Topics in asymmetric exchange rate pass-through to prices, digitalization, and environmental sustainability

by

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B.S., Damascus University, 2009
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AN ABSTRACT OF A DISSERTATION

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DOCTOR OF PHILOSOPHY

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Abstract

This thesis consists of three empirical chapters. Within the chapters, two investigating topics in international trade and finance using the state of the art time series Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) models, and the third investigating digitalization and environmental issues using panel data and Mediation Analysis.

The first chapter, "Asymmetries in Exchange Rate Pass-Through to Consumer Prices." We investigate whether there are asymmetric exchange rate pass-through (ERPTH) effects on consumer prices in both the short-run and long-run, which depend on whether there is a currency appreciation or depreciation. State of the art Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) models are used, which have a switching structure connected to whether the exchange rate is increasing or decreasing. These questions are investigated using data from Brazil and Mexico, two top emerging countries. We find short-run asymmetric responses to exchange rate changes for Brazil, with ERPTH estimates that are positive, significant, and incomplete. However, Brazil has no long-term asymmetries, and ERPTH is negative, significant, and incomplete. On the other hand, no short-run asymmetries for Mexico are found, with ERPTH estimates that are negative, significant, and incomplete. In addition, there is a long-run asymmetry for Mexico, with an ERPTH estimate that is negative, significant, and incomplete.

The second chapter, "Asymmetries in Exchange Rate Pass-Through to Trade Prices," undertakes a similar investigation as the first chapter, only here the question is whether trade (export and import) prices experience different levels of pass-through in the short-run and long-run, which depend on whether the currency is appreciating or depreciating. Again, the

investigation focuses on data from Brazil and Mexico and makes use of ARDL and switching NARDL models. Starting with export prices, no evidence that there are asymmetries for Brazil in either the short-run or long-run is found, and the ERPTH estimates are negative and significant. For Mexico, only long-run asymmetry with ERPTH estimates are found to be negative, significant, and incomplete. Next, for import prices, there are consistencies between the two countries, finding short-run asymmetries and no long-run asymmetries for both countries. The short-run ERPTH estimates for Brazil are negative, significant, and more than complete. However, for Mexico, only the ERPTH estimate associated with local currency depreciation is significant, positive and incomplete.

The third chapter, "Digitalization and Environmental Sustainability: Effects and Transmission Channels," examines whether the movement toward a more digital economy has helped lower the emission of carbon dioxide (CO_2) using a panel data set for the G20 countries over 30 years. Digitalization is measured with several measures for the connection between the various countries' populations and the outside world, including mobile phone usage, fixed telephone usage, and internet usage. One of the main concerns here is to break down the connection between digitalization and carbon dioxide into direct and indirect effects, where the indirect effects operate through other channels, including trade, electricity production, fossil and fuel energy consumption, industry, and renewable energy consumption. Mediation Analysis is used to disentangle the direct and indirect effects. The findings show that internet users indirectly negatively impact the environment (increased CO_2 emissions) through its impact on trade channels and adverse effects (decreased CO_2 emissions) through fossil and fuel energy consumption, industry, and renewable energy consumption channels. Fixed telephone subscriptions have indirectly increased CO_2 emissions through their effect on all channels except the trade channel.

Fixed telephone subscriptions have no indirect impact on CO_2 emissions through the trade channel. Finally, mobile cellular subscriptions have indirectly increased CO_2 emissions through trade, fossil and fuel energy consumption, and renewable energy consumption and decreased CO_2 emissions through their effect on the industry channel. Moreover, the total effects of fixed telephone usage negatively impact the environment (increased CO_2 emissions) through all channels, while the total impacts of internet users positively impact the environment (decreased CO_2 emissions) through all channels. Finally, the full effects of mobile cellular subscriptions are positive (reduced CO_2 emissions) through all channels except trade channels, where mobile cellular subscriptions increase CO_2 emissions through them.

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Table of Contents

List of Figures

List of Tables

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Dedication

To My First and Only Love, Ghiath..

and

To the Most Precious Humans in My Life, Amer and Mira..

Chapter 1 - Asymmetries in Exchange Rate Pass-Through to Consumer Prices

Introduction

Economists and researchers have always been interested in exchange rates since they impact everyone's life. Exchange rates determine the price consumers pay for imported goods and they influence the profits firms make on exported goods. One particularly noteworthy concept is exchange pass-through (ERPTH), which concerns how domestic prices respond to foreign currency fluctuations, in particular, how much changes in foreign currency valuations are passed through into domestic prices.

Many studies have investigated the link between domestic prices and changes in exchange rates and the extent of ERPTH to consumer prices through time. For instance, Taylor (2000) claimed that a decline in ERPTH is positively correlated with a decrease in the inflation level using data from the United States over the 1990s. Many other studies have investigated this issue, concentrating on advanced economies, like Campa and Goldberg (2002, 2005), Choudhri et al. (2005), Faruquess et al. (2002), and Takhtamanova (2010). Most of these studies ignored the possibility of an asymmetrical relationship between prices and the exchange rate.

Until recently, empirical research presumed a symmetric long-run relation between price levels and the exchange rate. Accordingly, it had been assumed that the exchange rate pass-through is symmetric – or that appreciations and depreciation are transferred similarly to the final price. Though asymmetries have been widely noted in the prices of final goods, they are mainly accounted for by rigidities, suggesting that prices are sticker downwards than they are upwards. Symmetric rigidities make up the hypothesis that a symmetric pass-through is unrealistic and too restrictive. Indeed, neglecting the asymmetric impacts of exchange rates on prices can seriously misrepresent the effects of monetary policies. That is why the standard assumption of a symmetric ERPTH is relaxed into a new element of the empirical literature.

Consequently, recent studies show the possible existence of an asymmetric exchange rate pass-through – that is, the effect of currency appreciations and depreciations may not have the same magnitude. These studies take into account nonlinearities and asymmetries in the investigation of the relationship between exchange rates and domestic prices among developed and emerging economies; for example as Brun-Aguerre et al. (2012, 2016), Choudhri and Hakura (2015), Yanamandra (2015), and Baharumshah et al. (2017). Indeed, these investigations showed an asymmetrical and nonlinear ERPTH to import prices and a more complete and higher pass-through at exchange rate depreciations than appreciations over the long-run.

Furthermore, as Ghosh and Rajan (2007) noted, the present literature indicates that the reaction of exporters to the exchange rate changes is often asymmetric, depending on whether the exchange rate appreciates or depreciates. Additionally, as observed by Aron et al. (2014), the import price might not be able to fall as far as an appreciation. Still, it might rise with depreciation which is reflected in scarce but mounting evidence of different kinds of nonlinearities in the pass-through literature.

Many earlier studies in ERPTH focused only on developed countries, and research on ERPTH in Brazil and Mexico remains limited. This study aims to investigate exchange rate pass-through (ERPTH), in a nonlinear fashion, for Brazil (from 1996 to 2018) and Mexico (from 1994 to 2018). The main question is whether domestic prices are more sensitive to currency appreciation or depreciation (i.e., asymmetric ERPTH). In line with Bussiere (2013), any conclusion based on a linear model can be misleading if nonlinearities are concentrated. The model used in the paper uses a linear autoregressive distributed lag (ARDL) model with an extension of the nonlinear autoregressive distributed lag (NARDL) framework proposed by Shin, Yu, and Greenwood-Nimmo (2009). The NARDL consists of a dynamic error correction representation associated with an asymmetric long-run cointegrating regression.

The main findings can be outlined as follows. Evidence of asymmetric exchange rate pass-through for appreciation and depreciation is provided in the short-run for Brazil and in the long-run for Mexico. However, the effects of currency appreciation and depreciation on consumer prices have the same magnitude in the long-run for Brazil and in the short-run for Mexico.

Apart from this introduction, this paper discusses literature relating to ERPTH in section 2. Section 3 describes the exchange rate concept. Section 4 is devoted to econometric methodology and data. Section 5 presents the results, and the last section draws some conclusions.

Literature Review

Many research papers examine the nature of the relationship between exchange rate and inflation in other countries using several quantitative techniques. Furthermore, since the 2000s, investigations have concentrated on macroeconomic factors affecting the degree of exchange rate pass-through to consumer prices. The common macroeconomic factors affecting exchange rate pass-through in numerous studies have included the inflation level, the exchange rate, inflation volatility, trade openness, output gap, and exchange rate regimes (Gagnon and Ihrig, 2004; Ghosh and Rajan, 2007).

The majority of these studies proposed a symmetrical and declining exchange rate pass-through to prices through the years, particularly in developed countries (Taylor 2000; Olivei 2002; Campa and Goldberg 2005, among others). For example, Otani et al. (2003) found lower ERPTH to import prices for Japanese industries in the 1990s using monthly data from 1987 to 2002 on both overall and disaggregated import prices. Similarly, Takhtamanova (2010) validated Taylor's

(2000) hypothesis of a shrinking ERPTH under a low inflationary regime during the 1990s in 14 developed nations. This finding has been supported by many other studies (Choudhri et al., 2005; Frankel et al., 2011; Ozkan and Erden, 2015). Numerous empirical studies concluded that pass-through to prices was incomplete and more minor in developed nations, which lies between 0 to 1, than in developing countries (Goldberg and Knetter 1997; Berner 2010; Bussiere et al. 2014; among others). Berner (2010) analyses the ERPTH to import prices in Germany using monthly data from 1988 to 2008. He found an incomplete and nonlinear ERPTH, which had been higher during depreciation of the euro than appreciation, varying throughout the trading partners.

Investigation of the relation between the exchange rate and prices has progressed by enabling asymmetric as well as nonlinear ERPTH in both developed and emerging countries (Delatte and Lopez-Villavicencio 2012; Yanamandra 2015; Brun-Aguerre et al. 2016; Baharumshah et al. 2017; Kassi et al. 2019, among others). Brun-Aguerre et al. (2016) examined ERPTH to import prices for an unbalanced panel data of 14 emerging markets and 19 developed markets from 1980Q1 to 2010Q4. Most of these studies utilized the nonlinear autoregressive distributed lag (NARDL) framework of Shin et al. (2014) and showed an asymmetrical ERPTH where exchange rate depreciations have been transmitted through to prices stronger than appreciations in the long-term. Furthermore, Kassi (2018) found an asymmetrical ERPTH in developing and emerging Asian countries utilizing NARDL framework on quarterly data from 1995Q1 to 2016Q4.

That hypothesis has been supported by several studies (Choudhri et al., 2005; Frankel et al., 2011; Ozkan and Erden, 2015). McCarthy (2007) showed proof of low ERPTH under low fluctuations. Growing literature strands have highlighted the opportunity of asymmetrical and nonlinear ERPTH to price levels. Campa et al. (2006) underlined the asymmetrical link between exchange rate changes and import prices for manufacturing industries in the European Union by employing a nonlinear error-correction model. They have announced that depreciation was handed over to prices at a lower extent than appreciation. On the other hand, Delatte and Lopez-Villavicencio (2012) discovered that in their research on four advanced economies (Japan, Germany, the UK, and the USA) from 1980 to 2009, deprecation was forwarded to prices at a higher speed than appreciation by using a NARDL model.

Moreover, Yanamandra (2015) examined the ERPTH to import prices in India from 2003M1 to 2013M3 by using an asymmetrical error-correction model. He proposed more than complete ERPTH in the short-term, a higher ERPTH in the long-term, and an asymmetrical ERPTH to prices relating to depreciation and appreciation. Brun-Aguerre et al. (2016) investigated the ERPTH to import prices for 14 emerging markets and 19 developed markets from 1980Q1 to 2010Q4. Utilizing the NARDL framework, they demonstrated an asymmetrical ERPTH in which prices responded more strongly to depreciation than appreciation in the long-term. Likewise, Baharumshah et al. (2017) considered the asymmetrical ERPTH to CPI on monthly data in Mexico from 1990M1 to 2015M12. They also confirmed stronger ERPTH to prices in the depreciation period compared with appreciation by using the NARDL models.

Exchange Rate Concept

Exchange rate pass-through is defined as a percentage change in domestic prices attributed to a percentage change in the nominal exchange rate; in other words, it is the exchange rate elasticity of prices. Fluctuations in the exchange rate affect the domestic price level and depend on the degree of openness, the inflation environment, the credibility of the monetary policy, and exchange rate volatility, among others.

When the exchange rate's appreciation (or depreciation) is fully transmitted into domestic prices, the ERPTH is said to be complete. In contrast, if the transmissions of exchange rate variations into domestic prices are less proportional, the ERPTH is partial.

Numerous empirical studies have discovered that ERPTH in many countries is partial. Indeed, the degree of ERPTH to prices varies from zero (no pass-through) to one (complete pass-through), in which the values in this interval are referred to as incomplete or partial ERPTH. Two possible reasons are at work: the behavior of exporting firms (exporters maintain their market share when there is an appreciation of the country's exporter currency) and nominal rigidities (price is unresponsive in short-run) (Betts and Devereux, 2000; Monacelli, 2005; and Lopez-Villavicencio and Mignon, 2017).

Fluctuations in exchange rates can influence domestic prices directly or indirectly. Instantly, it affects the costs of inputs used in domestic manufacturing and the prices of imported final goods. Hence, the magnitude of direct effects will depend on the share of imported goods on domestic consumption and production. Indirectly, fluctuations in the exchange rate influence the demand for domestic goods competing with imported commodities. Indirect influence depends on the elasticity of substitution between domestic and imported goods. Depreciation of the local currency, for instance, raises the internal demand for domestic goods vis-à-vis imported goods while boosting the competitiveness of local exports. At a particular supply level, a rise in exports may result in inflation pressure (on top of domestic inputs and wages). Moreover, administered (or government-controlled) prices formally or informally indexed to the exchange rate may also influence domestic inflation.

Most empirical research evaluating the degree of ERPTH to inflation assumes a symmetric relationship between the price level and the exchange rate, or which the impacts of appreciation and depreciation of the local currency on prices have the same magnitude. Nevertheless, there are several reasons why the relationship may not be symmetrical, referred to as an asymmetric relationship, where the consequences of currency appreciations and depreciations on prices are not the same magnitude. For example, an appreciation of the importer's currency could be less passed through to prices than a depreciation simply because producers are more willing to increase their mark-up than reduce it. Indeed, if downward rigidities exist, the pass-through determined after an appreciation might be lower than after a devaluation (Bussiere, 2007). However, if the depreciation occurs during a recession, prices might increase less than they decrease after an appreciation. This is because the devaluation frequently results from a downward adjustment of domestic aggregate demand. Consequentially recessions could depress domestic prices, thus implying that domestic prices do not react much to exchange rate depreciation (Carranza et al., 2009).

Empirical Model and Methodology

1. Data

This chapter investigates the exchange rate pass-through (ERPTH) to the consumer price index (CPI), and is based on the following price model as developed by Murshed and Nakibullah (2015):

CPI = f (GDP, MS, CPI*, ER),

where CPI is the home country consumer price index, GDP represents the gross domestic product of the home country, MS is the money supply of the home country, and CPI* is the price level of the foreign countries. Finally, ER represents the nominal effective exchange rate, an adjustment-weighted average rate that a country's currency exchanges for a basket of multiple foreign currencies. Note that the strategy in modeling the external factors (i.e., CPI* and ER) differs from that previously used, where exchange rate, oil prices, and foreign consumer price index are used as external factors. Thus, the following model will be taken into account:

CPI = f (GDP, MS, ER, OIL, FCPI)

Quarterly data ranging from 1996Q1 to 2018Q4 for Brazil and from 1994Q2 to 2018Q4 for Mexico are used. The Bank of International Settlements (BIS) provides nominal effective exchange rates, and foreign consumer price index data are calculated based on main trade partners. The rest of the variables are obtained from the Federal Reserve Bank of St. Louis (FRED).

2. Methodology

2.1. Linear Autoregressive Distributed Lag (ARDL) Cointegration Model

In this section, a symmetric cointegrating autoregressive distributed lag (ARDL) model is implemented to examine the responsiveness of consumer prices to fluctuations in exchange rates. This methodology was developed by Pesaran, Shin, and Smith (2001) in its symmetric form and expanded by Shin, Yu, and Greenwood-Nimmo (2009) for the asymmetric case, enabling us to test for the existence of short-term and long-term relationships.

The ARDL model and the "bounds test" for the long-run relationship have two critical advantages over the approach of Johansen and Juselius (1990). The first advantage is that this approach is applicable even when the variables are stationary, integrated, or mutually cointegrated. It does not require the series to be integrated of the same order to find a possible cointegrating connection between these variables. The second advantage is that the methodology has better statistical properties for small samples. The cointegration test obtained from Johansen and Juselius approach is not robust in small samples (Bejaoui, 2013).

In the literature, exchange rate pass-through is captured through the following symmetric relationships:

$$CPI_t = \alpha_0 + \alpha_1\, ER_t + \alpha_2\, OIL_t + \alpha_3\, MS_t + \alpha_4\, GDP_t + \alpha_5\, FCPI + \varepsilon_t \qquad (1)$$

The CPI, the consumer price index, is the dependent variable. Independent variables are ER, the nominal effective exchange rate; OIL, the price of crude oil; MS, the money supply; and FCPI, the foreign consumer price index. The last explanatory variable, GDP, is the gross domestic product. All the variables are expressed in logarithms, and ε_t is an iid process. In equation (1), α_1 represents the elasticity of the exchange rate pass-through to consumer prices (i.e., the pass-through), α_2 is the elasticity of the oil price variable (OIL), α_3 is the elasticity of the money supply variable (MS), α_4 refers to the elasticity of gross domestic product (GDP) on the consumer price, and α_5 is the elasticity of foreign consumer price index variable (FCPI).

To test for a linear long-run relationship, an ARDL model is being used. A different one from the previously listed advantages, an interesting feature of the ARDL is that it considers the error correction term. Consequently, the following linear error correction model is considered:

$$\Delta CPI_t = \beta_0 + \beta_1\, CPI_{t-1} + \beta_2\, ER_{t-1} + \beta_3\, OIL_{t-1} + \beta_4\, MS_{t-1} + \beta_5\, GDP_{t-1} + \beta_6\, FCPI + \sum_{i=1}^{p} \rho_{0,i}\, \Delta CPI_{t-i} + \sum_{i=0}^{q} \rho_{1,i}\, \Delta ER_{t-i} + \sum_{i=0}^{q} \rho_{2,i}\, \Delta OIL_{t-i} + \sum_{i=0}^{q} \rho_{3,i}\, \Delta MS_{t-i} + \sum_{i=0}^{q} \rho_{4,i}\, \Delta GDP_{t-i} + \sum_{i=0}^{q} \rho_{5,i}\, \Delta FCPI_{t-i} + \varepsilon_t \qquad (2)$$

Where, Δ is a difference operator, and p and q are the number of lags for the dependent variable and regressors, respectively. $\rho_{0,i}$, $\rho_{1,i}$, $\rho_{2,i}$, $\rho_{3,i}$, $\rho_{4,i}$, and $\rho_{5,i}$ in equation (2) are the short-run adjustment terms, and β_2, β_3, β_4, β_5, and β_6 are the long-run adjustment terms, $\sum_{i=0}^{q} \rho_{1,i}$ showing the short-term effects of variations of the local currency on consumer prices, and $-\beta_2 / \beta_1$ showing the long-term impact of variations of the local currency on consumer prices.

Additionally, equation (2) exhibits both long-run and short-run symmetric pass-through. The first part corresponds to the short-run relationship:

$\sum^{p}_{i=1} \rho_{0,i}\, \Delta CPI_{t-i} + \sum^{q}_{i=0} \rho_{1,i}\, \Delta ER_{t-i} + \sum^{q}_{i=0} \rho_{2,i}\, \Delta OIL_{t-i} + \sum^{q}_{i=0} \rho_{3,i}\, \Delta MS_{t-i} + \sum^{q}_{i=0} \rho_{4,i}\, \Delta GDP_{t-i}$ +

$\sum^{q}_{i=0} \rho_{5,i}\, \Delta FCPI_{t-i}$ (3)

Where:

$\rho_{0,i}$, $\rho_{1,i}$, $\rho_{2,i}$, $\rho_{3,i}$, $\rho_{4,i}$, and $\rho_{5,i}$ are the parameters estimated to represent the error correction dynamics.

The second part corresponds to a long-run relationship:

$\beta_1\, CPI_{t-1} + \beta_2\, ER_{t-1} + \beta_3\, OIL_{t-1} + \beta_4\, MS_{t-1} + \beta_5\, GDP_{t-1} + \beta_6\, FCPI$ (4)

where:

β_1 is the coefficient of error correction.

β_2, β_3, β_4, β_5, and β_6 are estimators of independent variables in the cointegration model, denoting the long-run relationship.

Two statistics are proposed to test the null hypothesis of no long-run relationship. The first one is named the tBDM, tests for the null of no significance of the error correction term. The second one, the F-test, is formulated as follows:

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$

Versus the

H_A: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$

Pesaran, Shin, and Smith (2001) have drawn up two critical thresholds to interpret test results. It is impossible to reject the null hypothesis of no long-run relationship when the calculated statistic is situated below its lower critical values. Vice versa, if the computed statistic is greater than the upper critical value, there is proof of a long-run relationship. However, no conclusion can be drawn when the statistic is between the two critical values.

Under the ARDL method, a single long-run relationship exists between independent and dependent variables in every single equation. After obtaining the long-run relationship (the cointegration model), the error correction model (ECM) is estimated to capture short-run dynamics (Foudeh, 2017). Hence, the error correction model for cointegrated variables can be presented as follows:

$$\Delta CPI_t = \beta_0 + \sum^{p}_{i=1} \rho_{0,i}\, \Delta CPI_{t-i} + \sum^{q}_{i=0} \rho_{1,i}\, \Delta ER_{t-i} + \sum^{q}_{i=0} \rho_{2,i}\, \Delta OIL_{t-i} + \sum^{q}_{i=0} \rho_{3,i}\, \Delta MS_{t-i} + \sum^{q}_{i=0} \rho_{4,i}\, \Delta GDP_{t-i} + \sum^{q}_{i=0} \rho_{5,i}\, \Delta FCPI_{t-i} + \beta_1\, ECT_{t-1} + \varepsilon_t \quad (5)$$

Where:

ECT: error correction term. It is the OLS residuals derived from the long-run estimated cointegration model.

β_1: the speed of adjustment that shows how quickly variables parameters return to the equilibrium in the long term. β_1 is anticipated to be negative and significant. It is ideal if it lies between 0 and -1. The more is near -1, the more muscular the equilibrium is, but it is a significant is must (Foudeh, 2017).

The error correction term (ECT_{t-1}) is the most critical component in the error correction model for cointegrated variables. For this reason, Table 1.9. reports the coefficients associated with ECT_{t-1} for both countries.

2.2. Non-Linear Autoregressive Distributed Lag (NARDL) Cointegration Model

The prior model (ARDL) does not consider the direction of exchange rate fluctuations in evaluating pass-through. In other words, the short-run or long-run pass-through is assumed to be of the same magnitude independently if the exchange rate appreciates or depreciates.

To allow for asymmetric exchange rate pass-through, the approach used in Schorderet (2004), and Shin, Yu, and Greenwood-Nimmo (2009) is followed. This procedure requires constructing new variables that capture appreciation and depreciation episodes. The point is to decompose a time series into two series, ER_t^+ and ER_t^- such as the following:

$$ER_t^+ = \sum_{j=1}^{t} \Delta ER_t^+ = \sum_{j=1}^{t} \max(\Delta ER_t^+, 0)$$

$$ER_t^- = \sum_{j=1}^{t} \Delta ER_t^- = \sum_{j=1}^{t} \min(\Delta ER_t^-, 0)$$

where ΔER_t^+ and ΔER_t^- are the partial sum processes of depreciation and appreciation, respectively. Following Shin et al. (2009), equation (2) can also be expressed to enable an asymmetric relationship.

For consumer prices, the following asymmetric ARDL model is assumed to be:

$$\Delta CPI_t = \beta_0 + \beta_1 CPI_{t-1} + \beta^+_2 ER^+_{t-1} + \beta^-_2 ER^-_{t-1} + \beta_3 OIL_{t-1} + \beta_4 MS_{t-1} + \beta_5 GDP_{t-1} + \beta_6 FCPI_{t-1} + \sum^{p}_{i=1} \rho_{0,i} \Delta CPI_{t-i} + \sum^{q}_{i=0} \rho_{1,i}^+ \Delta ER_{t-i}^+ + \sum^{q}_{i=0} \rho_{1,i}^- \Delta ER_{t-i}^- + \sum^{q}_{i=0} \rho_{2,i} \Delta OIL_{t-i} + \sum^{q}_{i=0} \rho_{3,i} \Delta MS_{t-i} + \sum^{q}_{i=0} \rho_{4,i} \Delta GDP_{t-i} + \sum^{q}_{i=0} \rho_{5,i} \Delta FCPI_{t-i} + \varepsilon_t \quad (6)$$

where, Δ is a difference operator, and p and q are the numbers of lags for dependent variables and regressors, respectively. $\rho_{0,i}$, $\rho_{1,i}^+$, $\rho_{1,i}^-$, $\rho_{2,i}$, $\rho_{3,i}$, $\rho_{4,i}$, and $\rho_{5,i}$ are the short-run adjustment terms β^+_2, β^-_2, β_3, β_4, β_5, and β_6 are the long-run adjustment terms, ER^+ represents the positive partial sums of the exchange rate, denoting local currency depreciation (positive exchange rate changes), ER^- represents the negative partial sums of the exchange rate, indicating local currency appreciation (negative exchange rate changes), $\sum^{q}_{i=0} \rho_{1,i}^+$ showing the short-term effects of the depreciation of the local currency on consumer prices, $\sum^{q}_{i=0} \rho_{1,i}^-$ showing the short-term impacts of local currency appreciation on consumer prices, $-\beta_2^+ / \beta_1$ showing the long-term effects of the depreciation of the local currency on consumer prices (local currency depreciation), and $-\beta_2^- / \beta_1$ showing the long-term impact of the appreciation of the local currency on consumer prices (local currency appreciation).

There are two parts on the right-hand side of equation (6). The first part corresponds to the short-run relationship:

$$\sum^{p}_{i=1} \rho_{0,i}\, \Delta CPI_{t-i} + \sum^{q}_{i=0} \rho_{1,i}^{+}\, \Delta ER_{t-i}^{+} + \sum^{q}_{i=0} \rho_{1,i}^{-}\, \Delta ER_{t-i}^{-} + \sum^{q}_{i=0} \rho_{2,i}\, \Delta OIL_{t-i} + \sum^{q}_{i=0} \rho_{3,i}\, \Delta MS_{t-i} + \sum^{q}_{i=0} \rho_{4,i}\, \Delta GDP_{t-i} + \sum^{q}_{i=0} \rho_{5,i}\, \Delta FCPI_{t-i} \quad (7)$$

Where:

$\rho_{0,i}$, $\rho_{1,i}^{+}$, $\rho_{1,i}^{-}$, $\rho_{2,i}$, $\rho_{3,i}$, $\rho_{4,i}$, and $\rho_{5,i}$ are the parameters estimated responding the error correction dynamics.

The second part is corresponding to the long-run relationship:

$$\beta_1\, CPI_{t-1} + \beta^{+}_2\, ER^{+}_{t-1} + \beta^{-}_2\, ER^{-}_{t-1} + \beta_3\, OIL_{t-1} + \beta_4\, MS_{t-1} + \beta_5\, GDP_{t-1} + \beta_6\, FCPI_{t-1} \quad (8)$$

where:

β_1 is the coefficient of error correction.

β^{+}_2, β^{-}_2, β_3, β_4, β_5, and β_6 are estimators of independent variables in the cointegration model, denoting the long-run relationship.

Two statistics are proposed to test the null hypothesis of no long-run relationship. The first one is named the tBDM test for the null of no significance of the error correction term.

The second one, the F-test is formulated as follows:

H_0: $\beta_1 = \beta^{+}_2 = \beta^{-}_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$

Versus the

H_A: $\beta_1 \neq \beta^{+}_2 \neq \beta^{-}_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$

Pesaran et al. (2001) have set up two critical thresholds to interpret the test results. It is impossible to reject the null hypothesis of no long-run relationship when the computed statistic is below its respective lower critical values. On the contrary, if the computed statistic is higher than the upper critical value, there is evidence of a long-run relationship. However, no conclusion can be drawn when the statistic is between the two critical values.

Results and Discussion

1. Unit Root Tests

In a recent study by Nkoro and Uko (2016) in the Journal of Statistical and Econometric Methods, the ARDL cointegration technique is adopted irrespective of whether the underlying variables are I(0), I(1), or a combination of both, and cannot be applied when the underlying variables are integrated of order I(2). Because of this, it is advisable to test for unit roots since variables that are the integration of order I(2) lead to the crashing of the technique.

The first step in this process is to verify if the variables are stationary in the first difference I(1). Therefore, the Augmented Dicky Fuller (ADF) test is used. The outcomes of the ADF test (Table 1.1.) demonstrate the absence of I(2) for all variables. This means we are able to continue testing for cointegration within the ARDL framework. ARDL models allow for using non-stationary and stationary series simultaneously to estimate the parameters of models that include lags of dependent variables and lags of independent variables.

ARDL does not require the series to be integrated in the same order to find a potential cointegrating relation between the variables. The ARDL method does not strictly require the classification of I(0) or I(1) (Pesaran et al., 2001). Furthermore, an exciting feature of the ARDL is that it considers the error correction term, and ARDL directly estimates the error term (cointegrating coefficient) in the short-run and long-run terms.

Table 1.1. *Augmented Dickey Fuller Test- Consumer Prices*

		Mexico		**Brazil**	
Variables		**I(0)**	**I(1)**	**I(0)**	**I(1)**
CPI	t-Stat.	-1.628679	-3.419235	-0.776579	-3.616270

	Prob.	0.4640	0.0128	0.8205	0.0073
ER	t-Stat. Prob.	-3.625892 0.0069		-2.071135 0.2568	-7.359625 0.0000
OIL	t-Stat. Prob.	-1.655888 0.4503	-7.628043 0.0000	-1.687378 0.4342	-7.291437 0.0000
MS	t-Stat. Prob.	-3.880633 0.0031		-2.506965 0.1172	-5.373053 0.0000
GDP	t-Stat. Prob.	-0.659083 0.8511	-7.035379 0.0000	-1.503720 0.5273	-7.230134 0.0000
FCPI	t-Stat. Prob.	-2.100659 0.2450	-7.745332 0.0000	0.500604 0.9859	-4.511198 0.0004

Findings and the conclusion of the unit root test (Table 1.1.) reveal that the majority of the variables are either I(0) or I(1), as well as none of them are found to be integrated of order two, i.e., I(2).

2. Models' Lags and their Primarily Statistical Results

Regarding the lag order selection criteria and depending on AIC, the number of lags for dependent variables and regressors is fixed to 8 lags for Brazil and 3 lags for Mexico. Table 1.2. and Table 1.3. give the primary statistical results for both models (ARDL and NARDL). Their R^2 and Adjusted R^2 are relatively large, with significant F-statistics at the 1% level.

Table 1.2. *Optimal Model Lags for ARDL (p,q) Models-Consumer Prices*

Dependent Variable: CPI							
Selected Model	**AIC**	**R^2**	**Adjust R^2**	**Sum Squared Residual**	**Mean Dependent Variable**	**F-statistic**	**Durbin-Watson Stat**
ARDL for Brazil (8, 8, 8, 8, 8, 8)	-9.029792	0.999927	0.999799	0.000163	1.811130	7794.563	2.035493
ARDL for Mexico (3, 3, 3, 3, 3, 3)	-8.454856	0.999768	0.999694	0.000726	1.821976	13482.03	2.156234

Table 1.3. *Optimal Model Lags for NARDL (p,q) Models - Consumer Prices*

Dependent Variable: CPI							
Selected Model	**AIC**	**R^2**	**Adjust R^2**	**Sum Squared Residual**	**Mean Dependent Variable**	**F-statistic**	**Durbin-Watson Stat**
NARDL for Brazil (8, 8, 8, 8, 8, 8, 8)	-9.488750	0.999963	0.999847	8.06E-05	1.814552	8648.315	2.010253
NARDL for Mexico (3, 3, 3, 3, 3, 3, 3)	-8.550359	0.999788	0.999702	0.000597	1.827841	11690.10	1.863006

Note: the results are presented using fix number of lags to 8 for Brazil and 3 for Mexico.

3. Diagnostic Tests (Foudeh, 2017)

3.1. Normality Test of Residuals

A normality test is an essential test since rejecting the null hypothesis invalidates the test statistics (H_0: normal distribution of residuals). The Jarque-Bera statistics show normality of residuals in both countries, i.e., Brazil and Mexico (Table 1.4.).

3.2. Autocorrelation Test

The Breusch-Godfrey Lagrange Multiplier test is used to investigates the presence of autocorrelation in the residuals. The Breusch-Godfrey Lagrange Multiplier test in Table 1.4. indicates that the null hypothesis can't be rejected for both countries, meaning that residuals aren't correlated.

3.3. Test of Heteroscedasticity

Breusch-Pagan-Godfrey test's result in Table 1.5. indicates that the null hypothesis of homoscedasticity cannot be rejected for all lagged models. The diagnostic test results in Table 1.5. show the absence of a heteroscedasticity problem, which means that the standard errors can be trusted, and T-statistics are asymptotically standard normal distributed and, therefore, the P-values.

3.4. Ramsey Reset Test

This test explores the null hypothesis of no problem of function misspecification. If the null hypothesis is rejected, some issues with the original model can be caused by autocorrelation, heteroscedasticity, or functionalism from misspecification. Testing results (Table 1.5.) show both countries' acceptance of the null hypothesis.

Table 1.4. *Diagnostic Test -Consumer Prices*

Country	**Jarque-Bera**			**Autocorrelation Test**		
	Value	**Probability**	**Result**	**F-statistic**	**Probability**	**Result**
Brazil	0.609198	0.737419	Fail to Reject H_0	0.555188	0.5835	Fail to Reject H_0
Mexico	1.411072	0.493844	Fail to Reject H_0	1.432358	0.2457	Fail to Reject H_0

Table 1.5. *Diagnostic Tests - Consumer Prices*

Country	**Test of Heteroskedasticity**			**Ramsey Reset Test**		
	F-statistic	**Probability**	**Result**	**F-statistic**	**Probability**	**Result**
Brazil	0.707464	0.8494	Fail to Reject H_0	0.054707	0.8176	Fail to Reject H_0
Mexico	0.800080	0.7201	Fail to Reject H_0	0.948305	0.3335	Fail to Reject H_0

4. Parameters Stability Tests

The stability test using the cumulative sum (CUSUM) of recursive residuals helps show whether coefficients are systematically changing. By contrast, the CUSUM of squared residuals helps to show if coefficients are changing suddenly (Bhatti et al., 2006).

4.1. Cumulative sum (CUSUM) of recursive residuals

The attending test demonstrates the stability of the model. The model coefficients are not switching systematically because the plot of CUSUM of recursive residuals for Brazil and Mexico that is represented by solid lines (blue lines) is within the 5% significance interval (back to Figure 1.1.).

4.2. Cumulative sum (CUSUM) of squared residuals

From Figure 1.2., the plots of CUSUM of squares residuals for both countries (Brazil and Mexico) represented by the solid lines (blue lines) are within the 5% critical bounds of parameter stability, which means estimated coefficients are stable, indicating that coefficients are not changing suddenly, and the estimated coefficients are stable.

Figure 1.1. *Cumulative Sum of Recursive Residuals - Consumer Prices*

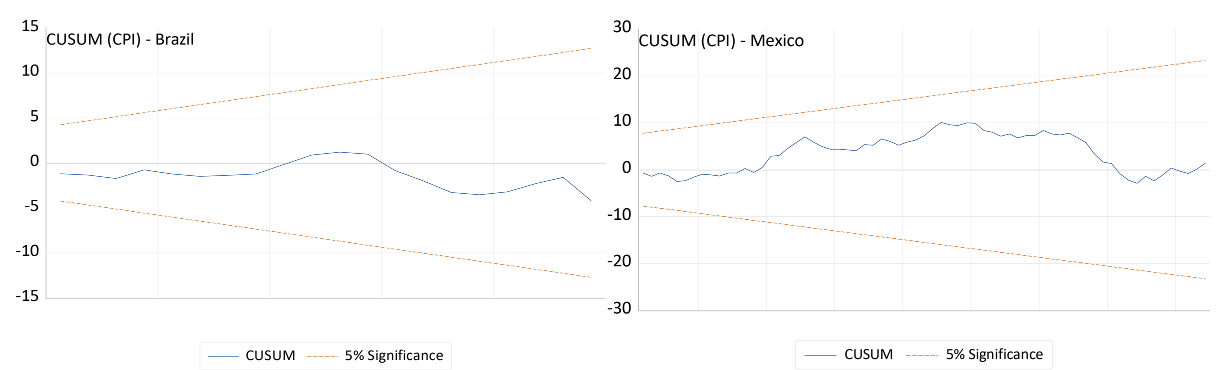
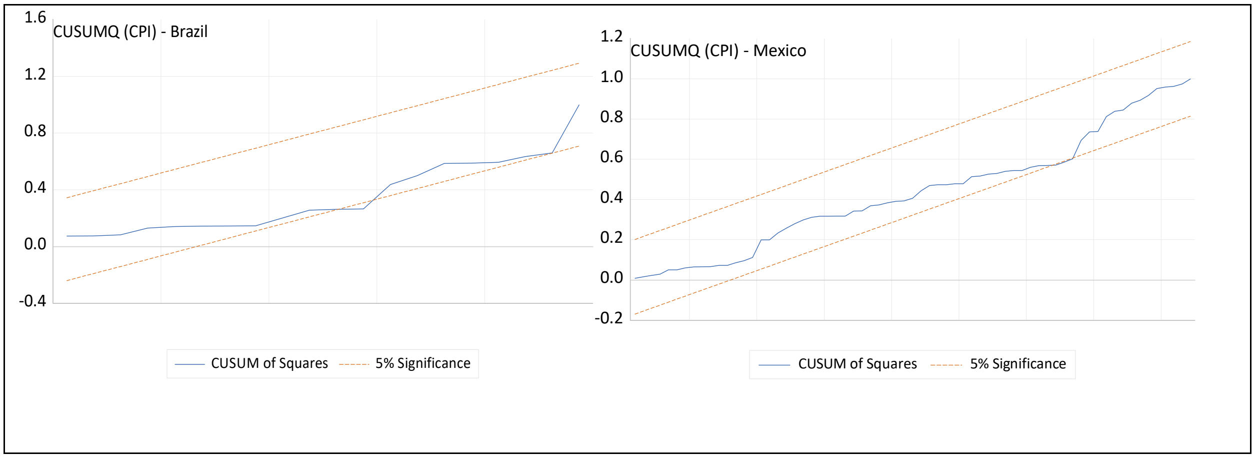


Figure 1.2. *Cumulative Sum of Squared Residuals - Consumer Prices*



5. Wald Test

Verifying the existence of an asymmetric effect of the exchange rate, the Wald test is employed by testing the null hypothesis of symmetry, where if the difference between the coefficients of positive and negative changes is statistically insignificant, then we have a regular symmetric relationship.

For the short-run Wald test, when we reject the null hypothesis, we do have evidence of short-run asymmetry concerning the exchange rate and short-run asymmetry. If we fail to reject the null hypothesis, we do not have evidence of short-run asymmetry regarding the exchange rate, and we do have short-run symmetry.

The null hypothesis of short-run symmetry is:

H_0: $\sum_{i=0}^{q} \rho_{1,i}^{+} = \sum_{i=0}^{q} \rho_{1,i}^{-}$

Versus the alternative hypothesis of short-run asymmetry:

H_A: $\sum_{i=0}^{q} \rho_{1,i}^{+} \neq \sum_{i=0}^{q} \rho_{1,i}^{-}$

The same thing for the long-run Wald test; when we reject the null hypothesis, then we do have evidence of long-run asymmetry with respect to the exchange rate, and we have long-run asymmetry. If we fail to reject the null hypothesis, then we do not have evidence of long-run asymmetry with respect to the exchange rate, and we have long-run symmetry.

The null hypothesis of long-run symmetry is:

H_0: $\alpha^+_1 = \alpha^-_1$

Versus the alternative hypothesis of long-run asymmetry:

H_A: $\alpha^+_1 \neq \alpha^-_1$

Where, $\alpha^+_1 = -\beta_2{}^+ / \beta_1$ and $\alpha^-_1 = -\beta_2{}^- / \beta_1$

Table 1.6. *Short-Run and Long-Run Symmetry Test - Consumer Prices*

Country	**Short-run W_{SR}**			**Long-run W_{LR}**		
	t-statistic	**Probability**	**Result**	**t-statistic**	**Probability**	**Result**
Brazil	-2.472891	0.0225	Reject H_0	0.407305	0.6881	Fail to Reject H_0
Mexico	0.119366	0.9053	Fail to Reject H_0	3.747848	0.0004	Reject H_0

The short-run and long-run findings of the Wald test are shown in Table 1.6. The null hypothesis of short-run symmetric exchange rate pass-through is rejected for Brazil. The conclusion reveals that the transmission of exchange rate fluctuation in consumer prices is asymmetrical with respect to depreciation (positive changes) and appreciation (negative changes) in Brazil in the short-run. However, the null hypothesis of long-run symmetric is failed to reject; then the results indicate that consumer prices responses to exchange rate variations are the same no matter if the exchange rate decrease or increases, and we do not have evidence of long-run asymmetry concerning the exchange rate, and we have long-run symmetry.

Regarding Mexico, we do have the exact opposite outcomes. The null hypothesis of short-run symmetric exchange rate pass-through fails to reject, and we have short-run symmetry. Also, we have proof of long-run asymmetry concerning the exchange rate in the long-run, and we do have long-run asymmetry.

Empirical Results

This section demonstrates the main results of the symmetric and asymmetric exchange rate pass-through for consumer prices. First, the findings are reported for testing the long-run relationship for both the symmetric and asymmetric models. The F-test (bounds test) and tBDM test results are shown in Tables 1.7., 1.8., and 1.9.

Table 1.7. *Bounds Results of the Linear ARDL - Consumer Prices*

$(H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0)$					
Country	**F-Test**	**Signif.**	**lower bound**	**Upper bound**	**Result**
Brazil	3.169870	5%	2.62	3.79	No conclusion
Mexico	18.44667	1%	3.41	4.68	Reject H_0

Findings in Table 1.7. point to the rejection of the null hypothesis of no level relationship among the variables in the ARDL model regarding Mexico. Though, F-statistics for Brazil fall between the two bounds, the test is inconclusive. And, to decide if there is possible cointegration among the variables, the significance of the error term coefficient should be considered and looked at. For Brazil, the coefficient is expected to be negative and significant. Then, there is a possible long-run relationship among variables.

Table 1.8. *Bounds Results of the Non-Linear ARDL (NARDL)- Consumer Prices*

$(H_0 = \beta_1 = \beta^+_2 = \beta^-_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0)$					
Country	**F-Test**	**Signif.**	**lower bound**	**Upper bound**	**Result**
Brazil	4.552966	1%	3.15	4.43	Reject H_0
Mexico	11.92124	1%	3.15	4.43	Reject H_0

Following the results in Table 1.8., the null hypothesis of no level relationship among the variables in the NARDL model is rejected regarding Brazil and Mexico.

Table 1.9. *tBDM Test (ECT coefficients) - Consumer Prices*

H_0: no significance of the error correction term				
Country	**ARDL**		**NARDL**	
	Coefficient	**t-Statistics**	**Coefficient**	**t-Statistics**

Brazil	-0.165286***	-4.710530	-0.360687***	-6.436768
Mexico	-0.148025***	-10.87962	-0.169260***	-9.535286

*** sign at 99%, ** sign at 95%, * sign at 90%.

Indeed, the ECM coefficients (tBDM test results) presented in Table 1.9. are negative, highly significant, and lie between 0 and -1, supporting adjustment towards the long-run. Subsequently, concerning both the bounds cointegration test and the tBDM test, there is a valid long-run relationship between consumer prices and the explanatory variables in the two countries. A conclusion that consumer prices are cointegrated with explanatory variables confirms existing evidence for both countries.

Table 1.10. *Estimates of Symmetric and Asymmetric ERPTH to Consumer Prices*

	ARDL Model			**NARDL Model**		
Country	**Variable**	**Coefficient**	**t-stat**	**Variable**	**Coefficient**	**t-stat**
	Short-run Pass-Through to Consumer Prices					
Brazil	-	-	-	$\sum^{q}_{i=0} \rho_{1,i}{}^{+}$ $\sum^{q}_{i=0} \rho_{1,i}{}^{-}$	0.164509** 0.480493***	2.395233 3.449980
Mexico	$\sum^{q}_{i=0} \rho_{1,i}$	-0.057081***	-5.885310	-	-	-
	Long-run Pass-Through to Consumer Prices					
Brazil	α_1	-0.382511***	-4.134156	-	-	-
Mexico	-	-	-	α^{+}_{1} α^{-}_{1}	-0.237503 -0.250352**	-1.015155 -2.236993

Notes: α_1, α^{+}_1, and α^{-}_1 are the LR coefficients associated with total, positive (local currency depreciation), or negative (local currency appreciation) changes in the exchange rate, respectively. $\sum^{q}_{i=0} \rho_{1,i}$, $\sum^{q}_{i=0} \rho_{1,i}{}^{+}$, and $\sum^{q}_{i=0} \rho_{1,i}{}^{-}$ are the sum of SR coefficient associated with total, positive (local currency depreciation), or negative (local currency appreciation) changes of the exchange rate. *** sign at 99%, ** sign at 95%, * sign at 90%.

In accordance with the Wald test results, the estimated short-run and long-run coefficients of the exchange rate pass-through are summarized in Table 1.10.

Discussion

Beginning with Brazil, consumer prices are significantly and positively associated with local currency depreciation and appreciation in the short-run but negatively linked to exchange rate changes over the long-run. In contrast, they do have a significant and negative influence and different impacts on consumer prices in the long-run. For instance, in the short-run, consumer prices increased by 0.16% for a 1% depreciation of the Brazilian real, whereas a 1% appreciation of the real induced a 0.48% increase in prices. Consumer prices decreased by 0.38% for a 1% exchange rate change in the long-run.

Moreover, in the short-run, the exchange rate pass-through to consumer prices has been more robust during periods of appreciation than during depreciation (in absolute values). And the evidence for incomplete exchange rate pass-through is observed in Brazil over the short-run and long-run.

Previous findings can be explained by the fact that, in 1999, a set of policies was adopted in Brazil, the so-called *macroeconomic tripod*, founded on: an inflation targeting regime, a floating exchange rate with high capital mobility, and a primary surplus target. Following the Taylor rule, price stability had been pursued by fixing the introductory interest rate (Selic rate). Consequently, the *Selic rate* was set to manage aggregate demand simultaneously and, though not directly, the exchange rate, the most relevant monetary policy transmission channel. Fiscal policy, in its turn, has taken over a supporting role, restricted to avoiding inflationary pressures and keeping stable debt/GDP relations (Reis et al., 2016). This policy was in line with the *New Consensus in Macroeconomics* (Modenesi et al.).

Taylor (2000) analyzes "the possibility that lower and more stable inflation is a factor behind the reduction in the degree to which firms "pass-through" (to their prices) both price increases at competing firms and cost increases due to exchange rate movements or other factors."

Then, low and stable inflation environments lead to low levels of exchange rate pass-through, contributing to a weakening of the "fear of floating" phenomenon experienced by some developing countries. Da Silva and Vernengo's (2008) paper suggests the "fear of inflation" remains the leading cause behind the "fear of floating" even though pass-through impacts have dropped in the developing world, and this appears to be the case in Brazil. Despite lower pass-through effects, the Brazilian Central Bank has maintained high-interest rates to control the exchange rate. Furthermore, adopting inflation targeting its advantage would improve the central bank's credibility in controlling inflation (Da Silva and Vernengo, 2008).

One positive shock to the exchange rate of the domestic currency (an unexpected deprecation) will make exports cheaper and imports more costly. And one negative shock to the exchange rate of the domestic currency (an unexpected appreciation) will make exports more expensive and imports less costly (compared with local goods). However, this is not the case for Brazil. Brazil is a member of the MERCOSUR customs union, established in 1991 and comprised Argentina, Brazil, Paraguay, and Uruguay. Along with other MERCOSUR members, Brazil approved tariff increases in the CET for hundreds of products. Additionally, Brazil applies federal and state taxes and charges to imports which can effectively double the actual cost of imported products, increasing consumer prices in Brazil.

For Mexico, consumer prices are significantly and negatively associated with exchange rate changes over the short-run. In the long-run, consumer prices are negatively and significantly linked to local currency appreciation and insignificantly linked to local currency depreciation. For example, in the short-run, consumer prices decreased by 0.057% for a 1% change in the exchange rate, whereas a 1% appreciation of the Mexican peso induced a 0.25% decrease in consumer prices in the long-run. Furthermore, the evidence for incomplete exchange rate pass-through is observed in Mexico over the short-run and long-run.

Preceding results can be explained by the fact that, by the end of 1994, Mexico had to leave the exchange rate peg regime to introduce a new floating rate regime instead. Under this situation, Banco de Mexico was challenging to provide the economy with a nominal anchor to achieve financial and price stability (Ramos-Francia and Torres Garcia, 2005). Monetary authorities' efforts aimed at reducing inflation, and in 2001, Banco de Mexico announced a formal adoption of an inflation-targeting framework that has significantly contributed to anchoring inflation expectation (Capistrian and Ramos-Francia, 2010). Numerous empirical studies have presented evidence showing that, once inflation targeting was introduced in Mexico, the transmission mechanism of monetary policy changed in the sense that monetary policy instruments are more effective in reducing the impact of shocks (Gaytan and Gonzalez-Garcia, 2006; Sidaoui and Ramos-Francia, 2008; and Ramos Francia and Torres Garcia, 2008). In particular, Capistran et al. (2012) "find that the exchange rate pass-through seems to have decreased substantially from 2001 onwards, which coincides with the adoption of an inflation-targeting regime by Banco de Mexico" (Peon and Brindis, 2014).

In conclusion, regarding the Mexican economy, the Central Bank's credibility and commitment to keeping low and stable inflation have contributed to a reduction in the exchange rate pass-through. Mainly, through his actions, the central bank has achieved orderly adjustments of exchange rate fluctuations onto price primarily by containing contamination to other prices, which the exchange rate variations should not necessarily influence. A low inflation environment is often associated with firms' lower frequency of price adjustments. Furthermore, a negative shock to the Mexican peso exchange rate (an unexpected appreciation) is going to make exports more costly and imports cheaper. Consequently, the demand for foreign products is going to increase, decreasing domestic output and price (Kandil, 2000)

Conclusion

Using quarterly data from 1996 to 2018 for Brazil and from 1994 to 2018 for Mexico, the possibility of asymmetries in the reaction of consumer prices to changes in the exchange rate is investigated. This exercise employs Autoregressive Distributed Lag (ARDL) and Non-Linear Autoregressive Distributed Lag (NARDL) models.

The main findings can be outlined as follows. First, starting with Brazil, the evidence of asymmetric exchange rate pass-through to appreciation and depreciation in the short-run is provided, which means in the short-run, consumer prices respond differently depending on the direction of the exchange rate variation. However, in the long-run, the effects of currency appreciation and depreciation on consumer prices have the same magnitude.

Specifically, consumer prices are significantly and positively associated with local currency depreciation and appreciation in the short-run, although negatively liked to exchange rate over the long-run. Likewise, in the short-run, the exchange rate pass-through to consumer prices has been more robust during times of appreciation than during depreciation (in absolute values). And the proof for incomplete exchange rate pass-through is observed in Brazil over the short-run and long-run.

Second, the evidence of asymmetric exchange rate pass-through to appreciation and depreciation in the long-run is being provided for Mexico. That means in long-run, consumer prices react differently depending on which direction of exchange rate fluctuates. However, the impacts of currency appreciation and depreciation on consumer prices have the same magnitude in the short-run.

In particular, consumer prices are significantly and negatively associated with exchange rate changes in the short-run. Over the long-run, consumer prices are negatively and significantly linked to local currency appreciation and insignificantly related to currency depreciation.

Furthermore, the evidence for incomplete exchange rate pass-through has been observed in Mexico in the short-run and long-run.

Chapter 2 - Asymmetries in Exchange Rate Pass-Through to Trade Prices

Introduction

The research on exchange rates has expanded following the spreading of floating exchange rate regimes worldwide. Objectives of this research include figuring out how economic cycles, trade imbalances, and exchange rate changes influence domestic prices and monetary policy. Additionally, movements in the exchange rate affect imports and exports. Depreciations or appreciations of the nominal exchange rate induce changes in the real exchange rate, significantly influencing the trade balance. Theoretically, imports are expected to decrease, and exports increase when there is a real depreciation of domestic currency since imports become more expensive and exports become cheaper; thus, the trade balance is improved.

Conversely, a real domestic currency appreciation is expected to increase imports and decrease exports. Examining the exchange rate's influence on import prices can help reveal the adjustment of the exchange rate's expenditure-switching effect on the international balance of payments, which theoretically and practically applies to picking a suitable exchange rate system (Hong and Zhang, 2016). Hence, many researchers focus on the effect of price exchange rate pass-through (ERPTH).

Exchange rate pass-through (ERPTH) is a percentage change in prices attributed to a percentage change in the nominal exchange rate; in other words, it is the exchange rate elasticity of prices. Fluctuations in the exchange rate affect the domestic price level and depend on the degree of openness, the inflation environment, the credibility of the monetary policy, and exchange rate volatility, among others.

Various studies have analyzed the ERPTH to prices in developed countries, and this research suggests that ERPTH has declined since the 1990s. Taylor (2000) found that ERPTH dropped under a low inflationary environment in the U.S. during the 1990s, and this result has been verified by other studies in advanced nations, such as Campa and Goldberg (2002, 2005), Choudhri et al. (2005), and Takhtamanova (2010).

Second, it has been argued that the ERPTH is asymmetric. For instance, Ghosh and Rajan (2007) noted the existing literature suggests the response of exporters to exchange rate fluctuations is frequently asymmetric, depending on whether the exchange rate appreciates or depreciates. Additionally, Aron et al. (2014) pointed out that import prices might not fall as far with an appreciation but tend to rise as far as with depreciation.

For policy purposes, it’s essential to understand the factors determining trade prices for at least three reasons. First, changes in import prices are eventually passed through to domestic prices, and understanding the degree of exchange rate pass-through is crucial for central banks. Second, the elasticity of export prices to exchange rate changes is the main element for measuring price competitiveness, influencing net exports and real activity. Third, the reaction of trade prices to the exchange rate also defines the response of trade quantities to the exchange rate. Therefore, the price measure of pass-through to trade prices is essential in understanding global imbalances, mainly how the trade balance responds to a change in the exchange rate (Bussiere, 2007).

Many earlier studies in ERPTH focused only on developed countries, and researchers on ERPTH in Brazil and Mexico still need to be expanded. Hence, this study aims to investigate exchange rate pass-through (ERPTH), in a nonlinear fashion, for Brazil and Mexico by collecting quarterly data from 1996 to 2018 for Brazil and 1994 to 2018 for Mexico from various sources. The main question is whether trade prices are more sensitive to currency appreciation or depreciation (i.e., asymmetric ERPTH). In line with Bussiere (2013), any conclusion based on a linear model would only be accurate if nonlinearities were concentrated. The model used in the paper uses a linear autoregressive distributed lag (ARDL) model with an extension of the nonlinear autoregressive distributed lag (NARDL) framework proposed by Shin, Yu, and Greenwood-Nimmo (2009). The NARDL consists of a dynamic error correction representation associated with an asymmetric long-run cointegrating regression.

The main findings can be outlined as follows. Starting with export prices, the evidence of asymmetric exchange rate pass-through in appreciation and depreciation is provided in the long-run for Mexico. However, the effects of currency appreciation and deprecation on export prices have the same magnitude in the short-run and long-run for Brazil and the sort-run for Mexico. Concerning import prices, the evidence of asymmetric ERPTH to appreciation and depreciation is provided in the short-run for both countries. However, the effect of currency appreciation and depreciation on import prices has the same long-term impact on Brazil and Mexico.

Apart from this introduction, this paper discusses literature relating to ERPTH in Section 2. Section 3 describes the exchange rate concept. Section 4 is devoted to econometric methodology and data. Section 5 presents the results, and the last section draws some conclusions.

Literature Review

Most studies of the relationship between exchange rate fluctuations and local prices propose a symmetrical and declining exchange rate pass-through to the prices, particularly in developed countries (Taylor 2000; Olivei 2002; Campa and Goldberg 2005; among others). For instance, Otani et al. (2003) found a lower ERPTH to import prices for Japanese industries in the 1990s using monthly data from 1978 to 2002 on both overall and disaggregated import prices. Similarly, Takhtamanova (2010) validated Taylor's (2000) hypothesis of a declining ERPTH following a low inflationary regime in the 1990s in 14 developed nations. This hypothesis has been supported by many other studies (Choudhri et al. 2005; Frankel et al. 2011; Ozkan and Erden 2015). Numerous empirical studies concluded that the pass-through to prices has been incomplete and smaller in developed nations, located between 0 and 1, than in developing countries (Goldberg and Knetter 1997; Berner 2010; Bussière et al. 2014, among others). Berner (2010) studied the ERPTH to import prices in Germany using monthly data from 1988 to 2008. He found an incomplete and nonlinear ERPTH that had been higher in the depreciation period than in appreciation.

Furthermore, Bailliu and Fujii (2004) show evidence that exchange rate pass-through to domestic prices (import, producer, and consumer prices) has diminished over time. This decline was due to a shift towards a low-inflation environment caused by a change in monetary policy. Also, Gagnon and Ihrig (2004) also explored the connection between monetary policy and exchange rate pass-through. They develop a theoretical model relating the decline in the degree of pass-through to a greater emphasis on inflation stabilization by central banks, using quarterly data from 1971 to 2003. Results show that pass-through is higher during the high inflation period. Yong-Jae (2013) found incomplete ERPTH in Korean export prices (-0.25 to -0.49) across 30 manufacturing industries.

Additionally, Lee (2014) adopted the ARDL model to estimate Korea's ERPTH into export and import prices in Japan. The U.S. Study concluded incomplete ERPTH into trading prices to both trading partners. Bhundia (2002) analyzed the ERPTH to consumer prices in South Africa and found a lower pass-through using the vector autoregressive (VAR) framework on quarterly data from 1976Q2 to 2000Q3.

Investigating the relationship between exchange rates and prices has moved forward by allowing asymmetric and nonlinear ERPTH to price levels in developed and emerging countries

(Delatte and Lòpez-Villavicencio 2012; Yanamandra 2015; Brun-Aguerre et al. 2017; Kassi et al. 2019, among others). Brun-Aguerre et al. (2017) examined ERPTH to import prices for panel data of 14 emerging and 19 developed markets from 1980Q1 to 2010Q4. Most of these studies used the nonlinear autoregressive distributed lag (NARDL) framework of Shin et al. (2014). They revealed an asymmetrical ERPTH where exchange rate depreciations were passed through to prices stronger than appreciations in the long term. Utku Özmen and Akçelik (2017) applied microdata to examine the impact of oil prices and exchange rates on retail motor fuel prices in Turkey. They demonstrated an asymmetrical response to motor fuel prices. They showed that the pass-through magnitude was inversely related to the level of positive cost shock and concluded that the market structure was the main reason for this asymmetry. Kassi et al. (2019) also discovered an asymmetrical ERPTH in developing and emerging Asian countries using a NARDL framework on quarterly data from 1995Q1 to 2016Q4.

Moreover, Pollard and Coughlin (2003) analyze exchange rate pass-through to U.S. import prices for 30 industries and test whether the direction and the size of exchange rate fluctuations affect pass-through; they test effects using interactive dummy variables. Their findings show that more than half of the industries react asymmetrically to appreciations and depreciations, even though the direction of the asymmetry varies by industry. Also, they discover substantial nonlinearities, the magnitude of the import price response being positively associated with the size of the exchange rate shock. They also conclude that the size effect is more important than the direction effect. Swamy and Thurmann (1994) also test for asymmetries in the elasticity of U.S. import prices by using the so-called Swamy-Tinsley time-varying estimator from 1972: Q4 to 1988: Q2, concluding that depreciations are characterized by higher pass-through. Moving to Japan, Marston (1990) tests for asymmetries in the elasticity of Japanese export prices for 17 products, with a sample of monthly data between 1980 and 1987. He finds out that appreciations have a more significant effect on five sectors.

Additionally, Feinberg (1989) and Mann (1986) tried to find asymmetric ERPTH in the U.S. market. The later works by Bugamelli and Tedeschi (2008), Cheung and Sengupta (2013), Delatte and Lopez-Villavicencio (2012), Jammazi, Lahiani, and Nguyen (2014), and Karoro, Aziakpono, and Cattaneo (2009) have shown that there were asymmetric ERPTH effects on trading prices. Concerning Korea, Hye-Kyung (2016) and Ohn (2014) proved that ERPTHs in Korea's trading prices to the global market are asymmetric by using the Johansen test and Vector Error Correction Model (VECM) technique. El Bejaoui (2013) notes that an appreciation is more passed into export prices than import prices for major developed countries. Robitaille (2019) analyzed many developed and emerging countries and discovered that the ERPTH is higher for emerging countries when compared to developed countries. Also, McCarthy (2007) considers the case for developed countries and justifies that the ERPTH for those countries is lower due to a less volatile exchange rate and stability of gross domestic product (GDP) growth. Brun-Aguerre, Fuertes, and Greenwood-Nimmo (2017) show that long-run ERPTH estimates for depreciation have more significant coefficients than appreciations.

Exchange Rate Concept

Exchange rate pass-through is defined as a percentage change in domestic prices attributed to a percentage change in the nominal exchange rate; in other words, it is the exchange rate elasticity of prices. Fluctuations in the exchange rate affect the domestic price level and depend on the degree of openness, the inflation environment, the credibility of the monetary policy, and exchange rate volatility, among others.

When the exchange rate's appreciation (or depreciation) is fully transmitted into domestic prices, the ERPTH is said to be complete. In contrast, if the transmissions of exchange rate variations into domestic prices are less proportional, the ERPTH is partial.

Numerous empirical studies have discovered that ERPTH in many countries is partial. Indeed, the degree of ERPTH to prices varies from zero (no pass-through) to one (complete pass-through), in which the values in this interval are referred to as incomplete or partial ERPTH. Two possible reasons are at work: the behavior of exporting firms (exporters maintain their market share when there is an appreciation of the country's exporter currency) and nominal rigidities (price is unresponsive in the short-run) (Betts and Devereux, 2000; Monacelli, 2005; and Lopez-Villavicencio and Mignon, 2017).

Fluctuations in exchange rates can influence domestic prices directly or indirectly. It affects the costs of inputs used in domestic manufacturing and the prices of imported final goods. Hence, the magnitude of direct effects will depend on the share of imported goods on domestic consumption and production. Indirectly, fluctuations in the exchange rate influence the demand for domestic goods competing with imported commodities. Indirect influence depends on the elasticity of substitution between domestic and imported goods. Local currency depreciation, for instance, raises the internal demand for domestic goods vis-à-vis imported goods while boosting the competitiveness of local exports. At a particular supply level, a rise in exports may result in inflation pressure (on top of domestic inputs and wages). Moreover, administered (or government-controlled) prices formally or informally indexed to the exchange rate may influence domestic inflation.

Most empirical research evaluating the degree of ERPTH to inflation assumes a symmetric relationship between the price level and the exchange rate or that the local currency's impacts of appreciation and depreciation on prices have the same magnitude. Nevertheless, there are several reasons why the relationship may not be symmetrical, referred to as an asymmetric relationship, where the consequences of currency appreciations and depreciations on prices are not of the same magnitude. For example, an appreciation of the importer's currency could be less passed through to prices than a depreciation simply because producers are more willing to increase their markup than reduce it. Indeed, if downward rigidities exist, the pass-through determined after an appreciation might be lower than after a devaluation (Bussiere, 2007). However, if the depreciation occurs during a recession, prices might increase less than they decrease after an appreciation. This is because the devaluation frequently results from a downward adjustment of domestic aggregate demand. Consequentially, recessions could depress domestic prices, thus implying that domestic prices do not react much to exchange rate depreciation (Carranza and Gomez-Bicarri, 2009).

Empirical Model and Methodology

1. Data

This chapter investigates the exchange rate pass-through (ERPTH) to the trade prices, export prices (EXP), and import prices (IMP). Where export and import prices are based on the following price models:

EXP = f (ER, PPI, GDP, OIL) and IMP = f (ER, CPI, OIL, TPI, GDP),

where EXP and IMP are denoted as the export and import prices indexes denominated in the export's currency, respectively, as the dependents variables. The explanatory variables are ER, the nominal effective exchange rate, an adjustment-weighted average rate that a country's currency exchanges for a basket of multiple foreign currencies. PPI, the producer price index of the exporting country, which serves as a proxy for the marginal costs borne by exporting firms, GDP, which is the real gross domestic product of the home country, OIL, is the price of crude oil, CPI, which is the consumer price index of the importing country. TPI is the total production index and the last explanatory variable. All variables are expressed in logarithms.

Quarterly data from 1996Q1 to 2018Q4 for Brazil and from 1994Q2 to 2018Q4 for Mexico is used. The Bank of International Settlement (BIS) provides nominal effective exchange rates, and International Monetary Fund (IMF) provides the producer price index data set. The remaining variables are obtained from the Federal Reserve Bank of St. Louis (FRED).

2. Methodology

2.1. Linear Autoregressive Distributed Lag (ARDL) Cointegration Model

In this section, a symmetric cointegration distributed lag (ARDL) model is implemented to examine the responsiveness of trade prices, export and import prices, to fluctuations in the exchange rate. This methodology was developed by Pesaran, Shin, and Smith (2001) in its symmetric form and extended by Shin, Yu, and Greenwood-Nimmo (2009) for the asymmetric case, enabling us to test the existence of a short-term and long-term relationships.

The ARDL model and the "bounds test" for the long-run relationship have two critical advantages over Johansen and Juselius's (1990) approach. The first advantage is that this approach is applicable even when the variables are stationary, integrated, or mutually cointegrated. It does not require the series to be integrated of the same order to find a possible cointegrating connection between these variables. The second advantage is that the methodology has better statistical properties for small samples. The cointegration test obtained from Johansen and Juselius's approach is not robust in small samples (Bejaoui, 2013).

The selection of the dependent and independent variables is explained by their association with exports and import prices. In literature, exchange rate pass-through is captured through the following symmetric relationships:

For export prices:

$$EXP_t = \alpha_0 + \alpha_1 ER_t + \alpha_2 PPI_t + \alpha_3 GDP_t + \alpha_4 OIL_t + \varepsilon_t \quad (1a)$$

All variables are expressed in logarithms, and ε_t is an iid process. In equation (1a), α_1 represents the elasticity of the exchange rate pass-through to export prices (i.e., the pass-through), α_2 is the elasticity of the producer price index variable (PPI), α_3 refers to the elasticity of gross domestic product (GDP) on the export prices, and α_4 is the elasticity of oil price variable (OIL).

And, for import prices:

$$IMP_t = \delta_0 + \delta_1 ER_t + \delta_2 CPI_t + \delta_3 Oil_t + \delta_4 TPI_t + \delta_5 GDP_t + \varepsilon_t \quad (1b)$$

All variables are expressed in logarithms, and ε_t is an iid process. In equation (1b), δ_1 represents the elasticity of the exchange rate pass-through to import prices (i.e., the pass-through), δ_2 is the elasticity of the consumer price index variable (CPI), δ_3 refers to the elasticity of oil prices (OIL) on the import prices, δ_4 is the elasticity of total production index variable (TPI), and finally, δ_5 refers to the elasticity of gross domestic product (GDP) on the import prices.

To test for a linear long-run relationship, an ARDL model is being used. A different one from the previously listed advantages, an interesting feature of the ARDL is that it considers the error correction term. Consequently, the following linear error correction models are considered:

For export prices:

$$\Delta EXP_t = \beta_0 + \beta_1 EXP_{t-1} + \beta_2 ER_{t-1} + \beta_3 PPI_{t-1} + \beta_4 GDP_{t-1} + \beta_5 OIL_{t-1} + \sum^{p}_{i=1} \rho_{0,i} \Delta EXP_{t-i} +$$

$$\sum^{q}_{i=0} \rho_{1,i} \Delta ER_{t-i} + \sum^{q}_{i=0} \rho_{2,i} \Delta PPI_{t-i} + \sum^{q}_{i=0} \rho_{3,i} \Delta GDP_{t-i} + \sum^{q}_{i=0} \rho_{4,i} \Delta OIL_{t-i} + \varepsilon_t \quad (2a)$$

And, for import prices:

$$\Delta IMP_t = \psi_0 + \psi_1 IMP_{t-1} + \psi_2 ER_{t-1} + \psi_3 CPI_{t-1} + \psi_4 OIL_{t-1} + \psi_5 TPI_{t-1} + \psi_6 GDP_{t-1} +$$

$$\sum^{p}_{i=1} \Upsilon_{0,i} \Delta IMP_{t-i} + \sum^{q}_{i=0} \Upsilon_{1,i} \Delta ER_{t-i} + \sum^{q}_{i=0} \Upsilon_{2,i} \Delta CPI_{t-i} + \sum^{q}_{i=0} \Upsilon_{3,i} \Delta OIL_{t-i} + \sum^{q}_{i=0} \Upsilon_{4,i} \Delta TPI_{t-i} +$$

$$\sum^{q}_{i=0} \Upsilon_{5,i} \Delta GDP_{t-I} + \varepsilon_t \quad (2b)$$

Where Δ is a difference operator, and p and q are the number of lags for the dependent variable and regressors, respectively. $\rho_{0,i}$, $\rho_{1,i}$, $\rho_{2,i}$, $\rho_{3,i}$, and $\rho_{4,i}$ in equation (2a) and $\Upsilon_{0,i}$, $\Upsilon_{1,i}$, $\Upsilon_{2,i}$, $\Upsilon_{3,i}$, $\Upsilon_{4,i}$, and $\Upsilon_{5,i}$ in equation (2b) are the short-run adjustment terms. β_2, β_3, β_4, and β_5 in equation (2a) and ψ_2, ψ_3, ψ_4, ψ_5, and ψ_6 in equation (2b) are the long-run adjustment terms. $\sum^{q}_{i=0} \rho_{1,i}$ in equation (2a) and $\sum^{p}_{i=1} \Upsilon_{1,i}$ in equation (2b), show the short-term effects of variations of the local currency on export and import prices, respectively. $(-\beta_2/\beta_1)$ in equation (2a) and $(-\psi_2/\psi_1)$ in equation (2b) shows the long-term effects of variations of the local currency on export and import prices, respectively.

Also, equations (2a and 2b) exhibit long-run and short-run symmetric pass-throughs. The first part corresponds to the short-run relationship:

For export prices:

$$\sum^{p}_{i=1} \rho_{0,i}\, \Delta EXP_{t-i} + \sum^{q}_{i=0} \rho_{1,i}\, \Delta ER_{t-i} + \sum^{q}_{i=0} \rho_{2,i}\, \Delta PPI_{t-i} + \sum^{q}_{i=0} \rho_{3,i}\, \Delta GDP_{t-i} + \sum^{q}_{i=0} \rho_{4,i}\, \Delta OIL_{t-i} \qquad (3a)$$

For import prices:

$$\sum^{p}_{i=1} \Upsilon_{0,i}\, \Delta IMP_{t-i} + \sum^{q}_{i=0} \Upsilon_{1,i}\, \Delta ER_{t-i} + \sum^{q}_{i=0} \Upsilon_{2,i}\, \Delta CPI_{t-i} + \sum^{q}_{i=0} \Upsilon_{3,i}\, \Delta OIL_{t-i} + \sum^{q}_{i=0} \Upsilon_{4,i}\, \Delta TPI_{t-i} + \sum^{q}_{i=0} \Upsilon_{5,i}\, \Delta GDP_{t-i} \qquad (3b)$$

Where:

$\rho_{0,i}$, $\rho_{1,i}$, $\rho_{2,i}$, $\rho_{3,i}$, and $\rho_{4,i}$ in equation (3a), and $\Upsilon_{0,i}$, $\Upsilon_{1,i}$, $\Upsilon_{2,i}$, $\Upsilon_{3,i}$, $\Upsilon_{4,i}$, and $\Upsilon_{5,i}$ in equation (3b) are the parameters estimated to represent the error correction dynamics.

The second part corresponds to the long-run relationship:

For export prices:

$$\beta_1\, EXP_{t-1} + \beta_2\, ER_{t-1} + \beta_3\, PPI_{t-1} + \beta_4\, GDP_{t-1} + \beta_5\, OIL_{t-1} \qquad (4a)$$

For import prices:

$$\psi_1\, IMP_{t-1} + \psi_2\, ER_{t-1} + \psi_3\, CPI_{t-1} + \psi_4\, OIL_{t-1} + \psi_5\, TPI_{t-1} + \psi_6\, GDP_{t-1} \qquad (4b)$$

where:

β_1 and ψ_1 are the coefficients of error correction.

β_2, β_3, β_4, and β_5 in equation (4a), and ψ_2, ψ_3, ψ_4, ψ_5, and ψ_6 in equation (4b) are estimators of independent variables in the cointegration model denoting the long-run relationship.

Two statistics are proposed to test the null hypothesis of no long-run relationship. The first one is named the tBDM, test for the null of no significance of the error correction term. The second one, the F-test, is formulated as follows:

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$ (for export prices)

H_0: $\psi_1 = \psi_2 = \psi_3 = \psi_4 = \psi_5 = \psi_6 = 0$ (for import prices)

Versus the

H_A: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$ (for export prices)

H_A: $= \psi_1 \neq \psi_2 \neq \psi_3 \neq \psi_4 \neq \psi_5 \neq \psi_6 \neq 0$ (for import prices)

Pesaran, Shin, and Smith (2001) have drawn up two critical thresholds to interpret test results. It is impossible to reject the null hypothesis of no long-run relationship when the calculated statistic is situated below its lower critical values. Vice versa, if the computed statistic is greater than the upper critical value, there is proof of a long-run relationship. However, no conclusion can be drawn when the statistic is between the two critical values.

Under the ARDL method, a single long-run relationship exists between independent and dependent variables in every single equation. After obtaining the long-run relationship (the cointegration model), the error correction model (ECM) is estimated to capture short-run dynamics (Foudeh, 2017). Hence, the error correction models for cointegrated variables can be presented as follows:

For export prices:

$$\Delta\ EXP_t = \beta_0 + \sum^{p}_{i=1} \rho_{0,i}\ \Delta EXP_{t-i} + \sum^{q}_{i=0}\ \rho_{1,i}\ \Delta ER_{t-i} + \sum^{q}_{i=0} \rho_{2,i}\ \Delta PPI_{t-i} + \sum^{q}_{i=0} \rho_{3,i}\ \Delta GDP_{t-i} + \sum^{q}_{i=0} \rho_{4,i}\ \Delta OIL_{t-i} + \beta_1\ ECT_{t-1} + \varepsilon_t \quad (5a)$$

And, for import prices:

$$\Delta\ IMP_t = \psi_0 + \sum^{p}_{i=1} \Upsilon_{0,i}\ \Delta IMP_{t-i} + \sum^{q}_{i=0}\ \Upsilon_{1,i}\ \Delta ER_{t-i} + \sum^{q}_{i=0}\ \Upsilon_{2,i}\ \Delta CPI_{t-i} + \sum^{q}_{i=0}\ \Upsilon_{3,i}\ \Delta OIL_{t-i} + \sum^{q}_{i=0}\ \Upsilon_{4,i}\ \Delta TPI_{t-i} + \sum^{q}_{i=0}\ \Upsilon_{5,i}\ \Delta GDP_{t-i} + \psi_1\ ECT_{t-1} + \varepsilon_t \quad (5b)$$

Where:

ECT is the error correction term. It is OLS residuals obtained from the long-run estimated cointegration model.

B_1 and ψ_1 are the speed of adjustment that shows how quickly variables parameters return to equilibrium in the long-term. β_1 and ψ_1 are anticipated to be negative and significant. It is ideal if it lies between 0 and -1. The more it is near -1, the stronger the equilibrium is, but it is a significant is must (Foudeh, 2017).

The error correction term (ECT_{t-1}) is the most critical component in the error correction model for cointegrated variables. For this reason, Tables 2.9.a. and 2.9.b. report the coefficients associated with ECT_{t-1} for both countries.

2.2. Non-Linear Autoregressive Distributed Lag (NARDL) Cointegration Model

The prior model (ARDL) does not consider the direction of exchange rate fluctuations in evaluating pass-through. In other words, the short-run or long-run pass-through is assumed to be of the same magnitude independently if the exchange rate appreciates or depreciates.

To allow for asymmetric exchange rate pass-through, the approach used in Schorderet (2004) and Shin, Yu, and Greenwood-Nimmo (2009) is followed. This procedure requires constructing new variables, which capture episodes of appreciation and depreciation. The point is to decompose a time series into two series, ER_t^+ and ER_t^- such as the following:

$ER_t^+ = \sum_{j=1}^{t} \Delta ER_t^+ = \sum_{j=1}^{t} \max(\Delta ER_t^+, 0)$

$ER_t^- = \sum_{j=1}^{t} \Delta ER_t^- = \sum_{j=1}^{t} \min(\Delta ER_t^-, 0)$,

where ΔER_t^+ and ΔER_t^- are the partial sum processes of depreciation and appreciations, respectively. Following Shin et al. (2009), equations (2a and 2b) can be expressed to enable an asymmetric relationship. The following asymmetric ARDL models are assumed to be:

For export prices:

$$\Delta EXP_t = \beta_0 + \beta_1 EXP_{t-1} + \beta^+_2 ER^+_{t-1} + \beta^-_2 ER^-_{t-1} + \beta_3 PPI_{t-1} + \beta_4 GDP_{t-1} + \beta_5 OIL_{t-1} + \sum^p_{i=1} \rho_{0,i} \Delta EXP_{t-i} + \sum^q_{i=0} \rho_{1,i}^+ \Delta ER_{t-i}^+ + \sum^q_{i=0} \rho_{1,i}^- \Delta ER_{t-i}^- + \sum^q_{i=0} \rho_{2,i} \Delta PPI_{t-i} + \sum^q_{i=0} \rho_{3,i} \Delta GDP_{t-i} + \sum^q_{i=0} \rho_{4,i} \Delta OIL_{t-i} + \varepsilon_t \quad (6a)$$

And, for import prices:

$$\Delta IMP_t = \psi_0 + \psi_1 IMP_{t-1} + \psi^+_2 ER^+_{t-1} + \psi^-_2 ER^-_{t-1} + \psi_3 CPI_{t-1} + \psi_4 OIL_{t-1} + \psi_5 TPI_{t-1} + \psi_6 GDP_{t-1} + \sum^p_{i=1} \Upsilon_{0,i} \Delta IMP_{t-i} + \sum^q_{i=0} \Upsilon_{1,i}^+ \Delta ER_{t-i}^+ + \sum^q_{i=0} \Upsilon_{1,i}^- \Delta ER_{t-i}^- + \sum^q_{i=0} \Upsilon_{2,i} \Delta CPI_{t-i} + \sum^q_{i=0} \Upsilon_{3,i} \Delta OIL_{t-i} + \sum^q_{i=0} \Upsilon_{4,i} \Delta TPI_{t-i} + \sum^q_{i=0} \Upsilon_{5,i} \Delta GDP_{t-i} + \varepsilon_t \quad (6b)$$

where, Δ is a difference operator, p and q are the numbers of lags for dependent variables and regressors, respectively. $\rho_{0,i}$, $\rho_{1,i}^+$, $\rho_{1,i}^-$, $\rho_{2,i}$, $\rho_{3,i}$, and $\rho_{4,i}$ in equation (6a) and $\Upsilon_{0,i}$, $\Upsilon_{1,i}^+$, $\Upsilon_{1,i}^-$, $\Upsilon_{2,i}$, $\Upsilon_{3,i}$, $\Upsilon_{4,i}$, and $\Upsilon_{5,i}$ in equation (6b) are the short-run adjustment terms. β_2^+, β_2^-, β_3, β_4, and β_5 in equation (6a) and ψ_2^+, ψ_2^-, ψ_3, ψ_4, ψ_5, and ψ_6 in equation (6b) are the long-run adjustment terms. ER^+ represents the positive partial sums of the exchange rate, denoting local currency depreciation (positive exchange rate changes), and ER^- represents the negative partial sums of the exchange rate, indicating local currency appreciation (negative exchange rate changes). $\sum^q_{i=0} \rho_{1,i}^+$ in equation (6a) and $\sum^q_{i=0} \Upsilon_{1,i}^+$ in equation (6b), respectively, show the short-term effects of the local currency depreciation on export and import prices. $\sum^q_{i=0} \rho_{1,i}^-$ in equation (6a) and $\sum^q_{i=0} \Upsilon_{1,i}^-$ in equation (6b), showing the short-term impacts of local currency appreciation on export and import prices, respectively. ($-\beta_2^+/\beta_1$) in equation (6a) and ($-\psi_2^+/\psi_1$) in equation (6b), respectively, show the long-term effects of the devaluation of the local currency on export and import prices. ($-\beta_2^-/\beta_1$) in equation (6a) and ($-\psi_2^-/\psi_1$) in equation (6b) shows the long-term effects of the local currency's appreciation on export and import prices, respectively.

There are two parts on the right-hand side of the equations (6a and 6b). The first part corresponds to the short-run relationship.

For export prices:

$$\sum_{i=1}^{p} \rho_{0,i}\, \Delta EXP_{t-i} + \sum_{i=0}^{q} \rho_{1,i}^{+}\, \Delta ER_{t-i}^{+} + \sum_{i=0}^{q} \rho_{1,i}^{-}\, \Delta ER_{t-i}^{-} + \sum_{i=0}^{q} \rho_{2,i}\, \Delta PPI_{t-i} + \sum_{i=0}^{q} \rho_{3,i}\, \Delta GDP_{t-i} + \sum_{i=0}^{q} \rho_{4,i}\, \Delta OIL_{t-I} \quad (7a)$$

And, for import prices:

$$\sum_{i=1}^{p} \Upsilon_{0,i}\, \Delta IMP_{t-i} + \sum_{i=0}^{q} \Upsilon_{1,i}^{+}\, \Delta ER_{t-i}^{+} + \sum_{i=0}^{q} \Upsilon_{1,i}^{-}\, \Delta ER_{t-i}^{-} + \sum_{i=0}^{q} \Upsilon_{2,i}\, \Delta CPI_{t-i} + \sum_{i=0}^{q} \Upsilon_{3,i}\, \Delta OIL_{t-i} + \sum_{i=0}^{q} \Upsilon_{4,i}\, \Delta TPI_{t-i} + \sum_{i=0}^{q} \Upsilon_{5,i}\, \Delta GDP_{t-i} \quad (7b)$$

Where:

$\rho_{0,i}$, $\rho_{1,i}^{+}$, $\rho_{1,i}^{-}$, $\rho_{2,i}$, $\rho_{3,i}$, and $\rho_{4,i}$ in equation (7a), and $\Upsilon_{0,i}$, $\Upsilon_{1,i}^{+}$, $\Upsilon_{1,i}^{-}$, $\Upsilon_{2,i}$, $\Upsilon_{3,i}$, $\Upsilon_{4,i}$, and $\Upsilon_{5,i}$ in equation (7b) are the parameters estimated responding the error correction dynamics.

The second part in equations (6a and 6b) corresponds to the long-run relationship:

For export prices:

$$\beta_1 EXP_{t-1} + \beta^{+}_2 ER^{+}_{t-1} + \beta^{-}_2 ER^{-}_{t-1} + \beta_3 PPI_{t-1} + \beta_4 GDP_{t-1} + \beta_5 OIL_{t-1} \quad (8a)$$

And, for import prices:

$$\psi_1\, IMP_{t-1} + \psi^{+}_2 ER^{+}_{t-1} + \psi^{-}_2 ER^{-}_{t-1} + \psi_3\, CPI_{t-1} + \psi_4\, OIL_{t-1} + \psi_5\, TPI_{t-1} + \psi_6\, GDP_{t-1} \quad (8b)$$

where:

β_1 and ψ_1 are the coefficients of error correction.

β^{+}_{2}, β^{-}_{2}, β_3, β_4, and β_5 in equation (8a) and ψ^{+}_{2}, ψ^{-}_{2}, ψ_3, ψ_4, ψ_5, and ψ_6 in equation (8b) are estimators of independent variables in the cointegration model, denoting the long-run relationship.

Two statistics are proposed to test the null hypothesis of no long-run relationship. The first one is named the tBDM test for the null of no significance of the error correction term.

The second one, the F-test, is formulated as follows:

H_0: $\beta_1 = \beta^{+}_{2} = \beta^{-}_{2} = \beta_3 = \beta_4 = \beta_5 = 0$ (for export prices)

H_0: $\psi_1 = \psi^{+}_{2} = \psi^{-}_{2} = \psi_3 = \psi_4 = \psi_5 = \psi_6 = 0$ (for import prices)

Versus the

H_A: $\beta_1 \neq \beta^{+}_{2} \neq \beta^{-}_{2} \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$ (for export prices)

H_A: $\psi_1 \neq \psi^{+}_{2} \neq \psi^{-}_{2} \neq \psi_3 \neq \psi_4 \neq \psi_5 \neq \psi_6 \neq 0$ (for import prices)

Pesaran, Shin, and Smith (2001) have set up two critical thresholds to interpret the test results. It is impossible to reject the null hypothesis of no long-run relationship when the computed statistic is below its respective lower critical values. On the contrary, if the computed statistic is higher than the upper critical value, there is evidence of a long-run relationship. However, no conclusion can be drawn when the statistic is between the two critical values.

Tests and Results

1. Unit Root Tests

In a recent study by Nkoro and Uko (2016) in the Journal of Statistical and Econometric Methods, the ARDL cointegration technique is adopted irrespective of whether the underlying variables are I(0), I(1), or a combination of both, and cannot be applied when the underlying variables are integrated of order I(2). Because of this, it is advisable to test for unit roots since variables that are the integration of order I(2) lead to the crashing of the technique.

The first step in this process is to verify if the variables are stationary in the first difference I(1). Therefore, the Augmented Dicky Fuller (ADF) test is used. The outcomes of the ADF test

(Table 2.1.) demonstrate the absence of I(2) for all variables. This means we are able to continue testing for cointegration within the ARDL framework. ARDL models allows for using non-stationary and stationary series simultaneously to estimate the parameters of models that include lags of dependent variables and lags of independent variables.

ARDL does not require the series to be integrated in the same order to find a potential cointegrating relation between the variables. The ARDL method does not strictly require the classification of I(0) or I(1) (Pesaran et al., 2001). Furthermore, an exciting feature of the ARDL is that it considers the error correction term, and ARDL directly estimates the error term (cointegrating coefficient) in the short-run and long-run terms.

Table 2.1. *Augmented Dickey Fuller Test-Trade Prices*

		Brazil		**Mexico**	
Variables		**I(0)**	**I(1)**	**I(0)**	**I(1)**
Exp	t-Stat.	-1.445289	-9.382746	-3.530914	
	Prob.	0.5567	0.0000	0.0091	
ER	t-Stat.	-2.071135	-7.359625	-3.625892	
	Prob.	0.2568	0.0000	0.0069	
PPI	t-Stat.	-2.026229	-6.162066	-5.003686	
	Prob.	0.2753	0.0000	0.0001	
GDP	t-Stat.	-1.503720	-7.230134	-0.659083	-7.035379
	Prob.	0.5273	0.0000	0.8511	0.0000
Oil	t-Stat.	-1.687378	-7.291437	-1.655888	-7.628043
	Prob.	0.4342	0.0000	0.4503	0.0000
IMP	t-Stat.	-1.876371	-10.11411	-3.214437	
	Prob.	0.3419	0.0000	0.0221	
CPI	t-Stat.	-0.776579	-3.616270	-1.628679	-3.419235
	Prob.	0.8205	0.0073	0.4640	0.0128
TPI	t-Stat.	-1.328451	-4.855269	-1.556626	-9.748210
	Prob.	0.6132	0.0001	0.5008	0.0000

Findings and the conclusion of the unit root test (Table 2.1.) reveal that the majority of the variables are either I(0) or I(1), as well as none of them are found to be integrated of order two, i.e., I(2).

2. Models' Lags and their Primarily Statistical Results

With respect to the lag order selection criteria and depending on AIC, with respect to the export price model, the number of lags for dependent variables and regressors is fixed to 2 lags for Brazil and Mexico. And, with respect to the import price model, the number of lags is fixed to 8 lags for Brazil and 4 lags for Mexico. Tables 2.2.a. and 2.3.a. give the primary statistical results for both models (ARDL and NARDL) for export prices, and Tables 2.2.b. and 2.3.b. give the primary statistical results for both models (ARDL and NARDL) for import prices. In general, their R^2 and Adjusted R^2 are relatively high, with significant F-statistics at the 1% level.

Table 2.2.a. *Optimal Model Lags for ARDL (p,q) Models- Export Prices*

Selected Model	AIC	R^2	Adjust R^2	Sum Squared Residual	Mean Dependent Variable	F-statistic	Durbin-Watson Stat
ARDL for Brazil (2, 2, 2, 2, 2)	-4.030628	0.993957	0.992829	0.067069	2.763530	881.2098	2.033585
ARDL for Mexico (2, 2, 2, 2, 2)	-6.336232	0.999382	0.999276	0.007382	3.161947	9466.573	1.931908

Note: the results be presented using fix number of lags to 2 for Brazil and Mexico.

Table 2.3.a. *Optimal Model Lags for NARDL (p,q) Models- Export Prices*

Selected Model	AIC	R^2	Adjust R^2	Sum Squared Residual	Mean Dependent Variable	F-statistic	Durbin-Watson Stat
NARDL for Brazil (2, 2, 2, 2, 2, 2)	-4.019113	0.994078	0.992661	0.062484	2.771798	701.1241	2.088474
NARDL for Mexico (2, 2, 2, 2, 2, 2)	-6.493345	0.999463	0.999346	0.005847	3.172603	8534.634	2.268476

Note: the results be presented using fix number of lags to 2 for Brazil and Mexico.

Table 2.2. b. *Optimal Model Lags for ARDL (p,q) Models-Import Prices*

Selected Model	AIC	R^2	Adjust R^2	Sum Squared Residual	Mean Dependent Variable	F-statistic	Durbin-Watson Stat
ARDL for Brazil (8, 8, 8, 8, 8, 8)	-4.305116	0.997464	0.993211	0.018797	2.789823	444.7776	2.108679
ARDL for Mexico (4, 4, 4, 4, 4, 4)	-5.840600	0.999142	0.998759	0.008598	3.116092	2609.535	1.983087

Note: the results be presented using fix number of lags to 8 for Brazil and to 4 for Mexico.

Table 2.3.b. *Optimal Model Lags for NARDL (p,q) Models-Import Prices*

Selected Model	AIC	R^2	Adjust R^2	Sum Squared Residual	Mean Dependent Variable	F-statistic	Durbin-Watson Stat
NARDL for Brazil (8, 8, 8, 8, 8, 8, 8)	-5.386836	0.999322	0.997076	0.004757	2.797323	444.7776	2.156591
NARDL for Mexico (4, 4, 4, 4, 4, 4, 4)	-5.881445	0.999223	0.998776	0.007294	3.124477	2232.568	1.959859

Note: the results be presented using fix number of lags to 8 for Brazil and to 4 for Mexico.

3. Diagnostic Tests (Foudeh, 2017)

3.1. Normality Test of Residuals

A normality test is essential since rejecting the null hypothesis invalidates the test statistics (H_0: normal distribution of residuals). The Jarque-Bera statistics show the normality of residuals for both countries, i.e., Brazil and Mexico (Tables 2.4.a. and 2.4.b.).

3.2. Autocorrelation Test

The Breusch-Godfrey Lagrange Multiplier test is used to investigate the presence of autocorrelation in the residuals. The Breusch-Godfrey Lagrange Multiplier test in Tables 2.4.a. and 2.4.b. indicates that the null hypothesis cannot be rejected for both countries, suggesting that the residuals are not correlated.

Table 2.4.a. *Diagnostic Test- Export Prices*

Country	Jarque-Bera			Autocorrelation Test		
	Value	Probability	Result	F-statistic	Probability	Result
Brazil	2.370722	0.304111	Fail to Reject H_0	2.269944	0.4400	Fail to Reject H_0
Mexico	1.171376	0.556723	Fail to Reject H_0	2.060360	0.1345	Fail to Reject H_0

Table 2.4.b. *Diagnostic Test- Import Prices*

Country	Jarque-Bera			Autocorrelation Test		
	Value	Probability	Result	F-statistic	Probability	Result
Brazil	1.079953	0.582762	Fail to Reject H_0	0.269592	0.7669	Fail to Reject H_0

3.3. Test of Heteroscedasticity

Breusch-Pagan-Godfrey test results in Tables 2.5.a. and 2.5.b. indicate that the null hypothesis of homoscedasticity cannot be rejected for all lagged models. The diagnostic test results in Tables 2.5.a. and 2.5.b. show the absence of a heteroscedasticity problem, which means that the standard errors can be trusted, and T-statistics are asymptotically standard normal distributed and, therefore, the P-values.

3.4. Ramsey Reset Test

This test explores the null hypothesis of no problem of function misspecification. If the null hypothesis is rejected, some issues with the original model can be caused by autocorrelation, heteroscedasticity, or functional form misspecification. Testing results (Tables 2.5.a. and 2.5.b.) show both countries' acceptance of the null hypothesis.

Table 2.5.a. *Diagnostic Test- Export Prices*

Country	Test of Heteroskedasticity			Ramsey Reset Test		
	F-statistic	Probability	Result	F-statistic	Probability	Result
Brazil	1.435967	0.1461	Fail to Reject H_0	0.180721	0.6721	Fail to Reject H_0
Mexico	1.438869	0.1417	Fail to Reject H_0	1.712401	0.1654	Fail to Reject H_0

Table 2.5.b. *Diagnostic Test- Import Prices*

Country	Test of Heteroskedasticity			Ramsey Reset Test		
	F-statistic	**Probability**	**Result**	**F-statistic**	**Probability**	**Result**
Brazil	1.147344	0.3830	Fail to Reject H_0	0.014441	0.9057	Fail to Reject H_0
Mexico	0.815894	0.7359	Fail to Reject H_0	0.264845	0.6088	Fail to Reject H_0

4. Parameters Stability Tests

The Stability test using the cumulative sum (CUSUM) of recursive residuals helps show whether coefficients are systematically changing. By contrast, the CUSUM of squared residuals helps to show if coefficients are changing suddenly (Bhatti et al., 2006).

4.1. Cumulative sum (CUSUM) of recursive residuals

The attending test demonstrates the stability of the model. The model coefficients are not switching systematically because the plot of CUSUM of recursive residuals for Brazil and Mexico, represented by solid lines (blue lines), is within the 5% significance interval (back to Figures 2.1.a. and 2.1.b.).

Figure 2.1.a. *Cumulative Sum of Recursive Residuals - Export Prices*

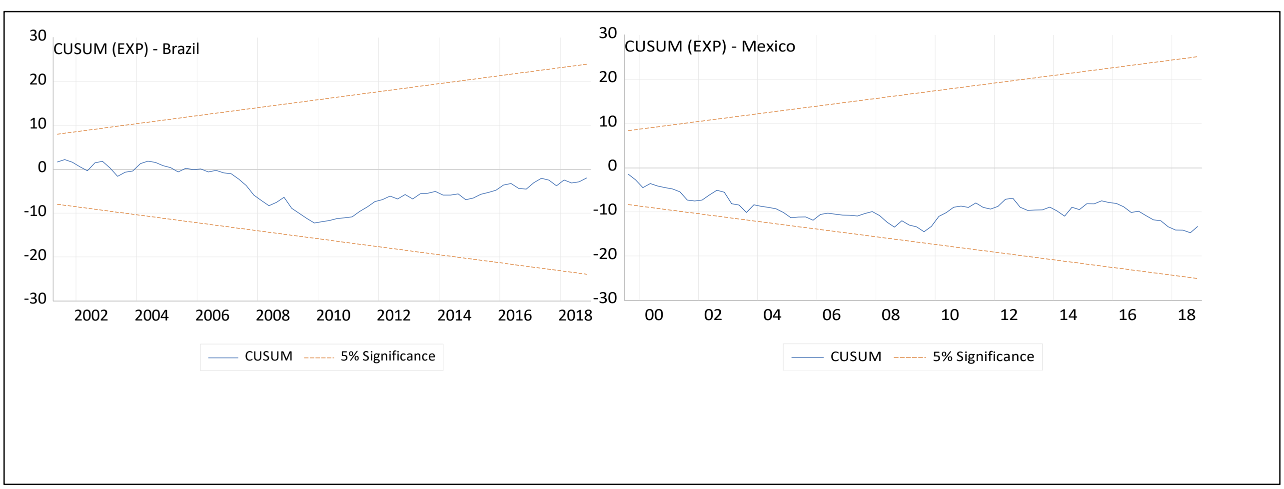
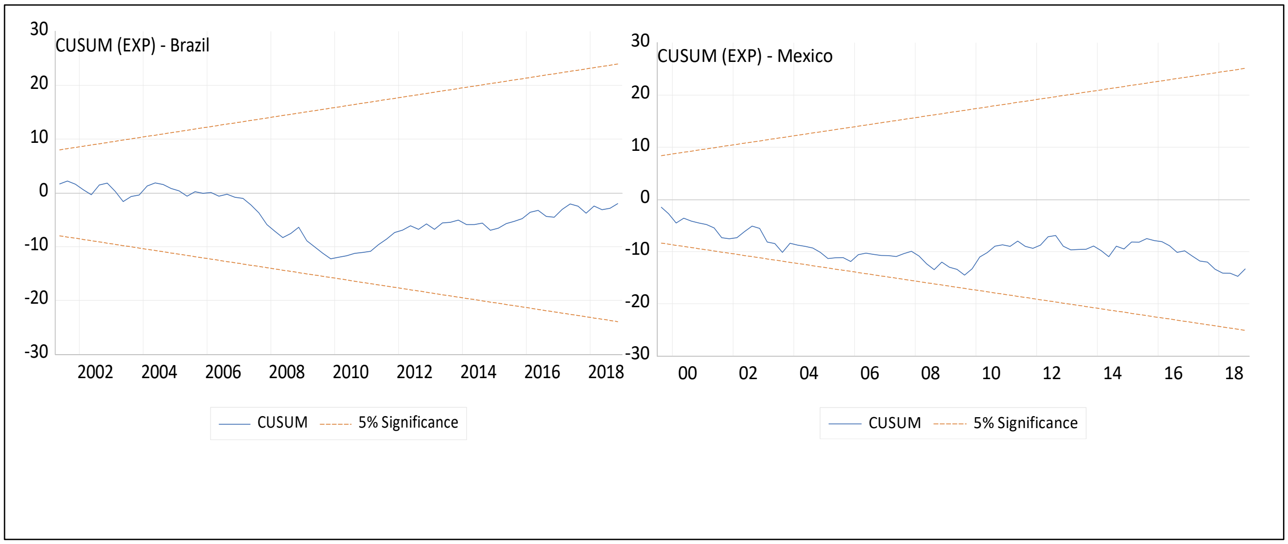


Figure 2.1.b. *Cumulative Sum of Recursive Residuals-Import Prices*



4.2. Cumulative sum (CUSUM) of squared residuals

From Figures 2.2.a. and 2.2.b., the plots of CUSUM of squares residuals for both countries (Brazil and Mexico) represented by the solid lines (blue lines) are within the 5% critical bounds of parameter stability, which means estimated coefficients are stable, indicating that coefficients are not changing suddenly, and the estimated coefficients are stable.

Figure 2.2..a. *Cumulative Sum of Squared Residuals - Export Prices*

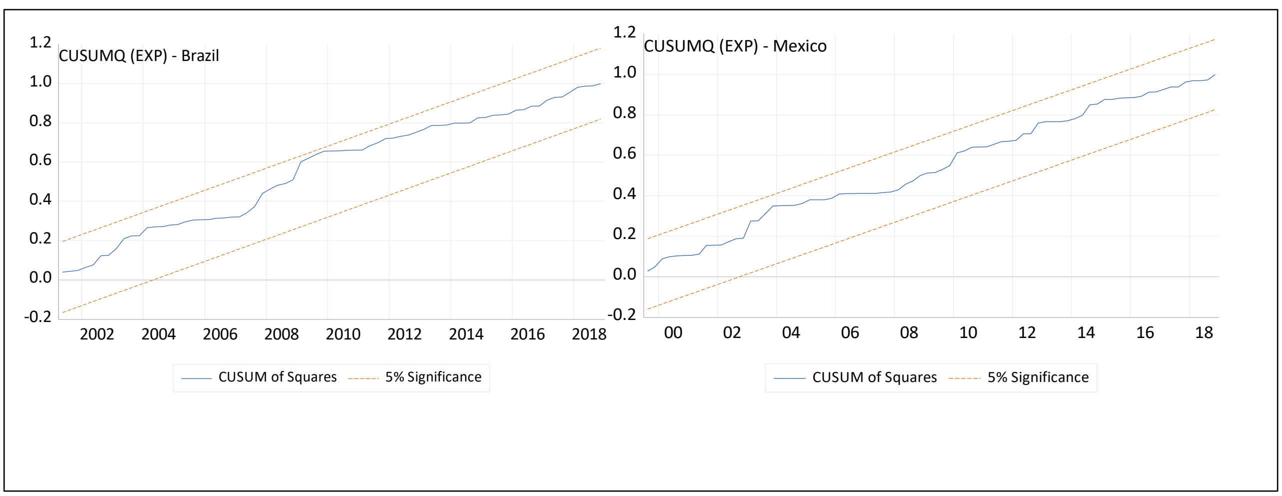
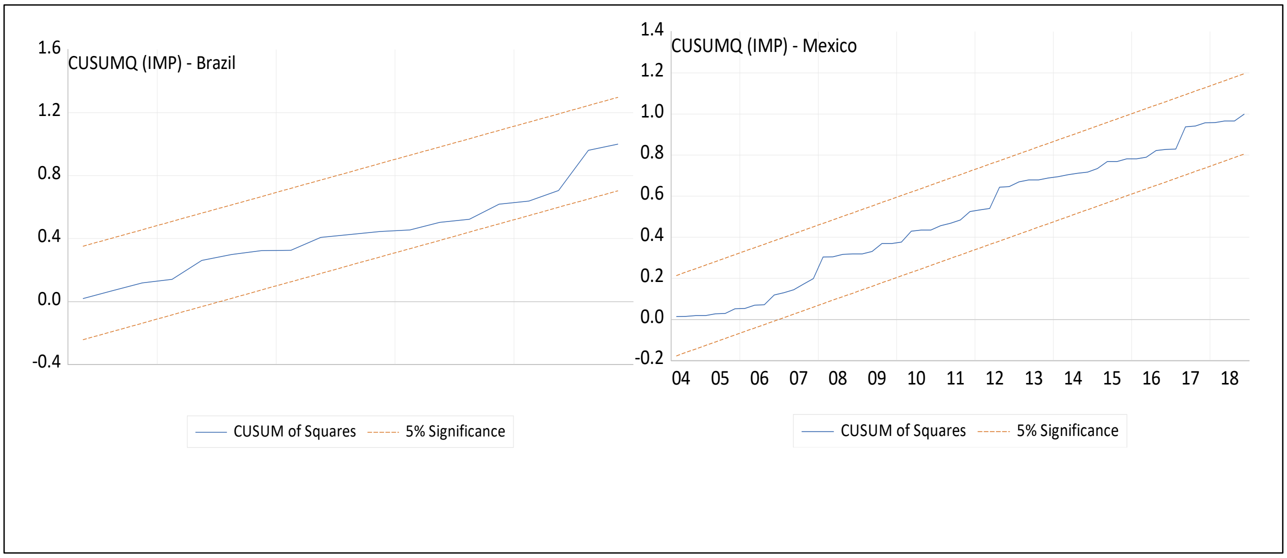


Figure 2.2.b. *Cumulative Sum of Squared Residuals - Import Prices*



5. Wald Test

Verifying the existence of an asymmetric effect of the exchange rate, the Wald test is employed by testing the null hypothesis of symmetry, where if the difference between the coefficients of positive and negative changes is statistically insignificant, then we have a regular symmetric relationship.

For the short-run Wald test, when we reject the null hypothesis, we do have evidence of short-run asymmetry concerning the exchange rate and short-run asymmetry. If we fail to reject the null hypothesis, we do not have evidence of short-run asymmetry regarding the exchange rate, and we do have short-run symmetry.

The null hypothesis of short-run symmetry is:

H_0: $\sum_{i=0}^{q} \rho_{1,i}^{+} = \sum_{i=0}^{q} \rho_{1,i}^{-}$ (for export prices)

H_0: $\sum_{i=0}^{q} \Upsilon_{1,i}^{+} = \sum_{i=0}^{q} \Upsilon_{1,i}^{-}$ (for import prices)

Versus the alternative hypothesis of short-run asymmetry:

H_A: $\sum_{i=0}^{q} \rho_{1,i}^{+} \neq \sum_{i=0}^{q} \rho_{1,i}^{-}$ (for export prices)

H_A: $\sum_{i=0}^{q} \Upsilon_{1,i}^{+} \neq \sum_{i=0}^{q} \Upsilon_{1,i}^{-}$ (for import prices)

The same thing for the long-run Wald test; when we reject the null hypothesis, then we do have evidence of long-run asymmetry with respect to the exchange rate, and we have long-run asymmetry. If we fail to reject the null hypothesis, then we do not have evidence of long-run asymmetry with respect to the exchange rate, and we have long-run symmetry.

The null hypothesis of long-run symmetry is:

H_0: $\alpha^+_1 = \alpha^-_1$ (for export prices)

H_0: $\delta^+_1 = \delta^-_1$ (for import prices)

Against, the alternative hypothesis of long-run asymmetry:

H_A: $\alpha^+_1 \neq \alpha^-_1$ (for export prices)

H_A: $\delta^+_1 \neq \delta^-_1$ (for import prices)

Where, $\alpha^+_1 = -\beta_2{}^+ / \beta_1$, $\alpha^-_1 = -\beta_2{}^- / \beta_1$, $\delta^+_1 = -\psi_2{}^+ / \psi_1$, and $\delta^-_1 = -\psi_2{}^- / \psi_1$

Table 2.6.a. *Short Run and Long-Run Symmetry Test-Export Prices*

Country	**Short-Run W_{SR}**			**Long-Run W_{LR}**		
	Value	**Probability**	**Result**	**Value**	**Probability**	**Result**
Brazil	-0.470584	0.6394	Fail to Reject H_0	-0.519995	0.6047	Fail to Reject H_0
Mexico	1.590534	0.1158	Fail to Reject H_0	-1.701392	0.0929	Reject H_0

For export prices, the short-run and long-run findings of the Wald test are shown in Table 2.6.a. The null hypothesis of short-run and long-run symmetric exchange rate pass-through is failed to reject for Brazil. The conclusion reveals that export price responses to exchange rate variations are the same no matter if the exchange rate decreases or increases, and no evidence of short-run and long-run asymmetry concerning the exchange rate is founded. We have short-run and long-run symmetry.

Regarding Mexico, the null hypothesis of short-run symmetric exchange rate pass-through fails to reject, and we have short-run symmetry. However, the null hypothesis of long-run symmetric exchange rate pass-through is rejected. The results indicate that the transmission of exchange rate fluctuation in export prices is asymmetrical with respect to depreciation (positive changes) and appreciation (negative changes).

Table 2.6.b. *Short-Run and Long-Run Symmetry Test- Import Prices*

Country	**Short-Run W_{SR}**			**Long-Run W_{LR}**		
	Value	**Probability**	**Result**	**Value**	**Probability**	**Result**
Brazil	2.056713	0.0537	Reject H_0	-0.657346	0.5188	Fail to Reject H_0
Mexico	-2.400374	0.0196	Reject H_0	-0.389302	0.6985	Fail to Reject H_0

For import prices, the short-run and long-run findings of the Wald test are shown in Table 2.6.b. The null hypothesis of short-run symmetric exchange rate pass-through is rejected for Brazil and Mexico. The conclusion reveals that the transmission of exchange rate fluctuation in import prices is asymmetrical with respect to depreciation (positive changes) and appreciation (negative changes).

However, the null hypothesis of long-run symmetric failed to reject for both countries; then the results indicate that import prices responses to exchange rate variations are the same no matter if the exchange rate decreases or increases, and no evidence of long-run asymmetry concerning the exchange rate is founded, and we have long-run symmetry.

Empirical Results

This section demonstrates the main results of the symmetric and asymmetric exchange rate pass-through for export and import prices. First, the findings are reported for testing the long-run relationship for both the symmetric and asymmetric models. The F-test (bounds test) and tBDM test results are shown in Tables 2.7.a., 2.7.b., 2.8.a., 2.8.b., 2.9.a., and 2.9.b.

Table 2.7.a. *Bounds Results of the Linear ARDL- Export Prices*

($H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$)					
Country	**F-Test**	**Signif.**	**lower bound**	**Upper bound**	**Result**

Brazil	4.106049	5%	2.86	4.01	Reject H_0
Mexico	8.832347	1%	3.74	5.06	Reject H_0

Table 2.7.b. *Bounds Results of the Linear ARDL- Import Prices*

($H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$)					
Country	**F-Test**	**Signif.**	**lower bound**	**Upper bound**	**Result**
Brazil	1.975591	10%	1.81	2.93	No Conclusion
Mexico	3.018371	10%	2.08	3	Reject H_0

Table 2.8.a. *Bounds Results of the Non-Linear ARDL (NARDL)- Export Prices*

($H_0 = \beta_1 = \beta^+_2 = \beta^-_2 = \beta_3 = \beta_4 = \beta_5 = 0$)					
Country	**F-Test**	**Signif.**	**lower bound**	**Upper bound**	**Result**
Brazil	3.752120	10%	2.26	3.35	Reject H_0
Mexico	11.25631	1%	3.41	4.68	Reject H_0

Table 2.8.b. *Bound Results of the Non-Linear ARDL (NARDL) - Import Prices*

($H_0 = \beta_1 = \beta^+_2 = \beta^-_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$)					
Country	**F-Test**	**Signif.**	**lower bound**	**Upper bound**	**Result**
Brazil	3.572429	10%	2.53	3.59	No Conclusion
Mexico	2.969824	10%	1.99	2.94	Reject H_0

Findings in Tables 2.7.a., 2.7.b., 2.8.a., and 2.8.b. point to the rejection of the null hypothesis of no level relationship among the variables in the ARDL and NARDL models regarding Mexico. For Brazil, the same thing is under the export prices model, where the null hypothesis is rejected too (in both ARDL and NARDL models). Though F-statistics fall between the two bounds under the import prices model, the test is inconclusive. And to decide if there is possible cointegration among the variables, the significance of the error term coefficient should be considered. For Brazil, the coefficient is expected to be negative and significant. Then, there is a possible long-run relationship among variables.

Table 2.9.a. *tBDM Test (ECT coefficients)- Export Prices*

H_0: no significance of the error correction term				
Country	**ARDL**		**NARDL**	
	Coefficient	**t-Statistics**	**Coefficient**	**t-Statistics**
Brazil	-0.702869***	-4.650289	-0.784725***	-4.908984
Mexico	-0.290417***	-6.805583	-0.371145***	-8.477452

*** sign at 99%, ** sign at 95%, * sign at 90%.

Table 2.9.b. *tBDM Test (ECT coefficients)- Import prices*

H_0: no significance of the error correction term				
Country	**Linear ARDL**		**Non-Linear ARDL**	
	Coefficient	**t-Statistics**	**Coefficient**	**t-Statistics**
Brazil	-0.083475***	-3.710177	-0.756446***	-5.736197
Mexico	-0.209587***	-4.804053	-0.209382***	-5.155329

*** sign at 99%, ** sign at 95%, * sign at 90%.

Indeed, the ECM coefficients (tBDM test results) presented in Tables 2.9.a. and 2.9.b. are negative, highly significant, and lie between 0 and -1, supporting adjustment towards the long-run. Subsequently, concerning the bounds cointegration test and the tBDM test, there is a valid long-run relationship between export and import prices and their explanatory variables in the two countries. A conclusion that exports and imports prices are cointegrated with their explanatory variables confirms existing evidence for both countries.

In accordance with the Wald test results, the estimated short-run and long-run coefficients of the exchange rate pass-through to the export prices are summarized in Table 2.10.a.

Table 2.10.a. *Estimates of the Symmetric and Asymmetric ERPTH to Export Prices*

	ARDL Model			**NARDL Model**		
Country	**Variable**	**Coefficient**	**t-stat**	**Variable**	**Coefficient**	**t-stat**
	Short-Run Pass-Through to Export Prices					
Brazil	$\sum^{q}_{i=0} \rho_{1,i}$	-0.195351	0.355416	-	-	-
Mexico	$\sum^{q}_{i=0} \rho_{1,i}$	-0.291906***	-7.934363	-	-	-
	Long-Run Pass-Through to Export Prices					

Brazil	α_1	-0.135555	-0.999054	-	-	-
Mexico	-	-	-	α^+_1	-0.417607**	-2.354054
				α^-_1	-0.515933***	-4.375013

Notes: α_1, α^+_1, and α^-_1 are the LR coefficients associated with total, positive (local currency depreciation), or negative (local currency appreciation) changes of the exchange rate, respectively. $\sum^q_{i=0} \rho_{1,i}$, $\sum^q_{i=0} \rho_{1,i}{}^+$, and $\sum^q_{i=0} \rho_{1,i}{}^-$ are the sum of SR coefficient associated with total, positive (local currency depreciation), or negative (local currency appreciation) changes of the exchange rate. *** sign at 99%, ** sign at 95%, * sign at 90%.

Beginning with Brazil, export prices are insignificantly and negatively associated with local currency fluctuations in the short-run and long-run. Then the results reveal that assuming exchange rates change by 1%, this change will not influence the export prices in the short-run and long-run.

According to the Office of the United States Trade Representative, previous findings can be explained by the fact that Brazil restored tax credits for exporters with the adoption of Law 11529, intended to help industries hurt by enhancing the local currency, the *real*. Present law enables companies in specific Brazilian industrial sectors (such as fabrics, furniture, gemstones, wood processing, leather goods, footwear, leather products, heavy duty and agricultural equipment manufacturers, clothing, and automobile including parts) and producers of certain agricultural products (which include fruits products, eggs, plant seeds, wheat and wheat flour, liquid and pasteurized milk, cheeses, blends for bakery products, fertilizers, and pesticides) applying for tax breaks within social integration (PIS) and social security (COFINS) programs used for purchases of capital equipment, all domestic and imported, that will be used for manufacturing finished goods. The law also expands the government's agenda for exporting companies purchasing capital goods. Within this program, be exempted from paying the 9.25 percent PIS-COFINS tax on these purchases, companies typically need to demonstrate that they obtain at least 70 percent of their earnings from exportation. The present benchmark was cut to 609 percent for businesses in the sectors covered by the law.

Furthermore, Brazil's National Bank for Economic and Social Development (BNDES) offers long-run funding to Brazilian industries through various programs, like R$75 billion (approximately $43.6 billion) Investment Maintenance Program. Between four percent and eight percent, interest rates on funding under this program are significantly lower than general market interest rates for commercial financing. One BNDES program, FINAME, funds Brazilian companies to buy Brazilian-made machines and equipment and capital goods with a high level of local content. Such programs may be used to fund capacity increases as well as equipment purchases in industries like steel and agriculture (Office of the United States Trade Representative).

Additionally, The *Brasil Maior* ("Greater Brazil") industrial policy provides an additional wide range of tax, tariff, and funding incentives to encourage production for export. The Reintegra Program, which started in December 2011 as part of *Brasil Maior*, exempts exports of goods covering 8,630 tariff codes, which account for R$80 billion (approximately $46.5 billion) of exports, from specific taxes and sets up tax credits for the exporters of industrial commodities equivalent to three percent of the value of its exports. To be eligible, the imported content of the exported goods should not exceed 40 percent, except in high-technology commodities such as medicines, electronics, and aircraft and parts, which are allowed to have imported content of up to 65 percent. *Brasil Maior* calls for establishing funds designed to assist small and medium-sized exporters and help cover non-payment by customers in countries where the risk of non-payment is high (Office of the United States Trade Representative).

For Mexico, export prices are significantly and negatively associated with exchange rate changes over the short-run and long-run. For example, export prices decreased by 0.291% for a 1% change in the exchange rate in the short-run. Moreover, in the long-run, a 1% depreciation of the Mexican peso induced a 0.417% decrease in export prices, whereas a 1% appreciation caused a 0.515% decrease in export prices.

Moreover, in the long-run, the exchange rate pass-through to export prices has been more robust during periods of appreciation than during deprecation (in absolute values). And the evidence for incomplete exchange rate pass-through is observed in Mexico over the short-run and long-run.

Preceding results can be explained by the fact that the exchange and debt markets have evolved significantly in Mexico over the past twenty years. Indeed, the independence of the Central Bank and various economic policy actions implemented within the past several decades, such as i) the acceptance of a floating exchange rate system; ii) the adoption of an inflation-targeting regime; iii) greater fiscal discipline; as well as iv) good financial rules, have contributed to a consolidation of the macroeconomic framework of the country and the creation of an atmosphere of certainty and confidence that, in its turn, led to the development of domestic financial markets. Specifically, the exchange rate market has been gaining importance globally. The Mexican peso has been positioned as one of the world's most traded currencies worldwide, as the BIS has released. Under these conditions, the Mexican peso has recorded various episodes of high-level fluctuations and depreciation rates related to internal and external factors. (Rodriguez, Ramirez, Moreno, and Sanchez-Amador, 2019).

Moreover, the literature has demonstrated exchange rate pass-through by considering how the exporter sets up export prices and how export prices change as the exchange rate changes. In particular, export prices have been set up as a markup over marginal costs. Exporter prices may vary due to the following factors: (i) a change in the bilateral nominal exchange rate, (ii) a shift in local prices, (iii) a shift in foreign prices, or (iv) a change in domestic demand. The first two elements, (i) and (ii), affect relative prices: a depreciation in local currency increases the price of foreign goods relative to local substitutes. If foreign exporters maintain their markup unchanged, they can lose market share at home, and to avoid losing market share, they have to lower their markup in this example. The third factor (iii), accounts for an increase in the marginal cost; if the foreign exporters maintain their markup steady, their export prices will go up with equal effect as the change either (i) or (ii). The role of the fourth element (iv), domestic demand, is typically found to be minor or even minimal compared to the other two factors; a possible explanation is that the price variables can capture the impact of demand (Bussiere, 2007).

According to Peltzman (2000), prices seem to “rise faster than they fall,” which applies to trade prices. Facing depreciation, exporters gain –all things being equal– price competitiveness. If they keep their prices unchanged in the domestic currency, they may increase the quantity of exported goods. And that is what has happened to Mexico. At the time, Mexico has a positive shock to the exchange rate of the domestic prices (an unexpected depreciation of a 1%), and the export prices fall by 0.417%. Though, in theory, if exporters reach full capacity or when the adjustment costs are high, it can be challenging to adjust their production upwards, and they may then decide to increase their prices on the other hand. On the contrary, facing an appreciation, exporters will lose their competitiveness and market shares as long as they keep their prices unchanged in the domestic currency, which explains why exporters generally recur to “pricing-to-market” to partially offset a loss in competitiveness resulting from an appreciation (Peltzman, 2000). Mexico, as an example, has a negative shock to the exchange rate of the domestic currency (an unexpected appreciation of 1%) will decrease the export prices by 0.515%.

Furthermore, the micro and macro channels of exchange rate pass-through have various implications for the effectiveness of exchange rate depreciation in improving the external balance position. Firstly, microeconomic factors ensure that a high level of exchange rate pass-through makes exchange rate depreciations more efficient because they generate competitive advantages for domestic producers, which can gain market share at the cost of imports. Meanwhile, higher levels of pass-through due to macroeconomic factors make exchange rate depreciations less effective because it causes higher rises in the prices of non-traded commodities as well as wages and discourages any gain in competitiveness caused by the exchange rate change (Adekunle, Odugbemi, and Tiamiyu, 2019).

In theory, an appreciation of the domestic currency increases export prices, making the home country's products more expensive in the international market (Dornbusch, 1987). Consequently, the currency's appreciation reduces the demand for goods in the home country. Exporters modify their markups to help prevent their market shares from going down. This is particularly true when the price elasticity of demand in the importing nation is high, which also explains incomplete pass-through and less than the proportional shift in prices because of exchange rate fluctuations. Key factors influencing the ERPTH are identified as market conditions and macroeconomic environment in the target market, and the effect on the manufacturing costs of exchange rate changes (Parsley et al., 2011 and Yanamandra, 2015).

Pursuant to the Wald test results, the estimated short-run and long-run coefficients of the exchange rate pass-through to the import prices presented in Table 2.10.b

Table 2.10.b. *Estimates of the Symmetric and Asymmetric ERPTH to Import Prices*

	ARDL Model	**NARDL Model**

Country	Variable	Coefficient	t-stat	Variable	Coefficient	t-stat
	Short-Run Pass-Through to Import Prices					
Brazil	-	-	-	$\sum^{q}_{i=0} \Upsilon_{1,i}^{+}$ $\sum^{q}_{i=0} \Upsilon_{1,i}^{-}$	-4.300928*** -2.604294**	-5.485302 -2.512255
Mexico	-	-	-	$\sum^{q}_{i=0} \Upsilon_{1,i}^{+}$ $\sum^{q}_{i=0} \Upsilon_{1,i}^{-}$	0.875763* -0.29458	1.938766 -1.420576
	Long-Run Pass-Through to Import Prices					
Brazil	δ_1	1.446532	0.130468	-	-	-
Mexico	δ_1	0.353773	0.304251	δ^{+}_1	-	-

Notes: δ_1, δ^{+}_1, and δ^{-}_1 are the LR coefficients associated with total, positive (local currency depreciation) or negative (local currency appreciation) changes of the exchange rate, respectively. $\sum^{q}_{i=0} \Upsilon_{1,i}$, $\sum^{q}_{i=0} \Upsilon_{1,i}^{+}$, and $\sum^{q}_{i=0} \Upsilon_{1,i}^{-}$ are the sum of SR coefficient associated with total, positive (depreciation), or negative (appreciation) changes of the exchange rate. *** sign at 99%, ** sign at 95%, * sign at 90%.

Starting with Brazil, import prices are significantly and negatively associated with local currency depreciation and appreciation in the short-run. However, in the long-run, import prices are insignificantly and positively associated with changes in the exchange rate. For instance, in the short-run, import prices decreased by 4.3% for a 1% depreciation of the Brazilian real, and a 1% appreciation of the real induced a 2.604% decrease in prices.

Moreover, in the short-run, the exchange rate pass-through to import prices has been more robust during periods of depreciation than during appreciation (in absolute values). And the evidence for a more than complete exchange rate pass-through is observed in Brazil over the short-run.

Previous findings can be explained by the fact that, in 1999, a set of policies was adopted in Brazil, the so-called *macroeconomic tripod*, founded on: an inflation targeting regime, a floating exchange rate with high capital mobility, and a primary surplus target. Following the Taylor rule, price stability was pursued by fixing the introductory interest rate (Selic rate). Consequently, the *Selic rate* was set to manage aggregate demand simultaneously and, though not directly, the exchange rate, the most relevant monetary policy transmission channel. Fiscal policy, in its turn, has taken over a supporting role, restricted to avoiding inflationary pressures and keeping stable debt/GDP relations (Reis et al., 2016). This policy aligned with the *New Consensus in Macroeconomics* (Modenesi et al., 2016).

Moreover, according to the Office of the United States Trade Representative, Brazil is a member of the MERCOSUR customs union, founded in 1991 and comprised Argentina, Brazil, Paraguay, and Uruguay. Along with other MERCOSUR members, Brazil endorsed the import tariff rises in CET over hundreds of products, including dairy, toys, textiles, bags, backpacks, and suitcases. Brazil also bans a number of imports, including foreign blood products and all the used consumer goods, like automobiles, clothing, and tires, plus used medical equipment and information and communications technology products. Brazil also limits the entry of certain types of refurbished goods (e.g., earthmoving equipment, vehicle parts, and medical equipment) through complex import licensing procedures. Generally, Brazil allows only the imports of such goods if the importer can prove that goods are not or cannot be produced domestically. Additionally, Brazil applies federal and state taxes and charges to imports that can effectively double the actual cost of imported products in Brazil.

Theoretically, local currency depreciation will raise the costs of import prices evaluated in domestic currency units. However, this is not the case in Mexico, where the import prices decrease with a positive shock to the exchange rate (an unexpected depreciation in the local currency). And that could be explained by the fact that the release of the Plano Real in 1994 proved to be the turning point. That plan, drawn by Henrique Cardoso, who later became Brazil's president, introduced a new currency, placed restrictions on government spending, and finished the indexation of the economy. The real, a new currency, had a crawling peg against the dollar as a nominal anchor and was somewhat overvalued, making importation cheap and limiting the space for domestic producers to increase the prices (Loman, 2014).

Short-run ERPT to import prices is found to be stronger for depreciation than appreciations. According to Raphael et al. (2016), a pattern is consistent with rent-seeking behavior by exporting companies. Exporters exercise pricing power by handing depreciations across to import prices while maintaining their markups and keeping prices for imports constant following appreciations as long as their markups increase. The extent of the asymmetry increases with the import dependence of the destination market. Still, it is moderated when the importer enjoys more freedom-to-trade and/or a more positive output gap.

For Mexico, the import prices are significantly and positively linked with local currency depreciation in the short-run only. And the evidence for an incomplete exchange rate pass-through is observed in Mexico over the short-run. For instance, in the short-run, import prices increased by 0.875% for a 1% depreciation of the Mexican peso.

Preceding results can be explained by the fact that, by the end of 1994, Mexico had to leave the exchange rate peg regime to introduce a new floating rate regime instead. Under this situation, Banco de Mexico was challenged to provide the economy with a nominal anchor to achieve financial and price stability (Ramos-Francia and Torres Garcia, 2005). Monetary authorities' efforts aimed at reducing inflation, and in 2001, Banco de Mexico announced a formal adoption of an inflation-targeting framework that has significantly contributed to anchoring inflation expectations (Capistran and Ramos-Francia, 2010). Numerous empirical studies have presented evidence showing that, once inflation targeting was introduced in Mexico, the transmission mechanism of monetary policy changed in the sense that monetary policy instruments are more effective in reducing the impact of shocks (Gaytan Gonzalez and Gonzalez Garcia, 2006; Sidaoui and Ramos-Francia, 2008; and Ramos-Francia and Torres Garcia, 2008). In particular, Capistran et al. (2010) "find that the exchange rate pass-through seems to have decreased substantially from 2001 onwards, which coincides with the adoption of an inflation-targeting regime by Banco de Mexico" (Peon and Brindis, 2014).

Worth to mention that in 1990, Mexico approached the United States with the idea of forming a free trade agreement (FTA). Mexico's primary motivation in pursuing an FTA with the United States was to stabilize the Mexican economy and promote economic development by attracting foreign direct investment, increasing exports, and creating jobs. The Mexican economy experienced many difficulties throughout the 1990s, with a significant deepening of poverty. The expectation among supporters at the time was that NAFTA would improve investor confidence in Mexico, increase export diversification, create higher-skilled jobs, increase wage rates, and reduce poverty.

Taylor (2000) investigates "the possibility that lower and more stable inflation is a factor behind the reduction in the degree to which firms "pass-through" (to their prices) at the same time increases in the price at competing firms and increases in costs due to exchange rate movements or other factors." According to Peon and Brindis (2014), local currency depreciation will increase the costs of imports evaluated in domestic currency units. When the depreciation is seen as temporary, firms will pass through less devaluation in the form of higher prices. Thus, less persistent fluctuations in exchange rates (less persistent cost fluctuations) will result in a smaller exchange rate pass-through size. However, Taylor's investigation also introduces econometric evidence to demonstrate a reduction in the persistence of aggregate inflation as the inflation rate has declined.

For this reason, low inflation is linked to the lower persistence of changes (shocks) in economic costs. Once again, if firms realize a shock to the exchange rate is temporary because of a low inflation rate in the economy, this will result in a smaller ERPT size. In this regard, Taylor's model explains that a change to a lower inflation environment (e.g., due to inflation targeting policy) can lead to a lower degree of persistence of price shocks, decreasing the size of the ERPTH.

Conclusion

Using quarterly data from 1996 to 2018 for Brazil and from 1994 to 2018 for Mexico. The possibility of asymmetries in the reaction of trade prices (export and import prices) to changes in the exchange rate is investigated. This exercise employs Autoregressive Distributed Lag (ARDL) and Non-Linear Autoregressive Distributed Lag (NARDL) models.

That begins with export prices; the main findings can be outlined as follows. First, starting with Brazil, export price responses to exchange rate variations are the same regardless of whether the exchange rate decreases or increases, and evidence of short-run and long-run symmetry are found. Additionally, export prices are insignificantly and negatively associated with short-term and long-term local currency fluctuations. Second, regarding Mexico, the null hypothesis of short-run symmetric exchange rate pass-through (ERPTH) is failed to reject, and evidence of short-run symmetry is found. However, the null hypothesis of long-run symmetric is rejected, and proof of long-run asymmetry is found. Specifically, export prices are significantly and negatively associated with exchange rate changes over the short-run and long-run. And in the long-run, the ERPTH to export prices has been more robust during periods of appreciation than during depreciation. The evidence for incomplete ERPTH is observed in Mexico over the short-run and long-run.

Concerning import prices, results can be summarized as follows. The null hypothesis of short-run symmetric ERPTH is rejected for both countries. However, the null hypothesis of long-run symmetric failed to reject for Brazil and Mexico. Moreover, for Brazil, import prices are significantly and negatively associated with local currency depreciation and appreciation in the short-run. However, import prices are insignificantly and positively related to changes in the exchange rate in the long-run.

Additionally, in short-run, ERPTH to import prices has been more robust during periods of depreciation than during appreciation, and the evidence for a more than complete ERPTH is observed over the short-run. Regarding Mexico, the import prices are significant and positively linked with local currency deprecation in the short-run only. The evidence for an incomplete ERPTH is observed over the short-run.

Chapter 3 -Digitalization and Environmental Sustainability: Effects and Transmission Channels

Introduction

Threats of climate change represent one of the most challenging issues of our time. To reach the objectives of the Paris Agreement, the estimated world economy needs to reduce its carbon dioxide emissions per dollar of income by 6.3% per year until the year 2100 (PricewaterhouseCoopers Index - PwC, 2018 and Hernnas, 2018). This raises questions regarding the structure of the future economy and how the world can enjoy growth and prosperity in the future without destroying the hopes of a habitable planet. At the same time, information and communication technologies (ICT) have dramatically changed how we can lead our lives and how societies and economies function. Evolution has raised hopes that ICT can be part of the solution to reach environmental targets.

In 2015, the 2030 sustainable development agenda was adopted by United Nations members, which includes 17 Sustainable Development Goals (SDGs). Put a footnote here that describes the goals. The agenda relies on the principle of "leaving no one behind," which is the universal call for action by all nations - developed countries and developing – into a global partnership agreement and take transformative steps to put an end to poverty, protect the planet, and enhance prosperity by 2030. Immediate action to reduce global warming to 1.5C is one of the 17 SDGs. Consequently, SDG 13 proposes six climate actions for governments to tackle climate change by reducing greenhouse gases (GHGs): decarbonization, sustainable growth, green economy, investment in sustainable solutions, combat climate risks, and cooperation (United Nations, 2015 and Alatas, 2021).

According to Avom et al. (2020), there is a growing debate over the influence of information and communication technologies (ICT) on the environment. Three key facts may justify this heightened interest. First, the world has experienced a digital revolution over recent years; developed nations have nearly reached saturation points in terms of ICT introduction and use, even though developing countries continue to experience low penetration rates (Asongu and Nwachukwu, 2016). Second, ICT significantly improved human interactions and brought different innovations which appear to promote economic growth (Sassi and Goaied, 2013), reduce income inequality (Tchamyou et al., 2019), stimulate financial development (Edo et al., 2019), and promote inclusive education (Asongu et al., 2019). Such achievements should be clear that ICT can also serve as a tool for achieving low-carbon development. Third, there needs to be a consensus on the environmental effects of ICT.

Two contradictory arguments exist in the literature regarding the environmental impact of ICT. The first presumes that ICT may reduce environmental pollution by improving energy efficiency, productivity gains, and renewable energy production and consumption. This positive influence is derived from improving productivity and lowering emissions by building smarter cities, transportation systems, electrical grids, and industrial processes (Houghton, 2010). The contrary argument suggests that higher levels of ICT penetration are related to higher pollution levels. This negative influence of ICT operates through several channels, including an increase in industrial production, energy consumption, globalization, and a wealthier financial system (Alcott, 2005). Mingay (2007) estimates that the ICT sector produced 2% of the global GHG emissions.

This study investigates the effect of adopting information and communication technology (ICT) on carbon emissions in G20 countries, focusing on several transmission channels. The objective is to answer several questions: Is ICT adoption harmful to the environment? If so, what are the transmission channels from ICT to environmental quality? What are the direct and indirect effects of ICT on environmental quality? To this end, the mediation analysis framework is used and covers G20 countries between 1990 and 2020.

Following the introduction, the rest of the paper has the following structure. Section 2 briefly reviews the related literature. Section 3 discusses the empirical methodology and the data and shows the empirical results. Section 4 discusses the empirical results. The conclusion is given in Section 5.

Literature Review

Assessing the impact of technology on CO_2 emissions has grown in importance over time and has become a national priority for many nations. However, despite its prominent standing for national and international governments, it remains controversial, and good scientific study continues to be needed. It is possible to group studies of the impact of ICT on CO_2 emissions into three broad areas.

1. The impact of ICT on carbon dioxide emissions

The first area investigates the direct impact of ICT on carbon dioxide emissions. Lee and Brahmasrene (2014) were the first to empirically examine this relationship in a panel of ASEAN countries from 1991 to 2009. They conclude that there is a positive and significant effect of ICT penetration on CO_2 emissions and economic growth. Salahuddin et al. (2016) investigate the short- and long-run effects of internet usage and economic growth on CO_2 emissions in a panel of OECD countries from 1991 to 2012 using a pooled mean group estimator. Their empirical findings also demonstrate that internet usage positively and significantly impacts CO_2 emissions. Furthermore, they show that economic growth does not have significant short-run and long-run effects on CO_2 emissions.

On the other hand, Al-Mulali et al. (2015) find that internet use decreases CO_2 in developed nations. However, the result is insignificant in developing countries. Danish et al. (2019) studied the relationship between ICT, economic growth, and energy consumption from 1990 to 2015. They show that ICT decreases CO_2 emissions in high-income and middle-income countries but increases them in low-income countries. They have also noticed that energy consumption raises CO_2 in all income groups, while an inverted U-shaped relationship between economic growth and CO_2 emissions has been detected.

Park et al. (2018) investigate the effect of ICT, financial development, growth, and trade openness on CO_2 emissions in selected countries from the European Union. Their results show that ICT penetration lowers the CO_2 emissions in the chosen sample. They also see that financial development, growth, and trade openness decrease CO_2 emissions while electricity consumption increases it. Ozcan and Apergis (2018) investigate the effect of ICT on CO_2 emissions in a sample of 20 emerging countries from 1990 to 2015. Empirical findings reveal that internet usage significantly reduces CO_2 emissions. Vice versa, Amri et al. (2019) found that ICT has a negative but not statistically significant effect on CO_2 emissions in Tunisia.

2. Studies on non-linear relationships

The second grouping of studies uses a non-linear framework to examine the effect of increasing ICT penetration on the environment. For these studies, the influence of ICT on the environment is described by an inverted U-shaped curve similar to Environmental Kuznets Curve. Such a relationship proposes that environmental degradation is positive in the early stages of ICT adoption. However, eventually, a threshold is reached. After this threshold, growth in ICT adoption decreases environmental degradation, which suggests that higher levels of ICT penetration are associated with a decrease in environmental degradation in the long-run.

Using this framework, Anon Higon et al. (2017) studied the effect of ICT on carbon dioxide emissions in a panel of 142 countries between 1995 and 2010. Empirical results confirm the inverted U-shaped relationship between ICT and CO_2 emissions for the global and sub-panels of developed and developing countries. Nevertheless, only developed countries have reached the threshold level of ICT, while developing countries are on the increasing phase of the curve.

Similarly, Asongu et al. (2017) examine the effect of increasing ICT penetration (measured by mobile phone and internet penetration) on CO_2 emissions in forty-four countries from SSA from 2000 to 2012. Conclusions from a Generalized Method of Moments (GMM) estimator show that internet adoption positively affects per capita CO_2 emissions. However, increasing mobile phone adoption negatively affects CO_2 emissions from liquid fuel consumption.

3. The connection between ICT and environmental quality

The third aspect is researching the relationship between ICT and environmental quality, assuming macroeconomic variables moderate this relationship. The authors include an interactive term between ICT and macroeconomic variables in their econometric model from this perspective. For example, Asongu (2018) examines the moderating role of ICT on the relationship between trade openness and carbon emissions in 44 counties from SSA over the 2000–2012 period. Empirical findings show that ICT diffusion, once complemented with trade openness, could reduce CO_2 emissions.

Similarly, Danish et al. (2018) find that ICT and economic growth significantly increase CO_2 emissions. At the same time, interaction terms are negative and significant. They conclude that ICT advancement because economic growth improves environmental quality by decreasing CO_2 emissions.

Furthermore, these existing studies investigating the links between ICTs and the environment can be classified into two groups. The first group illustrates the deteriorating ICTs effects, which shows the negative environmental impacts of ICTs. For instance, Salahuddin et al. (2016) showed the harmful effects of using ICTs on sustainability in the long run. They considered a panel dataset for OECD countries between 1991 and 2012, and their findings show that a 10% increase in internet adoption can raise carbon emissions by 1.6%. One more contribution is assigned to Avom et al. (2020), confirming the environmental hurting impacts of ICTs considering some African economies.

Similarly, Alatas (2021) examines the harmful effects of ICTs on sustainability concerning carbon emission augmentation. For example, a 1% increase in the rate of mobile cellular subscriptions is associated with a 0.0233% increase in CO_2 emissions in countries with higher per capita CO_2 emissions. Similarly, a 1% increase in internet use and fixed telephone subscriptions increase emissions in countries with lower per capita CO_2 emissions by 0.0398% and 0.146%, respectively. Moreover, Zhang and Liu (2015) find the negative effect of the ICT industry on CO_2

emissions in the case of China over the period 2000-2010, where they focus on the gross production of the electronic and information and manufacturing industry.

The second group demonstrates the positive environmental effects of ICTs. For instance, Wang et al. (2015) exhibited how ICTs mitigate CO_2 emissions from road freight transport. Their findings that ICTs improve environmental outcomes propose several ways to reduce emissions by lowering energy consumption. In the first place, transport companies can optimize logistics operations by adopting advanced ICTs to help reduce the environmental harm caused by road freight transport environmental outcomes, considering that 6% of atmospheric pollution is primarily due to road freight transport (McKinnon, 2010).

Ozcan and Apergis (2018) highlighted the positive environmental impacts of ICTs through a sample of 20 developing economies from 1995 to 2015. In the same framework, Lu (2018) confirmed the importance of using ICTs to relieve environmental damage to Asian economies between 1993 and 2013. In the same way, Sahoo et al. (2021) reported the favorable influence of mobile phones and the internet in diminishing carbon emissions in India between 1990 and 2018. Same as the positive effect Ahmed and Le (2021) showed during 1996–2017, including a set of Asian economies.

Empirical Methodology

1. Mediation Analysis

Generally, to investigate the effect of information communication technology (ICT) on carbon emissions, equation (1) is formulated as follows:

$$\ln CO2_{it} = \alpha_0 + \alpha_1 \ln IU_{it} + \alpha_2 \ln FTS_{it} + \alpha_3 \ln MCS_{it} + \alpha_4 \ln GDPC_{it} + \alpha_5 \ln POP_{it} + \Upsilon \ln Z_{it} + ŋ_i + \eta_t + \varepsilon_{it} \quad (1)$$

Where $CO2_{it}$ is the amount of CO_2 emitted in country i at time t; Information communication technology is captured by internet users (IU_{it} in % of the population), fixed telephone subscriptions (FTS_{it} in per 100 people), and mobile cellular subscriptions (MCS_{it} in per 100 people); $GDPC_{it}$ is per capita GDP in country i at period t; and POP_{it} population density in country i at period t. Z is a vector of other explanatory variables considered as transmission channels and includes trade ($Trade_{it}$ measured as % of GDP), electricity production mix from coal, gas, and oil ($ElecPro_{it}$ estimated as % of total), fossil and fuel energy consumption ($FFEC_{it}$ measured as % of total), industry (Ind_{it} measured as % of GDP), and renewable energy consumption (REC_{it} measured as % of total final energy consumption). α_0 is the constant term; $\alpha_{(1, 2, 3, 4, 5)}$, and Υ are interpreted as elasticities of carbon emissions concerning the independent variables; $ŋ_i$ is the individual specific effect, η_t is the fixed time effect, and ε_{it} is the stochastic error term.

Despite considerable progress in the empirical study of the influence of ICT on environmental quality, earlier studies are unable to empirically identify the mechanisms through which ICT impedes or improves environmental quality. For this reason, the following hypothesis is proposed to test: the effect of ICT on environmental quality operates through trade, electricity production mix, fossil and fuel energy consumption, industry, and renewable energy consumption.

To test the hypothesis of whether trade, electricity production mix, fossil and fuel energy consumption, industry, and renewable energy consumption mediate the effect of ICT on environmental quality, mediation analysis is used following Baron and Kenny (1986); Zhao et al. (2010), and Avom et al., 2020. This method is helpful in understanding if and to what extent the effect of ICT on carbon emissions is mediated through the mediators. Nevertheless, according to Avom et al. (2020), it appears crucial to point out that mediation analysis is based on the assumption that ICT adoption is before the transmission channels (trade, electricity production mix, fossil and fuel energy consumption, industry, and renewable energy consumption). Relaxing this assumption can overestimate or underestimate the indirect effect. Thus, the results will serve as simple guidelines for policymakers. This analysis also follows the methodology of Papyrakis and Gerlagh (2004), which examines transmission channels of the resource curse hypothesis. Moreover, Yogo and Mallaye (2015) also used mediation analysis to explore transmission channels from aid to health.

The mediation analysis is established through the estimation of the following model:

$$\ln Z^{j}_{it} = \beta_0 + \beta_1 \ln IU_{it} + \beta_2 \ln FTS_{it} + \beta_3 \ln MCS_{it} + \psi_{it} \quad (2)$$

Z^j is the j[th] channel (trade, electricity production mix, fossil and fuel energy consumption, industry, and renewable energy consumption). β_1, β_2, and β_3 are the effect of IU_{it}, FTS_{it}, and MCS_{it} on the transmission channel, respectively.

In the first phase of the proposed algorithm, equation (2) has been estimated to specify the impact of IU_{it}, FTS_{it}, and MCS_{it} on each transmission channel. If β_1 is statistically significant, i.e., IU_{it} explains part of the variation in the transmission channel, then the indirect effect of IU_{it} on carbon emissions can be calculated. Same thing for FTS_{it} and MCS_{it}. If β_2 is statistically significant, i.e., FTS_{it} explains part of the variation in the transmission channel, then the indirect effect of FTS_{it} on carbon emissions can be computed. If β_3 is statistically significant, i.e., MCS_{it} explains part of the variation in the transmission channel, then the indirect effect of MCS_{it} on carbon emissions can be computed. Substituting equation (2) in equation (1) yields:

$$\ln CO2_{it} = \alpha_0 + \alpha_1 \ln IU_{it} + \alpha_2 \ln FTS_{it} + \alpha_3 \ln MCS_{it} + \alpha_4 \ln GDPC_{it} + \alpha_5 \ln POP_{it} + \Upsilon (\beta_0 + \beta_1 \ln IU_{it} + \beta_2 \ln FTS_{it} + \beta_3 \ln MCS_{it} + \psi_{it}) + \eta_i + \eta_t + \varepsilon_{it} \quad (3a)$$

$$\ln CO2_{it} = \alpha_0 + (\alpha_1 + \Upsilon \beta_1) \ln IU_{it} + (\alpha_2 + \Upsilon \beta_2) \ln FTS_{it} + (\alpha_3 + \Upsilon \beta_3) \ln MCS_{it} + \alpha_4 \ln GDPC_{it} + \alpha_5 \ln POP_{it} + \Upsilon\beta_0 + \Upsilon\psi_{it} + \eta_i + \eta_t + \varepsilon_{it} \quad (3b)$$

α_1, α_2, and α_3 are the direct effects of IUit, FTS_{it}, and MCS_{it} on CO_2 emissions respectively; $\Upsilon\ \beta_1$, $\Upsilon\ \beta_2$, and $\Upsilon\ \beta_3$ are the indirect effects of IU_{it}, FTS_{it}, and MCS_{it} on CO_2 emissions respectively, and $(\alpha_1 + \beta_1\Upsilon)$, $(\alpha_2 + \beta_2\Upsilon)$, and $(\alpha_3 + \beta_3\Upsilon)$ are the total effects of IU_{it}, FTS_{it}, and MCS_{it} on CO_2 emissions respectively. In accordance with Zhao et al. (2010), the mediation is empirically valid only if the indirect effect (i.e., $\beta_1\Upsilon$, $\beta_2\Upsilon$, and $\beta_3\Upsilon$) are statistically significant.

Two-panel regressions techniques are used to estimate equations 1 and 2. Fixed effects (FE) and random effects (RE) regression techniques estimate the models. The Hausman specification test determines appropriate methods (RE and FE).

2. Data and Descriptive Analysis

Data for the study are sourced from the World Bank. These data cover the period from 1990 to 2020 for G20 countries. The corresponding list of countries is as follows: Indonesia, Mexico, Brazil, India, Argentina, China, Turkey, Saudi Arabia, South Africa, France, Japan, Australia, Canada, Italy, Russia, Germany, United Kingdom, United States, South Korea, and European Union.

The dependent variable is CO_2 emissions (in kilotons). Information communication technology (ICT) adoption is captured by fixed telephone subscriptions (per 100 people), mobile cellular subscriptions (per 100 people), and internet users (in % of the population). Per capita GDP measures economic growth, and people per sq. km of land area capture population density. Additional variables are included in the model to identify the mechanisms through which ICT improves environmental quality. Tarde (as % of GDP), electricity production mix from coal, gas, and oil (as % of total), fossil and fuel energy consumption (as % of total), industry (as % of GDP), and renewable energy consumption (as % of total final energy consumption) are used.

Figures 3.1. and 3.2. provide a visual description of the evolution of the key variables. From the first one, the mobile cellular subscriptions went up from 11078748 in 1990 to 5620198384 in 2020, at a time when the fixed telephone subscriptions skipped from 540012254 in 1990 to 825935981.7, and the internet users rose from 2.124674 % to 1505.065 % over the same period (Figure 3.1.).

Figure 0.1. *Information Communication Technology (ICT)*

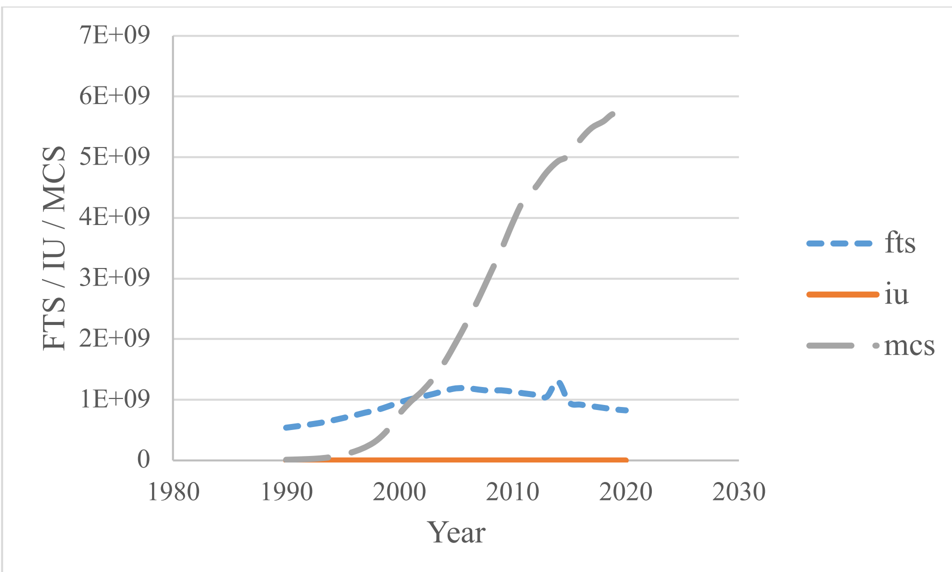
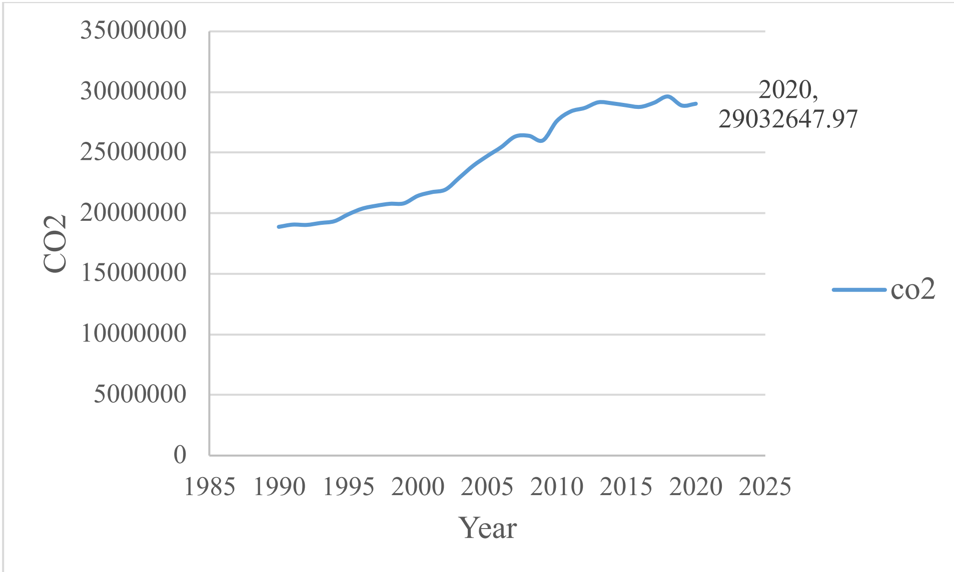


Figure 3.2. illustrates the evolution of CO_2 emissions into the atmosphere by G20 countries. The CO_2 followed an increasing trend, from 18873750 kilotons (kt) in 1990 to 29032647.97 kt in 2020.

Figure 0.2. *CO_2 Emissions (kt)*



A statistical description of the variables is shown in Table 3.1. The average level of CO_2 emissions (in kt) for the sample is 1219488, and their minimum value is recorded in Argentina (99840) in 1990 and the maximum in China (10313460) in 2018. The average GDP per capita in the sample is 19664.53, and India registered the minimum value (301.1590023) in 1993, while Australia witnessed the highest GDP per capita (68156.62792) in 2013. The average population density for the sample is 134.5671; its minimum value is registered in Australia (2.249847051) in 1990 and the highest in South Korea (530.9739438) in 2019. The sample's average of internet users (as the % of the population) is established at 35.80281; Saudi Arabia registered the maximum value (97.8623325%) in 2020. A set of countries, including India, Indonesia, Turkey, Mexico, South Africa, Brazil, Argentina, Russia, and Saudi Arabia, had the minimum value (0%) (between 1990 and 1994). Looking at the fixed telephone subscriptions (per 100 people), the average value of the sample is 4.68e+07. The minimum value (1066222%) was registered by Indonesia in 1990, although China witnessed an impressive increase in the number of subscribers to reach the highest value of 367786000% in 2006. The average of the mobile cellular subscriptions (per 100 people) in the sample is established at 1.22e+08, the minimum value (0) was registered by India and Russia in 1990, and the maximum (1746238000) belonged to China in 2019.

Table 0.1. *Descriptive Statistics of the Variables*

Variable	Obs.	Mean	Std. Dev.	Minimum	Maximum
CO_2 (CO2)	620	1219488	1791506	99840	1.03e+07
Fixed Telephone Subscriptions (FTS)	620	4.68e+07	6.35e+07	1066222	3.68e+08
Mobile Cellular Subscriptions (MCS)	620	1.22e+08	2.41e+08	0	1.75e+09
Internet Users (IU)	620	35.80281	33.26559	0	97.86234
GDP/Capita (GDPC)	620	19664.53	16290.88	301.159	68156.63
Population Density (POP)	620	134.5671	140.735	2.249847	530.9739
Trade (trade)	620	49.30938	18.76661	13.75305	110.5771
Electricity Production Mix (ElecPro)	620	63.47735	24.52343	0	95.73087
Fossil and Fuel Energy Consumption (FFEC)	620	80.73093	12.79895	46.22592	99.99677
Industry (Ind)	620	29.71108	8.83421	16.44503	66.75666
Renewable Energy Consumption (REC)	620	14.71081	14.25667	0.0066	58.65286

Empirical Evidence and Results

This section reports the empirical findings from the mediation analysis. Causal mediation analysis has highlighted the importance and significance of information communication technology (ICT) channels to environmental quality.

1. Internet Users (IU)

The influence of internet users (IU) on each transmission channel is reported in Table 3.2. (equation 2).

Table 0.2. *Estimation of the Effect of Internet Users (IU) on Each Channel*

Channels	IU (β_1)
Trade (trade)	0.0198813***
Electricity Production Mix (ElecPro)	0.006746
Fossil and Fuel Energy Consumption (FFEC)	-0.0056588***
Industry (Ind)	-0.0110523***
Renewable Energy Consumption (REC)	0.0602675***

*** sign at 99%, ** sign at 95%, * sign at 90%.

From Table 3.2., the results indicate that internet users (IU) have a positive and significant impact on trade (trade) and renewable energy consumption (REC) channels. However, they negatively and significantly affect fossil and fuel energy consumption (FFEC) and industry (Ind) channels. Furthermore, internet users (IU) have a positive and insignificant impact on the electricity production mix channel (ElecPro), which means that there is no indirect effect of internet users (IU) on CO_2 emissions through the electricity production mix channel. Other things being equal, increasing internet users (IU) significantly stimulates trade (trade) and renewable energy consumption (REC) and significantly decreases fossil and fuel energy consumption (FFEC) and Industry (Ind). A 1% growth in internet users will significantly boost trade and REC by 0.0198% and 0.0602%, respectively, and significantly reduce FFEC and Ind by 0.0056% and 0.0110%, respectively.

Given that those internet users (IU) clarify the part of the variation in the transmission channel (β_1), the direct and indirect effects of internet users (IU) on environmental quality are computed. The estimated coefficients of equation (3b) are shown in Table 3.3. Moreover, the coefficient of internet users (IU) includes direct and indirect effects.

Table 0.3. *Estimation of the Effect of the Internet Users (IU) on CO_2 Emission*

Channels	Direct Effects (α_1)	Indirect Effects ($\Upsilon\beta_1$)	Total Effects ($\alpha_1 + \Upsilon\beta_1$)	% of the Mediated Effects ($\Upsilon\beta_1 / \alpha_1 + \Upsilon\beta_1$)
Trade	-0.010322***	0.0004503512***	-0.0098716488***	4.56%
Electricity Production Mix	-0.0119111***	0.0018107047	-0.0119111***	0%
Fossil and Fuel Energy Consumption	0.0053311*	-0.012795373***	-0.007464273***	171.42%
Industry	-0.0038823	-0.0059051986***	-0.0059051986***	100%
Renewable Energy Consumption	0.0038793	-0.0125703963***	-0.0125703963***	100%

*** sign at 99%, ** sign at 95%, * sign at 90%.

From Table 3.3., internet users (IU) have directly diminished CO_2 emissions with trade and ElecPro mix channels in the study period. At the same time, internet users (IU) have directly increased CO_2 emissions with the FFEC channel. Likewise, internet users (IU) have indirectly increased CO_2 emissions through the trade channel and indirectly decreased CO_2 emissions through FFEC, Ind, and REC channels. For the overall effects, a 1% increase in the internet users (IU) leads to a reduction in CO_2 emissions with the trade channel by 0.0098%, the ElecPro mix channel by 0.0119%, the FFEC channel by 0.0074%, the Ind channel by 0.0059%, and finally REC channel by 0.0125%.

Furthermore, the contribution of each channel to the total effect of internet users (IU) on CO_2 emissions as $(\Upsilon\beta_1 / \alpha_1 + \Upsilon\beta_1)$ is computed. Approximately 4.56% of the total positive impact (decreased CO_2 emissions) of internet users (IU) on environmental quality is mediated by trade channel. In comparison, 171.42% comes from the FFEC and 100% from each Ind and REC channels. Additionally, the ElecPro mix channel does not indirectly affect CO_2 emissions.

2. Fixed Telephone Subscriptions (FTS)

The effects of the fixed telephone subscriptions (FTS) on each transmission channel are reported in Table 3.4. (equation 2).

Table 0.4. *Estimation of the Effect of Fixed Telephone Subscriptions (FTS) on Each Channel*

Channels	FTS (β_2)
Trade (trade)	-0.0086099
Electricity Production Mix (ElecPro)	0.0433043***
Fossil and Fuel Energy Consumption (FFEC)	0.031776***
Industry (Ind)	0.091282***
Renewable Energy Consumption (REC)	-0.2117947***

*** sign at 99%, ** sign at 95%, * sign at 90%.

Fixed telephone subscriptions (FTS) have a positive and significant effect on the electricity production mix (ElecPro), fossil and fuel energy consumption (FFEC), and industry (Ind) channels. Although they have a negative and significant effect on renewable energy consumption (REC), they have a negative and insignificant effect on trade channels, implying no indirect effect of fixed telephone subscriptions (FTS) on CO_2 emissions through the trade channel. All things are equal, the increase in fixed telephone subscriptions (FTS) significantly stimulates the electricity production mix (ElecPro), fossil and fuel energy consumption (FFEC), and industry (Ind) channels. Furthermore, it will significantly decrease the renewable energy consumption (REC) channel and have a negative and insignificant effect on the trade channel. Indeed, a 1% rise in the number of fixed telephone subscriptions (FTS) will significantly boost electricity production mix (ElecPro), fossil and fuel energy consumption (FFEC), and industry (Ind) by 0.0433%, 0.0317%, and 0.0912% respectively, and will significantly decrease renewable energy consumption (REC) by 0.2117%.

Ever since fixed telephone subscriptions (FTS) account for part of the change in transmission channels (β_2), the direct and indirect consequences of fixed telephone subscriptions (FTS) on environmental quality are computed. The approximate coefficients of equation (3b) are presented in Table 3.5. And the coefficient of fixed telephone subscriptions (FTS) includes both direct and indirect effects.

Table 0.5. *Estimation of the Effects of Fixed Telephone Subscriptions (FTS) on CO_2 Emissions*

Channels	Direct Effects (α_2)	Indirect Effects ($\Upsilon\beta_2$)	Total Effects ($\alpha_2 + \Upsilon\beta_2$)	% of the Mediated Effects ($\Upsilon\beta_2 / \alpha_2 + \Upsilon\beta_2$)
Trade	0.1480306***	-0.0001950315	0.1480306***	0%
Electricity Production Mix	0.135031***	0.0116233764***	0.1466543764***	7.92%
Fossil and Fuel Energy Consumption	0.0770352***	0.0718501753***	0.1488853753***	48.26%
Industry	0.0987465***	0.0487715983***	0.1475180983***	33.06%
Renewable Energy Consumption	0.1023779***	0.0441754396***	0.1465533396***	30.14%

*** sign at 99%, ** sign at 95%, * sign at 90%.

From Table 3.5., fixed telephone subscriptions (FTS) have directly increased CO_2 emissions throughout the study. Additionally, fixed telephone subscriptions (FTS) have indirectly boosted CO_2 emissions across all channels except for the trade channel, in which fixed telephone subscriptions (FTS) do not indirectly affect CO_2 emissions through the trade channel. For the total effects, a 1% increase in fixed telephone subscriptions (FTS) leads to a rise in CO_2 emissions, with the trade channel by 0.1480%, the electricity production mix (ElecPro) channel by 0.1466%, the fossil and fuel energy consumption (FFEC) channel by 0.1488%, the industry (Ind) channel by 0.1475%, and finally renewable energy consumption (REC) channel by 0.1465%.

Additionally, the contribution of each channel to the overall effect of fixed telephone subscriptions (FTS) on CO_2 emissions is calculated as ($\Upsilon\beta_2 / \alpha_2 + \Upsilon\beta_2$). Approximately 7.92% of the total negative impact (increased CO_2 emissions) of fixed telephone subscriptions (FTS) on the environmental quality is mediated by the electricity production mix (ElecPro) channel, 48.26% by fossil and fuel energy consumption (FFEC) channel, 33.06% by industry (Ind) channel, and 30.14% by renewable energy consumption (REC) channel. Moreover, the trade channel does not indirectly affect CO_2 emissions.

3. Mobile Cellular Subscriptions (MCS)

The influence of mobile cellular subscriptions (MCS) on each transmission channel is reported in Table 3.6. (equation 2).

Table 0.6. *Estimation of the Effects of Mobile Cellular Subscriptions (MCS) on Each Channel*

Channels	MCS (β_3)
Trade (trade)	0.0363004***
Electricity Production Mix (ElecPro)	0.0060612
Fossil and Fuel Energy Consumption (FFEC)	0.0056114***
Industry (Ind)	-0.0216493***
Renewable Energy Consumption (REC)	-0.0341246***

*** sign at 99%, ** sign at 95%, * sign at 90%.

Mobile cellular subscriptions (MCS) positively and significantly impact trade and fossil and fuel energy consumption (FFEC) channels. Although they have a negative and significant effect on industry (Ind) and renewable energy consumption (REC) channels, also they have a positive and insignificant influence on the electricity production mix (ElecPro) channel. All things are equal, increasing mobile cellular subscriptions (MCS) significantly stimulates trade and fossil and fuel energy consumption (FFEC). Also, it significantly reduces the industry (Ind) and renewable energy consumption (REC), and it has a positive and insignificant effect on the electricity production mix (ElecPro) channel, which means no indirect effect of mobile cellular subscriptions (MCS) on CO_2 emissions through electricity production mix (ElecPro) channel. Indeed, a 1% increase in the number of mobile cellular subscriptions (MCS) will significantly increase trade and fossil and fuel energy consumption (FFEC) by 0.0363% and 0.0056%, respectively, and significantly decrease industry (Ind) and renewable energy consumption (REC) by 0.0216% and 0.0341% respectively.

Since mobile cellular subscriptions (MCS) clarifies the part of the variation in the transmission channels (β_3), the direct and indirect effects of mobile cellular subscriptions (MCS) on environmental quality are calculated. Estimates relating to equation (3b) coefficients are shown in Table 3.7. And the coefficient of mobile cellular subscriptions (MCS) contains direct and indirect effects.

Table 0.7. *Estimation of the Effects of Mobile Cellular Subscriptions (MCS) on CO_2 Emissions*

Channels	Direct Effects (α_3)	Indirect Effects ($\Upsilon\beta_3$)	Total Effects ($\alpha_3 + \Upsilon\beta_3$)	% of the Mediated Effects ($\Upsilon\beta_3 / \alpha_3 + \Upsilon\beta_3$)
Trade	-0.0078256	0.0008222767***	0.0008222767	100%
Electricity Production Mix	-0.0083825*	0.0016268964	-0.0083825	0%
Fossil and Fuel Energy Consumption	-0.0132093***	0.0126881947***	-0.0005211053	2434.86%
Industry	0.0055016	-0.0115671322***	-0.0115671322	100%
Renewable Energy Consumption	-0.0097521**	0.0071175965***	-0.0026345035	270.17%

*** sign at 99%, ** sign at 95%, * sign at 90%.

From Table 3.7., during the period of the study, mobile cellular subscriptions (MCS) have directly diminished CO_2 emissions with electricity production mix (ElecPro), fossil and fuel energy consumption (FFEC), and renewable energy consumption (REC) channels only. Likewise, mobile cellular subscriptions (MCS) have indirectly increased CO_2 emissions through trade, fossil and fuel energy consumption (FFEC), and renewable energy consumption (REC) channels, even though they indirectly decrease CO_2 emissions through the industry (Ind) channel. Mobile cellular subscriptions (MCS) do not indirectly affect CO_2 emissions through the electricity production mix

(ElecPro) channel. For total effects, a 1% growth in mobile cellular subscriptions (MCS) leads to a decrease in the CO_2 emissions with the electricity production mix (ElecPro) channel by 0.0083%, the fossil and fuel energy consumption (FFEC) channel by 0.0005%, the industry (Ind) channel by 0.0115%, and finally renewable energy consumption (REC) channel by 0.0026%. The same increase in mobile cellular subscriptions (MCS) increases CO_2 emissions with trade channels.

Additionally, the contribution of each channel to the aggregate effect of mobile cellular subscriptions (MCS) on CO_2 emissions is calculated as the ($\Upsilon\beta_3$ / $\alpha_3 + \Upsilon\beta_3$). Just about 2434.86% of the aggregate positive influence (decreased CO_2 emissions) of mobile cellular subscriptions (MCS) on environmental quality is mediated by fossil and fuel energy consumption (FFEC) channel, at the same time as 100% comes from industry (Ind) channel, and 270.17% from renewable energy consumption (REC) channel. Moreover, 100% of the total negative effect (increased CO_2 emissions) of mobile cellular subscriptions (MCS) on environmental quality is mediated by trade channels.

Discussion

Literature on information communication technology (ICT) and CO_2 emissions can be classified into two strands. The first strand of literature views ICT development as favorable for environmental sustainability. The ICT is seen as a solution to strengthen environmental protection, mitigate the negative effect created in the environment through human activities, and address critical environmental challenges, including climate and sustainability. ICT can also help reduce environmental pollution by increasing awareness of environmental issues and utilizing environmentally friendly technology (Plepys, 2002; and Lashkarizadeh and Salatin, 2012).

ICT applications help predict and then manage environmental-related risks. For instance, computerized simulation tools can make learning "learning by simulation" easier for decisionmaking procedures and prevent trial and error severe effects. The other aspect of ICT is the "internet network," which positively affects the knowledge of the environment (Majeed, 2018).

Additionally, Majeed (2018) referred to "greening through ICTs," which is the contribution of ICT services in lowering industrial and societal energy consumption by utilizing ICT to make various activities more efficient. Examples: e-commerce, video conferencing, paperless office, BEMS, HEMS, smart grid, smart cities, and intelligent manufacturing.

Furthermore, ICT-based solutions have been considered favorable for environmental sustainability and reducing greenhouse gas emissions (Webb, 2008; Uddin and Rahman, 2012). Dematerializing effect of ICT suggests a shift from delivering physical products to providing services.

Moreover, ICT helps mitigate CO_2 emissions, which are corroborated by the contributions to measuring, monitoring, managing, and enabling more efficient resource utilization and operation of infrastructure through dematerialization (Houghton, 2010). For instance, from books to e-books, paper mail to email, and newspaper to electronic paper, thus minimizing waste. Also, teleconference and videoconference instead of traveling, staying, and working at home rather than going to the workplace, ordering food online instead of cooking at home, and online shopping minimize outdoor activities, saving fossil and fuel consumed in vehicles and resulting in less carbon emissions. Intelligent transport system logistics and freight rationalization, intelligent buildings, and home automation are the implications that can help in energy efficiency improvements, thus mitigating pollution. One more mechanism contributing to ICT's productive role is that the induction of ICT contributes to energy saving in some areas of life that go beyond ICT-induced additional energy consumption in other areas. For instance, using smaller ICT devices, laptops, smartphones, and others is energy efficient. Thanks to significant progress in innovation in the last three decades, the world is taking advantage of the technology spillover effect. Due to ICT use, traditional industries switch to higher energy efficiency and a low carbon economy (Danish, 2019).

At the same time, the growing use of e-commerce and e-banking is making it easier for online transactions, which would, in turn, cut down on physical travel, thus reducing greenhouse gas emissions. Besides decreasing dependence on physical traveling, ICT also delivers intelligent and automated solutions in various industries like power generation, agriculture, and manufacturing. ICT is considered a low-carbon driving force and a crucial determinant of environmental sustainability that can reduce carbon emissions across sectors such as power, transportation, and buildings (Webb, 2008).

Moving to the second strand, which views ICT development as unfavorable for environmental sustainability. According to the OECD (2018) and Houghton (2015), ICT growth worsens the environment by increasing the production, use, and disposal of ICT products. Such as an increase in e-waste and greater use of energy in production adversely affect the quality of the environment. Moreover, the life cycle theory of ICT proposes that several stages of the life of ICT lead to pollution. The life cycle of ICT-related products spans over 'production, delivery, transport, use, and disposal' (Yi and Thomas, 2007; Zhang and Liu, 2015).

E-waste, the other dimension of ICT infrastructure, includes the disposal of many ICT-related goods like computers, cell phones, LCD screens, and RCT screens. Widmer et al. (2005) claim that e-waste is a growing worldwide challenge and even a business opportunity as it contains both toxic and valuable material in them. They additionally argue that e-waste is poorly managed, causing a burden on the environment.

Liu et al. (2006) examine the effects of e-waste in China. They claim that the recycled process of e-waste is causing harmful effects on the environment and human health. Furthermore, they note that the illegal transfer of e-waste from other countries into China exacerbates problems associated with e-waste. They claim that e-waste recycling has yet to be officially managed. Specifically, they show that 60% of the e-wastes has been sold to private collectors that were passed into informal recycling processes. Additionally, they demonstrate that more than 90% of Chines are unwilling to pay to recycle their e-waste.

Osibango and Nnorom (2007) maintain that ICT growth has caused an improvement in the ability of computers but at the cost of their lifetime. As a result, a significant quantity of e-waste will be generated annually. They state that ICT development in third-world countries depends largely on imports of second-hand or refurbished electrical and electronic equipment (EEEs) without testing for functionality. Consequently, a large quantity of e-waste is currently managed in developing countries. They also underlined the challenges faced by developing countries while managing e-waste. These include a shortage of suitable infrastructures for e-waste, inadequate legislation policy for e-waste, and an absence of any frameworks for implementing extended producer responsibility (EPR). Emmanouil et al. (2013) also highlight the improved management of e-waste to reduce environmental impacts.

The 2014 number of mobile devices has exceeded the number of people on the ground. Likewise, the ratio of all devices to humans is even high. This relationship is likely to grow in the future as technology is moving forward at a fast rate. Additionally, lately, the vehicular network has developed to compensate for the side effects of road traffic and accidents. This intelligent transport system enables vehicles to interact with each other in different regions. Estimates of the number of cars will reach 1.5 billion by 2035. If these cars are connected to a vehicular network, ICT pressure will increase (Majeed, 2018).

Accordingly, since technology is growing and the world is becoming more connected, the energy consumed by ICT and the carbon emitted by ICT also increase. The ICT industry is now becoming a power drainer, contributing 2% of global carbon emissions. This value represents a total carbon footprint of 830MtCO2e as of 2007; this sum of carbon footprint is equal to the carbon footprint emitted from the air industry. As a result of improving technological developments, the carbon footprint of ICT is expected to increase by 75%, equal to 1430MtCO2e. The growing carbon footprint of ICT has become an increasing concern for societies because carbon emissions impact the climate, which affects the natural environment and society (Majeed, 2018).

Noteworthy, Majeed (2018) stated the so-called rebound effects of ICT. The links of ICT with the environment depend on the rebound impacts of ICT. Theories of rebound effects imply that the positive consequences of technology can be offset in the long-run. If, for example, ICT developments result in cheaper production, which causes the demand for a product to increase, and then increases pollution. These rebound effects are creating unclear impacts of ICT on environmental sustainability.

Conclusion

This paper investigates whether the movement toward a more digital economy has helped lower the emission of carbon dioxide by using a panel data set for the G20 countries over 30 years. Digitalization is measured with several measures to connect the various countries' populations and the outside world, including internet usage, fixed telephone usage, and mobile phone usage. The main concern is to break down the connection between digitalization and carbon dioxide into direct and indirect effects. The indirect effects operate through other channels, including trade, electricity production, fossil and fuel energy consumption, industry, and renewable energy consumption.

Mediation analysis is used to distinguish the direct and indirect effects. More specially, internet users indirectly negatively impact the environment (increased CO_2 emissions) through its impact on trade channels and adverse effects (decreased CO_2 emissions) through fossil and fuel energy consumption, industry, and renewable energy consumption channels. Fixed telephone subscriptions have indirectly increased CO_2 emissions through their effect on all channels except the trade channel. Fixed telephone subscriptions have no indirect effect on CO_2 emissions through the trade channel. Finally, mobile cellular subscriptions have indirectly increased CO_2 emissions through trade, fossil and fuel energy consumption, and renewable energy consumption and decreased CO_2 emissions through their effect on the industry channel.

Moreover, the total effects of fixed telephone usage negatively impact the environment (increased CO_2 emissions) through all channels, while the total impacts of internet users positively impact the environment (decreased CO_2 emissions) through all channels. Finally, the full effects of mobile cellular subscriptions are positive (decreased CO_2 emissions) through all channels except trade channels, where mobile cellular subscriptions increase CO_2 emissions through them.

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