copyright © 2018 Inter-American Development Bank. This work is licensed under a Creative Commons IGO 3.0 Attribution-NonCommercial-NoDerivatives (CC-IGO BY-NC-ND 3.0 IGO) license (<http://creativecommons.org/licenses/by-nc-nd/3.0/igo/legalcode>) and may be reproduced with attribution to the IDB and for any non-commercial purpose, as provided below. No derivative work is allowed.

Any dispute related to the use of the works of the IDB that cannot be settled amicably shall be submitted to arbitration pursuant to the UNCITRAL rules. The use of the IDB's name for any purpose other than for attribution, and the use of IDB's logo shall be subject to a separate written license agreement between the IDB and the user and is not authorized as part of this CC-IGO license.

Following a peer review process, and with previous written consent by the Inter-American Development Bank (IDB), a revised version of this work may also be reproduced in any academic journal, including those indexed by the American Economic Association's EconLit, provided that the IDB is credited and that the author(s) receive no income from the publication. Therefore, the restriction to receive income from such publication shall only extend to the publication's author(s). With regard to such restriction, in case of any inconsistency between the Creative Commons IGO 3.0 Attribution-NonCommercial-NoDerivatives license and these statements, the latter shall prevail.

Note that link provided above includes additional terms and conditions of the license.

The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its Board of Directors, or the countries they represent.



Why Does the Mexican Peso Depreciate against the Dollar? The Role of Productivity Differentials*

Arnoldo López-Marmolejo[†] Daniel Ventosa-Santaulària[‡]

October 16, 2018

Abstract

Over the last three decades, Mexico's macroeconomic policy has been driven by a sound orthodox strategy: an open economy via many trade agreements signed since the mid-1980s, a nominal exchange rate under a flexible regime since 1994, central bank autonomy, and responsible fiscal policy, among other benchmarks. Nevertheless, the exchange rate has continued on a path of depreciation against the US dollar. In this paper, we show that although an equilibrium relationship exists between the exchange rate and prices in Mexico and the US (its main commercial partner), there are other forces affecting the former. The main factor in this relentless long-term depreciation is the loss of productivity in Mexico relative to the US. In addition, we show that the extraordinary liquidity supplied by the US during the 2008 crisis caused the Mexican peso to appreciate against the dollar.

JEL classification: C13, C22, E24, O11, O19, O47.

Keywords: Nominal Exchange Rate, Productivity, Federal Reserve Assets, Prices.

1 Introduction

This paper explores why the nominal peso-dollar exchange rate (NER) has tended to depreciate over the last few decades. The Mexican peso has depreciated by more than 50% against the dollar in the last 5 years, 70% in the last 10, 100% in the last 15, 150% in the last 20, and 500% in the last 25 years. While the literature would suggest that floating exchange rates with little public intervention in the foreign exchange market behave stochastically (Mussa 1984), the change in exchange rate policy in Mexico towards such a regime has not altered the historical (long-term) trend of the currency. We argue that the underlying explanation for this pattern is a reduction in relative productivity (GDP per working population) with respect to the US. Figure 1 shows the evolution over time of both the NER and the productivity ratio

*The opinions expressed in this article are the authors' own and do not reflect the views of either the IADB or CIDE.

[†]Inter-American Development Bank (IADB). E-mail address: arnoldol@iadb.org

[‡]Corresponding author. Centro de Investigación y Docencia Económicas, CIDE [Carretera México-Toluca 3655, Col. Lomas de Santa Fe, Del. Álvaro Obregón, México D.F, C.P. 01210. E-mail address: daniel.ventosa@cide.edu Ph. +52 (55) 57279800 Ext. 2723.

between Mexico and the US, as defined above. Explaining the depreciation trend against the dollar of the Mexican peso is very important for the Mexican economy because of the following reasons:

- i It is a behavior that has been occurring since the 1960's and that has not stopped. The 1963-2017 average annual depreciation of the NER is 18.68%.¹
- ii The depreciation has a relevant effect on inflation. In the 1980's and 1990's the exchange rate pass-through was high (see (Capistrán, Ibarra, and Ramos Francia 2012)), and since 2017, it affects prices not only through the import component of merchandises but through gasolines, as their prices were liberated in 2017 as part of an energy reform.
- iii It affects the global wealth of Mexicans as a sizeable portion of their assets is denominated in local currency and the access to dollar-denominated bank accounts is limited by regulation only to firms whose operation justifies it (e.g. exporters).²
- iv Its depreciation path shows that the reforms implemented in the last 20 years have not been enough to find stability on the exchange rate.

The relationship between productivity differentials and the exchange rate has been a topic of study in economics since at least Harrod (1939). Balassa and Samuelson (see Balassa, 1964 and Samuelson, 1964) later rationalize this relationship by focusing on the productivity of the tradeable sector. The relevance of productivity differentials to the exchange rate is well documented, as noted in De Gregorio and Wolf (1994, p.1), “*productivity differentials across countries have long been identified as a major determinant of exchange rate movements.*” In particular, the relationship between nominal exchange rate and productivity differentials is an important one because:

- i It is a link between a nominal variable (the exchange rate) and real variables (the productivities); studying it adds support to the actual link and allows the practitioner to quantify the time needed for the complete transmission process between nominal and real variables.
- ii Productivity differentials is probably the most important area of concern for developing economies (see OECD, (2015)).
- iii To the best of our knowledge, it remains unclear why the depreciation trend has continued in Mexico in spite of many economics reforms (trade, independence of the central bank, flexibility of the exchange rate, among other).
- iv The nominal exchange rate-productivity link is a strong argument favourable to output per worker-oriented reforms.

¹Source: own calculations with FRED Saint Louis data: National Currency to US Dollar Exchange Rate: Average of Daily Rates for Mexico, National Currency Units per US Dollar, Annual.

²See for instance Lane and Milesi-Ferretti (2001).

In sum, we argue that in Mexico's case the productivity differential with the US has long since played a crucial role in the behavior of the NER. In this regard, it is important to provide a brief explanation of Mexico's economic path and its relationship to the exchange rate management schemes employed there.

2 The Mexican Economy

Like many other countries in Latin America, between 1960 and 1975 Mexico had a fixed exchange rate. During this period, its average annual GDP growth rate was 6.5%. In September 1976, the first depreciation in more than 15 years occurred and the fixed exchange rate was abandoned in favor of a controlled floating system. According to Mexico's central bank,³ the factors underlying this decision included a "significant hike in inflation and a strong reduction in the pace of economic activity." Under this regime, the central bank would not necessarily intervene to maintain the exchange rate at a certain level, only to avoid abrupt fluctuations. The controlled floating regime lasted from September 1, 1976 to August 5, 1982, during which time the NER went from 20.5 pesos per dollar to 48.8. In 1982 and 1983, real GDP fell 0.6% and 4.2%, respectively. Mexico's international reserves plummeted, and as a result, a controlled exchange rate regime was decreed. This regime lasted from August 6, 1982 to August 4, 1985. During this period, there were multiple exchange rates: a preferential exchange rate for priority goods and payments, a general exchange rate determined by supply and demand, and an exchange rate to mandatorily convert to pesos dollar-denominated liabilities payable in the country.

These controls were subject to minor variations and all the exchange rates depreciated constantly, with a fixed depreciation in the final months. To give flexibility to the exchange rate and enable it to adjust to economic conditions, a regulated floating regime was introduced, which lasted from August 5, 1985 to November 11, 1991, during which the exchange rate depreciated by 800%. In the country's shift towards trade openness, it was decided to switch to an exchange rate with crawling bands to stimulate exports and *maquila*. In 1994, in an environment of fiscal, external, and institutional weakness, violent political turmoil generated uncertainty over the capacity of the economy to finance its foreign and fiscal accounts. Furthermore, and probably as a result of these weaknesses, the country's reserves suffered a speculative attack.

All this resulted in the unsustainability of the crawling bands; there was an abrupt depreciation and a flexible exchange rate regime had to be adopted, which remains in place to this day (for further details on the various exchange rate regimes in Mexico, see Banco de México, 2009). In 1994, Mexico's central bank was granted autonomy and, in 2002, implemented a framework of inflation targeting. The inflation target was set at 3% for CPI inflation with an interval of variability of +/-1%. Inflation fell from two digits in 2000 and has been kept under control ever since, reaching a minimum of 2.1% in December 2015. After the 1995 crisis, fiscal policy became more orthodox. The average term of maturity of government securities rose from 9 months in 1994 to 6 years in 2008, and to 8 years in 2017. External debt as a percentage of total debt decreased from 59% in 1994 to 20% in 2008. In 2017, this rose to 40%, influenced

³See Banco de México (2009).

by a sharp depreciation of the currency (43% between 2014 and 2016) and fiscal expansion. The average real GDP growth rate between 1995 and 2016 was 2.5% p.a.

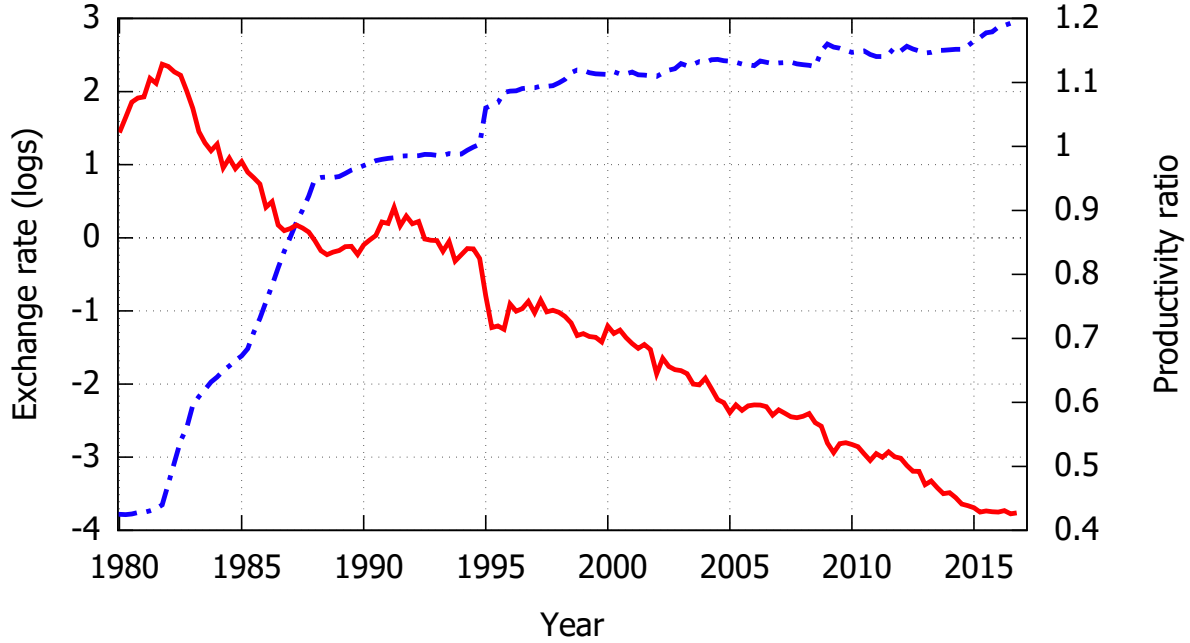


Figure 1: Nominal Exchange rate (dot-dashed line, left axis, $\ln(MXP/USD)$) and productivity ratio (continuous line, right axis, $\ln[(GDP_{mx}/WP_{mx})/(GDP_{us}/WP_{us})]$, where GDP and WP stand for Gross Domestic Product and Working Population, respectively), 1980-2016; quarterly data, seasonally adjusted.

The last recession in Mexico and the US occurred during the 2008-2009 crisis. Given the extraordinary monetary measures taken by the US to bolster its economy, some of which remain in place, we also analyze the effect of the increase in liquidity in that country on the peso-dollar exchange rate. We estimate that the increase in liquidity in the US contributed to a temporary appreciation of the exchange rate of around 1 peso per dollar in the period between the first and the third programs of Quantitative Easing (QE). This result contributes to the recent discussion of the effects of QEs on emerging markets (see, for example, Bhattarai, Chatterjee, and Park (2015); Tillmann (2016); Mohanty (2014); Borrillo, Hernando, and Vallés (2016)).

It is worth noting that, from the outset, the financial community questioned the potential effects of the normalization of US monetary policy on emerging markets (henceforth, EMEs).⁴ Here we show an

⁴For example, the annual economic policy symposium of the Federal Reserve Bank of Kansas City held in Jackson Hole in August 2013 was dedicated to the “Global Dimensions of Unconventional Monetary Policy.” In his remarks to the panel, the Governor of Mexico’s central bank (Carstens 2013) stated that “the most pressing challenge that emerging economies are currently facing and will face in the coming months is how to react to the implementation of the exit of unconventional monetary policies by some major central banks.” Carstens also stated that “...we have seen impressive capital reversals from emerging market economies, [...] a substantial upward shift in the yield curve of several countries [...], and a sharp depreciation of their

estimation of the effect of the unconventional US policies on a currency that was both liquid and that of a country financially linked to the US. In terms of liquidity, the Mexican peso is the eleventh most traded currency in the world and the second among EMEs, after the Chinese yuan. The average daily foreign exchange market turnover of the Mexican peso in 2016 was 97 billion dollars. Trading with the US dollar—90 billion dollars a day on average—accounts for ninety-three per cent of the Mexican peso turnover (BIS, 2016).⁵

It is also important to note that even when we analyze the effects on the nominal exchange rate (NER), we include relative prices in the specification, which implies that as long as there is a long-run relationship between the three variables (the nominal exchange rate and the price indexes in Mexico and the US), it can be regarded as a real exchange rate (RER). To be fair, our results show that these variables alone do not ensure a stable relationship, and, in fact, three additional variables are required to ensure this: (a) the productivity ratio between Mexico and the US; (b) Mexico's total debt (internal and external) and; (c) the liquidity conditions in the US. Together, the three offer insightful evidence on the dynamics of the NER:

- a Productivity: Papers studying the dynamics of the Mexican RER whose working hypothesis is that the one-price law holds (PPP hypothesis) usually find that the RER actually behaves not as a stationary process, but rather a trend-stationary one, i.e., they find evidence against the PPP hypothesis (see, inter alia, Gómez-Zaldívar, Ventosa-Santaulària, and Wallace (2013) and Ventosa-Santaulària and Gómez-Zaldívar (2013)). The deterministic trending mechanism is usually assumed to be controlling for productivity-related Balassa-Samuelson effects (Papell and Prodan (2006) and Lothian and Taylor (2008)). Our estimates provide more sound evidence that such a trending mechanism actually represents a relative-productivity mechanism: roughly speaking, Mexico has been losing productivity relative to the US⁶ and this loss implies a weaker currency.
- b Debt: When modeling exchange rates over time (often referred to as behavioral equilibrium exchange rates (Driver and Westaway 2004), time-varying risk premiums have been shown to be relevant variables. This risk premium is usually proxied using outstanding government debt. The close link between country risk and government debt is well acknowledged, as noted in Powell and Martinez (2008). Moreover, concepts such as “original sin” and “debt intolerance” derive from this link (see Eichengreen, Hausmann, and Panizza (2005) and Eichengreen, Hausmann, and Panizza (2007)).
- c Liquidity: The liquidity provided by the Federal Reserve as a result of its increasing its assets not only contributed to supporting the US economy, but also, at a zero lower bound, led to investors

currencies against the US dollar.” In this line, in its February 2014 Monetary Policy Report, the Federal Reserve published a study concluding that the economic fundamentals were important to avoid external pressures on the currencies of EMEs.

⁵Triennial Central Bank Survey. Foreign exchange turnover in April 2016. Available at <http://www.bis.org/publ/rpfx16fx.pdf>

⁶Stagnation of productivity seems to be a common phenomenon across the sectors in the economy. The National Statistics Institute (INEGI) estimates that the average growth rate of Total Factor Productivity in the period 1991-2016 was -0.63% in the industrial sector, -0.27% in the services sector and -0.35% in the aggregate. Source: <http://www.inegi.org.mx/est/contenidos/proyectos/cn/ptf/default.aspx>.

seeking higher returns in EMEs. Consequently, capital inflows to these countries increased, their long-term bond yields decreased, and their exchange rates appreciated, as Bhattarai, Chatterjee, and Park (2015) documented. Mexico cannot be an exception, since its strong financial links to the US make it an easily accessible market.

Our empirical strategy is described in detail in the next section. The results are discussed in section 3, while section 4 concludes with some of the implications of the results.

3 Estimating the drivers of the exchange rate dynamics

We study the nominal exchange rate between the Mexican peso and the US dollar (MXN/USD, e_t hereafter) and also the variables that affect it. In doing so, we build a macroeconomic quarterly dataset spanning the period 1996-2016. According to the macroeconomic literature, the number of potential channels through which e_t can be affected and cause an effect is nontrivial including the productivity and price differentials between Mexico and its main commercial partner, the US. To be precise, we construct the Productivity Ratio, $x_t^{<r>}$, as Mexico's Gross Domestic Product/Working Population (GDP_{mx}/WP_{mx}) divided by US's GDP_{us}/WP_{us} ; the price differential ($p_t^{<r>}$) is computed as the ratio between Mexico's and the US's consumer price indexes. Other channels considered in this study are: Mexico's debt, d_t (built as the sum of its internal and external debt at constant prices); the current account balance (ca_t^b , in US Dollars); and other external variables, such as the price of oil (O_t , US dollar price per barrel of West Texas Intermediate, WTI). Mexico's nominal exchange rate is also affected by liquidity conditions in the US and Mexico. Our dataset therefore includes the variable *Total Assets held by the Federal Reserve* (A_t) to control for this channel.⁷ Further details of the dataset can be found in Appendix C.

The relationship between e_t , $x_t^{<r>}$ and $p_t^{<r>}$ is studied using a cointegration analysis (the long-term equilibrium relationship includes these three variables). The variables d_t and A_t also play an important role and are included as restricted exogenous variables. Furthermore, to analyze the dynamics of e_t , we estimate a Vector Error Correction Model (VEC), from which we extract its short-term determinants. Short-term dynamics are also affected by O_t and ca_t^b .

It is worth noting that recent research (Hagerdon 2017) on nominal exchange determinacy shows the determinants of the nominal exchange rate to be productivity, monetary policy, net foreign assets, and government debt.⁸ All these variables are considered determinants of the NER. The current account is employed as a proxy of net foreign assets, as this is equal to the financial account plus reserves. Moreover, historically the current account deficit has been financed through the financial account and the reserves

⁷US Federal fund rates (including the shadow rate of Wu and Xia, 2016) and Mexican treasury bills (Certificados de la Tesorería, CETES with a 91-days maturity), r_t^{us} , r_t^{us*} , r_t , respectively, were also used in an attempt to measure liquidity conditions, but the correlation between these variables was positive and very strong; the sign of the parameters was not as expected, and the econometric results proved inadequate when these liquidity measures were incorporated into the VEC. The aforementioned interest rate series are included in the dataset made available to the readership along this paper.

⁸The assumptions required for this determinacy are: incomplete asset markets within each country, presence of aggregate risk in each country, and nominal assets.

have never played a prominent role. For literature on the relevance of productivity to the exchange rate, see, for example, De Broeck and Sløk (2006), and Zakaria and Ahmad (2009). In these studies, productivity is proxied by using GDP per capita and GDP per worker, respectively. Theoretical justification for the inclusion of liquidity conditions, foreign asset position, and other financial variables is also provided in Mussa (1984), MacDonald and Taylor (1992), and Driver and Westaway (2004).

The aforementioned macro variables are known to have trending mechanisms that can negatively affect the validity of the statistical inference. If the variables have a stochastic trending mechanism (i.e., behave as a nonstationary processes), the appropriate modeling strategy would thus be a VEC. In other words, stochastic trending of the variables is required to ensure the statistical validity of the cointegration analysis. Using a battery of standard unit-root tests (ADF, ADF-GLS, and PP tests), we show that all these variables do exhibit such a stochastic trending mechanism. Once evidence of nonstationarity is found, we look for possible additional structural breaks. To this end, we apply the Bai and Perron (1998) and Bai and Perron (2003) (henceforth, BP) procedure to the first difference of each variable.⁹ We also study possible breaks in the level series using the VSG test to explore whether there is a drift (a deterministic trend) and a drift break. Details of the unit-root tests and structural breaks appear in Tables 6 and 7 in appendix A, although Table 1 summarizes the results.

Table 1: Unit-root and stability tests

Variable	UR tests	Breaks (sequential Bai-Perron)	VSG	
			Drift	Break
e_t	I(1)	1988:2	Yes	Yes (1990:3)
$x_t^{<r>}$	I(1)	1983:3	Yes	No
$p_t^{<r>}$	I(1)	1988:2, 1999:4	Yes	Yes (1991:4)
d_t	I(1)	2005:1, 2008:4	No	–
A_t	I(1)	none	Yes	No
ca_t^b	I(0)	2012:4	–	–
O_t	I(1)	2014:4	No	–
r_t^{mx}	I(1)	none	No	–
r_t^{us}	I(1)	none	No	–
r_t^{us*}	I(1)	none	No	–

All variables expressed in logs except the current account balance and the interest rates.

Bai-Perron procedure applied to first-differenced variables (except ca_t^b).

On the one hand, it is clear from Table 1 that the inference drawn from standard UR tests points to the presence of unit roots in all of these macro series except for ca_t^b ,¹⁰ hence cointegration analysis is

⁹BP's procedure is valid only with stationary variables.

¹⁰Persistence estimates such as the Whittle and the GPH estimates also support this evidence; see Table 6 in Appendix A.

justified. On the other, the evidence of structural shifts points to some well-known events, such as the 1983 crisis (US and Mexico) in the productivity ratio, the 2008 debt crisis, and the drop in oil prices after 2014, though there is scant evidence of the 1994 Mexican crisis. More importantly, such breaks may either affect the parameters of the relationship or not; the former possibility would threaten the validity of the estimated relationship, whereas the latter would not. We provide evidence below that the relationship between the cointegrated variables seems to remain unaltered despite the structural breaks in the variables. To be more precise, the residual behavior of the VEC satisfied every assumption and the dummy variables used to account for level breaks in both the long- and short-term equations did not prove to be statistically relevant.

As stated previously, evidence of nonstationarity allows us to test whether or not a stationary linear combination of some of these variables exists. In other words, we test whether the nominal exchange rate, the productivity ratio, and the price ratio cointegrate. We find evidence to support the existence a cointegrated relationship between these three. Liquidity effects, modelled using *Total Assets held by the Federal Reserve* as a restricted exogenous variable, affect the long-term relationship. The current account balance and the price of oil (first-differenced) were included in the specification as unconstrained variables in the VEC. To be precise, Johansen's L_{max} and Trace (both tests are modified to account for the presence of two exogenous variables) tests indicate the existence of one cointegration vector. The results are shown in Table 2.¹¹

Table 2: Johansen cointegration tests

Null hypothesis	Eigenvalue	Trace test ¹	λ -max test
0 cointegrating vectors	0.392	54.515**	41.361***
1 cointegrating vector	0.144	13.174	12.912
2 cointegrating vectors	0.003	—	—

¹: Note that the test is conditional on two I(1) variables; (otherwise the results are similar). Specification: restricted constant; lag order: 5.

** and *** denote rejection of the null at 5 and 1%, respectively.

Once evidence of cointegration is found, we proceed to obtain the long-term relationship and the VEC. We estimate the cointegrating vector (according to the Johansen test result, there is evidence of a single cointegrating vector). The results appear below:

¹¹The maximum allowed lag order was set using the standard *ad hoc* rule, $\text{Lag}_{max} = \left\lceil 12 \left(\frac{T}{100} \right)^{1/4} \right\rceil = 11$, where $[z]$ denotes the integer part of z . Initial selection (required to perform Johansen's cointegration test) was performed using the usual Bayesian Information Criterion (BIC), which is optimized with 2 lags. The lag order of the VEC was then adjusted to ensure adequate statistical properties of the residuals of the short term regressions: no-autocorrelation, homoskedasticity and normality. An additional criterion to select the number of lags was to satisfy the coherence of the parameter estimates with economic intuition. We ultimately set the lag order at 5.

$$e_t = 10.055 - 4.901x_t^{<r>} + 3.360p_t^{<r>} + 0.226d_t - 0.742A_t. \quad (1)$$

The short-run equations (VEC) are as follows:

$$\begin{aligned} \Delta e_t &= \sum_{i=1}^{\kappa} \beta_{1,i} \Delta e_{t-i} + \sum_{i=1}^{\kappa} \gamma_{1,i} \Delta x_{t-i}^{<r>} + \sum_{i=1}^{\kappa} \omega_{1,i} \Delta p_{t-i}^{<r>} - 2.52 \times 10^{-12} ca_t^b - 0.125 \Delta O_t + u_{1t}, \\ \Delta x_t^{<r>} &= 0.018 ECM_{t-1} + \sum_{i=1}^{\kappa} \beta_{1,i} \Delta e_{t-i} + \sum_{i=1}^{\kappa} \gamma_{1,i} \Delta x_{t-i}^{<r>} + \sum_{i=1}^{\kappa} \omega_{1,i} \Delta p_{t-i}^{<r>} + u_{2t}, \\ \Delta p_t^{<r>} &= 0.029 ECM_{t-1} + \sum_{i=1}^{\kappa} \beta_{1,i} \Delta e_{t-i} + \sum_{i=1}^{\kappa} \gamma_{1,i} \Delta x_{t-i}^{<r>} + \sum_{i=1}^{\kappa} \omega_{1,i} \Delta p_{t-i}^{<r>} - 0.026 \Delta O_t + u_{3t}, \end{aligned}$$

where $\kappa = 5$ (the order of the VEC). Detailed results can be found in Table 8 in Appendix B. The inverse roots are shown in Figure 5 and also in the appendix.

The properties of the VEC can therefore be studied using standard econometrics, provided there is evidence that the residuals are well behaved, i.e., they behave as normally distributed variables, and are homoskedastic and independent. See Table 3 for detailed results:

Table 3: Normality, autocorrelation, and homoskedasticity tests

Modality	Normality [†]			Autocorrelation [‡]			Heteroskedasticity [*]		
	Eq. 1	Eq. 2	Eq. 3	Eq. 1	Eq. 2	Eq. 3	Eq. 1	Eq. 2	Eq. 3
Univariate (a)	—	—	—	1.460	3.246	1.316	2.062	0.482	8.087*
Univariate (b)	—	—	—	1.713	9.154	4.725	3.074	5.235	12.113
Multivariate (a)	9.447			1.329			171.187*		
Multivariate (b)				1.121			289.441		

* denotes rejection of the null at 10%. [†], Doornik-Hansen multivariate test. [‡], univariate: Ljung-Box Q; multivariate Rao \mathcal{F} test. *, uni/multi-variate: ARCH LM test; (a) four lags, (b) eight lags.

4 Interpreting the results

The cointegrating vector obtained shows the relevance of the productivity and CPI ratios to the long-term behavior of the exchange rate (the long-run relationship is shown in Figure 2, along with the observed exchange rate). The long-run elasticities of these variables are estimated to be -4.9 and 3.4, respectively (see Table 4). According to these estimations, through the productivity channel and leaving the rest of

the variables constant, a permanent increase in GDP growth of 1 percentage point in Mexico is associated with an appreciation of the Mexican peso against the dollar of 4.9%. An annual inflation rate 1 percentage point higher in Mexico implies that the exchange rate would depreciate by 3.4% more in the long run.

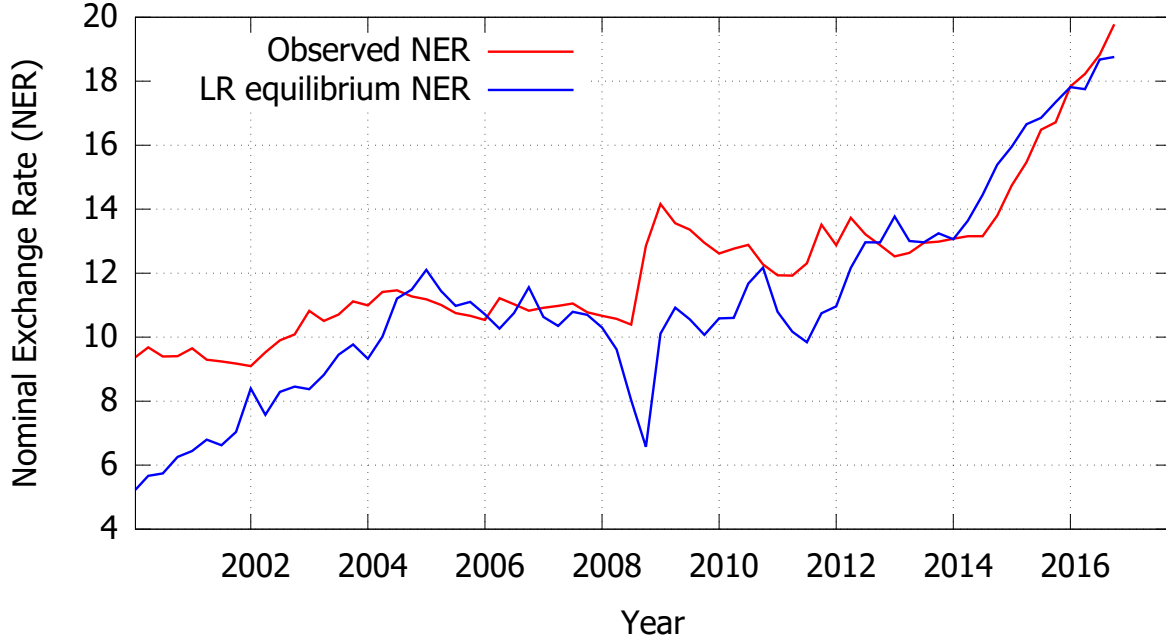


Figure 2: Long-run equilibrium and observed nominal exchange rate, (MX Pesos/US Dollars).

One percentage point represents an important change in these variables. Average annual GDP growth and inflation in the last 10 years in Mexico were, respectively 2.4% and 3.9%.

Table 4: Expected and estimated signs

Variable	Expected sign	Estimated Sign		LR elasticity
		Long-run sign	Short-run sign	
$x_t^{<r>}$	< 0	< 0	—	-4.901
$p_t^{<r>}$	> 0	> 0	—	3.360
d_t	> 0	> 0	—	0.226
A_t	< 0	< 0	—	-0.742
O_t	< 0	—	< 0	—
ca_t^b	< 0	—	< 0	—

To quantify the impact of QEs on the NER, we calculate a counterfactual of the peso-dollar level by re-estimating the model using the subsample 1996:1-2012:4¹² and eliminating A_t as an exogenous restricted variable from the specification. The resulting estimates should shed light on the impact of QEs in the

¹²We would like to thank an anonymous referee for suggesting this exercise.

NER, i.e. what its level would have been if the Fed had not increased its balance sheet. According to our results, without the increase in liquidity in the US brought about by the rise in the Fed's assets between the first and the third programs of Quantitative Easing (QE),¹³ the MXN/USD exchange rate would have been approximately 1.08 pesos per dollar higher. It is important to note that our counterfactual model estimates the "long-run" equilibrium NER, and therefore should be rather compared with the equivalent estimate of the original model presented above. When we do this, the difference slightly shrinks to 0.72 pesos per dollar (see Table 13 in Appendix D). In both cases the spread is non trivial. Details of the econometric procedure can be found in Appendix D. It is important to consider that the exchange rate will not necessarily lose those two pesos in the future when the Fed's balance sheet contracts because the equilibrium of the determinants of the exchange rate in the future might be different from what they were prior to the crisis.

Considering only the variables that correspond to Mexico, one implication of the results obtained is that a change in the depreciation trend of the peso against the dollar towards appreciation would require higher real GDP growth in Mexico, given the country's demographic composition: Mexico's population is comprised predominantly of young people that will join the labor market in the coming years: those aged between 0 and 14 years account for 27% of the total population. As a result, Mexico's working population is expected to continue growing at a similar rate for the next few years. In the period 2000-2016, real GDP growth in Mexico was not very different from that in the US, i.e., 2.4% and 1.9% on average per year, respectively. However, the working populations of the two countries grew at markedly different paces: by 2% p.a. on average in Mexico and only 0.2% p.a. on average in the US. Therefore, Mexico's GDP per working population has remained largely unchanged over the last 17 years, while in the US it has been moderately growing.

It is extremely relevant that the error-correction mechanism in the short-run NER equation is not statistically significant, as this implies that NER is weakly exogenous to the other two variables, i.e., the price ratio and the productivity ratio. In other words, any disequilibrium in the long-run relationship will be adjusted via prices and productivity (see Table 5).

Table 5: Adjustment velocities

ECM (α 's) in VECS			
ECM_i	Δe_t	$\Delta x_t^{<r>}$	$\Delta p_t^{<r>}$
	0.041	-0.018**	0.029***

** and *** denote rejection of the null at 5 and 1%, respectively.

Therefore, our results show that there is a long-term equilibrium relationship between the nominal exchange rate, the productivity ratio, and the price-index ratio. Whenever any unforeseen event affects the latter, a correction adjustment will be made via productivity and prices. Nonetheless, weak exogeneity

¹³i.e., between November 2008 and the end of June 2013, when a possible "tapering" was announced.

cannot be interpreted as causality; it is therefore relevant to study the causal direction between these three variables. We carry out a study of causality in the sense of Granger (henceforth, gc). The statical concept of gc implies that a variable (granger-) causes another when the former's past behavior contains information capable of improving predictions of the latter. Standard gc tests are performed using a classical \mathcal{F} with the typical restricted/unrestricted regression procedure. The latter requires the practitioner to define the number of lags to be considered as sufficient, and provides a binary result (there is or not evidence of gc). We opted for a more informative version of the gc test proposed by Breitung and Candelon (2006), that allows the practitioner not only to test for gc between two variables (while controlling for a third variable, as in our case), but also to infer when the gc occurs, i.e. there may be evidence of gc between a variable with the immediate past of the other variable (say, its first four lags) but not with its farthest past. The procedure is based in the spectral analysis of frequencies. To be precise, Breitung-Candelon tests gc on many frequencies, $0 - \pi$, which can be easily be interpreted in the time domain as quarters (as in our case). We can therefore test gc of less than 1 year up to more than 8 years.¹⁴ In other words, this testing procedure allows us to infer short- and long-run causalities. Figure 3 shows the results.

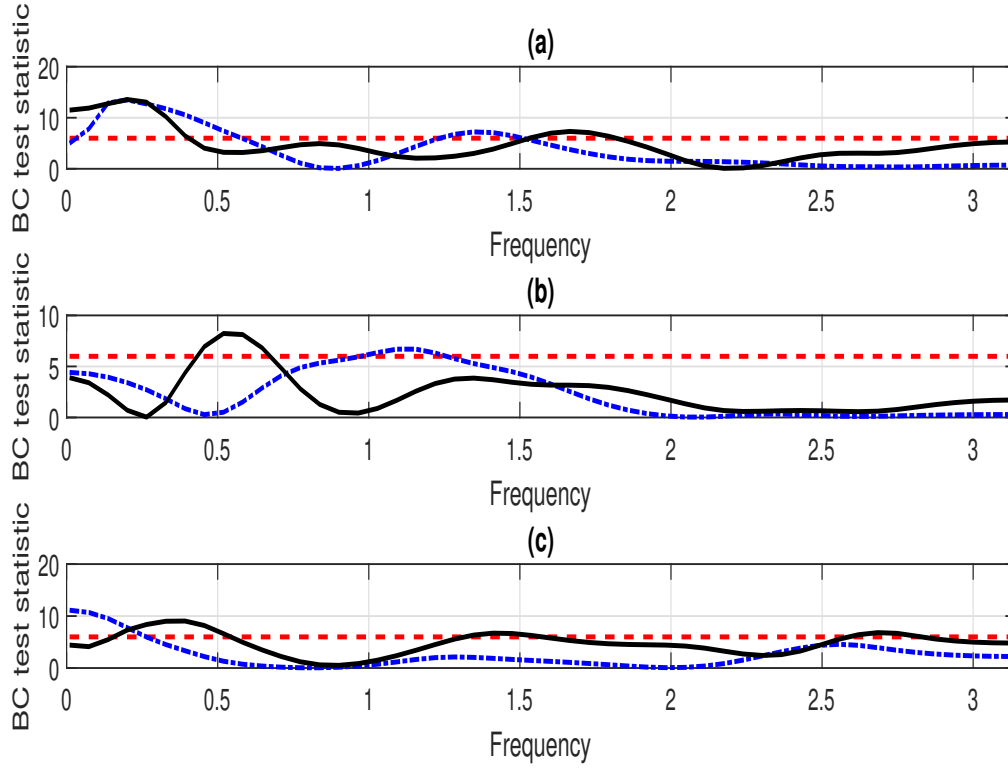


Figure 3: Long- and short-run Granger-causalities between the three cointegrated variables. Breitung-Candelon test results; red dashed line: 5% critical value, (a) blue line: $x_t^{<r>} \xrightarrow{gc} e_t$, black line: $e_t \xrightarrow{gc} x_t^{<r>}$. (b) blue line: $p_t^{<r>} \xrightarrow{gc} e_t$, black line: $e_t \xrightarrow{gc} p_t^{<r>}$. (c) blue line: $p_t^{<r>} \xrightarrow{gc} x_t^{<r>}$, black line: $x_t^{<r>} \xrightarrow{gc} p_t^{<r>}$.

¹⁴The Breitung-Candelon test was programmed by Sven Schreiber for Gretl and is available for free.

We find evidence of bivariate gc between any pair of cointegrated variables (detailed numerical results can be found in Table 10 in Appendix B). More precisely, non-causality was rejected in the following cases:

1. $x_t^{<r>} \xrightarrow{gc} e_t$: for ranges corresponding to (1) a cycle length of 1 year and 1 quarter (short run) and (2) cycles longer than 3 years and 1 quarter.
2. $e_t \xrightarrow{gc} x_t^{<r>}$: for ranges corresponding to (1) a cycle length of 1 year and 1 or 2 quarters (short run), and (2) cycles longer than 4 years and 1 quarter.
3. $p_t^{<r>} \xrightarrow{gc} e_t$: for ranges corresponding to a cycle length of 1 year and 2 or 3 quarters (short run).
4. $e_t \xrightarrow{gc} p_t^{<r>}$: for ranges corresponding to cycle lengths of 2 years and 2 quarters up to 3 years and 1 quarter (short run).
5. $p_t^{<r>} \xrightarrow{gc} x_t^{<r>}$: for ranges corresponding to cycle lengths longer than 8 years (long run).
6. $x_t^{<r>} \xrightarrow{gc} p_t^{<r>}$: for ranges corresponding to (1) cycle lengths of 3 quarters to 1 year and 1 quarter (short run), and (2) cycles lasting between 3 years and 1 quarter and 8 years.

In short, the three cointegrated variables seem to be connected via bi-variate Granger-causal links. On the one hand, we find evidence of ‘short-run’ bi-variate causality (less than 3 years) for all variables (in only one case was no evidence of causality obtained: $p_t^{<r>} \xrightarrow{gc} x_t^{<r>}$). On the other, we find no evidence of long-run bi-variate causality (above 3 years) for $p_t^{<r>} \xrightarrow{gc} e_t$, $e_t \xrightarrow{gc} p_t^{<r>}$. The only long-term (i.e. 8 years or more) causal link found is that running from $x_t^{<r>}$ to $p_t^{<r>}$.

In other words, most of the causal links between the variables seem to take place in the first 3-4 years. The three variables clearly Granger-cause each other in the short run.¹⁵ The evidence from the impulse-response functions (see Figure 4) is in line with this interpretation, as they show little impact on the variables after 12-16 quarters (3-4 years).

In addition to gc and impulse response evidence, we show the forecast error variance (FEV) decomposition provided by the VEC. The latter provides confirming evidence of bi-variate forecasting capabilities among the three cointegrated variables.¹⁶ To be precise, the decomposition shows that in the short run (say, two quarters), the forecast error variance is mostly due to its own past dynamics (above 90%). Nevertheless, as we explore further in the past, the other two variables slowly get a bigger share of the FEV. In particular, e_t and $x_t^{<r>}$ explain 61% and 28% respectively of the FEV of $p_t^{<r>}$ after 20 quarters. As for productivity, after 20 quarters, $p_t^{<r>}$ and e_t account for 18% and 6% of its FEV. The case of e_t ’s FEV is interesting. Most of its FEV remains explained by its own past dynamics; $x_t^{<r>}$ and $p_t^{<r>}$ only explain 2% and 3% of the FEV after 20 quarters. This is probably due to the many conjunctural factors that affect the exchange rate and were absorbed by the autoregressive part of the model. See Table 11 in Appendix B for further details.

¹⁵The procedure tests for causality between two variables and controls for the other.

¹⁶It is well-known that gc mostly implies prediction capabilities of one variable onto another.

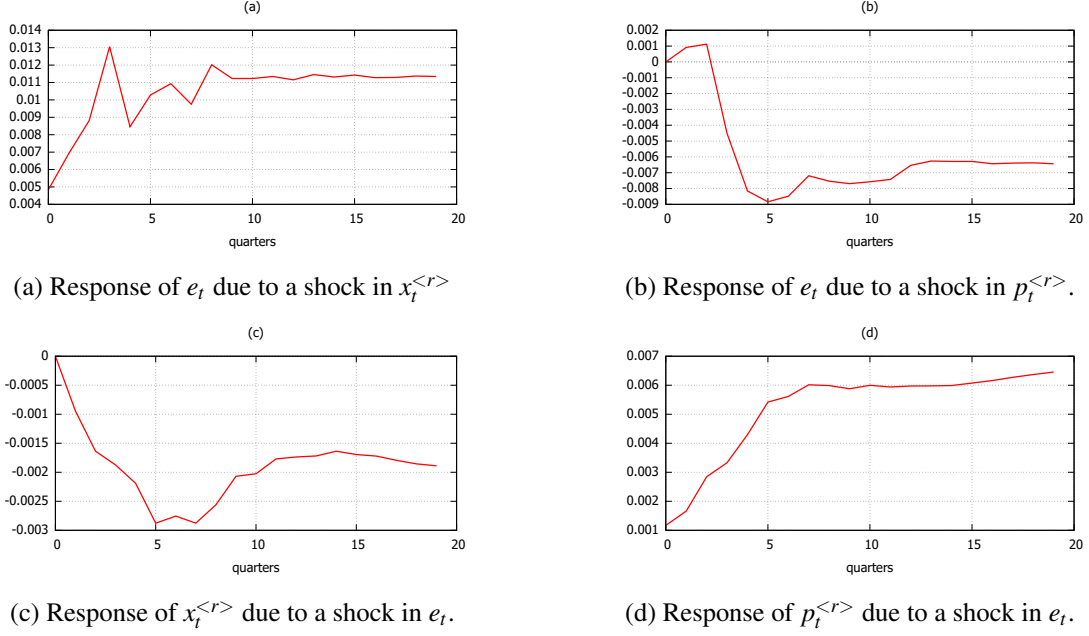


Figure 4: Selected impulse-response functions; 20 Quarters. Shock size: one standard deviation

Importantly, our measurement of productivity takes into account, imperfectly, the growth rate differentials between working age population and general population. This is so because Mexico is currently benefiting from the demographic dividend. To see its effect in our estimations, we carried out a robustness check, by recomputing the productivity ratio of Mexico and the US using the total population instead of the working-age population. Results are very similar. Moreover, a second limitation of our former productivity measurement lies in the fact that the latter mostly concerns labour productivity. To provide evidence that broader measures of productivity have a similar effect of the exchange rate, we performed a second robustness check. This time we replaced x_t^r with the total factor productivity of Mexico relative to USA's. Total Factor Productivity is a viable alternative since it includes many other definitions of productivity. In concrete, it includes all the determinants of GDP growth that cannot be attributed to capital, labour, and intermediate goods (in KLEMS methodology). It represents the efficiency, economies of scale, and capacity utilization, among other factors. Results, once again, are rather similar although in this occasion several differences are worth noting.¹⁷

Our main result is presented using the productivity measurement built with working age population because (i) it takes into account the demographic dividend, and; (ii) it is the largest available time-series

¹⁷The signs and sizes of the cointegrating parameters are similar, but with TFP we found evidence of two cointegrating vectors, rather than only one. It is noteworthy to mention that we made a third robustness check. The latter employs the original specification (and the original variables) but also includes a new unrestricted exogenous variable, ΔVIX_t , a measurement of risk (first differenced because it was found to behave as nonstationary). Including ΔVIX_t does not modify statistically neither any parameter size nor any sign. The parameter associated to ΔVIX_t is positive; this is intuitive; the exchange rate depreciates when there is more risk.

we could obtain. All the estimations concerning the robustness checks can be found in Appendix E.¹⁸ Our main result is presented using the productivity measurement built with working age population because (i) it takes into account the demographic dividend, and (ii) it is the largest available time-series we could obtain. All the estimations concerning the robustness checks can be found in Appendix E.¹⁹

5 Concluding remarks

In this paper, we find evidence that (1) a long-run relationship exists between the nominal exchange rate and relative productivities-given the systematic decay of Mexican productivity (relative to the US), the latter accounts for the negative trend in the NER, i.e., the loss of productivity in Mexico can be considered a force that made the NER depreciate in the mid and long terms; (2) the equilibrium relationship also includes prices in Mexico and the US-if we consider the loss of productivity of Mexico relative to the US as a negative trending force, our results support the idea that the Mexican exchange rate may have suffered a negative Balassa-Samuelson effect; (3) liquidity conditions in the US affected the NER-this can be seen as a side effect of the unconventional monetary policies implemented in response to the 2009 crisis; (4) public debt affected the NER, and; (5) the current account balance and oil prices affected the short-term dynamics of the NER.

A better understanding MXP/USD exchange rate long run trend, requires the role of productivity to be acknowledged. In other words, economic policies capable of augmenting Mexico's productivity would entail a driving force to appreciate the exchange rate in the long run.

¹⁸We would like to thank an anonymous referee for this suggestion.

¹⁹We would like to thank an anonymous referee for this suggestion.

References

- BAI, J., AND P. PERRON (1998): “Estimating and Testing Linear Models with Multiple Structural Changes,” *Econometrica*, 66(1), 47–78.
- (2003): “Computation and analysis of multiple structural change models,” *Journal of applied econometrics*, 18(1), 1–22.
- BALASSA, B. (1964): “The Purchasing-Power Parity Doctrine: A Reappraisal,” *Journal of Political Economy*, 72(6), 584–596.
- BANCO DE MÉXICO, B. (2009): “Regímenes cambiarios en México a partir de 1954,” retrieved from <http://www.banxico.org.mx/mercados/d/%7BC260B142-835E-2F6B-D7BD-3C9E182BB8B9%7D.pdf> (26 09 2018).
- BHATTARAI, S., A. CHATTERJEE, AND W. Y. PARK (2015): “Effects of US quantitative easing on emerging market economies,” *Federal Reserve Bank of Dallas. Globalization and Monetary Policy Institute*, Working paper No 255, Available at <http://dx.doi.org/10.2139/ssrn.2700497>.
- BORRALLO, F., I. HERNANDO, AND J. VALLÉS (2016): “The effects of us unconventional monetary policies in Latin America,” Banco de España Working Paper No. 1606. Available at <http://dx.doi.org/10.2139/ssrn.2752888>.
- BREITUNG, J., AND B. CANDELON (2006): “Testing for short-and long-run causality: A frequency-domain approach,” *Journal of Econometrics*, 132(2), 363–378.
- CAPISTRÁN, C., R. IBARRA, AND M. RAMOS FRANCIA (2012): “El traspaso de movimientos del tipo de cambio a los precios. Un análisis para la economía mexicana,” *El trimestre económico*, 79(316), 813–838.
- CARSTENS, A. G. (2013): “Remarks in the Panel on monetary policy options and tools,” in *Proceedings-Economic Policy Symposium-Jackson Hole*. Federal Reserve Bank of Kansas City, retrieved from <https://www.kansascityfed.org/publicat/sympos/2013/2013Carstenshandout.pdf> (26 09 2018).
- DE BROECK, M., AND T. SLØK (2006): “Interpreting real exchange rate movements in transition countries,” *Journal of International Economics*, 68(2), 368–383.
- DE GREGORIO, J., AND H. C. WOLF (1994): “Terms of trade, productivity, and the real exchange rate,” Discussion Paper 4807, National Bureau of Economic Research, Retrieved from <http://www.nber.org/papers/w4807.pdf> (26 09 2018).
- DRIVER, R. L., AND P. F. WESTAWAY (2004): “Concepts of equilibrium exchange rates,” Bank of England. Quarterly Bulletin No 248 Retrieved from <https://www.bankofengland.co.uk/-/media/boe/files/working-paper/2004/conceptsofequilibriumexchangerates.pdf> (26 09 2018).

- EICHENGREEN, B., R. HAUSMANN, AND U. PANIZZA (2005): “The pain of original sin,” in *Other People’s Money: Debt Denomination and Financial Instability in Emerging Market Economies*, ed. by B. Eichengreen, and R. Hausman, pp. 1–49. University of Chicago Press, Chicago.
- (2007): “Currency mismatches, debt intolerance, and the original sin: Why they are not the same and why it matters,” in *Capital controls and capital flows in emerging economies: Policies, practices and consequences*, pp. 121–170. University of Chicago Press.
- GÓMEZ-ZALDÍVAR, M., D. VENTOSA-SANTAUÀRIA, AND F. H. WALLACE (2013): “The PPP hypothesis and structural breaks: the case of Mexico,” *Empirical Economics*, 45(3), 1351–1359.
- HAGERDON, M. (2017): “An Equilibrium Theory of Determinate Nominal Exchange Rates, Current Accounts and Asset Flows,” 25th CEPR European Summer Symposium in International Macroeconomics. Retrieved from https://www.bde.es/f/webbde/INF/MenuHorizontal/SobreElBanco/Conferencias/2017/papers/170526_IMF_09.40-10.30.HAGEDORN.pdf.
- HARROD, R. (1939): *International Economics*. Cambridge University Press. New York.
- LANE, P. R., AND G. M. MILESI-FERRETTI (2001): “The external wealth of nations: measures of foreign assets and liabilities for industrial and developing countries,” *Journal of international Economics*, 55(2), 263–294.
- LOTHIAN, J. R., AND M. P. TAYLOR (2008): “Real Exchange Rates Over the Past Two Centuries: How Important is the Harrod-Balassa-Samuelson Effect?,” *The Economic Journal*, 118(532), 1742–1763.
- MACDONALD, R., AND M. P. TAYLOR (1992): “Exchange rate economics: a survey,” *IMF Economic Review*, 39(1), 1–57.
- MOHANTY, M. S. (2014): “The transmission of unconventional monetary policy to the emerging markets—An overview,” *BIS Papers*, 78, 1–24.
- MUSSA, M. L. (1984): “The theory of exchange rate determination,” in *Exchange rate theory and practice*, pp. 13–78. University of Chicago Press, Chicago.
- OECD (2015): “The future of productivity,” Discussion paper, Organization of Economic Cooperation and Development, Retrieved from <http://www.oecd.org/eco/OECD-2015-The-future-of-productivity-book.pdf> (26 09 2018).
- PAPELL, D. H., AND R. PRODAN (2006): “Additional evidence of long-run purchasing power parity with restricted structural change,” *Journal of Money, Credit, and Banking*, 38(5), 1329–1349.
- POWELL, A., AND S. MARTINEZ (2008): “On emerging economy sovereign spreads and ratings,” *IADB Research Department*, (629).

- SAMUELSON, P. A. (1964): "Theoretical Notes on Trade Problems," *The Review of Economics and Statistics*, 46(2), 145–154.
- TILLMANN, P. (2016): "Unconventional monetary policy and the spillovers to emerging markets," *Journal of International Money and Finance*, 66, 136–156.
- VENTOSA-SANTAULÀRIA, D., AND M. GÓMEZ-ZALDÍVAR (2013): "A comment on 'Testing the validity of quasi-PPP hypothesis: evidence from a recent panel unit-root test with structural breaks'," *Applied Economics Letters*, 20(2), 111–113.
- ZAKARIA, M., AND E. AHMAD (2009): "Productivity Shocks and Nominal Exchange Rate Variability: a Case Study of Pakistan," *Journal of Economic Integration*, 24(1), 175–189.

A Detailed statistical results

Table 6: Unit-root test results

Variable	Tests						
	ADF-GLS [†]	Phillips-Perron [‡]	GVS			Persistence [°]	
			R^2	t-ratio	Obs	Whittle	GPH
e_t	-0.898	-1.081	0.981***	3.310***	1990:3	1.057	1.061
$x_t^{<r>}$	-2.444	-3.223	0.979***	0.632	—	1.090	1.100
$p_t^{<r>}$	-0.850	-0.599	0.985***	3.620***	1991:4	1.071	1.074
d_t	0.702	-1.169	0.694	—	—	0.938	0.970
A_t	-1.445	-1.997	0.968***	1.170	—	1.060	1.101
O_t	-0.066	-1.418	0.738	—	—	0.915	0.776
ca_t^b	-1.976**	-3.153**	0.390	—	—	0.654	0.637
r_t^{mx}	-1.494	-1.970	0.605	—	—	0.984	1.020
r_t^{us}	-3.843***	-1.335	0.783	—	—	1.210	1.323
r_t^{us*}	-3.790***	-1.301	0.805	—	—	1.268	1.332

[†] constant and trend except for d_t , r_t , O_t , and ca_t^b because of GVS test results. Maximum number of lags = $\lceil 12 \times (T/100)^{1/4} \rceil$; lag selection criterion: Perron and Qu (2007) modified-BIC (BIC for the aforementioned variables). [‡] constant and trend except for r_t , O_t , and ca_t^b because of GVS test results; Bartlett window = $\lceil 4 \times (T/100)^{2/9} \rceil$. [°] Order = $\min\{T/2, T^{0.6}\}$. Interest rates not in logs.

Table 7: Bai & Perron structural break procedure results

Variable*	Evidence of Breaks			Number and location of breaks	
	UD max	WD max	LWZ [†]	Sequential procedure (at the 1% level)	95% Confidence interval [‡]
e_t	283.250***	390.82***	-5.320 (1)	1988:2	1987:4 – 1990:3
$x_t^{<r>}$	52.600***	60.05***	-8.394 (0)	1983:3	1983:1 – 1984:1
$p_t^{<r>}$	320.481***	442.19***	-7.665 (5)	1988:2 & 1999:2	1987:4 – 1988:2 & 1998:4 – 2005:3
d_t	57.018***	78.67***	4.376 (2)	2005:1 & 2008:4	2003:4 – 2005:2 & 2008:3 – 2008:4
A_t	62.469***	101.12***	-6.060 (2)	None	—
O_t	118.930***	179.91***	-3.927 (0)	2014:4	2014:2 – 2014:4
r_t^{MX}	16.077**	24.32***	4.271 (0)	None	—
r_t^{US}	14.860**	23.72***	-0.276 (2)	None [°]	—
r_t^{US*}	16.962***	27.46***	-0.252 (2)	None [°]	—

Robust standard errors; trimming: 0.1; maximum number of breaks: 5. * All variables but $\Delta r_t^{<r>}$ in first differences. † number of breaks (in parentheses) according to the Bayesian Information Criterion. ‡ The confidence interval building procedure is independent to the sequential testing procedure. ° Evidence of breaks in 1983:2 and 2007:4 is found at the 10% level. *, **, and *** denote rejection of the null at the 10, 5, and 1% level, respectively.

B Short-run equations (VEC) and roots

Table 8: VECM equation estimates.

Parameter	Eq. 1: Δe_t	Eq. 2: $\Delta x_t^{<r>}$	Eq. 3: $\Delta p_t^{<r>}$
Δe_{t-1}	0.0512	-0.0075	-0.0026
Δe_{t-2}	-0.0155	-0.0084	0.0129
Δe_{t-3}	0.1479	0.0011	-0.0044
Δe_{t-4}	-0.1011	-0.0007	0.0216
Δe_{t-5}	0.0514	-0.0224	0.0234
$\Delta x_{t-1}^{<r>}$	-0.0042	-0.4454 ***	-0.2005 *
$\Delta x_{t-2}^{<r>}$	0.1122	0.0296	-0.0685
$\Delta x_{t-3}^{<r>}$	0.3759	0.2455 **	0.0409
$\Delta x_{t-4}^{<r>}$	-0.6483 *	0.1368	-0.1166
$\Delta x_{t-5}^{<r>}$	-0.2602	0.1491 *	-0.1398 **
$\Delta p_{t-1}^{<r>}$	0.3040	-0.2379 *	-0.1395
$\Delta p_{t-2}^{<r>}$	0.2349	-0.2918 **	0.0518
$\Delta p_{t-3}^{<r>}$	-0.7944	0.1524	0.0580
$\Delta p_{t-4}^{<r>}$	-0.6071	0.4928 ***	-0.1868 **
$\Delta p_{t-5}^{<r>}$	-0.1765	0.2256 *	-0.0180
Δo_t	-0.1253 ***	-0.0016	-0.0262 ***
ca_t^b	-2.5×10^{-12} **	-5.8×10^{-13} *	-1.8×10^{-13}
ECM_{t-1}	0.0411	-0.0178 **	-0.0292 ***
R^2	0.50	0.49	0.90
\bar{R}^2	0.36	0.35	0.87
\mathcal{DW}	2.00	2.15	1.75

*, **, and *** denote rejection of the null at the 10, 5, and 1% level, respectively.

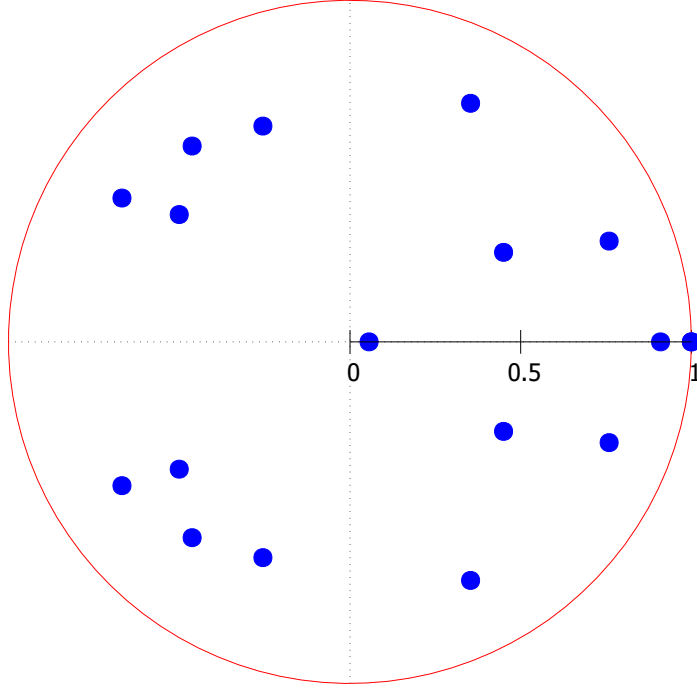


Figure 5: Unit root circle. Roots of the VEC.

Table 9: Impulse responses functions due to a standard deviation shock.

Period	$e_t \rightarrow$			$x_t^{<r>} \rightarrow$			$p_t^{<r>} \rightarrow$		
	e_t	$x_t^{<r>}$	$p_t^{<r>}$	e_t	$x_t^{<r>}$	$p_t^{<r>}$	e_t	$x_t^{<r>}$	$p_t^{<r>}$
1	0.0294	0.0013	0.0012	—	0.0077	0.0004	—	—	0.0055
2	0.0326	-0.0004	0.0017	0.0016	0.0035	-0.0002	0.0009	-0.0010	0.0042
3	0.0339	-0.0008	0.0030	0.0033	0.0053	0.0008	0.0011	-0.0015	0.0044
4	0.0389	-0.0009	0.0037	0.0067	0.0058	0.0017	-0.0045	0.0002	0.0042
5	0.0354	-0.0014	0.0045	0.0027	0.0047	0.0011	-0.0082	0.0021	0.0022
6	0.0366	-0.0020	0.0058	0.0043	0.0056	0.0018	-0.0088	0.0024	0.0022
7	0.0375	-0.0020	0.0061	0.0048	0.0049	0.0026	-0.0085	0.0029	0.0020
8	0.0359	-0.0021	0.0066	0.0039	0.0051	0.0028	-0.0072	0.0030	0.0017
9	0.0355	-0.0018	0.0067	0.0063	0.0045	0.0036	-0.0075	0.0028	0.0014
10	0.0349	-0.0014	0.0066	0.0056	0.0044	0.0039	-0.0077	0.0031	0.0011
11	0.0342	-0.0013	0.0068	0.0057	0.0044	0.0043	-0.0076	0.0030	0.0011
12	0.0344	-0.0011	0.0068	0.0058	0.0042	0.0047	-0.0074	0.0029	0.0012
13	0.0345	-0.0010	0.0069	0.0055	0.0044	0.0050	-0.0065	0.0026	0.0013
14	0.0343	-0.0010	0.0070	0.0059	0.0042	0.0054	-0.0062	0.0024	0.0015
15	0.0345	-0.0010	0.0070	0.0057	0.0042	0.0055	-0.0063	0.0024	0.0015
16	0.0345	-0.0010	0.0071	0.0058	0.0042	0.0057	-0.0063	0.0023	0.0016
17	0.0345	-0.0011	0.0072	0.0057	0.0042	0.0059	-0.0064	0.0023	0.0016
18	0.0348	-0.0012	0.0074	0.0056	0.0043	0.0060	-0.0064	0.0023	0.0016

Table 10: Breitung-Candelon Granger-causality test results

Freq	$x_t^{<r>} \xrightarrow{BC} e_t$	$e_t \xrightarrow{BC} x_t^{<r>}$	$p_t^{<r>} \xrightarrow{BC} e_t$	$e_t \xrightarrow{BC} p_t^{<r>}$	$x_t^{<r>} \xrightarrow{BC} p_t^{<r>}$	$p_t^{<r>} \xrightarrow{BC} x_t^{<r>}$	Freq	$x_t^{<r>} \xrightarrow{BC} e_t$	$e_t \xrightarrow{BC} x_t^{<r>}$	$p_t^{<r>} \xrightarrow{BC} e_t$	$e_t \xrightarrow{BC} p_t^{<r>}$	$x_t^{<r>} \xrightarrow{BC} p_t^{<r>}$	$p_t^{<r>} \xrightarrow{BC} x_t^{<r>}$
0.010	4.996	11.491*	4.413	3.900	11.124*	4.415	1.602	4.647	6.967*	3.283	3.172	1.277	5.773
0.074	7.83*	11.885*	4.283	3.402	10.692*	4.114	1.666	3.764	7.317*	2.544	3.162	1.087	5.297
0.137	12.881*	12.757*	3.945	2.208	9.526*	5.471	1.729	2.986	7.089*	1.831	3.118	0.875	4.921
0.201	13.5*	13.566*	3.411	0.705	7.764*	7.309*	1.793	2.347	6.386*	1.217	2.949	0.637	4.672
0.265	12.701*	13.041*	2.712	0.035	5.962	8.38*	1.857	1.880	5.401	0.732	2.637	0.390	4.538
0.328	11.767*	10.213*	1.830	1.460	4.520	9.002*	1.920	1.602	4.250	0.380	2.234	0.179	4.477
0.392	10.565*	6.469*	0.865	4.365	3.322	9.042*	1.984	1.486	2.943	0.153	1.792	0.071	4.412
0.456	9.019*	4.035	0.278	6.938*	2.204	8.186*	2.048	1.460	1.593	0.043	1.338	0.128	4.229
0.519	7.408*	3.224	0.514	8.229*	1.306	6.613*	2.111	1.442	0.549	0.039	0.936	0.381	3.831
0.583	5.914	3.191	1.521	8.120*	0.728	4.948	2.175	1.384	0.089	0.119	0.678	0.850	3.253
0.647	4.355	3.537	2.884	6.831*	0.380	3.489	2.239	1.283	0.169	0.237	0.588	1.528	2.702
0.710	2.643	4.134	4.097	4.835	0.166	2.215	2.302	1.146	0.631	0.323	0.610	2.336	2.420
0.774	1.100	4.707	4.895	2.795	0.056	1.195	2.366	0.969	1.351	0.334	0.660	3.141	2.587
0.838	0.187	4.938	5.333	1.278	0.050	0.604	2.430	0.759	2.134	0.278	0.682	3.852	3.287
0.901	0.068	4.673	5.615	0.509	0.157	0.514	2.493	0.562	2.738	0.195	0.659	4.375	4.400
0.965	0.606	3.987	5.939	0.432	0.384	0.853	2.557	0.443	3.031	0.127	0.606	4.568	5.559
1.029	1.611	3.123	6.357*	0.884	0.731	1.506	2.621	0.407	3.057	0.104	0.569	4.368	6.411*
1.092	2.929	2.406	6.691*	1.677	1.177	2.385	2.684	0.389	3.026	0.122	0.616	3.915	6.81*
1.156	4.382	2.074	6.692*	2.575	1.647	3.418	2.748	0.360	3.177	0.160	0.780	3.420	6.673*
1.220	5.740	2.133	6.311*	3.325	2.000	4.522	2.812	0.380	3.571	0.199	1.020	3.002	6.138*
1.283	6.753*	2.455	5.766	3.760	2.128	5.558	2.875	0.465	4.080	0.232	1.262	2.691	5.594
1.347	7.223*	3.002	5.284	3.856	2.050	6.339*	2.939	0.562	4.559	0.256	1.458	2.473	5.214
1.411	7.087*	3.840	4.893	3.699	1.864	6.706*	3.003	0.638	4.927	0.274	1.596	2.331	4.981
1.474	6.465*	4.949	4.483	3.448	1.656	6.64*	3.066	0.686	5.159	0.284	1.679	2.248	4.853
1.538	5.586	6.099*	3.953	3.253	1.461	6.268*	3.130	0.705	5.252	0.288	1.711	2.216	4.804

*. Significant at 5%.

Table 11: Forecast Error Variance Decomposition, FEVD[†]

Variable	e_t			x_t^r			$p_t^{<r>}$		
Period	e_t	x_t^r	$p_t^{<r>}$	e_t	x_t^r	$p_t^{<r>}$	e_t	x_t^r	$p_t^{<r>}$
1	100.00	0.0000	0.0000	2.7091	97.2909	0.0000	4.8181	0.3912	94.7907
2	99.8262	0.1303	0.0435	2.3956	96.3163	1.2881	8.1465	0.2954	91.5581
3	99.5026	0.4294	0.0680	2.2642	94.6170	3.1187	16.4526	0.9671	82.5804
4	98.2580	1.2606	0.4814	2.3410	95.2578	2.4013	23.2875	3.1871	73.5254
5	97.4167	1.0989	1.4844	3.1850	92.2520	4.5630	33.4184	3.4357	63.1459
6	96.6118	1.1387	2.2496	4.4222	89.2713	6.3066	44.0961	4.3753	51.5286
7	96.1137	1.2078	2.6785	5.3394	85.8877	8.7729	51.0946	6.2827	42.6227
8	95.9755	1.1957	2.8287	6.1028	83.2124	10.6848	56.6026	7.8035	35.5939
9	95.6191	1.3936	2.9874	6.5816	81.3394	12.0790	59.7222	10.2813	29.9965
10	95.3666	1.4910	3.1423	6.5360	79.7238	13.7402	61.6036	12.5833	25.8131
11	95.1478	1.5851	3.2672	6.4618	78.4892	15.0490	62.7688	14.7889	22.4423
12	94.9750	1.6697	3.3553	6.3291	77.6117	16.0592	63.2246	16.9802	19.7952
13	94.9166	1.7269	3.3564	6.1784	77.1646	16.6570	63.3314	18.9602	17.7085
14	94.8593	1.7995	3.3412	6.0863	76.8707	17.0430	63.0739	20.9294	15.9967
15	94.8203	1.8517	3.3280	5.9700	76.7062	17.3238	62.7412	22.6544	14.6044
16	94.7812	1.9030	3.3157	5.8861	76.5807	17.5332	62.3529	24.2199	13.4272
17	94.7470	1.9400	3.3131	5.8229	76.4431	17.7340	61.9680	25.6042	12.4278
18	94.7244	1.9697	3.3059	5.7813	76.3385	17.8801	61.6248	26.8004	11.5748
19	94.7022	1.9996	3.2982	5.7743	76.2079	18.0178	61.2811	27.8912	10.8277
20	94.6820	2.0244	3.2936	5.7762	76.0721	18.1517	60.9749	28.8545	10.1707

[†] The forecast error variance of each cointegrated variable is decomposed by the contribution of itself and the remaining cointegrated variables. The figures denote the contribution percentages.

C Data sources

The main data sources were the Federal Reserve of Saint Louis and Mexico's National Statistics Institute (INEGI), Central Bank (Banxico), and Tax Ministry (SHCP). Most series (specially for the US) were already seasonally adjusted; when not, we used X-13 ARIMA to obtain seasonally adjusted series.²⁰ All data were downloaded in June 2017.

1. e_t (Nominal exchange rate): Banco de México, 'Tipo de cambio Pesos por dólar E.U.A. para solventar obligaciones denominadas en moneda extranjera'.

²⁰The final dataset is available upon request.

2. $x_t^{<r>}$ (Productivity Ratio). The employed formula is:

$$x_t^{<r>} = \frac{GDP_t^{mx}/\text{Working Population (MX)}}{GDP_t^{us}/\text{Working Population (US)}},$$

where

- (a) GDPs and deflators: Federal Reserve Saint Louis (US): ‘Real Gross Domestic Product, Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted Annual Rate’; and INEGI (Mexico): Growth rate of ‘Producto Interno Bruto trimestral (base 1993, series originales a precios de 1993, por sector de actividad económica (en valores básicos) Total’, and ‘Producto Interno Bruto trimestral (base 2008, valores a precios de 2008, Producto interno bruto a precios de mercado’. The latter series was converted to 2003 prices (using the deflator); then the growth rate of the former series was used to generate a chained series.
 - (b) Working Population: Federal Reserve Saint Louis (US): ‘Active Population: Aged 25-54: All Persons for the United States, Persons, Quarterly, Seasonally Adjusted’; and MOXLAD, 1980-1990, World Bank, 1990-2016 (Mexico): the growth rate of the former was used to chain the latter. The Mexican series was made quarterly by means of linear interpolation.
3. Price Indexes: Banxico (INPC) for Mexico; and Federal Reserve Saint Louis (CPI) for the US.
4. Total Assets of the Federal Reserve: Board of Governors of the Federal Reserve System.
5. Debt: SHCP ‘(XEB00) Deuda Neta, Saldos, Deuda Externa, Sector Público Federal’ 1990 to date.
6. Current Account Balance: Bank of Mexico’s balance of payment data.
7. Oil: Federal Reserve Saint Louis, ‘Global price of WTI Crude, U.S. Dollars per Barrel, Quarterly, Not Seasonally Adjusted’.
8. Robustness checks: the robustness checks implied the computation of two additional measures of productivity.
- (a) Total population for Mexico and the US was obtained from CONAPO (National Council of Population, <https://www.gob.mx/conapo>) and BEA (Bureau of Economic Analysis).
 - (b) TFP of Mexico relative to the US was obtained from the Federal Reserve Saint Louis.
 - (c) VIX: downloaded from the Federal Reserve Saint Louis.

All the estimations of these robustness checks can be reproducing by executing the following codes:

1. COD_RU_bid: performs the unit root test to the new variables.
2. COD_PB_bid: performs the Bai-Perron test to the new variables.
3. COD_CORR_bid: estimates the correlation and cross-correlograms between the new variables.

4. COD_CO_bid: performs the cointegration analysis using the new proxies of productivity and the VIX as a new unrestricted exogenous variable.

D The impact of QE1

To evaluate the impact of QE programs, we re-estimate the model, only with two important modifications. The sample size is reduced to cover the period that goes from 1996:01 to 2012:4. and, importantly, eliminated the variable A_t as an exogenous restricted regressor from the specification.

It is worth noting that neither the sample size reduction, nor the removal of A_t affect statistical inference concerning cointegration evidence (although the evidence is less strong, see Table 12). The cointegration evidence using the short-run equations equally holds (although, again, slightly weaker); there remains two significant Error Correction Mechanisms (ECM_{t-1}).

Table 12: Johansen cointegration tests. Sub-sample 1996:1-2008:2

Null hypothesis	Eigenvalue	Trace test ¹	λ -max test
0 cointegrating vectors	0.245	40.014*	19.089
1 cointegrating vector	0.180	20.925	13.489
2 cointegrating vectors	0.104	—	—

¹: Note that the trace test is conditional on one I(1) variable; (Debt).

Specification: restricted constant; lag order: 5.

** and *** denote rejection of the null at 5 and 1%, respectively.

The Nominal Exchange Rate for the period 2008:3-2013:2 is then obtained simply by generating the “out-of-sample” TCN predictions via the estimated model.

Table 13: Counterfactual NER with QE1 effect removed

Quarter	Observed e_t	Equilibrium e_t	Counterfactual e_t
2013:1	12.53	13.77	13.71
2013:2	12.64	13.00	13.72
2013:3	12.95	12.96	13.89
2013:4	12.98	13.25	14.09

E Robustness checks

Measurement of productivity is not a trivial task. In this work we opted to proxy it by dividing the GDP by Working Population (WP). The rationale behind this is that WP only includes people of working age and thus includes the famous demographic dividend (the latter is defined by the United Nations as “the economic growth potential that can result from shifts in a population’s age structure, mainly when the share of the working-age population (15 to 64) is larger than the non-working-age share of the population (14 and younger, and 65 and older)”) from which Mexico should be said to be benefiting. We are aware that our approach may fail to consider relevant features of productivity. Because of the availability of data, we nonetheless consider that GDP/WP remains the best option. We were able to employ two alternative proxies of productivity: (i) Total Factor Productivity, TFP (z_t), and; (ii) GDP / Population ($x_t^{<p,r>}$).

On the one hand, measuring the productivity using the total population instead of the economic active population does not alter the measurement substantially; the correlation between both proposals²¹ is rather high, 0.901. On the other hand, TFP measures a different aspect of productivity, and this can be confirmed with the low correlation it holds with x_t^r , and $x_t^{<p,r>}$, 0.19 and 0.18, respectively.²² The cross-correlogram between Δz_t and Δx_t^r further indicates that the former (and its first 3 lags) are lowly but significantly (at 5%) correlated with the latter ($\rho_{z_{t-3}, x_t^{<p,r>}} = 0.26$, $\rho_{z_{t-2}, x_t^{<p,r>}} = 0.32$, $\rho_{z_{t-1}, x_t^{<p,r>}} = 0.36$)

Table 14: Unit-root test results

Variable	Tests						
	ADF [†]	Phillips-Perron [‡]	GVS			Persistence [°]	
			R^2	t-ratio	Obs	Whittle	GPH
z_t	-0.198	-0.947	0.908	—	—	1.178	1.170
$x_t^{<p,r>}$	-0.022	-2.137	0.641	—	—	0.848	0.699
VIX_t	-0.518	-2.773*	0.121	—	—	0.923	0.885

[†] neither constant nor trend because of GVS test results. Maximum number of lags = $\lceil 12 \times (T/100)^{1/4} \rceil$; lag selection criterion: Perron and Qu (2007) modified-BIC (BIC for the aforementioned variables). [‡] only constant because of GVS test results; Bartlett window = $\lceil 4 \times (T/100)^{2/9} \rceil$. [°] Order = $\min \{T/2, T^{0.6}\}$.

The resulting estimates of the model are as follows:

²¹ The correlation is computed using first-differenced series, as there is sound evidence of nonstationarity.

²² Again, the series are first-differenced because of evidence of nonstationarity as shown in Table 14.

Table 15: Bai & Perron structural break procedure results

Variable*	Evidence of Breaks			Number and location of breaks	
	UD max	WD max	LWZ [†]	Sequential procedure (at the 1% level)	95% Confidence interval [‡]
z_t	58.904***	95.35***	-9.331 (2)	1987:1 & 2009:1	1986:3 – 1988:1 & 2008:1 – 2009:1
$x_t^{<p,r>}$	102.082***	154.42***	-8.731 (0)	None	—
VIX_t	50.394***	81.57***	-3.513 (0)	None	—

Robust standard errors; trimming: 0.1; maximum number of breaks: 5. * All variables in first differences. † number of breaks (in parentheses) according to the Bayesian Information Criterion. ‡ The confidence interval building procedure is independent to the sequential testing procedure.

*, **, and *** denote rejection of the null at the 10, 5, and 1% level, respectively.

Table 16: Alternative specification estimates

Results	Specification		
	(1)	(2)	(3)
Johansen test [†]	6.664	21.772	13.229
(No of Coint Vectors)	[2]	[1]	[1]
Signs			
$x_t^{i,r}$	< 0	< 0	< 0
$p_t^{<r>}$	> 0	> 0	> 0
d_t	< 0	> 0	> 0
A_t	> 0	< 0	< 0
O_t	< 0	< 0	< 0
ca_t^b	> 0	— [‡]	— [‡]
VIX_t	—	—	> 0
Residual tests			
Normality	Ok*	Ok*	Ok*
Autocorrelation	Ok*	Ok*	Ok*
Heteroskedasticity	Ok*	Ok*	Ok*
Long-run elasticities			
$e_t/x_t^{i,r}$	-2.081	-3.854	-5.291
$e_t/p_t^{<r>}$	0.415	3.486	3.472
e_t/d_t	-0.579	0.175	0.218
e_t/A_t	0.165	-0.247	-0.793

[†]: trace statistic, conditioned on two restricted exogenous variables. [‡]: Not statistically significant at 5% level. *: Null not rejected at 5% level.