Wage gaps and manufacturing output: A comparison between production workers in Mexico and the United States

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Working paper

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A substantial wage gap between Mexican and United States continues to exist between manufacturing production workers. This is despite a free trade agreement NAFTA (North America Free Trade Agreement) in which both countries are partners since 1994. While skill endowments, consumption patterns and social status are ostensibly heterogeneous in both countries, trade openness should render them comparable and eventually converging, according to the Factor Price Equalization (FPE) theorem. This study focuses exclusively on production and nonsupervisory workers in inland manufacturing in non-durable industries i) food; ii) textile products and mills; iii) chemicals, and durable industries iv) primary metal; v) machinery; vi) transportation equipment. The estimation technique relies on a time series error correction model during pre and post-NAFTA periods. The main findings of this research point out that the wage gap has expanded during the post-NAFTA period with respect to pre-NAFTA period. The post-NAFTA wage gap is affected negatively by a persistent Mexican currency undervaluation and an increase in the manufacturing output index ratio. As a result, the above FPE has not proved itself its validity in the present case.

Keywords: wage gap; Mexico; United States; NAFTA; factor price equalization theorem.

JEL codes: J3; F02; F00; F11; F15; F16; F66.

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Introduction

The sizable manufacturing wage gap between Mexico and United States continues to grow.[2] Descriptive statistics expose the persistence of a manufacturing wage gap increase over time. On average for the pre-NAFTA (North American Free Trade Agreement) time period, *i.e.*, 1987-1994 a Mexican worker earned 0.15 of his United States counterpart. Such differential increased from 2007 to 2013, as such fraction fell to 0.11. Hence, during the first period, Mexican wages in manufacturing were almost one seventh *vis-à-vis* the United States. During this last period, the difference grew close to one tenth.[3]

The theoretical framework for this research is provided by the well-known theorem pertaining to international free trade, *i.e.*, Factor Price Equalization (FPE). In 1994, Mexico joined a free trade agreement previously signed between Canada and the United States in 1988. As a result, the North American Free Trade Agreement was established. The North American region composed of Mexico, the United States, and Canada signed and implemented an international free trade agreement (NAFTA) in 1994. This treaty does not gives consideration to labor mobility among countries, although it seeks to deregulate trade in goods and services, as well as capital flows. According to the FPE, it is expected that free trade by itself would effectively contribute to reduce wage differentials among trade partners. This is based on the assumption that labor is to compete indirectly, *i.e.*, through traded goods. Essentially, factor prices would be equalized thanks to international trade.[4] Therefore, if FPE holds labor mobility would not be needed to achieve labor compensation equality across countries.

Wage gaps for manufacturing production and nonsupervisory workers between Mexico and United States is empirically examined both for manufacturing sector as a whole, as well as regarding six selected industries.[5] An error correction model provides the econometric method to empirically gauge the manufacturing wage gap.[6] Two bilateral econometric determinants are introduced in this model: the real exchange rate and the manufacturing production index ratio. These determinants help in explaining the empirical rationale behind the wage gap. It is important to note that the wage gap computation for production workers for Mexico and the United States with respect to selected industries is grounded in the North America Industrial Classification System (NAICS),[7] duly applied by both countries.

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[2] It is in the manufacturing sector where the best paid production jobs are found. In here, production workers represent the larger portion on the manufacturing labor force.

[3] These wage gap mean figures refer to the number of dollar cents paid on average per hour for a Mexican production worker *vis-à-vis* 100 cents paid on average per hour for an American production worker of the same type. Consequently, the Mexican compensation represents 15 cents for each dollar paid for an American worker for 1987-1994. This same ratio reduces to 11 cents for 2007-2013. This implies that the wage gap has increased in spite of two decades of free trade agreement between the two nations.

[4] Usually factor prices are regarded as factor compensations.

[5] It should be added that *maquiladora* production (Mexican offshore assembly for export) is excluded in this study. While they are outside the above-mentioned Mexican manufacturing survey, its importance merits an analysis of their own.

[6] While the empirical literature has considered the wage gap subject, to the author knowledge, no analysis has yet been made for manufacturing with this technique involving Mexico and the United States.

[7] National statistic offices match production workers industrial work types in Mexico and the United States, when they issue the corresponding concordance tables. Further information is available at Morisi (2003).

The aim of this paper is to explain why the wage gap has persistently increased despite the international free trade tenets. The results could provide a guideline regarding public policies concerned with international free trade.

This paper is organized as follows: in the first section, a brief literature review is presented regarding free trade theoretic tenets, as well as empirical studies regarding the wage differentials between Mexico and the United States. The second section analyses the data based on descriptive statistics of data performance. The third section presents an error correction econometric model, which is followed by its results. The fourth section contains the conclusions.

1. Brief literature review

In the theoretical literature the FPE theorem tenets assume two production factors: labor type one and labor type two, within two countries. Free international trade would ensure labor factor payments type one and two equalization in these two countries. If this result holds, then it would imply that no labor mobility is required for attaining this outcome.

According to Samuelson (1948), factor payments equalization is not only possible and probable, but also in a wide variety of circumstances it becomes inevitable:

> "(1) So long as there is partial specialization, with each country producing something of both goods, factor prices will be equalized, absolutely and relatively, by free international trade.
> (2) Unless initial factor endowments are too unequal, commodity mobility will always be a perfect substitute for factor mobility."

Samuelson (1948) provides adequate proof for the above propositions for a two-regions, two-commodities, and two-factors case. There is a caveat, however, which Samuelson introduces in the second proposition. Factor endowments could be made responsible for not attaining such wage convergence; thus, a possible wage differential could be related to a capital-labor gap.

According with Baldwing (2008) the familiar two-countries, two-goods and two factors propositions are often referred to as the Heckscher-Ohlin Samuelson (HOS) model in recognition of Samuelson's contributions in formulating the Stolper-Samuelson and factor price equalization theorem. The basic proposition of the HO is also named Rybczynsky theorem.[8]

For the specific case of Mexico and the United States empirical literature, there are researchers who have accomplished the task of linking the international trade theory and its effect on the wage and income gaps. In what follows some reviews on this empirical literature are put forward.

For example, Reynolds (1995) assumes that productivity, factor prices, and wages have a common prior distribution in these two countries. He sees two possible scenarios after

[8] Hanson and Slaughter (1991) explained that the empirical evidence for the United States related with the Rybczynsky theorem points out, that endowment shocks via changes in output are absorb without any changes in relative regional factor prices.

NAFTA implementation: the first one is an upward convergence for the wage gap, implying that those starting at the low end of the distribution move up, toward those at the high end of the distribution. Thus the ones at the high end of the distribution do not go down. The second possible scenario is less favorable, as it comprises a downward convergence. This could happen when wages increase modestly at the low end of the distribution and wages at the high-end decrease to the low end.

For their part, Peach and Adkisson (2002) analyse whether there has been an income convergence between the United States and Mexico. They give the following income figures: $34,950 for the United States, Gross Domestic Product (GDP) *per capita* from 2000—figure drawn from the Department of Commerce 2001, United States.[9] The corresponding figure for Mexico is $5,720 on 2001, with data extracted from the Mexican Central Bank. The difference between both countries, in terms of GDP *per capita* in dollar terms, was over six fold after six years of NAFTA implementation. These authors restate findings by Samuelson (1949), Samuelson (1971), and Mundell (1957), whose theoretical free trade framework was used to explain income convergence. When Peach and Adkisson (2002) do not observe empirically researched wage convergence, they explain income divergence as a result of institutional rigidities, which in turn causes market failures.[10] They mention that Mexico attained its highest income GDP *per capita* when market-oriented policies were at their weakest. Paradoxically, market-oriented polices are a result of government interventions, which are regarded as the principal cause for market failures. Also, they point out the following puzzle: when market-oriented policies were weakest, income shows the highest convergence between both countries. As a result, income gap is a most important contemporary policy issue for these authors.

The wage gap empirical analysis takes a different dimension for Robertson (2005). He investigates labor market integration between Mexico and the United States before and after NAFTA, and uses different approaches to accomplish this task.[11] For example, he measures the responsiveness of Mexican wages to United States wage shocks. He interprets this responsiveness in two ways: i) the speed at which relative wages return or do not return to a long-run differential and ii) absolute wage convergence growth rate. Robertson implements the use of a wage equation with data generated from a pseudo-panel technique as well as data collected from the Mexican National Survey of Urban Employment and the United States Current Population Survey. His econometric results suggest that trade variables (measured as exports plus imports) and foreign direct investment do in fact positively contribute to labor market integration. At the same time, he finds that border enforcement depresses Mexican wages. In his view, border enforcement could mask the positive benefits of market integration. It is important to note, that Robertson (2004) uses as a proxy of relative wages an employment weighted hourly of non-production to production wage ratio.

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[9] Although these authors do not refer directly to wages, it should be acknowledged that wages are an important income component.

[10] Institutional rigidities are identified in the literature, *i.e.*, with education (skilled and unskilled workers), technology, minimum wage, to mention a few.

[11] It is important to note, that Robertson (2004) uses as a proxy of relative wages an employment weighted hourly of non-production to production workers.

In a discussion paper Gandolfi, Halliday and Robertson (2014) find no evidence of long run factor price convergence for the time period of 1988-2011, among population cohorts characterized by low migration propensities. These authors try to explain this apparent contradictory result with the neoclassical trade theory, arguing that major macroeconomic shocks such as the 1994 Mexican peso crisis are the culprits. The authors use two complementary methodologies. The first one is applied to survey data with a synthetic panel approach and an econometric analysis. The second methodology uses descriptive statistics, resorting on information observed only once every ten years, *i.e*., 1990, 2000 and 2010. For the United States the authors use the U.S. Census and the American Community Survey; for Mexico they utilize the *Censo de Poblacion y Vivienda*.

From this literature review, it is clear that income or wage gap analysis between Mexico and the United States has not definitely been identified as converging or narrowing since NAFTA implementation. In fact, evidence for this identification is nil or, at best, inconclusive.

2. Data

Three discontinuous longitudinal data sets on Mexico regarding wages and output are available. These sets are based on official manufacturing surveys. In the case of Mexico, the data set discontinuity happens when the local statistic office enlarged the industry sample size, *i.e.,* from 205 industrial activities to 240 for the last period of 2007-2013.

On the basis of the above data availability, three different non-overlapping monthly time periods are being selected for the econometric estimation. First, a pre-NAFTA time period comprises one sub-period, *i.e*., from January 1987 to December 1994 (1987:01-1994:12). Besides, a post-NAFTA time period, containing two sub-periods: from January 1995 to February 2006 (1995:01-2006:02) and from January 2007 to December 2013 (2007:01-2013:12).

The manufacturing industries reported in Table 1 were selected on the basis of their relevance in total Mexican exports.[12] Also, these industries are arranged according to United States manufacturing goods classification on non-durable and durable goods. Consequently, the selected non-durable industries are: i) *food*; ii) *textile products and mills*, and iii) *chemicals*. The durable industries are: iv) *primary metal*; v) *machinery*, and vi) *transportation equipment*.

The wage gap for manufacturing is defined as the relation of Mexican wage divided by the American wage, both in dollar terms.[13] Thus, the wage gap could be read as follows:

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[12] This selection includes three industries for non-durable goods and another three industries for durable goods. The first group of industries represent 10.2% of the total Mexican exports for 2012, while the remaining three durable industries represent 81.7% out of these exports. These trade shares were computed using the Mexican balance of payments for manufacturing products 2012.

[13] Since the wage gap is a fraction, the presence (or not) of a producer price index to obtain a real production wage gap in dollar terms is not relevant. This is it, in so far as the presence of the same producer price index in the numerator and denominator is cancelled out.

the number of dollars paid on average per hour for a Mexican manufacturing worker in relation to dollars paid on average per hour for its American counterpart. It is considered that workers in the selected industries perform similar industrial tasks, given the existence of a common North American industrial classification.[14] If the wage gap would be equal to one, it would imply that Mexican and American workers receive equal labor compensation. This hypothetical value would indicate a wage gap absence. If the wage gap would approach zero, it would indicate that labor compensation is diverging in these two countries. If such were the case, it would indicate that the wage gap is increasing.

2.1. Descriptive statistics

The principal trends of the wage gap under study are examined by means of descriptive statistics. Table 1 presents the wage gap *mean* (first moment of a distribution) and *CV* (coefficient of variation), for the whole manufacturing sector and six selected industries, considering pre- and post-NAFTA periods.

Table 1. Descriptive statistics. Wage gap trends. Manufacturing production workers.* Mexico-United States. Selected periods and industries

Sector	**Statistic**	**Pre-NAFTA**	**Post-NAFTA**	
industry		1987:01-1994:12	1995:01-2006:12	2007:01-2013:12
Manufacturing	*mean*	0.15	0.14	0.11
	CV	0.29	0.23	0.12
food	*mean*	0.14	0.17	0.10
	CV	0.30	0.24	0.13
textile products and mills	*mean*	0.18	0.16	0.12
	CV	0.30	0.28	0.17
chemicals	*mean*	0.15	0.14	0.19
	CV	0.31	0.24	0.20
primary metal	*mean*	0.14	0.14	0.13
	CV	0.25	0.19	0.09
machinery	*mean*	0.14	0.15	0.13
	CV	0.32	0.26	0.11
transportation equipment	*mean*	0.12	0.15	0.09
	CV	0.31	0.30	0.12
	n	96	144	84

Notes:
* Adjusted for inflation with the producer price index (finished goods), not seasonally adjusted; *mean* stands for the first moment of the time series, *CV* stands for the coefficient of variation, being the standard deviation divided by the mean; *n* stands for the number of observations.
Source: Own estimates based on *Banco de Mexico*, Bureau of Labor Statistics and *Instituto Nacional de Estadistica y Geografia*.

Table 1 illustrates that the *mean* wage gap for the whole manufacturing sector between Mexico and United States has decreased across time, *i.e.*, 0.15, 0.14, and 0.11. As a result, the wage gap has continued to grow, despite NAFTA implementation. In contrast, the whole manufacturing sector *CV* has decreased across the three time periods

[14] The corresponding concordance tables for the North American Industrial Classification System (NAICS) were consulted in order to match Mexican and American manufacturing industries. For its part, Schott (2003) develops a technique grouping countries according to the subset of goods produced, using a cross section of countries and the International Standard Industrial Classification (ISIC). These two approaches seem to conform to one of the accepted traditions on international trade theory: “The same technical knowledge is available in both countries.” Lerner (1952).

under analysis. That is to say, it exhibits values of 0.29, 0.23, and 0.12. These *CV* values imply that the wage gap has gained in stability over time.[15]

For the pre-NAFTA period (1987-1994), the wage gap regarding *chemicals* manufacturing remains above the *manufacturing mean*, with a reported value of 0.15. For this same time period, the *textile products and mills mean* is 0.18. Below *manufacturing mean* are four manufacturing sectors, *i.e., food*; *primary metal*; *machinery*, and *transportation equipment* with values of 0.14; 0.14; 0.14, and 0.12 respectively. For its part, *CV* for all industries takes values on the range of 0.25 to 0.31 for this time period.

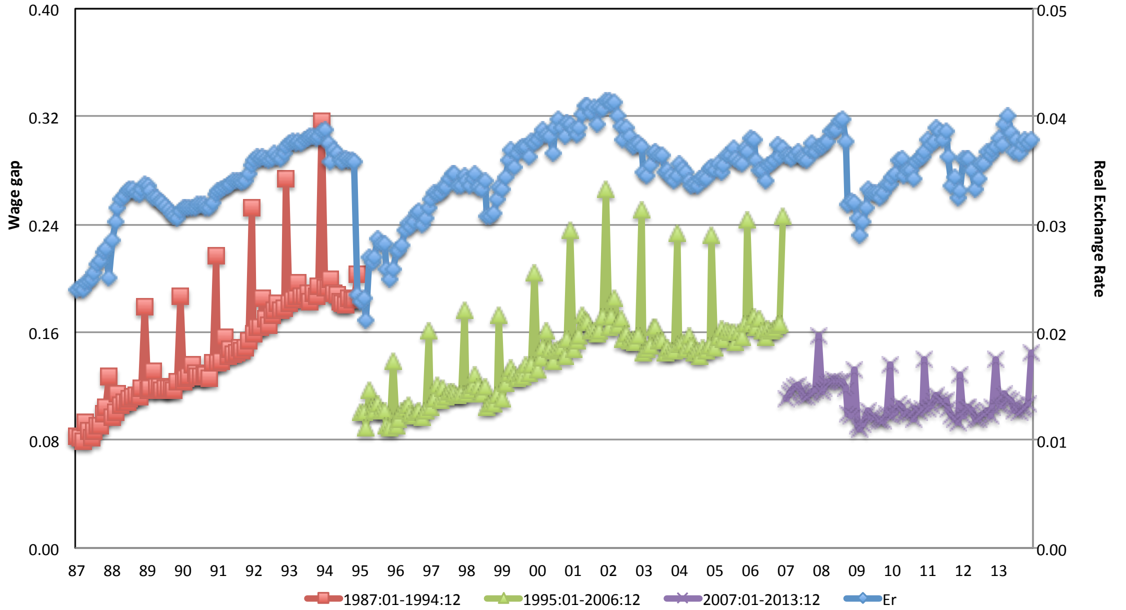
By comparing the two post-NAFTA time periods, 1995-2006 and 2007-2013 with respect to the previous period, it is ostensible that both *mean* and *CV* patterns for all industries under study have similar decreasing rates trends. The only exception is the *chemicals* sector, which increases its wage gap *mean* from 0.14 to 0.19. From 2007 to date, only *food* and *transportation equipment* exhibit a *mean* wage gap below *manufacturing*. Meanwhile, the rest of industries show wage gaps *mean* ranging 0.12 to 0.13. During the last period, all industries' *CV* decrease with respect to the two previous periods. That is to say, the *CV* for all the industries selected fell by more than a half between 2007 and 2013, in comparison with the previous periods. Overall, Table 1 indicates an increase in the wage gap during the last period, with the exception of *chemicals*.[16]

2.2. Figure analysis

Figure 1 shows almost a parallel movement between the bilateral real exchange rate and wage gap. This bilateral real exchange rate for Mexico and United States is computed as the ratio of United States and Mexican consumer prices divided by the nominal exchange rate, *i.e.*, pesos per dollar. This parallel movement displays that a real exchange rate overvaluation is accompanied by a wage gap reduction and *vice-versa*: when the bilateral real exchange rate depreciated, the wage gap increases.[17] An example of this last case can be easily observed in December 1994, when the Mexican peso was depreciated from 0.035 to 0.02, as measured by the real exchange rate and the wage gap registered a drop from 0.15 to 0.09. In this same direction, the 2009 Mexican peso depreciation matches with a low wage gap value of 0.08. In an opposite direction, when the real exchange rate was overvalued around 2002 the wage gap registered its highest value during the post-NAFTA period, *i.e.*, 0.25. In so far as changes in the wage gap follow changes in the bilateral real exchange rate, this last variable is included in the econometric model.[18]

[15] The *CV* statistic lacks units and is unbiased. It represents a measure of data dispersion around the mean.
[16] In Appendix 2, an explanation about data units and sources is provided.
[17] At the end of each year, Figure 1 displays wage gap peaks. These peaks match a Mexican statutory end of the year payment: *aguinaldo*. This payment amounts to at least two weeks of labor compensation.
[18] The existence of a real long-run relationship between wage gap and real exchange rate will be assessed econometrically by means of cointegration tests. These tests results are reported in Appendix 1.

Figure 1. Wage Gap and Real Exchange Rate. United States-Mexico. Total Manufacturing Production Workers. Monthly Frequency. Selected Periods



Source: Own estimates based on *Banco de Mexico*, Bureau of Labor Statistics and *Instituto Nacional de Estadística y Geografía*.

Figure 1 illustrates a wage gap trends decrease in each time period, *i.e.*, from 1987-1994 to 1995-2006 and from 1995-2006 to 2007-2013. That is to say, the lines that represent the wage gap diminished their slope throughout time.

As a brief summary of this data section, the wage gap increases and *CV* decreases throughout time. These trends did not happen immediately after NAFTA was enacted. It took 12 years after the agreement was signed for the manufacturing activities of both nations to reflect changes in the wage gap. These changes are presented in both wage gap increases as well as in an increase in its stability. These changes display that a structural change happens with NAFTA implementation, despite taking 12 years to be seen. Besides, the wage gap statistics regarding *mean* and *CV* and its graphic trends did not conform to the expected free international trade theory outcomes.

3. Econometric model

In this section, the derivation of the econometric model is put forward. This model basically sets the production workers' manufacturing wage gap for Mexico and the United States in dollar terms, as a function of a bilateral Mexico-United States real exchange rate,[19] and a manufacturing production index. Thus, the corresponding econometric equation is:

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[19] If the law of one price was to hold, the inclusion of a bilateral real exchange rate would be superfluous, since its elasticity coefficient would be zero. On the contrary, if the law of one price does not hold, wage differentials between Mexico and United States would be expected. As this last option appears in the data section, the inclusion of a bilateral real exchange rate on the econometric model seems to be necessary. The bilateral real exchange rate in the econometric model plays an inflationary differential adjustment role. This is because it allows the equality between left and right hand sides of the equation (1). In this

$$log\left(\frac{w^i_{mx,k}}{w^i_{us,k}}\right) = c + \alpha log\left(Er_{k,t-j}\right) + \beta log\left(\frac{Q^i_{mx,k,t-j}}{Q^i_{us,k,t-j}}\right) + \varepsilon_t \qquad (1)$$

where:

- $\frac{w^i_{mx,k}}{w^i_{us,k}}$ stands for production workers' manufacturing wage gap between Mexico and the United States;

- The superscript i expresses the time period under consideration and takes the following values: $i = 1,\ 2,\ 3$; where $i=1$ covers from January of 1987 to December of 1994; $i=2$ stands for January 1995 to December 2006; $i=3$ comprises January 2007 to December 2013.[20]

- The subscript k refers to the whole manufacturing and selected industries as follows: $k = 1$ whole manufacturing. The six selected industries can be classified in non-durable and durable goods attending to their duration time.[21] Thus, non-durable goods industries comprise: $k = 2$ food; $k = 3$ textile products and mills, and $k = 4$ chemicals. For its part, durable goods are: $k = 5$ primary metal; $k = 6$ machinery, and $k = 7$ transportation equipment. The subscript t refers to current time period; $t - j$ signals time lags where $j = 1, 2, \dots, n$. The subscript mx refers to Mexico and us to the United States.[22]

- $w^i_{mx,k} = \frac{\frac{W^i_{mx,k}}{h^i_{mx,k}}}{E_0}$ stands for average hourly earnings of manufacturing production and nonsupervisory workers in Mexico. It is computed as the ratio of $W^i_{mx,k}$ total earnings, manufacturing production, and nonsupervisory workers in Mexico, divided by $h^i_{mx,k}$ total number of hours of manufacturing production workers and nonsupervisory workers in Mexico and divided by E_0 the nominal exchange rate pesos per dollar;

- $w^i_{us,k}$ is the average hourly earnings of manufacturing production and nonsupervisory workers in the United States;

- c is the constant or intercept;

- α is the elasticity coefficient for $log\left(Er_{k,t-j}\right)$;

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respect, an attempt to measure real exchange rate adjustments speeds in nine European countries is made by Juvenal and Taylor (2008), finding that transaction costs vary significantly across sectors and countries.

[20] In so far as Mexican manufacturing data is not continuous, equation (1) is to be estimated for each available time period.

[21] National statistic offices make the classification between non-durable and durable goods using United Nations guidelines.

[22] The functional form for the econometric model presented in equation (1) is double logarithmic. This feature allows reading directly the coefficients as elasticities. The estimation method uses ordinary least square in two stages taking into account the error correction model specification. The first stage involves the long-run relationship estimation among the time series reported on equation (1). The long-run equation is also known as cointegrating equation. The second stage is related with the short run estimation of equation (1). For obtaining short run estimators, the difference operator is added to each variable in equation (1). Also, the short run estimation includes the corresponding cointegrating errors computed at the first stage. This econometric approach is based on the error correction model in two stages procedure implemented by Sargan (1984).

$Er_{k,t-j}$ is the bilateral real exchange rate between Mexico and the United States, *i.e.*, pesos per dollar.[23] It is computed as the ratio of consumer prices indexes divided by the nominal exchange rate: $Er = \frac{\frac{P^*}{E_0}}{P}$, where P^* is the United States national consumer price index; P is the Mexican consumer price index-all urban consumers, and E_0 is the nominal exchange rate;

- β is the elasticity coefficient of $log\left(\frac{Q^i_{mx,k,t-j}}{Q^i_{us,k,t-j}}\right)$;

- $\frac{Q^i_{mx,k,t-j}}{Q^i_{us,k,t-j}}$ is the manufacturing production index ratio between Mexico and the United States. Here $Q^i_{mx,k,t-j}$ is the manufacturing production index for Mexico; and $Q^i_{us,k,t-j}$ is the manufacturing production index for the United States.

- ε_t stands for the error term. It is assumed that this term is independent and identically distributed (i.i.d.).

The estimators robustness check is made using equation (1) variations: i) different time periods, *i.e.*, pre-NAFTA and post-NAFTA; ii) different manufacturing sectors, *i.e.*, *manufacturing; food; textile product and mills; chemicals; primary metal; machinery*, and *transportation equipment*. These estimators represent the econometric model sensitivities to different time specifications and types of manufacturing industries.

It is important to note that if the law of one price holds, then equation (1) is reduced to two ratios. One of these ratios is in the left-hand side and the other in the right-hand side of this equation. Thus equation (1) would equal these two ratios, *i.e.*, numerator to numerator and denominator to denominator, after the elimination of the bilateral real exchange. If this were the case, factor compensations (left side) would be equal to manufacturing production index (right side). Thus, this equation could be a representation of Shepard's lemma: in equilibrium, labor payments are proportional to their productivities.

If the law of one price does not hold, then the inclusion of the bilateral real exchange rate between Mexico and the United States seems to be necessary. According with Samuelson (1994) the Penn effect consists on income ratios exaggerations between countries, when conventional exchange-rate conversions are used.[24] To avoid this undesirable effect, Balassa and Samuelson independently explain in 1964 the correctness of using real-income estimations, which are computed with the local prices and incomes from those parties under analysis.

For their part, Lawrence and Slaughter (1993) argue that the empirical performance of average real wages, on an international trade framework, is expected to mirror the performance of output per worker. In the same fashion, Burgman and Geppert (1993) claim that if FPE holds, marginal productivity and real wages must get equal across

[23] As mentioned in the figure analysis section 2.2, the bilateral real exchange rate for Mexico and the United States is computed as the ratio of the United States and Mexican consumer prices divided by the nominal exchange rate pesos per dollar.
[24] Appendix 4 presents a detail explanation in this regard.

economies. In this sense, the inclusion of the manufacturing index ratio in equation (1) has also a practical rationale.[25]

Conforming with the information presented in this section, the expected values or hypothesis for the estimators on equation (1), are as follows: α is expected to have a value close to zero if the FPE holds; β is expected to be positive and unitary if Shepard's lemma is fulfilled.[26]

3.1. Econometric model contributions

The proposed model contributes to the existing econometric wage gap literature in the following five aspects, as the author does not have knowledge that they exist in the current literature:

1. The whole manufacturing sector is considered, as well as its disaggregation by selected manufacturing industries, *i.e.*, non-durable and durable goods;

2. An error correction model is implemented within a time series framework. The monthly data and its time periodization, which match available Mexican manufacturing surveys are used to evaluate pre and post-NAFTA periods. The data used in this research follows NAICS across time, allowing comparisons between periods, industries, and nations;

3. A bilateral real exchange rate is computed considering consumer price indexes for both countries as well as the nominal exchange rate. It is used for estimating Mexican peso *vis-à-vis* the United States dollar appreciation or depreciation. Its inclusion is particularly important in so far as no monetary union exists between both trade partners;

4. The manufacturing production index ratio for Mexico and the United States is introduced in the econometric model as a wage gap determinant. Its importance is extracted from Shepard's lemma implications—that is to say, that factor compensations are proportional to some measure of their productivity.

4. Error correction model empirical results

Equation (1) is estimated for three monthly time periods, *i.e.*, pre-NAFTA (1987-1994) and post-NAFTA (1995-2006 and 2007-2013), for the whole manufacturing sector and six selected industries. For simplicity, these three time periods will be referred in what follows as first, second, and third periods, respectively. To facilitate equation (1) interpretation, its estimators are grouped in two different tables: Table 2 and Table 3.

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[25] Rayp (1998) uses cointegration estimations to test FPE in a specific form for the case of France, Belgium and the Netherlands. This author underlines the importance of cointegration techniques on determining free trade international influences on factor endowments.

[26] Similar hypothesis are found in Bernard *et al.* (2002), but for regions within a country. Nonetheless, these authors applied international free tenets for their national case. This is because they consider analogies between international regions with national regions.

Table 2 reports the bilateral real exchange rate estimators and Table 3 the manufacturing production index ratio estimators.[27]

4.1. Bilateral real exchange rate

Table 2 reports long and short run results for equation (1) with respect to bilateral real exchange rate. For the long run, the *manufacturing* elasticity coefficient reports a value of 1.60 during the first period.[28] For the last one, the coefficient almost halved (0.80), with respect to the second period (1.40). In the short run, for the first two periods the estimators are elastic (1.08 and 1.33, respectively) while attaining a value below the unit (0.87) during the third period. This result is replicated for the rest of durable industries under consideration: *primary metal*; *machinery*, and *transportation equipment*, with the exception of *machinery* for the short run (1.05).

For its part, *food* reaches coefficients above two units (2.45 and 2.89 for the long and short run, respectively)[29] during the first period. It falls to a value around the unit in the second and third periods. While this reduction phenomena for the first period is replicated in *textile products and mills* and *chemicals* sectors, with coefficients approaching two units in the long and short run in the first period; in the third period they become ostensibly inelastic in the long run (0.64 and 0.51, respectively for these two industries)[30] and elastic but below one (0.78 and 0.85, respectively) in the short run.

Table 2. Bilateral real exchange rate Mexico-United States, equation (1) results. Selected periods and industries (standard error) [lag]

Sector industry	Pre-NAFTA 1987:01-1994:12	Post-NAFTA 1995:01-2006:12	2007:01-2013:12
Manufacturing			
long run	1.60	1.40	0.80
	(0.1607)[1]	(0.0993)[0]	(0.1306)[0]
short run	1.08	1.33	0.87
	(0.7412)[1]	(0.3324)[0]	(0.2553)[0]
food			
long run	2.45	1.06	1.12
	(0.1386)[1]	(0.0889)[0]	(0.1486)[0]
short run	2.89	1.06	0.94
	(1.3576)[1]	(0.3257)[0]	(0.2169)[0]
textile products and mills			
long run	1.71	0.48	0.64
	(0.2751)[1]	(0.1794)[0]	(0.2293)[0]
short run	1.65	1.13	0.78
	(0.3551)[1]	(0.4620)[0]	(0.4565)[0]
chemicals			
long run	1.97	1.30	0.51
	(0.1019)[1]	(0.0984)[0]	(0.2858)[1]
short run	1.37	1.21	0.85
	(0.5664)[1]	(0.3232)[0]	(0.5220)[1]
primary metal			

[27] Appendix 3 reports the long run cointegrating errors unit root tests results. All of them are equilibrium errors, since they are integrated of order zero. Their integration order implies that they are stationary in levels. These results imply the existence of true long run relationships among the time series that composed equation (1). Johansen cointegration tests verified these findings (reported in Appendix 1).
[28] Lagged one period.
[29] Both coefficients with one lag.
[30] With one lag in both cases.

long run	1.95	1.03	0.75
	(0.2490)[1]	(0.0939)[0]	(0.1093)[0]
short run	1.96	1.26	0.83
	(0.0876)[1]	(0.1920)[0]	(0.2104)[0]
machinery			
long run	1.76	1.19	0.96
	(0.3045)[1]	(0.1096)[0]	(0.1231)[0]
short run	2.18	1.39	1.05
	(0.0703)[1]	(0.3545)[0]	(0.3643)[0]
transportation equipment			
long run	1.79	1.09	1.22
	(0.2761)[1]	(0.1614)[0]	(0.1323)[0]
short run	1.93	1.78	0.77
	(0.1323)[1]	(0.4109)[0]	(0.2335)[0]
	96	144	84

Notes:

Bilateral real exchange rate Mexico-United States computed on the basis of consumer price index; *n* stands for the number of observations; for brevity the constant is not reported; no dummy variable was needed for modelling the *aguinaldo*; all reported elasticities are statistically significative at least to 95% percent; long and short run equations are computed using ordinary least squares in a two stages procedure, as in Sargan (1974).

Source: Own estimates based on Mexican Central Bank, Bureau of Labor Statistics and *Instituto Nacional de Estadistica y Geografia*.

Above, the bilateral real exchange rate effect in the wage gap is measured by their elasticity coefficients. In summary, all of them expose positive elasticities, frequently found in the vicinity of the unit value. Therefore, it could be confirmed that a Mexican peso undervaluation *vis-à-vis* the American dollar have the effect of increasing the wage gap. This can be confirmed clearly in Figure 1 around December 1994 and December 2009, where the most drastic Mexican peso devaluations are observed. Overall, the bilateral real exchange rate is a decisive determinant regarding the wage gap performance. However, its impact extent has diminished as time advances during the three time periods under analysis.

4.2. Manufacturing production index ratio

In Table 3, during the third time period, 2007-2013, persistently negative coefficients of the wage gap arise with respect to the Mexico-United States manufacturing production index ratio. As an example, *food* has an elastic coefficient for the long run of -1.00, and in the short run it is -0.70.[31] *Textiles products and mills* shows negative and inelastic coefficients for the long (-0.20) and (-0.56) short run.[32] It should be noted that this industry is the only one that exposes negative coefficients for the first time period, *i.e.*, -0.460 and -1.17 for the long and short run, respectively. *Machinery* also has a negative coefficient in the first period (-0.66), although this behavior is restricted for the short run. For the remaining industries, this coefficient has turned from positive in the pre-NAFTA period to negative in the two post-NAFTA periods.

Table 3. Manufacturing production index ratio between Mexico-United States, equation (1) results. Selected periods and industries (standard error) [lag]

Sector	**Pre-NAFTA**	**Post-NAFTA**	
industry	1987:01-1994:12	1995:01-2006:12	2007:01-2013:12
Manufacturing			
long run	1.05	-1.72	-1.08
	(0.2762)[1]	(0.3332)[0]	(0.1618)[0]
short run	0.7	-1.62	-1.25
	(0.2644)[1]	(0.2497)[0]	(0.1890)[0]
food			

[31] Both with a three-month lag.

[32] Both with a three-month lag.

long run	0.41	1.82	-1.00
	(0.2287)[1]	(0.1740)[1]	(0.2771)[3]
short run	n.s.	-0.64	-0.70
		(0.2684)[1]	(0.2501)[3]
textile products and mills			
long run	-0.46	0.67	-0.20
	(0.2615)[0]	(0.1447)[1]	(-0.4023)[3]
short run	-1.17	-0.49	-0.56
	(0.1374)[0]	(0.1630)[0]	(0.1555)[3]
chemicals			
long run	1.37	-1.47	-0.56
	(0.2808)[1]	(0.1883)[0]	(0.3533)[3]
short run	0.79	-1.45	-0.47
	(0.2483)[1]	(0.1435)[0]	(0.3109)[3]
primary metal			
long run	0.63	0.32	-0.35
	(0.2369)[1]	(0.0879)[3]	(0.1251)[0]
short run	0.52	-0.58	-0.43
	(0.1952)[1]	(0.1104)[3]	(0.1311)[0]
machinery			
long run	0.38	-0.33	-0.27
	(0.1363)[3]	(0.0979)[0]	(0.0509)[0]
short run	-0.66	-0.46	-0.44
	(0.1924)[0]	(0.0903)[3]	(0.1466)[0]
transportation equipment			
long run	0.52	0.52	-0.40
	(0.1017)[1]	(0.1229)[2]	(0.0929)[0]
short run	0.46	-0.32	-0.66
	(0.1016)[1]	(0.1474)[2]	(0.0739)[0]
	96	144	84

Notes:
Manufacturing production index ratio between Mexico-United States adjusted for local implicit price indexes; *n* stands for the number of observations; n.s. stands for not significative; for brevity the constant is not reported; no dummy variable was needed for modelling the *aguinaldo*; all reported elasticities are statistically significative at least to 95% percent; long and short run equations are computed using ordinary least squares in a two stages procedure, as in Sargan (1974).
Source: Own estimates based on Mexican Central Bank, Bureau of Labor Statistics and *Instituto Nacional de Estadistica y Geografia*.

Negative coefficients during the last post-NAFTA period are neatly exposed in different industries. For its part, *chemicals* exposes negative and inelastic coefficients in the long (-0.56) and short (-0.47) run.[33] Likewise, *primary metal* exposes inelastic and negative elasticities in the long and short run (-0.35 and -0.43, respectively) in the third period. For the last time period, a similar case is seen with *machinery*, with reported elasticities of -0.27 and -0.44 for the long and short run, respectively. In a similar manner, this trend is also shown in the case for *transportation equipment* with negative coefficients of -0.40 and -0.66 in the long and short run, respectively. In this third period, *manufacturing* displays likewise as the six selected industries' negative and elastic coefficients, *i.e.*, -1.08 and -1.25, for long and short run, respectively.

In summary, at least for the post-NAFTA period, the increase in the manufacturing output index ratio negatively affects the wage gap, with a coefficient fast approaching the unit. Specifically in the long run *manufacturing* and *food* exhibit the coefficient value of -1.08, and -1.00, respectively. When manufacturing is disaggregated on durable and non-durable goods, their short run elasticities coefficients frequently become inelastic and close to half the unit for the three time periods under consideration. In the long run, their elasticities coefficients basically display positive values for the pre-NAFTA period changing to negative in the post-NAFTA period (second and third

[33] Both with a three-month lag.

periods). These changes on the coefficients sign from the pre-NAFTA to the post-NAFTA periods, indicate that NAFTA has introduce a structural change in Mexico and the United States manufacturing performance.

A robustness check can be performed on Tables 2 and 3. This is because the estimation of equation (1) comprehends different time periods and manufacturing industries. Across these specifications, the estimated coefficients behave systematically. This systematic behavior is manifested as all reported coefficients are closely related in values ranges to each other, all of them with a statistical significance level of at least 95 percent ($\alpha = 5\%$). Therefore, the econometric model sensitivities under different specifications, *i.e.*, time periods and manufacturing industries prove to be statistically robust. Structural changes, for example, the one represented by NAFTA implementation cause modifications in the estimators signs and values. However, these modifications turn out to be stable across manufacturing industries and time periods once the structural change took place. The existence of a true economic relationship in the error correction model is confirmed by long run stationary cointegrating errors. The cointegrating errors unit root test are reported in Appendix 3, and the Johansen cointegration test results are reported in Appendix 1. Together, these two tests support the existence of a true economic relationship.

Conclusions

The empirical evidence presented herein in terms of descriptive statistics, figure analysis, and long and short run estimators illustrate, that the bilateral real exchange rate and the manufacturing production index ratio are relevant empirical determinants in the wage gap for manufacturing production and nonsupervisory workers between Mexico and the United States.

The wage gap process becomes persistent during the three time periods under analysis, as expressed in its decreasing coefficient of variation. The wage gap increases once NAFTA is implemented, as attested in the descriptive statistics by its decreasing mean.

The elasticity coefficients obtained between the wage gap and the bilateral real exchange rate expose a systematic relationship (Table 2). This relationship is represented by frequently elastic coefficients with positive values. This conveys the meaning that changes in the bilateral real exchange rate is transmitted almost completely to changes in the wage gap. Thus, undervaluation of the Mexican peso with respect to the American dollar increases the wage gap, but with a lesser intensity as time evolves. The increase in the wage gap is shown by the descriptive statistics reported in Table 1 from pre- to post-NAFTA periods. As the wage gap trend follows the one belonging to the bilateral real exchange (Figure 1), and their coefficient values are elastic and positive (Equation 1), it must therefore follow that the bilateral real exchange rate has been indeed undervalued throughout the time periods under analysis (*i.e.*, pre- and post-NAFTA periods).

Wage gap increases are also associated with the behavior of the manufacturing production index ratio. During the last post-NAFTA period, a negative relationship is reported between the wage gap and the manufacturing production index ratio (Table 3). It is important to note that for this same post-NAFTA period, the descriptive statistics

(Table 1) show an increase in the wage gap. Therefore, these two results together indicate that the manufacturing production index ratio increases have a deleterious effect over the wage gap.

The expected values for the elasticity coefficients α and β are not observed given the empirical results reported. This is because the expected elasticity coefficients of zero for the bilateral real exchange and the wage gap, as well as a unitary positive elasticity coefficient for manufacturing production index ratio and the wage gap, are far from being observed.

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Appendix 1. Johansen Cointegration Test Results

By means of a Johansen cointegration test, it is evaluated whether there is at least one cointegrating vector, between Mexico-United States wage gap for production workers in manufacturing, and the bilateral Mexico-United States real exchange rate, and the output index ratio. This test is performed using equation (1) long run specification, with monthly frequency. Next, Table 4 contains these test results.

Table 4. Johansen Cointegration test results. Wage gap, bilateral real exchange rate and manufacturing production index ratio Mexico-United States. Selected periods and industries

Sector	**Statistic**	**Pre-NAFTA**	**Post-NAFTA**	
industry		1987:01-1994:12	1995:01-2006:12	2007:01-2013:12
Manufacturing	*p*	1	3	1
	EV	0.28	0.19	0.29
	TS	46.00	49.20	36.39
	CVU	42.92	29.80	29.8
	PB	0.02	$1x10^{-4}$	0.01
food	*p*	1	1	1
	EV	0.35	0.41	0.39
	TS	55.48	88.21	51.10
	CVU	29.80	29.80	29.80
	PB	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$
textile products and mills	*p*	1	3	1
	EV	0.26	0.26	0.20
	TS	37.18	60.58	30.36
	CVU	29.80	29.80	29.80
	PB	0.05	$1x10^{-5}$	0.04
chemicals	*p*	1	3	1
	EV	0.19	0.12	0.28
	TS	29.80	34.99	39.94
	CVU	29.80	29.80	29.80
	PB	0.05	0.01	0.002
primary metal	*p*	1	1	1
	EV	0.23	0.18	0.24
	TS	42.18	37.18	37.55
	CVU	42.92	29.8	29.8
	PB	0.06	0.01	0.01
machinery	*p*	1	3	1
	EV	0.29	0.20	0.29
	TS	43.44	50.44	37.07
	CVU	42.92	29.8	29.8
	PB	0.04	$1x10^{-4}$	0.01

transportation equipment	*p*	1	3	1
	EV	0.28	0.32	0.28
	TS	46.37	70.6	37.92
	CVU	42.92	29.8	29.80
	PB	0.02	$1x10^{-5}$	0.005
	n	96	139	84

Notes:
p is the number of cointegrating vectors, Mackinnon-Haug-Michelis (1999) p-values. Test results are statistically significative at least to 95% percent; *EV* stands for eigenvalue; *TS* stands for trace statistics; *CVU* stands for 0.05 critical value and *PB* stands for probability; linear deterministic trend in data, intercept and trend in cointegrating equations and no intercept in vector autoregressive; the test results are for the wage gap pairs with the bilateral real exchange rate and manufacturing production index ratio Mexico-United States.
Source: Own estimates based on *Banco de Mexico*, Bureau of Labor Statistics and *Instituto Nacional de Estadistica y Geografia*.

The third time period (2007:01–2013:12) comprises 81 observations regarding non-durable. Following are the number of cointegrating vectors for each industry: for *chemicals*, two cointegrating vectors were found.[34] For *food* and *textile products and mills*, one cointegrating vector was observed. As for durable goods, both *primary metal,* and *machinery* registered two cointegrating vectors. In the case of *transportation and equipment*, only one cointegrating vector was obtained. For *manufacturing*, two cointegrating vectors were reported.

Regarding the second time period (1995:01-2006:12), by means of 139 observations, in the case of non-durable *textile products and mills* and *chemicals*, two cointegrating vectors were found, while only one was found in the case of *food*. For durable goods, both *transportation equipment* and *machinery* registered two cointegrating vectors, while only one was registered in the case of *primary metals*. For this time period, two cointegrating vectors were registered for *manufacturing*.

As for the first time period (1987:01–1994:12), in the case of non-durable goods, *i.e.*, *food*; *textile products and mills,* and *chemicals*, one cointegrating vector was found. This is also the case with durable goods, *i.e.*, *primary metal*; *machinery* ,and *transportation equipment*, where one cointegrating vector was found. *Manufacturing* shows the existence of one cointegrating vector. A total of 93 observations were made.

As a result of these cointegration test results, it could be asserted that the Mexico-United States wage gap in manufacturing regarding production workers, and the bilateral real exchange and output index ratio bear a true long-run relationship. The Engle and Granger (1987) representation theorem assures that if there is at least one cointegration vector or cointegrating equation, then they could then represent a long-run relationship among the regression variables.

Appendix 2. Data Sources

Table 5. Data Sources

Data ID	Description, units	Source	Country
E_0	Nominal exchange rate, pesos per dollar	D	*mx*
E_R	Bilateral real exchange rate Mexico-United States, pesos per dollar, using consumer prices	$\frac{P^*}{\frac{E_0}{P}}$	*us*, *mx*
h_{mx}	Total number of hours, manufacturing production, and nonsupervisory workers, thousands	F	*mx*
P	Consumer price index-all urban consumers, n.s.a.	E	*mx*

[34] According with Dwyer (2015) Johansen cointegration test gauges whether the largest eigenvalue is zero relative to the alternative hypothesis that the next largest eigenvalue is zero.

	1982-84=100		
P^*	National consumer price index 2010=100	B	*us*
Q_{mx}	Manufacturing production index 2007=100	F	*mx*
Q_{mx}	Producer price index-commodities, finished goods n.s.a. 1982=100	B	*mx*
Q_{us}	Manufacturing production index 2007=100 n.s.a. NAICS	F	*us*
W_{mx}	Total earnings, manufacturing production, and nonsupervisory workers, thousands of pesos	C	*mx*
w_{us}	Average hourly earnings of manufacturing production and nonsupervisory workers, n.s.a. dollars	A	*us*
w_{mx}	Average hourly earnings of manufacturing production and nonsupervisory workers, n.s.a. dollars	$\frac{\frac{W_{mx}}{h_{mx}}}{E_0}$	*us, mx*

Sources:
A BLS (Bureau of Labor Statistics), CES (Current Employment Statistics) survey. National;
B BLS (Bureau of Labor Statistics). Consumer Price Index;
C Board of Governors of the Federal Reserve System. Industrial Production and Capacity Utilization;
D *Banco de Mexico*. Financial markets;
E *Banco de Mexico*. Prices and inflation;
F *Instituto Nacional de Estadistica y Geografia*. Monthly Industrial Survey: 1987:01-1994:12; 1995:01-2006:12 and 2007:01-2013:02;
Notes:
us stands for United States; *mx* stands for Mexico; *n.s.a.* means not seasonally adjusted; *NAICS* stands for North American Industrial Classification System;
The definition of average hourly earnings of manufacturing production and nonsupervisory workers is available at BLS (2011) *Handbook of Methods*.

Appendix 3. Phillips-Perron Unit Root Test Results

Table 6. Unit root test results. Phillips-Perron. Mexico-United States. Long run cointegration errors, equation (1) estimations. Selected periods and industries[35]

Sector industry	**Statistic**	**Pre-NAFTA**	**Post-NAFTA**	
		1987:01-1994:12	1995:01-2006:12	2007:01-2013:12
Manufacturing	*t*	-27.40	-40.40	-57.88
	BW	9	58	81
	CVU	-2.89	-2.88	-2.90
	I(0)	0	0	0
food	*t*	-36.59	-49.57	-20.34
	BW	31	36	6
	CVU	-2.89	-2.88	-2.90
	I(0)	0	0	0
textile products and mills	*t*	-66.01	-41.29	-26.44
	BW	60	21	11
	CVU	-2.89	-2.88	-2.90
	I(0)	0	0	0
chemicals	*t*	-27.75	-39.69	-26.05
	BW	8	29	16
	CVU	-2.89	-2.88	-2.90
	I(0)	0	0	0
primary metal	*t*	-22.46	-38.21	-29.96
	BW	3	89	25
	CVU	-2.89	-2.88	-2.90
	I(0)	0	0	0
machinery	*t*	-30.56	-46.76	-44.40
	BW	21	35	39
	CVU	-2.89	-2.88	-2.89
	I(0)	0	0	0
transportation equipment	*t*	-28.20	-66.92	-27.98
	BW	13	32	15
	CVU	-2.89	-2.88	-2.90
	I(0)	0	0	0

Notes:

[35] According with Perron (1990) methodology.

t stands for t-statistic for rejecting the null hypothesis of having a unit root, Mackinnon (1996); *BW* stands for bandwidth; *CVU* stands for critical values at the 5% level of confidence interval; *I(0)* stands for integration order zero; included in the Phillips-Perron unit root test: constant; constant and linear trend, and none. This test is recommended when standard unit-root test are shown to be biased toward no rejection of the hypothesis of a unit root, when full sample information is used.
Source: Own estimates based on *Banco de Mexico*; Bureau of Labor Statistics and *Instituto Nacional de Estadistica y Geografia*.

Appendix 4. Theoretical Aspects. Free International Theory and General Equilibrium

In this section it is presented a free international trade theory general equilibrium setting. This setting may demonstrate the Factor Price Equalization (FPE) theorem.[36] This presentation has not been drawn from an article or a book. It is an author attempt to explain how different economic activities layers in different countries reach a general equilibrium under the assumptions of free international trade theory.

Partial Equilibrium. Consumer's Problem

Consider the following consumer optimization problem:

$$U(x, y) = x^{\alpha}\, y^{\beta}$$
$$s.t. m = p_x x + p_y y$$

where $U(x, y)$ is a Cobb-Douglas utility function; m stands for income; p_x is price of good x; p_y is price of good y. The lagrangian $\mathcal{L}$ for this optimization problem is:

$$\mathcal{L} = x^{\alpha}\, y^{\beta} - \lambda(m - p_x x + p_y y)$$

Its First Order Conditions (FOCs) are:

[x] $U_x(x, y) = \lambda\, p_x$

[y] $U_y(x, y) = \lambda\, p_y$

where $U_x(x, y)$ and $U_y(x, y)$ are marginal utilities for good x and y, respectively. Dividing x and y FOCs yields an equimarginality condition. This condition represents an equilibrium between utility function and budget constrain slopes.

$$\frac{U_x(x,y)}{U_y(x,y)} = \frac{p_x}{p_y} \qquad (1)$$

Consumer partial equilibrium is provided by the above equimarginality condition. If marginal utilities for each good could be thought as marginal disutility price for each unit of good that is not consumed, then the good price ratio could provide conditional good demands information. Here conditionality is related to utility functional specification.

Partial Equilibrium. Producer's Problem

Consider the following constraint producer optimization problem:

$$Q(w_1, w_2) = {w_1}^{\alpha}\, {w_2}^{\beta}$$
$$s.t. C = p_{w_1} w_1 + p_{w_2} w_2$$

where $Q(w_1, w_2)$ is a Cobb-Douglas production function; C stands for cost; p_{w_1} is the price of production factor w_1 or labor type 1 wage; p_{w_2} is the price of production factor w_2 or labor type 2 wage. The corresponding Lagrangian $\mathcal{L}$ is:

$$\mathcal{L} = {w_1}^{\alpha}\, {w_2}^{\beta} - \lambda(C - p_{w_1} w_1 + p_{w_2} w_2)$$

FOCs

$[w_1]$ $Q_{w_1}(w_1, w_2) = \lambda\, p_{w_1}$

$[w_2]$ $Q_{w_2}(w_1, w_2) = \lambda\, p_{w_2}$

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[36] All the FPE assumptions revised in the theoretical framework section apply in this Appendix as well.

where $Q_{w_1}(w_1, w_2)$ and $Q_{w_2}(w_1, w_2)$ are marginal product for production factors w_1 and w_2.The marginal rate of technical substitution (MRTS) is computed by dividing w_1 and w_2 FOCs. MRTS sets the rate where the slopes of the isoquant and isocost graphs are equal.

$$\frac{Q_{w_1}(w_1,w_2)}{Q_{w_2}(w_1,w_2)} = \frac{p_{w_1}}{p_{w_2}} \qquad (2)$$

The above MRTS provides the producer partial equilibrium. If each marginal productivity factor could be thought as marginal output cost for each unit of product, then factor prices ratio could provide conditional factor demands information. Here conditionality refers to output functional specification.

For convenience, consider next the dual for the producer maximization problem. This dual consists on producer cost minimization subject to conditional factor demands. Conditionality refers to a fix maximum output level. Also, applied Shepard's lemma to the dual and dividing its results for each production factor delivers the following equimarginality cost condition:

$$\frac{C_{w_1}(w_1,w_2)}{C_{w_2}(w_1,w_2)} = \frac{p_{w_1}}{p_{w_2}} \qquad (3)$$

where $C_{w_i}(w_1, w_2)$ stands for marginal cost with respect to production factor i, where $i \epsilon \{1, 2\}$. Next, equations (2) and (3) are rewritten in only one equation:

$$\frac{Q_{w_1}(w_1,w_2)}{Q_{w_2}(w_1,w_2)} = \frac{C_{w_1}(w_1,w_2)}{C_{w_2}(w_1,w_2)} = \frac{p_{w_1}}{p_{w_2}} \qquad (4)$$

Equation (4) will be used to explain general equilibrium in next subsection.

General Equilibrium. Demand equals Supply

The general equilibrium is set when demand and supply meet. Here, demand and supply are represented by consumer and producer partial equilibriums. Euler theorem under perfect competition and constant returns to scale establishes equality between marginal utility and marginal product. Consider Euler equality expressed as a ratio for equations (1) and (2) left hand sides.

$$\frac{U_x(x,y)}{U_y(x,y)} = \frac{Q_{w_1}(w_1, w_2)}{Q_{w_2}(w_1, w_2)}$$

Alternatively, Euler theorem could be written as an equality between equations (1) and (2) right hand sides.

$$\frac{p_x}{p_y} = \frac{p_{w_1}}{p_{w_2}} \qquad (5)$$

Equation (5) expresses a general equilibrium between consumer and producer equimarginality conditions. If p_x and p_y are thought as representing world prices of good x and y and p_{w_1} and p_{w_2} represent world wages for labor factors types 1 and 2. Thus, the above expression may represent a world general equilibrium. Without lost of generality equation (5) could also represent specific countries, *i.e.*, the U.S. and Mexico. For instance, for the U.S. equation (5) could be stated as follows:

$$\frac{p_x^{us}}{p_y^{us}} = \frac{p_{w_1}^{us}}{p_{w_2}^{us}} \qquad (6)$$

and for Mexico:

$$\frac{p_x^{mx}}{p_y^{mx}} = \frac{p_{w_1}^{mx}}{p_{w_2}^{mx}} \qquad (7)$$

where superscript us and mx stand for the U.S. and Mexico, respectively.

For the moment assume that free international trade is implemented in the North America region. In fact, the North America Free Trade Agreement (NAFTA) is an example of a free international trade policy implemented in 1994. In specific the U.S. and Mexico are examples of a large and small country with different factor endowments or factor proportions. These two countries characteristics are ideal to test free international trade theory effects. For instance, Heckscher (1919) mentions that free international trade policy effects could equalize endowments between large and small countries. For its part, Cassel (1918) explains that if the law of only one price holds, then the effects of free international trade theory is the equalization between factor and good prices across countries. If free international trade theoretical effects holds, then equations (5), (6) and (7) could be written as equalities.

$$\frac{p_x}{p_y} = \frac{p_{w_1}}{p_{w_2}} = \frac{p_x^{us}}{p_y^{us}} = \frac{p_{w_1}^{us}}{p_{w_2}^{us}} = \frac{p_x^{mx}}{p_y^{mx}} = \frac{p_{w_1}^{mx}}{p_{w_2}^{mx}} \quad (8)$$

Reducing terms in the above expression yields:

$$\frac{p_x}{p_y} = \frac{p_{w_1}^{us}}{p_{w_2}^{us}} = \frac{p_{w_1}^{mx}}{p_{w_2}^{mx}} \quad (9)$$

Equation (9) keeps a close resemble with Samuelson (1948) FPE equation. For the sake of comparison between equation (9) and FPE Samuelson equation, this last equation is reproduced next. Also, for the sake of simplicity Samuelson labels have been changed as follows: England for us and Portugal for mx

$$\left(\frac{price\ of\ good\ x}{rice\ of\ good\ y}\right) = \left(\frac{marginal\ cost\ of\ good\ x}{marginal\ cost\ of\ good\ y}\right)_{us} = \left(\frac{marginal\ cost\ of\ good\ x}{marginal\ cost\ of\ good\ y}\right)_{mx} \quad (10)$$

Remember that equation (9) is obtained through the following equalities transitions: equation (4) sets the equality between marginal productivities with marginal costs and factor prices. Then, equation (5) sets the equality between factor and good prices. Then equations (6)-(9) define Euler theorem for the world, the U.S. and Mexico. Thus, marginal factor costs, *i.e.*, labor prices, *i.e.*, wages in terms of good prices could be written for the U.S. and Mexico.

The theoretical equality between wages as a producer cost or product wages with good prices has been already envisioned by one of the FPE fathers "The price of the goods a worker buys is the cost of his labor to the employer." Ohlin (1967, p. 146). Thus, equation (9) reflects this Ohlin idea. That is to say, good price ratio is equalized to marginal cost ratio, where marginal cost ratio is represented by production factor price ratio.

Two countries geographic region is specified using equation (9) providing the next equation:

$$\frac{p_x^{us}}{p_y^{us}} = \frac{p_x^{mx}}{p_y^{mx}} = \frac{p_{w_1}^{us}}{p_{w_2}^{us}} = \frac{p_{w_1}^{mx}}{p_{w_2}^{mx}} \quad (11)$$

Equation (11) could hold, if and only if numerators and denominator are equal. Next, consider only the numerators equality on equation (11).

$$p_x^{us} = p_x^{mx} = p_{w_1}^{us} = p_{w_1}^{mx} \quad (12)$$

which after some arranging yields:

$$\frac{p_{w_1}^{mx}}{p_{w_1}^{us}} = \frac{p_x^{mx}}{p_x^{us}} \quad (13)$$

This research FPE theoretical approximation is represented by equation (13), which in turn is based on Samuelson equation (10). This paper econometric model is based on equation (13) and its empirical approximation is implemented in the following subsection.

Implications of the Penn effect

For explaining why the econometric model includes the bilateral real exchange between the U.S. and Mexico, it is worth reviewing some empirical facts, i.e., the existence of the "Peen effect." This empirical effect consists on theoretical equation (9) or alternatively equation (13) are not verified by econometric models. To explain this, for instance, Samuelson (1994) argues that empirically the "Peen effect" holds because of exaggerate exchange rates that do not allow the law of only one price to hold, under free international trade agreements. Nonetheless, this author mentions that if factor and good prices in two countries are equation parts is thanks to the exchange rate mediation.

The exchange rate mediation as an adjustment factor takes into account transaction and transportation costs or other costly barriers to free international trade. Samuelson (1994) defines nominal exchange rate as the ratio of local to foreign general prices levels.

$$E = \frac{p_j}{p_j^*}$$

where p_j stands for local general prices level in country j and p_j^* is foreign general prices level in country j.

If the exchange rate were no needed, then the law of only one would hold. That is to say, the nominal exchange rate above described would be equaled to one:

$$E = \frac{p_j}{p_j^*} = 1$$

since it is assumed that local and foreign price levels are equal. In absence of the exchange rate adjustment factor, equation (13) could be observed empirically. But, because the "Peen effect" the law of only one price does not hold empirically and equation (13) cannot actually be verified. The existence of the "Penn effect" implies for equation (13) the nominal exchange rate addition. Next, Samuelson (1994) empirical equation that exemplifies the "Penn effect" is reproduced:

$$\frac{Y_e^*}{Y_e} = E\frac{\sum_1^n p_j^* Q_j^*}{\sum_1^n p_j Q_j} \equiv \frac{1}{E^*}\frac{\sum_1^n p_j^* Q_j^*}{\sum_1^n p_j Q_j} \qquad (14)$$

where $\frac{Y_e^*}{Y_e}$ is GDP or GNP or VA per capita ratio; Y_e^* is foreign is GDP or GNP or VA; Y_e is local is GDP or GNP or VA; E is the nominal exchange rate; $\frac{1}{E^*}$ is the inverse of the nominal exchange rate E; $p_j^* Q_j^*$ is foreign country is GDP or GNP or VA for agent j; $p_j Q_j$ is local country is GDP or GNP or VA for agent j.

Importantly, Samuelson (1994) does not provide a theoretical justification for the set up of equation (14) that explains the inclusion of the exchange rate. In contrast, the inclusion of the exchange rate on equation (14) is explained in terms of an empirical adjustment on light of the "Penn effect." Under this point of view equation (13) could include E in the same way as Samuelson (1994) introduces E in equation (14).

Next, consider the following research equivalences to set an analogy between equations (13) and (14).

$p_{w_1}^{mx} = Y_e^*$, wages of labor type 1 is equal to gross national product in mx

$p_{w_1}^{us} = Y_e$, wages of labor type 1 is equal to gross national product in the us

$p_x^{mx} = \sum_1^n p_j^* Q_j^*$, aggregate good prices x are equal to the sum of agent j VA in mx

$p_x^{us} = \sum_1^n p_j Q_j$, aggregate good prices x are equal to the sum of agent j VA in the us

In the above two last equations, the left hand side is the aggregate and the right hand side is the sum of agents j, which are identified with an index that takes values from 1 to n. Substituting the above four expressions on equation (13) yields.

$$\frac{p_{w_1}^{mx}}{p_{w_1}^{us}} = E\,\frac{p_x^{mx}}{p_x^{us}} \qquad (15)$$

There are other explanations for the inclusion of the exchange rate on equation (15). For example, Commander and Coricelly (1991) explain that exchange rates are used as public policy anchor instrument to target inflation: "The deceleration of inflation post-February 1990 can be attributed not only to a major fiscal correction but to the reinstallation of anchors in the system. The exchange rate and wages have been the principal anchors in the system." For their part, Sachs (1986); Simonsen (1986), and Dornbusch and Fisher (1991) use exchange rates as exogenous policy shock instrument to stabilize disequilibria in economy fundamentals. The exchange rate as a stability policy tool could have different grades of intervention, i.e., pegging; crawling or monitoring bands; free float; just to mention a few.

The exchange rate inclusion on equation (15) also could be related with lack of perfect competition conditions, which is a FPE fundamental assumption. For instance, Samuelson (1994) considers that equation (14) left hand side represents the non-tradable sector. In this research this sector corresponds with inland production workers wages. Robertson (2005) has noted the non-tradable characteristic of production workers and describes migrant workers data as difficult to measure and probably endogenous. It appears that perfect competition does not applied to production workers given their non-tradable characteristics and lack of mobility between countries borders. It is worth mention that migrant workers are not considered in this research, because data sparse problems and their annual frequency. Remember that this research uses monthly frequency data. Monthly frequency is preserved, since lowering monthly to annual frequency involves degree of freedom lost, which may cause less accurate estimators.

For Samuelson (1994) the right hand side of equation (14) represents the tradable goods sector. For their part, De Gregorio, Giovannini and Wolf (1994) define a tradable sector if more than 10% of its total production is exported. Durable goods considered in this research *primary metal; machinery and transportation equipment* represent 81% of total 2012 Mexican exports; while the non durable goods amounts *together food; textile product and mills and chemical* 10.2% of total 2012 Mexican exports. Therefore, durable and non-durable goods are meeting De Gregorio, Giovannini and Wolf tradable sector criteria. Moreover, according with these authors perfect intersectorial factor mobility ensures FPE across tradable and non-tradable sectors regardless of economy sizes: "The small open economy thus takes the world interest rate as given, which determines uniquely the wage rate by equalization of marginal cost and the given world price." This quote implies that if FPE holds, then wage gap would not exist. In a different vein, if the FPE does not hold, then perhaps country size does matter, in order with Samuelson (1948) insights quoted in the brief literature review section.

An Empirical Adjustment: Factor Price Equalization Theorem

Once equation (15) is derived above, the next steps imply an empirical adjustment of it with respect to the U.S. and Mexico data. This adjustment has the end of illustrating this research econometric model empirical specification for testing the FPE.

1. Applied a monotonic log-log transformation on equation (15).

$$log\left(\frac{p_{w_1}^{mx}}{p_{w_1}^{us}}\right) = log\left(E\frac{p_x^{mx}}{p_x^{us}}\right) \quad (16)$$

Applying the logarithm laws to equation (16) right hand side yields:

$$log\left(\frac{p_{w_1}^{mx}}{p_{w_1}^{us}}\right) = logE + log\left(E\frac{p_x^{mx}}{p_x^{us}}\right) \quad (17)$$

2. Equation (17) theoretical moments are matched with those from the U.S. and Mexico manufacturing data as follows. Departing from Samuelson (1994) national account identity

$$Y_e = \sum_1^n p_j Q_j$$

where Y_e could stand for Gross Domestic Product (GDP) or Gross National Product (GNP) or Value Added (VA). According with an alternative Euler theorem described above on equation (5), in aggregate terms last expression could imply an equality between production factor price, i.e., wages with good prices, i.e., VA. Caveat: this Euler theorem in aggregate terms interpretation alludes only to local labor payments excluding those for capital and land, respectively; and refers only to final good prices excluding intermediate materials prices. This is the identification of the above expression theoretical moments with available empirical data moments.

The above moment identification between production factors income in terms of VA is an empirical approximation, based on proxy variables. Tica and Družić (2006) explain the use of proxy variables "Although the theoretical discussion was never finished, most researchers selected TFP as the best productivity proxy and used average labor productivity in their empirical papers." Thus, marginal costs are a good proxy for labor income and final good prices.

$$(labor\ production\ factor\ income)_i = (Value\ added)_i \quad (18)$$

where $i = us$ stands for the U.S. and $i = mx$ stands for Mexico.

3. National accounts value added has quarterly frequency. To avoid degrees of freedom lost, a monthly proxy variable for quarterly value added is used. This proxy variable is identified in this research with industrial monthly output indexes Q_{us}^N and Q_{mx}^N for the U.S. and Mexico, respectively. Thus last expression is rewritten as follows:

$$(labor\ production\ factor\ income)_i = Q_i^N \quad (19)$$

where N stands for national.

4. The left hand side on equation (19) expresses labor production factor income at a national level. As this research is focusing only on manufacturing industry production workers, it is necessary to perform a variable adjustment to refer only to this industry and to type of labor. Thus, labor production factor income at a national level is substituted with average hourly earnings of manufacturing production and nonsupervisory workers and industrial monthly output indexes is substituted for manufacturing monthly output indexes (Q_{us} and Q_{mx}).

$$(hourly\ earning\ of\ manufacturing\ production\ and\ nonsupervisory\ workers)_{us} = Q_{us} \quad (20)$$

and

$$(hourly\ earning\ of\ manufacturing\ production\ and\ nonsupervisory\ workers)_{mx} = Q_{mx} \quad (21)$$

where

$$(hourly\ earning\ of\ manufacturing\ production\ and\ nonsupervisory\ workers)_{mx} = \frac{W_{mx}E_0}{h_{mx}} \quad (22)$$

and $\frac{W_{mx}E_0}{h_{mx}} = w_{mx}$; W_{mx} is total earnings manufacturing production and nonsupervisory workers in Mexico; E_0 is nominal exchange rate pesos per dollar; h_{mx} stands for total number of hours of manufacturing production workers and nonsupervisory workers in Mexico, and w_{mx} is hourly earning of manufacturing production and nonsupervisory workers in Mexico in dollar currency.

Since in this research wage gap is referred to the relationship between wages in the U.S. and Mexico, these comparisons are made in dollars. This is why equation (22) considers a currency transformation on Mexican production workers from Mexican pesos to the U.S. dollars. Thus wage gap computation is straightforward.

5. To express only the U.S. and Mexico transaction costs the bilateral real exchange rate between both countries. The bilateral real exchange rate replaces the exchange rate on equation (15). Drine and Rault (2003) real exchange rate definition is used here with some modification. Thus, let E_r represents the bilateral real exchange rate between Mexico and the U.S, which is computed as follows:

$$E_r = \frac{P^*}{E_0 P}$$

where E_0 stands for the nominal exchange rate; P^* represents the U.S. prices level; P represents Mexico prices level. Next, equation (23) incorporates the bilateral real exchange rate between Mexico and the U.S. This equation also includes the empirical identification and transformation from previous steps.

$$log\left(\frac{\frac{W_{mx}E_0}{h_{mx}}}{w_{us}}\right) = \log(E_r) + log\left(\frac{Q_{mx}}{Q_{us}}\right) \qquad (23)$$

For obtaining the econometric model presented on equation (1) in section 3, equation (23) should be modified as to incorporate each variable estimator; constant and error term.

$$log\left(\frac{\frac{W_{mx}E_0}{h_{mx}}}{w_{us}}\right) = c + \alpha\log(E_r) + \beta log\left(\frac{Q_{mx}}{Q_{us}}\right) + \varepsilon_t \qquad (24)$$

Equation (24) expresses this research econometric model equation (1).