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Research Article

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Abstract

We analyze the inflation dynamics in Mexico during inflation targeting period by a GMM estimate of the hybrid New Keynesian Phillips Curve in its open and closed economy versions. We update and discuss previous results and expand the capacity of this tool to analyze inflationary dynamics by incorporating the exchange rate on labor costs. We found: a) robust evidence of adaptive and rational expectations; b) incorporating the exchange rate improves the inflation fit; c) this version of the Phillips Curve has strengthened since the Great Recession; and d) expectations formation process changes during inflationary episodes according to the origin of shocks.

Resumen

Analizamos la dinámica inflacionaria en México a partir de la adopción formal del Esquema de Objetivos de Inflación mediante la estimación de la Curva de Phillips Híbrida Neokeynesiana en sus versiones de economía abierta y cerrada utilizando el Método Generalizado de Momentos (GMM). Actualizamos y discutimos los resultados previos y expandimos la capacidad de esta herramienta para aproximar la dinámica de la inflación incorporando el tipo de cambio en los costos laborales. Nuestros principales hallazgos son: a) evidencia robusta de expectativas racionales y adaptativas; b) la incorporación del tipo de cambio mejora el ajuste de la inflación; c) esta versión de la Curva de Phillips se ha fortalecido desde la Gran Recesión; d) el proceso de formación de expectativas cambia durante episodios inflacionarios dependiendo del origen de los choques.

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In short, the Phillips curve is still there. But its current shape raises serious challenges for monetary policy in the future.

Oliver Blanchard, 2016

My view is that the data continue to show a relationship between the overall state of the labor market and the change in inflation over time. [...] I believe it continues to be meaningful for monetary policy.

Jerome H. Powell, 2018

I. INTRODUCTION

[A. W. Phillips \(1958\)](#) found a negative and apparently stable relationship between the growth rate of monetary wages and the unemployment rate for the UK (1861-1957). Later, [Samuelson and Solow \(1960\)](#) generalized this relationship by applying it to the United States (1934-1959) and called it Phillips Curve (PC). In their new version, inflation (the Consumer Price Index rate of growth) was explained by the unemployment rate and from then on was incorporated into the theoretical body of neoclassical synthesis as a central instrument of economic policy.

Since then, the form, strength, and theoretical and econometric characteristics of the PC have been central to the development of economic theory and it has become a fundamental tool for macroeconomic policymaking, particularly monetary.

With the incorporation of rational expectations ([Muth, 1961](#); [Lucas, 1972](#); [Lucas and Rapping, 1976](#)), it was assumed that the PC would become vertical even in the short run if agents could anticipate or adapt quickly to the expansionary demand policy, thereby generating only inflation with an invariant unemployment rate.

However, by accepting that there are nominal rigidities that allow the existence of suboptimal equilibria in the short term, the New Keynesian Approach—represented by [Blanchard \(2008\)](#); [Blanchard, Dell’Ariccia and Mauro \(2010\)](#); and [Carlin and Soskice \(2015\)](#)—recovers the trade-off between inflation and the unemployment gap, albeit within a fully rehabilitated microfounded theoretical approach, and assumes that although the PC is vertical in the long run, in the short run there are real effects derived from shocks and economic policy.¹

In this context, [Galí and Gertler \(1999\)](#) [GG] introduced a microfounded specification of the original PC that considers the nominal rigidities based on the idea of the phased price increase of [Calvo \(1983\)](#). Since then, the Hybrid New Keynesian Phillips Curve (HNKPC) considers expectations (both adaptive and rational)² and the real marginal cost (as a measure of the business cycle) as crucial variables in determining inflation, which reflects the behavior of labor markets.

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¹It should be noted that in this approach the duration of the short term is not clear, which has allowed for the pragmatic and discretionary policy of central banks since, at least, the Great Recession.

²What is commonly called in the literature as backward-looking and forward-looking, respectively.

According to [Ramos-Francia and Torres \(2008\)](#) [RFT], this specification has three advantages over the previous ones: 1) it allows modeling the pricing process within a monopolistic competition with firms that have temporary limitations to set prices; 2) it considers the formation of expectations as a prospective (rational) and a retrospective (adaptive) process; and 3) it uses a more adequate indicator of the business cycle, referred to marginal labor costs.

The PC is central to the macroeconomic theory and even more to economic policy, since it is probably the most important analytical, diagnostic, and action tool available for central banks to determine their monetary policy stance. In addition, according to [Rumler and Valderrama \(2010\)](#), this curve is the most efficient tool to make long-term inflation forecasts, which is what concerns the central banks the most. Nevertheless, although the estimates of this curve for the United States and Europe are abundant, in Mexico, despite its long history of inflation, there are very few applications and there are no official nor academic systematic estimates available; the most recent academic publication for Mexico is that of [Cunha \(2017\)](#). On the other hand, only [Rodríguez \(2012\)](#) incorporates the individual effect of the exchange rate in his estimate notwithstanding that according to RFT (p. 276), “given that Mexico is a small open economy, including variables that measure changes in relative prices with respect to the rest of the world (e.g., exchange rate variations) improves the results”.

We update the HNKPC inflationary dynamics analysis and we strengthen it by incorporating the real bilateral exchange rate (Mexico-United States) affecting the real marginal cost to analyze the impact of the external sector on the labor market, and subsequently on inflation through the labor market.³ Since all the variables are stationary, $I(0)$, we use the Generalized Method of Moments (GMM) [[Hansen, 1982](#); and [Hansen and Singleton, 1982](#)] to estimate closed and open economy versions of the HNKPC for Mexico (2002Q1-2020Q1), thus obtaining asymptotically efficient and consistent non-autocorrelated nor heteroscedastic estimators and solving the possible endogeneity and simultaneity problems that could exist between the inflation expectation and the error term. We chose this period because it corresponds to the formal adoption of Inflation Targeting by Banco de Mexico ([Ramos-Francia and Torres, 2005](#)) around its long-term operational target, that since 2002 has been set at $3\% \pm 1\%$.⁴

We found the following to be the main results: a) there is robust empirical evidence that the HNKPC applies for the Mexican economy, so it offers a guide to understand the inflation dynamics and the monetary policy, and shows that inflationary expectations respond to both prospective and retrospective rules, while the business cycle measured with the real marginal cost —where the exchange rate is included—positively impacts inflation; b) by testing in-sample and pseudo out-of-sample forecasts accuracy (with expanding and rolling windows), for the open economy and closed economy versions, which is one of our main contributions, we prove that the open economy specification fits better the inflation data and provide better forecasts than the closed economy version of the curve; c) we find two structural changes (2009Q2 and 2017Q1) that can be associated with the *Great Recession* and with the onset of the latest inflation episode in Mexico; d) following the 2008-2009 financial crisis, this version of the PC has strengthened; f) the real marginal cost gap is more appropriate indicator of the business cycle than the output or unemployment gaps given that these variables produce inconsistent

³ Although the exchange rate directly affects inflation, we do not take it into consideration given that our goal is to see its impact on inflation through the labor market.

⁴ We estimate until 2020Q1 because when incorporating the following quarters, the multiple shocks derived from the Coronacrisis affected considerably the sensitivity of inflation to the business cycle (see Section IV). Nevertheless, we consider our estimates robust, and coherent on the pricing process in Mexico.

results with the economic theory;⁵ and g) in order to rule out the existence of nonlinearities in this version of the PC, we prove that there is no evidence of asymmetries or diminishing marginal returns coming from monetary policy.

The work is organized as follows: in addition to this introduction, in section two we conduct a literature review, in the third section we present the stylized facts of the main variables, in section four we present the econometric issues, in the following section we discuss the main statistical results, and finally, we conclude.

II. LITERATURE REVIEW

Applied studies of the HNKPC are abundant for the United States and Europe, and there are some studies for Latin America, but for Mexico there are very few, including those of RFT, [Rodríguez \(2012\)](#), and [Cunha \(2017\)](#).

According to Medel (2015), the main methodological differences that arise when estimating this version of the PC reside in the variables used to approximate inflation expectations and the business cycle. [Stock and Watson \(1999\)](#) point out that using the output gap offers better results if the objective is to make inflation forecasts. However, GG; [Galí, Gertler and López-Salido \(2005\)](#), and RFT emphasize the importance of using real marginal costs as a measure of the business cycle because the output gap is usually not significant, generates aberrant parameters or, as in our case, the estimation presents opposite sign. An additional advantage is that the marginal costs incorporate the possible effect of gains or losses in efficiency (labor productivity) on inflation.

Cermeño, [Villagómez and Orellana \(2012\)](#) explain that there are essentially two ways to incorporate rational inflation expectations: a) by taking proxy variables that could come from surveys, newspapers and forecast consensus, or b) like GG and RFT did it—and the way we make it in this work—assuming that expectations equal the first lead of inflation data (i.e. $\pi_t^E = \pi_{(t+1)}$). In this respect, [Nunes \(2010\)](#) estimates the HNKPC—in its reduced and structural versions—for the United States (1968Q4–2007Q4) using inflation leads and information from surveys and forecast consensus as measures of the rational expectations. He finds that, although the latter is a good approximation for rational expectations, the former one has greater explanatory and predictive power of inflationary dynamics.

According to [Ferreira et al. \(2018\)](#), the HNKPC is fundamental for the decision-making of the central banks since they can implement disinflationary policies minimizing social costs,⁶ mostly if inflation is a prospective process. This explains the systematic effort of the central banks to anchor inflationary (forward) expectations and, thereby, avoid second-order effects.⁷ By doing so reduces the real effects generated by the policy. These authors find that, if inflation has a high retrospective component, indicating inflationary persistence, the sacrifice ratio of disinflationary policies is higher. In this way, the correct estimation gives the central bank the empirical elements to define the best (most efficient) stabilizing policy.

⁵In line with GG and Ferreira, Arruda and Castelar (2018).

⁶Since the work of Romer and Romer (1989) it has been widely accepted that the stabilizing monetary policy has real effects. The theoretical approach we take here considers it.

⁷This has been a permanent and systematic concern of Banco de Mexico and it is always present in its policy statements and in its minutes of the governing board meetings.

GG were the first in estimate the HNKPC for the United States (1960-1997) and found that expectation and the real marginal cost gap are significant to explain inflation. They show that the prospective component of inflation is much higher than the retrospective one.

[Nason and Smith \(2005\)](#) estimate the HNKPC for the United States (1949Q1-2002Q1), England (1961Q1-2000Q4), and Canada (1963Q1-2000Q4) and find in all cases a positive and significant relationship between the real marginal cost gap and inflation. They warn that the estimates are very sensitive to the Instrumental Variables (IV) and making estimates with different IV they find that in the United States rational expectations have always a greater impact than the adaptive ones.

For the Euro Zone (1970-1998), [Galí, Gertler and López-Salido \(2001\)](#) find that the prospective component is statistically significant, greater than the retrospective one and higher than that observed in the United States, and that the HNKPC fits better in the European Union than in the United States.

[Vašíček \(2011\)](#) estimates the open economy HNKPC (OEHNKPC) for four European Union economies (Czech Republic, Hungary, Poland and Slovakia) and finds, unlike us, that the real marginal cost might not be the best measure to approximate the business cycle, that inflation is determined in an important way by external factors, and that for these small economies the inflationary persistence is greater than in the developed ones.

For Hong Kong (1983-2002), [Genberg and Pauwels \(2003\)](#) estimate the OEHNKPC, and they find that the model fits better by incorporating the cost of imported inputs in the measure of the real marginal cost and the adaptive expectations component is higher than that of the rational one. They also warn about the sensitivity of the parameters to the set of IV.

[Medel \(2015\)](#) finds —with monthly data for Chile (2000-2013)— that the HNKPC has the capacity not only to explain inflationary dynamics, but also to make short-term forecasts. He estimates an unrestricted version of the HNKPC and shows that it is more efficient than the version that considers only the retrospective component and verifies the robustness of its results by estimating the same specifications for core inflation. He also estimates open economy versions⁸ and concludes that neither the real exchange rate nor the price of oil is statistically significant to inflation.

For Brazil (2001-2015), [Ferreira et al. \(2018\)](#) argue that the HNKPC generates different results depending on the variable used to measure the business cycle. They make several estimates using the three gaps (output, unemployment, and real marginal cost), in combination with two different measures of inflation expectations.⁹ They find that the output gap is either not statistically significant or shows the opposite sign to that predicted by the theory.¹⁰ In addition, under the hypothesis of lower foresight capability by firms, inflation is more sensitive to the cyclical component of economic activity. They find that inflation is more sensitive to its retrospective component, indicating greater inflationary persistence and the importance of high inflation history in the country.

[Chowdhury and Sarkar \(2017\)](#) use the output gap to estimate the BRIC economies PC (1994-2011). They find structural change and divide the estimates into two subperiods. By doing that, they show

⁸For this purpose, he incorporates the real exchange rate and the price of oil as individual regressors.

⁹Expected inflation, through the inflation lead, and the expected inflation values from the Focus report of Brazil's Central Bank.

¹⁰This is in line with those of GG and Galí et al. (2001) and is consistent with our findings.

that both the prospective and retrospective components are significant, where the first one is in a range of 0.608-0.766, while the second one is between 0.218-0.387. The parameter of the output gap in most cases was not significant.

For Mexico we find only three references. RFT estimate the curve with monthly data (1996-2006) using the real marginal cost gap calculated as the logarithmic deviation of the unit labor cost of the manufacturing industry with respect to its trend, as it is done in the present work. They find that all parameters are statistically significant and that when the simple specification of the PC is used,¹¹ the short-term dynamics of inflation is largely explained by its own lags; that is to say, inflation shows great persistence. However, when estimating the HNKPC they find that both types of expectations are statistically significant, as well as the real marginal cost gap. In addition, they show that inflationary persistence decreased at the end of the period; so, to a greater extent, inflation was explained by its prospective component.

The second reference for Mexico is that of [Rodríguez \(2012\)](#), who estimates the HNKPC for 1969-2008 with annual data using the output gap and incorporating the real exchange rate and the real wage as additional regressors. He finds that the closest lag of inflation is the most important in explaining it and that, although the prospective factor of inflation is significant, the estimates are not robust because it requires a very large number of IV to obtain satisfactory results and reducing them results in incorrect signs.

Finally, [Cunha \(2017\)](#), for 2001-2015,¹² unlike GG and RFT, uses the output gap and his estimation method (Two-Stage Least Squares and State-Space) differs from that used by the bulk of the literature (GMM). In his estimate, there is evidence that both prospective and retrospective components are significant in explaining core inflation, in addition to being more important, in relative terms, than the output gap and imported inflation. Unlike RFT, he finds that the retrospective component gained strength against the prospective one.¹³

III. STYLIZED FACTS

Figure 1 shows the evolution of inflation (π_t) in Mexico, defined as the annual growth rate of the National Consumer Price Index (NCPI) [[INEGI, 2020a](#)].¹⁴ Since 2001 Banco de Mexico has formally adopted the inflation targeting approach ([Ramos-Francia and Torres, 2005](#)), which explains that since 2002Q1 inflation has reduced and has been essentially stable, so it presents a stationary behavior ([Table IA](#) of the Statistical Appendix) fluctuating at an arithmetic average of 4.25% and a standard deviation of 0.96. It is worth mentioning that just a few years before inflation used to be much higher, for example, in 1998 it reached 18% and in 2000, 11%.

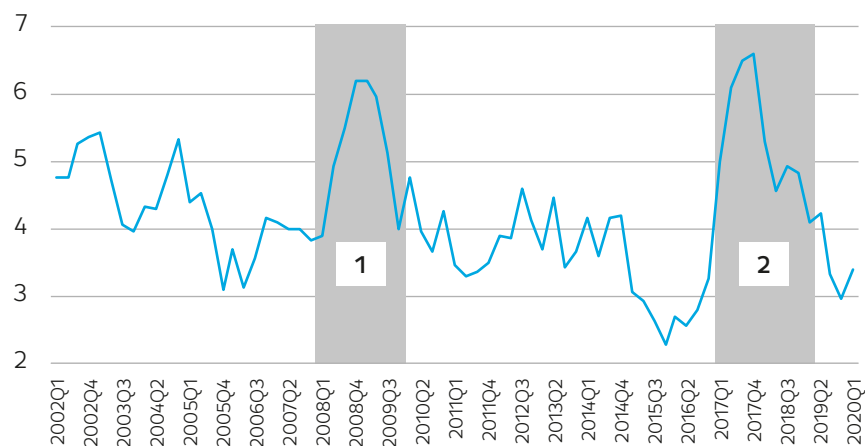
¹¹The authors call a "simple PC" the one that assumes only adaptive expectations and uses the output gap.

¹²He also defines the estimation period by the adoption of Inflation Targeting by Banco de Mexico.

¹³This result is opposite to what we present here.

¹⁴Although there are studies that use core inflation, here we use headline inflation because it is the one Banco de Mexico uses to set its target and its monetary policy stance.

Figure 1. Inflation (NCPI, annual growth rate), 2002Q1-2020Q1



Source: Prepared by the authors with data from INEGI (2020a).

During the analyzed period there were two inflationary episodes: 2008Q1-2009Q4 of essentially foreign origin (*Great Recession*), in which inflation reached up to 6.2%; and 2017Q1-2019Q1, whose origin was essentially domestic —although external factors were also involved—, during which it reached up to 6.6%. The former is explained by increases in the international prices of raw materials and by strong exchange depreciations that began in September 2008 as a result of the *Great Recession* (Banco de México, 2009). The latter was explained by the increase in the prices of food and non-food goods, agricultural and energy products,¹⁵ the increase in the minimum wage (December 2017) and the exchange depreciation explained by the fear of the electoral triumph of Donald Trump in 2016 (“Trump Effect”) [Martínez, 2017; Díaz, 2018; Expansion, 2019]. If we eliminate these two episodes, the mean and standard deviation for the entire period is 3.96 and 0.64, respectively.

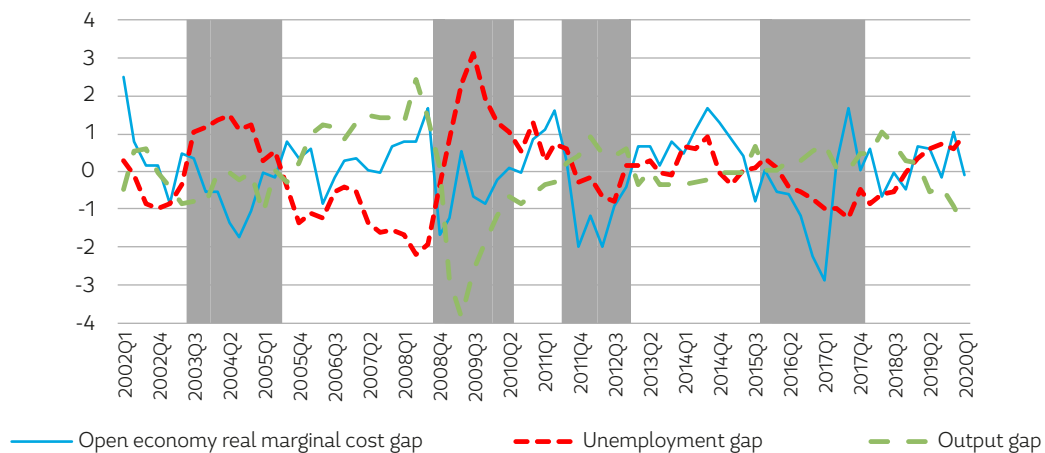
Figure 2 shows the gap for the open economy real marginal cost (mc_t^{OE}). Negative gaps are mainly associated to: a) imported recessions (*dot com crisis* in 2001¹⁶ and the *Great Recession* in 2009) which caused strong declines in employment and in the real wage in manufacturing, and important exchange rate depreciations in Mexico (see Figure 3); and b) strong reduction in the wage bill combined with the increase in average labor productivity (2011-2012 and 2015-2016) [Banco de México, 2012] and with a strong exchange depreciation in 2016 (see Figure 3), respectively. This clearly shows that, consistent with our theoretical approach, recessions and depreciations¹⁷ reduce —with lags— the real marginal cost (below their steady state trajectory) due to the loss of workers’ negotiation power.

¹⁵ Caused by the liberalization of the price of gasoline throughout the country (January 2017).

¹⁶ In Mexico the recession lasted until 2003.

¹⁷ It is noteworthy that in Mexico both things happen together.

Figure 2. Gaps: open economy real marginal cost, unemployment, and output
Normalized data, 2002Q1-2020Q1



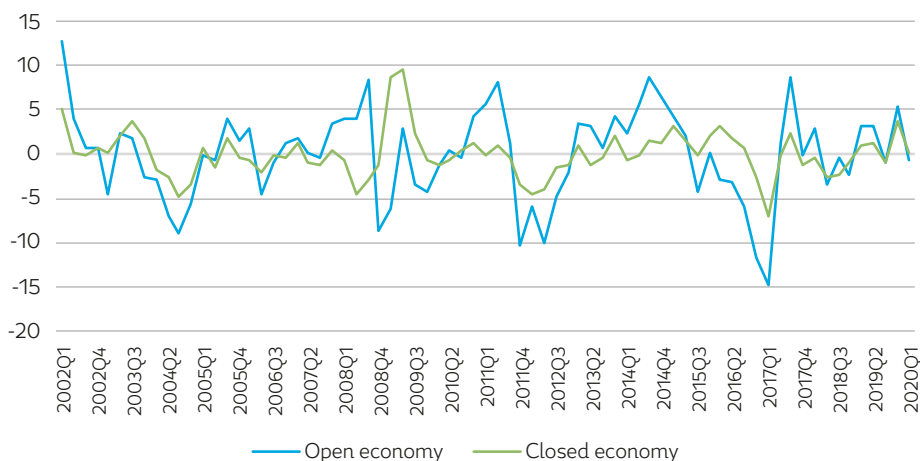
Note: gaps are calculated with the Hodrick Prescott filter [Hodrick and Prescott, 1997]. To be visually comparable, data were normalized by the following statistical procedure: $x_t = \frac{x_t - \bar{X}}{\sigma_x}$, where \bar{X} is the arithmetic mean and σ is the standard deviation.

Source: Own estimate with data from Banco de México (2020), Federal Reserve Bank of St. Louis (2020) and INEGI (2008, 2020a and 2020b).

It is easy to see that the real marginal cost gap is less volatile than the output and unemployment gaps, which highlights the nominal rigidities that lower the sensitivity of the relation between the real average pay and average productivity, given the dynamics of the business cycle.

Figure 3 contrasts the open economy real marginal cost gap (mc_t^{OE}) with that of closed economy (mc_t^{CE}). Calculation process can be found in equations (1B) and (2B) in the [Methodological Appendix](#). It is noteworthy that, although they present essentially the same evolution, the measurement of the closed economy is smoother, indicating that the exchange rate increases the business cycle volatility.

Figure 3. Open and closed real marginal cost gaps, 2002Q1-2020Q1

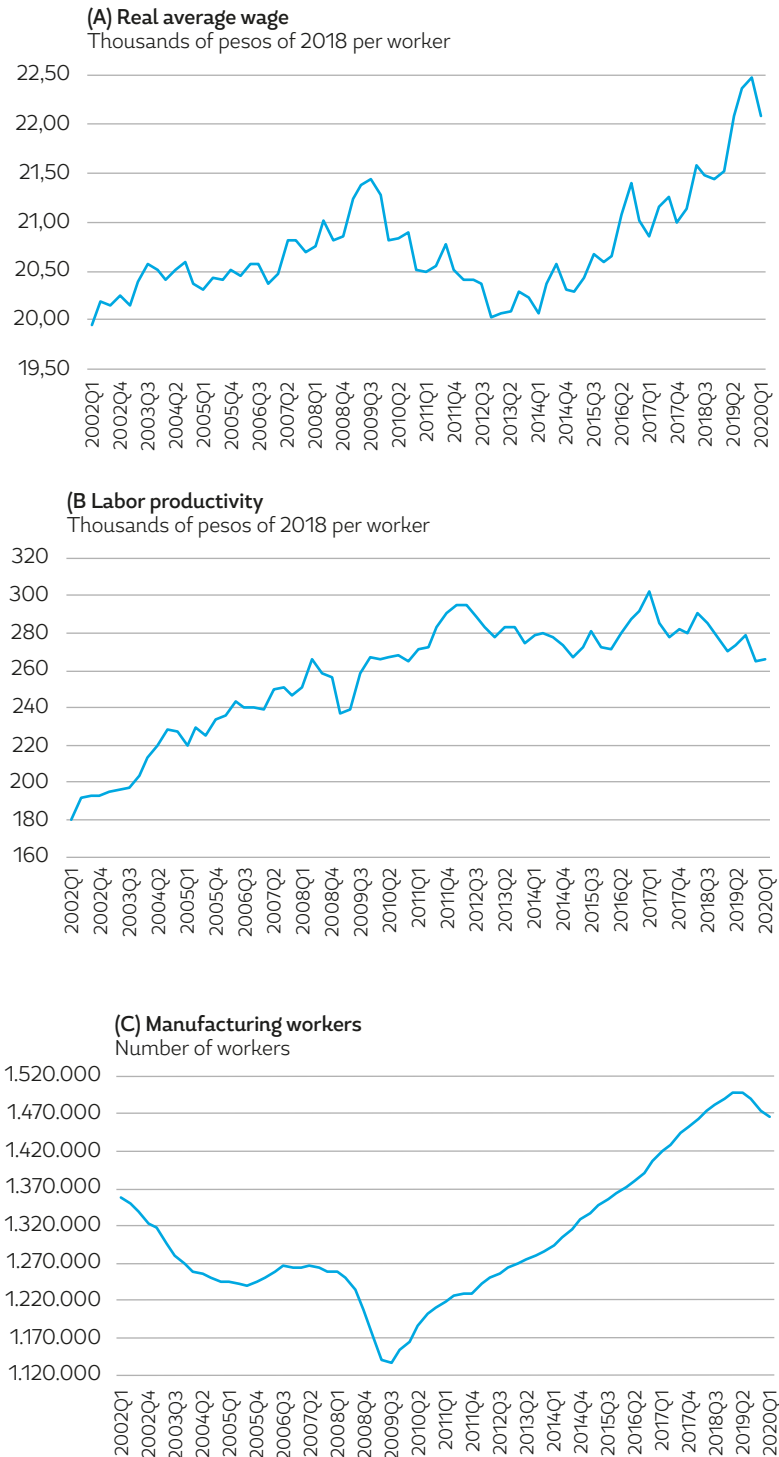


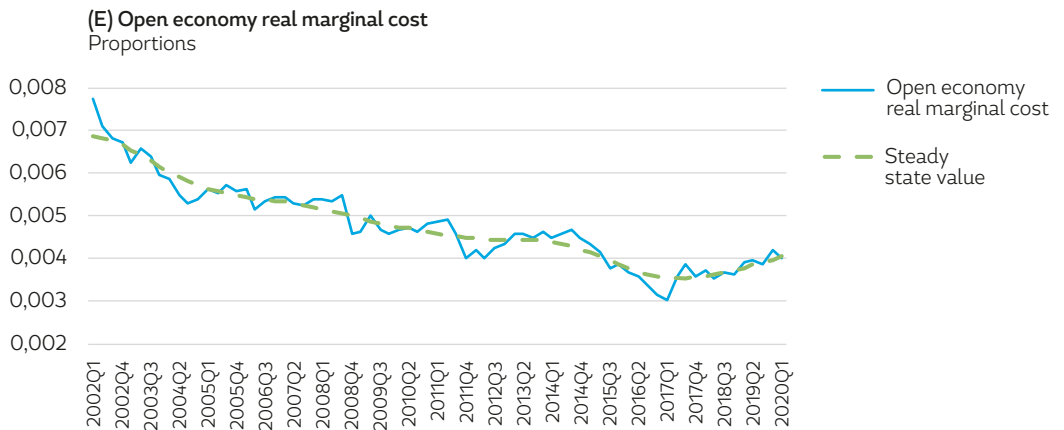
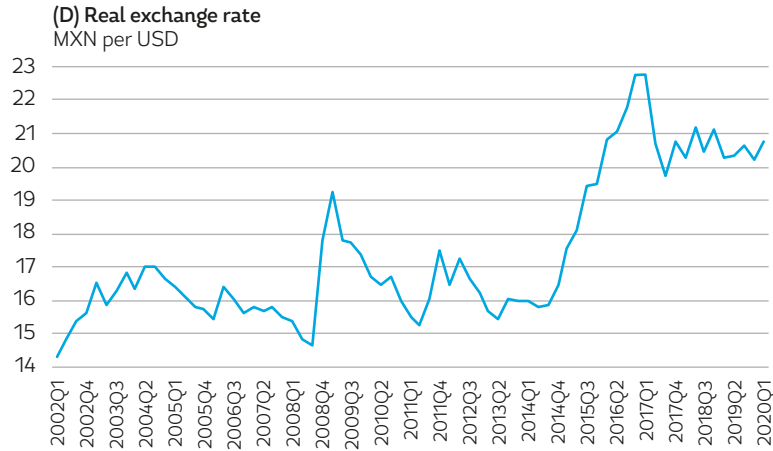
Note: Data is presented as logarithmic deviations, so they reflect the quarterly percentage deviation with respect to their stationary state value.

Source: Own elaboration with Banco de México (2020) and INEGI (2008 and 2020b) data.

Figure 4 shows the unit marginal cost and its steady state value (panel E), and the four factors that make up this measure of the business cycle (panels A, B, C and D).

Figure 4. Marginal cost and its components, 2002Q1-2020Q1





Source: Own elaboration with data from Banco de México (2020) and INEGI (2008, 2020a and 2020b).

IV. ECONOMETRIC ISSUES

In this paper, we estimate the HNKPC for open economy (OEHNKPC, [equation 1](#)) and for closed economy (CEHNKPC, [equation 2](#)):

$$(1) \quad \pi_t = \gamma_b \pi_{t-1} + \gamma_f \pi_{t+1} + \lambda mc_t^{OE}$$

$$(2) \quad \pi_t = \gamma_b \pi_{t-1} + \gamma_f \pi_{t+1} + \lambda mc_t^{CE}$$

Where mc_t^{OE} and mc_t^{CE} are the real marginal cost gaps for open and closed economy, respectively, and are calculated as the logarithmic percentage deviations of the marginal cost for open economy (MC_t^{OE}) and closed economy (MC_t^{CE}), in each case, related to their steady state values obtained with the Hodrick Prescott filter ([Hodrick and Prescott, 1997](#)). π_{t-1} and π_{t+1} are the retrospective and prospective components, respectively.

Like RFT, we implicitly assume a Cobb-Douglas production function, so the marginal cost equals the Unit Labor Cost, whose specification for closed and open economy can be found in [equations \(1B\)](#) and [\(2B\)](#) in the [Methodological Appendix](#).

The estimates of [\(1\)](#) and [\(2\)](#) are for 2002Q1-2020Q1 due to the formal adoption of the inflation—targeting approach and that inflation became stationary since 2002Q1, which is required by GMM approach. In [Table IA](#) we prove that all variables are integrated of order 0, $I(0)$.¹⁸

According to [Cermeño et al. \(2012\)](#), incorporating the expected values of a variable —such as the rational expectation of inflation $E[\pi_{t+1}]$ — can be done by assuming that ex post values are equal to their expected values plus a forecast error term ($\pi_{t+1} = E[\pi_{t+1}] + \varepsilon_{t+1}$), so that these values can be used to model inflationary expectations of the form $E[\pi_{t+1}] = \pi_{t+1} - \varepsilon_{t+1}$, which can generate endogeneity and simultaneity in the estimate because can be correlated with the residual ε_{t+1} .

To avoid this problem, the literature on the subject suggests using GMM ([Hansen, 1982](#); [Hansen and Singleton, 1982](#)) which consists in the selection of a set of instruments that should be correlated with the regressors but not with the residual term, accomplishing the orthogonality condition for the two specifications:

$$(3) \quad E[(\pi_t - \gamma_b \pi_{t-1} - \gamma_f \pi_{t+1} - \lambda mc_t^{OE}) Z_t] = 0$$

$$(4) \quad E[(\pi_t - \gamma_b \pi_{t-1} - \gamma_f \pi_{t+1} - \lambda mc_t^{CE}) Z_t] = 0$$

The high sensitivity of GMM estimates due to IV has been widely documented ([Nason and Smith, 2005](#)), so to address this problem, we selected the most efficient IV set by making a wide number of estimations with different sets that accomplished statistical significance, goodness-of-fit, Schwartz and Hannan-Quinn criteria ([Andrews, 1999](#)), and the Criterion on Relevant Moment Selection ([Hall, Inoue, Jana and Shin, 2007](#)).¹⁹

Outputs are presented in [Table I](#), where it is observed that in both estimates all the parameters are statistically different from zero and, according to the J-statistic, it cannot be rejected that equations are correctly overidentified.

¹⁸ According to Hansen (1982) and Kitamura and Phillips (1997), to properly use GMM all variables must be stationary to ensure that the estimated parameters are asymptotically efficient.

¹⁹ See IHS Markit Inc. (2017).

Table I. Estimates of the open and closed economy HNRPC, 2002Q1-2020Q1

Parameter	Open economy ^{3/}	Closed economy ^{4/}
$\gamma_b^{-1/}$	0.471 (9.850)	0.153 (1.962)
$\gamma_f^{-1/}$	0.531 (10.661)	0.852 (10.510)
$\lambda^{-1/}$	0.025 (2.752)	0.046 (3.996)
R^2	0.803	0.725
J-Stat ^{2/}	4.125 (0.531)	4.810 (0.307)

^{1/} In parenthesis t statistic.

^{2/} P-value in parenthesis.

^{3/} Instruments: π_t [2 and 3 lags], output gap (Y_t^g) [2 to 5 lags], unemployment gap (U_t^g) [2 to 5 lags], US annual GDP growth rate (\dot{Y}_t^{US}) [5th lag] and the first difference of the bilateral real exchange rate (Mexico-US) [Δq_t] [current, 1 and 2 lags]. Y_t^g and U_t^g were calculated with the HP filter.

^{4/} Instruments: π_t [current, 1 and 2 lags], mc_t^{CE} [current and 1 to 5 lags], Δq_t and the first difference in the real interest rate (Δr_t) [4th lag]. $r_t = i_t - \pi_t$ where r_t is the real interest rate, and i_t is the nominal interest rate (28 days-CETES).

All IV were obtained from Banco de México (2020), Federal Reserve of St. Louis (2020) and INEGI (2020a).

The HAC weighting matrix was used in all estimates to obtain consistent and efficient estimators.

Table IIA shows that instrumental variables are orthogonal to the error.

It should be noted that the model was estimated until 2020Q1 because when incorporating the following quarters, despite the parameters associated with the prospective and retrospective components remain almost unchanged, the ones associated with the marginal cost gap alters significantly. This result shows that as usual, inflation is especially sensitive to the slack in the business cycle.

V. DISCUSSION

To evaluate the explicative capacity of (1) and (2) we tested *in-sample-forecast and pseudo-out-of-sample forecast* for 2017Q1-2020Q1.²⁰

We observe that the open economy specification generates a more accurate forecast since the performance statistics are lower due to the distance between the forecasted and observed errors are minimized, see [Table II](#).

Table II. Forecasts accuracy: fixed window

Accuracy statistic	Open economy	Closed economy
In-sample forecast		
RMSE	0.419	0.496
Theil	0.048	0.057
MAE	0.347	0.406
Pseudo out-of-sample forecast		
RMSE	0.461	0.521
Theil	0.047	0.053
MAE	0.426	0.428

²⁰ According to Stock and Watson (2007, p.572), when having different models, pseudo out-of-sample forecasting provides a convenient way to compare and select the best.

Complementarily, we use the *expanding and rolling window* schemes to evaluate the estimations forecast accuracy at different horizons.

In both cases, the first window started in 2002Q1 and the last one in 2018Q4. We set the forecast to 4 quarters onward. In the second procedure, the window rotated 8 times and we considered 50 quarters.²¹

[Table III](#) shows that with both approaches the specification for the open economy generates more accurate inflation forecast for all horizons.

Table III. Pseudo out-of-sample-forecasts accuracy: expanding and rolling window

h quarters ahead	Open economy				Closed economy			
	1	2	3	4	1	2	3	4
Expanding window								
Bias	0.279	0.284	0.259	0.166	0.385	0.554	0.742	0.477
RMSE	0.628	0.708	0.622	0.567	0.795	0.836	0.891	0.670
MAE	0.565	0.598	0.462	0.414	0.613	0.673	0.742	0.560
Rolling window								
Bias	0.314	0.327	0.287	0.182	0.421	0.609	0.802	0.512
RMSE	0.681	0.785	0.657	0.583	0.820	0.895	0.937	0.690
MAE	0.590	0.645	0.478	0.404	0.629	0.713	0.802	0.569

Thus, RMSE and MAE, after considering the variance and the forecasting bias, confirm that by incorporating the exchange rate the forecasting accuracy improved the dynamics of Mexico's inflation. Subsequently, the rest of the analysis is completed on that specification.

The statistical significance of the estimated parameters demonstrates that OEHNKPC fits the inflation process in Mexican economy and the values of γ_f and γ_b claim that economic agents form their expectations according to prospective and retrospective rules: 0.53 vs. 0.47, respectively. The λ parameter indicates that for each percentage point that mc_t^{OE} is above its long-term value, inflation increases by 0.025. [Table IV](#) shows that output and unemployment gaps have an inconsistent relationship (statistically significant but with opposite signs) to inflation, as pointed out by GG and [Ferreira et al. \(2018\)](#), proving that using the real marginal cost gap as an indicator of the business cycle—as it is done in this paper—is appropriate.

²¹For the expanding window, we choose less observations than the whole sample (2002Q1-2017Q4), and we estimate for the next period (2018Q1). For the next window, we incorporate 2018Q1 to make the estimate and the forecast for 2018Q2, and so on. See Stock and Watson (2007 and 2008).

Table IV. Estimates of the closed economy HNKPC with different measures of business cycle, 2002Q1-2020Q1

Parameter	Y_t^G ^{1/}	U_t^G ^{2/}
γ_b	0.304 (9.014)	0.370 (13.629)
γ_f	0.697 (18.834)	0.632(24.041)
λ	-0.067 (-2.999)	0.206 (2.545)
R^2	0.785	0.807
J-Stat ^{3/}	7.48 (0.06)	1.97 (0.853)

t-statistic in parenthesis.

^{1/} Instruments: π_t [1 to 3 lags], Y_t^G [1 to 5 lags], U_t^G [1 to 3 lags], π_t .

^{2/} Instruments: π_t , π_t [1 to 2 lags], U_t^G [1 to 3 lags], Y_t^G [1 to 3 lags], mc_t^{OE} [1 to 4 lags] and Δr_t [1 to 6 lags].

^{3/} P-value in parenthesis.

Another main issue in the literature is about the presence of non-linearities. Accordingly, we estimate the quadratic functional form that turned out to be statistically non-significant in both parameters of marginal costs. Thus, we rule out the fact that the OEHNKPC estimated here presents asymmetries and diminishing marginal yields of the policy, [Table V](#).

Table V. OEHNKPC quadratic functional form, 2002Q1-2020Q1

Variable	Parameter
π_{t-1}	0.421 (7.238)
π_{t+1}	0.594 (9.455)
mc_t^{OE}	0.016 (1.215)
$mc_t^{OE^2}$	-0.002 (-1.287)
R^2	0.805
J-Stat ^{3/}	4.475 (0.483)

t-statistic in parenthesis.

Instruments: π_t [2 and 3 lags], Y_t^G [2 to 5 lags], U_t^G [2 to 5 lags], Y_t^{US} [5th lag] Δq_t [current, 1 and 2 lags].

^{3/} P-value in parenthesis.

Regarding the results for developed countries ([GG and Galí et al., 2001](#)) and in this work (for the entire period), the prospective component is higher than the retrospective one; while in developing economies such as Brazil ([Ferreira et al., 2018](#)), with strong inflationary history, the retrospective component is higher.

For Mexico, RFT (1992M1-2006M6) —for closed economy— find that both components are similar, but that the prospective one has gained strength since 1997, which points out in the same direction as the one we found here. [Rodríguez \(2012\)](#) estimates for the open economy and obtains results that show that the prospective component is higher, but there are inconsistencies with his estimate due to the expectations parameters sum is very different from one. Finally, [Cunha \(2017\)](#), who also estimates for the open economy, claims that the rational expectations component is higher.

We found that our business cycle parameter is similar to that for developed economies ([GG and Galí et al., 2001](#)), but is very low compared to that for developing economies ([Medel, 2015](#); [Ferreira et al.](#)

2018).²² We also found that this relationship has strengthened given that it is higher than the estimated by RFT and more similar to that of Cunha (2017).

By applying the Andrews-Fair Wald and Andrews-Fair LR-Type D tests (Andrews and Fair, 1988) we found two structural changes in the regression in 2009Q2 and in 2017Q1, see table IIIA. Both dates coincide with the beginnings of inflationary shocks. From the first structural break we suggest that the *Great Recession* had permanent strong recessive and inflationary effects in Mexico, and it is likely that it modified the inflation dynamics in terms of its relation between the labor market and pricing, and even in the formation of agents' expectations. To prove it, we estimated by subperiods, see Table VI.²³

Table VI. OEHNKPC. Estimates by sub-periods

	2002Q1-2020Q1	2002Q1-2009Q1	2009Q2-2020Q1
γ_b	0.471 (9.85)	0.42 (10.51)	0.458 (8.79)
γ_f	0.531 (10.66)	0.58 (14.74)	0.544 (9.53)
λ	0.025 (2.75)	-0.01 (-1.50)	0.026 (2.54)
R^2	0.80	0.81	0.81
$J\text{-Stat}^{24}$	4.125 (0.531)	3.37 (0.643)	4.39 (0.49)

t statistic in parenthesis.

²¹ Ho: the instruments are jointly valid. P-value in parenthesis.

Instruments: π_t [2 and 3 lags], output gap (Y_t^g) [2 to 5 lags], unemployment gap (U_t^g) [2 to 5 lags], US annual GDP growth rate (Y_t^{US}) [5th lag] and the first difference of the bilateral real exchange rate (Mexico-US) [Δq_t] [current, 1 and 2 lags].

HAC weighting matrix was used in order to obtain consistent and efficient estimators.

For the entire sample and for the two subsamples both components—prospective and retrospective—are quite similar. However, for the period 2002Q1-2009Q1, the business cycle is not statistically significant, but rather it is statistically significant after the *Great Recession*.²⁴ The results imply that since then the PC has strengthened given that the business cycle has greater impact on price setting, contrary to what occurred in other developed and emerging countries, where this impact decreased giving rise to the hypothesis of the flattening of this curve that has emerged in recent years.²⁵

Finally, it would be interesting to analyze how inflation dynamics switched after the last structural change (2017Q1), which is associated to the onset of the most recent inflationary episode. Nonetheless, the lack of degrees of freedom does not allow to carry out this estimation. However, the presence of structural change allows to suggest that during inflation shocks, agents expectations and the sensitivity of inflation to business cycle could change.

²² These findings can be linked to the monetary policy that Banco de Mexico has implemented since 2001. In recent decades, the policy has been more effective compared to that of developing countries such as Argentina and Brazil. Since the adoption of Inflation Targeting by Banco de Mexico, inflation subsided and became stationary at low levels; thus, the inflation expectations have been anchored and reduced the impact of business cycle in inflation.

²³ Due to the absence of degrees of freedom, we only consider 2009Q2 as a break point.

²⁴ Cunha (2017) obtains the same result but by using the output gap.

²⁵ See Galí and Gambetti (2019) and Szafranek (2017).

VI. CONCLUSIONS

In order to update and strengthen the analysis of the inflation dynamics in Mexico, we estimate the OEHNKPC for the Mexican economy (2002Q1-2020Q1) with GMM by which we obtained asymptotically efficient, non-autocorrelated nor heteroscedastic estimators.

We demonstrate that this model keeps on fitting the determinants of pricing in Mexico since gives good explanation of the inflation expectations (both prospective and retrospective). Likewise, this approach explains that the business cycle measured through the real marginal cost gap has a significant and positive impact on inflation.

We also show that the open economy specification fits better the inflationary process and generates a more accurate and efficient in-sample and pseudo-out-of-sample-forecast, making it more suitable for economic policy.

We find that the open economy model reports structural change in 2009Q2 and in 2017Q1, which coincides with the beginning of the *Great Recession* and the impact of inflationary domestic policies, respectively. Although after 2009Q2 the formation of expectations was not modified, the impact of the business cycle on inflation was notably greater, suggesting that the PC in Mexico is not flattening as it occurs in other economies, developed and developing. On the other hand, it is plausible to suggest that after 2017Q1 the inflation dynamics could have affected the formation of expectations and the sensitivity of inflation to the business cycle. However, the absence of degrees of freedom prevents us from proving it econometrically.

In addition, and in line with [GG](#) and [Ferreira et al. \(2018\)](#), we find that both the unemployment gap and the output gap give opposite sign to that claimed by the theory, whereas using the marginal cost gap, satisfactory results are obtained. Similarly, there is no evidence of non-linearities within the model, which indicates the absence of asymmetries in inflation determination under this approach and that monetary policy has no diminishing marginal yields.

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STATISTICAL APPENDIX

Table IA. Unit Root Tests

	π_t	mc_t^{OE}	mc_t^{CE}	Y_t^G	U_t^G	Δq_t	\dot{Y}_t^{USA}	Δr_t
Augmented Dickey-Fuller								
T&I	-2.937*	-3.477	-3.698	-3.875	-4.034	-7.658	-3.161*	-8.570
Cons	-3.102	-3.588	-3.832	-3.885	-4.061	-7.721	-3.184	-8.546
N	-0.978*	-3.614	-3.863	-3.897	-4.079	-7.700	-0.784*	-8.603
Philips-Perron								
T&I	-3.050*	-3.477	-3.421*	-8.155	-5.419	-7.634	-2.778*	-8.567
Cons	-3.066	-3.613	-3.606	-8.110	-5.412	-7.700	-2.790*	-8.544
N	-0.841*	-3.639	-3.642	-8.130	-5.426	-7.689	-1.437*	-8.599

Note: Ho: \exists unit root.

* Indicates unit root at 95% confidence, T&I = trend and intercept, Cons = constant, N = nothing.

π_t is inflation, mc_t^{OE} is the real marginal cost gap for open economy, mc_t^{CE} is the real marginal cost gap for closed economy, Y_t^G is the output gap, U_t^G is the unemployment gap, Δq_t is the depreciation of the Mexico-United States real exchange rate, \dot{Y}_t^{USA} is the growth rate of United States output and Δr_t is the first difference of the real interest rate.

The gaps are calculated with the HP filter.

Although π_t and \dot{Y}_t^{USA} may seem to have a unit root, by using the procedure of Dolado, Jenkinson & Sosvilla-Rivero (Enders, 2004, p. 213), it is concluded that they are stationary, $I(0)$.

Table IIA. Orthogonality Test

Instrument	Difference in J-stats	Probability
Open economy		
π_t	1.06	0.303
Y_t^G	1.07	0.300
U_t^G	1.528	0.216
Δq_t	0.521	0.470
\dot{Y}_t^{USA}	0.292	0.588
Closed economy		
π_t	1.873	0.171
mc_t^{CE}	0.634	0.426
Δq_t	0.624	0.429
Δr_t	0.003	0.953

Ho: X_i is orthogonal.

Table IIIA. OE-HNKPC structural change

Test	2009Q2	2017Q1
Andrews-Fair Wald (Andrews y Fair, 1988) ^{1/}	11.293 (0.01) *	19.937 (0.000) *
Andrews-Fair Wald LR-Type D Stat (Andrews y Fair, 1988) ^{2/}	28.482 (0.000) *	NA
Hall and Sen O (Hall y Sen, 1999) ^{2/}	15.154 (0.916)	15.328 (0.910)

The probability of non-rejection of Ho associated with the distribution X^2 is shown in parentheses.

^{1/} Ho: no structural change (IHS Markit Inc., 2017).

^{2/} Ho: over-identification restrictions are stable in the sample (IHS Markit Inc., 2017).

* Indicate rejection of Ho at 1% of confidence.

NA: not applicable.

METHODOLOGICAL APPENDIX

Calculation of the open economy real marginal cost (RMC_t^{OE})

According to a broader definition, the unit labor cost (ULC) is defined as the ratio of the average real wage in manufacturing (per worker) to their average productivity (INEGI, 2015):

$$[1B] \quad ULC_t^{CE} = \frac{W_t/L_t}{Y_t/L_t}$$

Where ULC_t^{CE} is the closed economy unit labor cost; W_t is the average real wage of manufacturing workers; L_t is the number of workers employed in the manufacturing industry; Y_t is the real output of the manufacturing industry; W_t/L_t is the real average wage per worker and Y_t/L_t is the average labor productivity. Real output and wage were deflated with the National Producer Price Index for manufacturing (INPP_m) [INEGI, 2020a] and all series were seasonally adjusted with the CENSUS-X12 method (U.S. Census Bureau, 2011).

Since W_t , L_t and Y_t come from different sources,²⁶ long run series (1993Q1-2020Q1) were built, thus linking them through their growth rates.

To calculate the open economy ULC, which incorporates the effect of the real exchange rate on labor costs, we propose to multiply ULC_t by the inverse of the Real Exchange Rate (q_t):

$$[2B] \quad ULC_t^{OE} = \frac{W_t/L_t}{Y_t/L_t} * \frac{1}{q_t}$$

Where ULC_t^{OE} is the open economy unit labor cost for Open Economy; q_t is the Mexico-United States Bilateral Real Exchange Rate, which is calculated as follows:

$$[3B] \quad q_t = \frac{e_t * PCE_t}{NCPI_t}$$

Where e_t is the Nominal Exchange Rate (pesos per US) [Banco de México, 2020]; PCE_t is the United States Personal Consumption Expenditure Chain Type Price Index (Federal Reserve Bank of St. Louis, 2020), and $NCPI_t$ is the National Consumer Price Index of Mexico (INEGI, 2020a).

²⁶ From 1993Q1 to 2007Q4, the data comes from the Monthly Industrial Survey (INEGI, 2008) and from 2008Q1 to 2020Q1, it comes from the Monthly Survey of the Manufacturing Industry (INEGI, 2020b). Each source has its own methodology and measurement basis.