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DYNAMIC ADJUSTMENTS OF ENERGY DEMAND TO EXCHANGE RATE AND INCOME DIFFERENTIALS: EVIDENCE FROM SELECTED OPEC ECONOMIES – NARDL APPROACH

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Abstract: *The study explores the adjustments process of energy demand to exchange rates and incomes differentials in Iran, Venezuela, Nigeria and Algeria. It is expected that as exchange rates witness appreciations or depreciation; and national income fluctuates between positives and negatives, nations adjust their expenditure patterns and pricing policies for various good and services including energy. Coupled with inconclusive findings, previous studies ignored the potential effects of exchange rate in their energy demand specifications and this pave way for further studies. Our findings reveal the presence of varying effects of the exchange rates and income changes on energy demand in these economies. Exchange rate affects energy demand asymmetrically in Nigeria in both long- and short-run, only in the short-run in Iran and Algeria, without such effects in Venezuela. National income changes affect energy demand in Iran asymmetrically in both long- and short-run, only in the long-run in Venezuela, while it has symmetry effects in Nigeria and Algeria. Energy demand adjust faster to rising than falling incomes in Iran, while adjustment of equal rates to income changes was discovered in Venezuela. For exchange rates, energy demand in Nigeria adjusts faster to depreciation than appreciation while adjustments of equal rate are recorded in Algeria. The varying effects of the exchange rates and income on energy demand in these economies highlights the significance of country-specific and non-linear specifications. The findings are relevant for energy demand policy moderations.*

Keywords: Exchange Rate, Energy Demand, National income, Asymmetry, OPEC

1. Introduction

Considerable large volumes of studies have been carried out in the past by energy experts and other scholars to provide empirical explanations about the relevant determinants of energy demands. Such a large number of studies dedicated to energy and its related variants is not a mere coincidence but it was borne out of the recognition and realization of the critical role of energy in today's modern economy. In the modern economy, various activities including manufacturing, transportations of all types, technological advancements, communications, domestic and other related activities depend on energy in one way or the other for proper functioning. Notably, it is not surprising to see such large number of studies dedicated to unravelling the key factors that determine energy demand. Within the existing studies, scholars have identified factors like income, prices, the energy intensity of production processes as key variables affecting energy demand (Al-Salman, 2007; Brons et al 2008; Adeywmi & Hunt, 2010; Arthur et al., 2011; Belke, 2011; Havranek et al., 2012; Adofo et al., 2013; Adeywmi & Hunt, 2014; Pal & Mitra, 2015, 2016; Labandeira et al., 2017; Salisu & Ayinde, 2018; Chang et al., 2019; Liddle & Sardosky, 2020; Liddle & Huntington, 2020). Some authors, Akmal et al (2001), Bigano et al (2006), Adeyemo et al. (2007), Sa'ad, (2011), Adom 2015), Li & Su (2020), differ in their choices of variables and identify factors like weather and climatic conditions in their energy specifications. In another dimension, studies by a few researchers identified the exchange rate as a critical factor in energy demand model. These includes, Gately & Huntington (2002); De Schryder & Peersman (2013), Shahbaz et al (2018), and Ghoddusi et al. (2019).

Unarguably, energy demand and its determinants are well documented in the literature but most scholars did not consider the exchange rate as a relevant factor in their energy demand specifications, with the exceptions of few (see Gately & Huntington 2002; De Schryder et al., 2013; Shahbaz et al., 2018; Ghoddusi et al., 2019). Furthermore, the role of the exchange rate in energy demand cannot be overemphasized. There is a high degree of interdependencies and interconnectedness of economies and most economies depend on external sources for domestic supplies of energy. On that ground, the exchange rate being the value by which a currency exchanges for another will invariably affect the capacity of an economy to demand for more or less energy. Economic theory postulates that the relative value of a currency of a particular economy in relationship with that of her trading partners determines her level of competitiveness in the global market (Bahmmani-Oskooee et al 2018). On several occasions, the exchange rate fluctuates between positives (appreciations) and negatives (depreciation). Such movements have the potential to affect energy demand capacities of an economy. This line of argument is manifested in the meta-analysis and reviews by both Labandeira et al (2017) and Salisu et al (2018) report that income and prices have remained predominant as key variables affecting energy demand in almost all studies with a focus on energy demand determinants. With this observation, we identify this as a great limitation in extant literature; we therefore, incorporate exchange rate it in our energy demand model. We hypothesize that as exchange rate appreciates or depreciates, the energy demand capacity of a net-energy importer will be affected.

Another dimension to the shortcomings in previous studies lies on the inability of researchers to establish a common ground concerning how these factors affect energy demand in the various economies as their findings are divergent and utterly inconclusive. Adeyemi et al (2010) relied on panel data of 17 OECD economies and report that the underlying energy demand trend respond asymmetrically to price changes, while Chang et al. (2019) in their study of some OECD industrial sectors reveal that the response of energy demand to output and price changes are more elastic in the long- compared to short-run. The findings from Liddle et al (2020) for 91 OECD and non-OECD countries within a panel data framework report that energy demand declines more in response to falling national income than rising national income. Sa'ad, (2011) and Adom (2015) in separate studies identify the prevalence of asymmetry in energy demand and its determinants in Nigeria and recommends a diversified approach for future specifications. In a related study, Liddle & Huntington (2020) relying on evidence from their panel research of OECD economies re-emphasize the role of economic growth in energy demand specifications. The study of Shahbaz et al (2018) identified foreign capital as a determinant factor of energy demand, while studies by Adeyemi & Hunt (2014) and that of Kanjilal et al (2017) identified prices and income as the key determinants of energy demand. Fotis et al (2017) report from a dynamic panel data estimation that energy demand is elastic to price changes with an evidence of asymmetry in the relationship. The few studies that incorporated the exchange rate in their energy demand specification are not equally free from these limitations. They have dissenting views about the effects of exchange rate on energy demand. De Schryder et al (2013) explore the effects of the US dollar on energy demand of 61 oil-importing countries. Their panel data estimation provides evidence that appreciation of the US dollar exchange rate (depreciation of local currency) results in a proportionate reduction in energy demand. Ghoddusi et al (2019) on their part, reveal from their estimation of energy demand - exchange rate nexus in Iran that as exchange rate depreciates, the demand for energy declines. They equally indicate that the reactions of energy demand are more pronounced in the period of less volatile exchange rate. The foregoing dissenting views provide the needed platform for further research.

Another issue to ponder about is the assumptions of linearity and symmetry in most studies. The assumption of linearity is too restrictive and invariably provides unreliable estimations. Hamilton (2003) reports that the response of energy demand and most other economic fundamentals to the changes in its determinants is mainly non-linear and asymmetry. He observed that the degree of changes that occur as a result of either a positive shock is not always completely offset by opposite shock of equal proportions. The adjustment process in response to a perturbation from either positive or negative shocks are not always equal as erroneously assumed in a linear model. And this prominently renders the findings therewith spurious and unreliable. In response to this notion, several studies have explored this assertion but their findings remain inconclusive. (see Salisu et al. 2016; Labandeira et al., 2017; Uche, 2019; Liddle et al 2020). To fill these missing links and by way of providing new evidence in energy demand specifications, we included the exchange rate within a non-linear and asymmetry model. Our major aim is to explore the possible differential effects of exchange rate appreciations and depreciation on energy demand in Iran, Venezuela, Nigeria and Algeria. Economic theory postulates an inverse relationship between imports and exchange rate, i.e. it is expected that demand for imports declines in response to exchange rate depreciation and vice-versa. With the recognition that these economies depends heavily on external sources for local energy supplies, we postulate that as the value of their currencies fluctuates between positive and negatives, their demand for energy will be affected. But how these changes affect their demand for energy constitute the major factor to be determined by this study. Another ground to cover is the provision of country-specific analysis as most previous studies were carried out based on panel data aggregation. The shortcoming here is that panel estimation is incapacitated by heterogeneity bias; equally countries differ in terms of structures, energy intensities and regulations. Another issues noted is that most previous studies considered mainly the advanced economies within the OECD without such considerations given to the developing and emerging economies. This equally makes this study timely and pertinent as most of these developing economies are more vulnerable to exchange rate fluctuations. The study will provide necessary policy guidelines for appropriate exchange rate alignment and consistent policies to avert welfare losses.

In response to these yarning gaps, we applied the non-linear autoregressive distributed lag (NARDL) model and incorporate the exchange rate in our energy demand specification. The NARDl proposed recently by Shin et al (2014) is an extension of the ARDL of Pesaran and Shin (1998) and the bounds tests of Pesaran et al (2001). The model has the capacity to decompose variables into positive and negative partial sums and thereby revealing the differential effects on the regresand. With regards to the exchange rate, Verheyen (2013) contends that the model provides an avenue to assess how the dependent variable responds to either exchange rate appreciations or depreciation in the short- and long-run. The flexibility of the model and its capacity to accommodate variables of different integration as against the restrictive nature of the OLS and the VECM models makes it more appealing and the very first choice for this type of study. The model provides opportunities to test three forms of asymmetries, namely; short-run asymmetry, long-run asymmetry and the dynamic adjustment asymmetry (Meo et al., 2018; Omoke et al. 2020). The short-run asymmetry reveals the

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immediate response of the dependent variable to changes in the partial sums of the independent variable. Long-run asymmetry reveals the long-run response to both positive and negative changes, while the dynamic adjustment multiplier graph depicts the dynamic adjustment process to equilibrium.

To confirm the relevance of the popular opinion in literature with regards to income and energy demand as it affects these selected economies, we added the national income in our specification to reassess its differential effects on energy demand in these economies. Previous studies are equally divergent in their opinions about the relationship existing between energy demand and national income. Some findings describe linear effects, some identified that such effects are non-linear and asymmetry. Some studies report the prevalence of both linear and nonlinear responses. (see Adeyemo et al., 2007; Adeyemi et al., 2010, 2014; Kanjilal et al., 2017; Labandeira et al., 2017; Shahbaz et al., 2018; Salisu & Ayinde, 2018; Chang et al., 2019). As noted earlier, most of these studies were analyzed within a panel data framework and their case studies are mainly the advanced economies without much consideration to the developing economies. Energy is seen as an essential commodity (normal good) which its demand increases in response to rising incomes. In line with this, it is expected that the demand for energy within these economies increases (declines) as their income levels rises (falls).

The foregoing represents the introductions to the survey, the remaining parts are thus planned. The methodology and data source were unveiled in the next session; followed by the estimations and discussions in the next session. We present the summary and policy implications in the last session.

Data and Methodology

Data

We used quarterly time series data of each economy (the Iran, Venezuela, Nigeria and Algeria) and cover the period from first-quarter of 2000 to fourth-quarter of 2018 (2000Q1-2018Q4). The data are obtainable from the data bank of International Financial Statistics (IFS) and Enerdata's global energy data streams. The variables used include quarterly data of energy demand (*led*) (million tons of oil equivalents), exchange rate (*lex*) (the value of national currency per US dollar), nominal GDP expressed in local currency equivalent (*lni*) and West Texas Intermediate (WTI) regular crude spot price in US dollars per barrel (*lop*). All the variables are reported in their natural logarithm values.

Model Specification

As pointed out earlier, studies abound that have previously modelled the determinants of energy demand with different variables. Most researchers evaluated the critical roles of energy prices and incomes in energy demand. These studies among several others include Pal, et al (2015), Chang, et al (2019), Zhu & Chen (2019), Liddle, et al (2020). From the meta-analysis on the price elasticity of energy demand carried out by Labandeira et al (2017), it was reported that several studies confirmed the asymmetric effects of price on energy demand. While a good number of studies evaluate the impacts of income differentials, only but a handful had tried relating energy demand with the exchange rate of the local currency against the US dollar. As equally hypothesized earlier, it is expected that as the local currency gains or losses value against the US dollar, and based on the current interconnectedness of the global economy, her energy demand levels will be affected either positively or negatively. Such is equally expected when her income levels changes as several studies revealed. To provide empirical explanations to the stated hypotheses, we present our model below.

$$led_{jt} = f\,(lex_{jt},\, lni_{jt},\, lop_{jt}) \tag{1}$$

where *led*, *lex*, *lni* and *lop* refers to logarithmic values of energy demand, exchange rate, national income and crude oil prices respectively of country j at different quarters t. *f* is a functional notation. Specification (1) is used to form the econometrics specification with the stochastic error term and represented as specification (2).

$$led_{jt} = b_0 + b_1 lex_{jt} + b_2 lni_{jt} + b_3 lop_{jt} + \varepsilon_t \tag{2}$$

Other variables are as described earlier with the inclusion of their natural logarithm values, the ε_t is the stochastic factor that takes care of other factors not included in the model. Our choice of variables is to conform with economic theory's specification that the quantity of a product demanded is a function of income, price, but based on international interdependencies, the exchange rate of the local currency against the US dollars regularly affects such factors as energy and many other consumables (De Schryder *et al* 2013). The empirical details of the above relationship are based on the Autoregressive Distributed Lag (ARDL) technique advanced by Pesaran and Shin (1999) and Pesaran et al. (2001). The model is preferred based on its capacity to simultaneously produce long- and short-run estimations. The model can accommodate fractionally integrated variables, and it can equally be applied even when the explanatory variables are endogenous (Peseran et al., 2001) and cited by Pal et al. (2015, 2016). The dynamic error correction linear ARDL model is provided as follows:

$$ln\Delta\gamma_t = \beta_0 + ln\beta_1\gamma_{t-1} + ln\beta_2 x_{t-1} + \sum_{i=1}^{n}\varphi_i ln\Delta\gamma_{t-i} + \sum_{i=0}^{n}\pi_1 ln\Delta x_{t-i} + \varepsilon_t \quad (3)$$

where γ_t is the dependent variable, x_t is the independent variable, Δ is difference operator, *ln* is the natural logarithm notation, while ε_t is the stochastic term. $\sum_{i=1}^{n}\varphi_i ln\Delta\gamma_{t-i}$ represents the short-run dynamics, $\beta_1\gamma_{t-1}$represents the long-run equilibrium relationship.

Equation 3 is the typical ARDL model which we modify with our variables to form equation 4 presented as follows:

$$\Delta led_t = \beta_0 + \beta_1 led_{t-1} + \beta_2 lex_{t-1} + \beta_3 lni_{t-1} + \beta_4 lop_{t-1} + \sum_{i=1}^{n}\varphi_i\Delta led_{t-i} + \sum_{i=0}^{n}\pi_1\Delta lex_{t-i} + \sum_{i=0}^{n}\pi_2\Delta lni_{t-i} + \sum_{i=0}^{n}\pi_3\Delta lop_{t-i} + \varepsilon_t \quad (4)$$

The ARDL model (equation 4) is a linear model subsumed with the assumption of linearity and symmetric relationships between the variables, but several recent studies have shown that most economic fundamentals display non-linear (asymmetric) dynamics, equally economic variables are being affected by structural breaks (Shahbaz et al., 2018; Golit et al., 2019). Thus, we present the non-linear version of the ARDL tagged NARDL that can accommodate our hypothesis of asymmetry, the model is as specified in equation (5) below:

To begin, we present the long-run specification of the NARDL model as follows:

$$led_t = \beta_0 + \beta_1 lex_t^+ + \beta_2 lex_t^- + \beta_3 lni_t^+ + \beta_4 lni_t^- + \beta_5 lop + \varepsilon_t \quad (5)$$

where lex_t^+, lex_t^-, $lni_t^+$and $lni_t^-$are respectively the positive and negative partial sums of the exchange rate and income which we intend to check their differential effects on energy demand with oil price (*lop*) included as a control variable. The process to generate the partial sums of positive and negative changes illustrated by Shin et al. (2014) and many researchers including Bahmani-Oskooee & Mohammadian (2018), Shin et al (2018); Meo et al (2018), Uche (2019), is replicated in equations 6a, 6b, 7a, and 7b below:

$$lex_t^+ = \sum_{i=1}^{t}\Delta lex_t^+ = \sum_{i=1}^{t}\max(\Delta lex_i, 0) \quad (6a)$$

and

$$lex_t^- = \sum_{i=1}^{t}\Delta lex_t^- = \sum_{i=1}^{t}\min(\Delta lex_i, 0) \quad (6b)$$

$$lni_t^+ = \sum_{i=1}^{t} \Delta lni_t^+ = \sum_{i=1}^{t} \max(\Delta lni_i, 0) \quad (7a)$$

and

$$lni_t^- = \sum_{i=1}^{t} \Delta lni_t^- = \sum_{i=1}^{t} \min(\Delta lni_i, 0) \quad (7b)$$

where $lex_t = lex_0 + lex_t^+ + lex_t^-$. and $lni_t = lni_0 + lni_t^+ + lni_t^-$.

From the above specifications, the long run coefficients of positive and negative partial sums of exchange rate and income differentials of energy demand are respectively given as β_1 , β_2, β_3 and β_4, while, β_0 is the coefficient of the dependent variable, while β_5 is the coefficient of prices which was included as a control variable.

For empirical estimation, we form the long run equation (8a) in an NARDL setting as in Shin et al. (2014). That is,

$$\Delta led_t = \beta_0 + \beta_1 led_{t-1} + \beta_2 lex_{t-1}^+ + \beta_3 lex_{t-1}^- + \beta_4 lni_{t-1}^+ + \beta_5 lni_{t-1}^- + \beta_6 lop_{t-1} + \sum_{i=1}^{n} \varphi_i \Delta led_{t-i} + \sum_{i=0}^{n} (\theta_i^+ \Delta lex_{t-i}^+ + \theta_i^- \Delta lex_{t-i}^- + \theta_{II}^+ \Delta lni_{t-i}^+ + \theta_{II}^- \Delta lni_{t-i}^-) + \sum_{i=0}^{n} \pi_2 \Delta lop_{t-i} + \varepsilon_t \quad (8a)$$

Where n is the number of lag determined by AIC in this case, lag length of 2 is chosen, β_1, β_2, β_3, β_4, $\beta_5$and β_6 are long-run coefficients including the positive and negative partial sums of exchange rate and income previously identified, $\beta_0, and\, \beta_6$ are the coefficients of the independent variable and the control variable respectively. Equation (8b) below is the short-run representation of the NARDL model.

$$\sum_{i=1}^{n} \varphi_i \Delta led_{t-i} + \sum_{i=0}^{n} (\theta_i^+ \Delta lex_{t-i}^+ + \theta_i^- \Delta lex_{t-i}^- + \theta_{II}^+ \Delta lni_{t-i}^+ + \theta_{II}^- \Delta lni_{t-i}^-) + \sum_{i=0}^{n} \pi_2 \Delta lop_{t-i} + \varepsilon_t \quad (8b)$$

The dynamic adjustment multiplier which shows the asymmetric adjustment process is obtained the equations below (9a) and (9b) for the exchange rate and income differentials respectively.

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial led_{t+j}}{\partial lex_t^+},\ m_h^- = \sum_{j=0}^{h} \frac{\partial led_{t+j}}{\partial lex_t^-},\ h = 0, 1, 2, \ldots \quad (9a)$$

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial led_{t+j}}{\partial lni_t^+},\ m_h^- = \sum_{j=0}^{h} \frac{\partial led_{t+j}}{\partial lni_t^-},\ h = 0, 1, 2, \ldots \quad (9b)$$

Note that as $h \to \infty, m_h^+ \to \alpha_1$and $m_h^- \to \alpha_2$

Data estimations and discussions

The empirical analysis commenced with the examination of the characteristics of the individual variable from pre-estimation tests consisting of descriptive statistics and the unit root-tests. The outcomes of these initial investigations are reported in tables 1 and 2 for descriptive statistics and the two unit-root tests respectively. The unit-root tests consist of the popular Augmented Dickey-Fuller (Dickey and Fuller, 1979) and Phillips-Perron (Phillips and Perron, 1988) unit-root tests. From the evidence in table 1, the volume of energy demand is highest in Iran followed by Nigeria and the least in the Algeria judging from the mean values. Secondly, Iran has the weakest currency, while Venezuela has the most volatile exchange rate judging by the mean and standard deviation values of the exchange rates respectively. The kurtosis of all the series in all the economies is platykurtic with the exceptions of Venezuela

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and Iranian exchange rates. The series are predominantly negatively skewed with the exceptions of energy demand (*led*) in Venezuela and exchange rates (*lex*) in Venezuela, Nigeria and Algeria that are positively skewed. Table 2 reports the unit-root test (ADF) and Phillips-Perron test. The tests did not record any integration order higher than order-one, rather we discovered that the variables are fractionally integrated between order-zero I(0) and order-one I(1). This mixed order of integrations recorded from the unit-test results justify the application of the ARDL model and its non-linear extension (NARDL).

Table 1: Descriptive Statistics

	LED	**LEX**	**LNI**	**LOP**	**LED**	**LEX**	**LNI**	**LOP**
Des	**Iran**				**Venezuela**			
Mean	5.25	9.31	22.1	4.05	4.08	2.03	12.1	4.05
	6642	0874	0855	1062	7937	1065	1915	1062
Std D	0.22	0.87	1.02	0.506	0.12	3.73	0.46	0.50
	8470	1599	8156	444	2913	4958	5342	6444
Ske	-0.50	-0.82	-0.25	-0.32	0.00	2.96	-0.21	-0.32
Kurt	2.10	3.96	1.86	1.898	2.13	10.3	1.60	1.898
osis	4059	9917	9696	664	8428	9220	8184	664
	Nigeria				**Algeria**			
Mea	4.78	5.04	17.4	4.05	3.67	4.39	16.1	4.05
n	3343	4228	6965	1062	7449	1035	3934	1062
Std.								
Dev	0.19	0.32	0.91	0.506	0.24	0.16	0.53	0.50
.	3198	5547	3146	444	7533	7780	4683	6444
Ske	-0.09	1.13	-0.46	-0.32	-0.01	1.14	-0.43	-0.32
Kurt	1.52	3.20	1.96	1.898	1.69	3.00	1.78	1.898
osis	5143	5412	0001	664	6634	9485	7705	664

Table 2: Unit Root Tests

		ADF TEST			**PHILIPS-PERRON TEST**		
Country	**Series**	**Statistics**	**Prob.**	**I(d)**	**Statistics**	**Prob.**	**I(d)**
Iran	LED	-4.49368	0.0005	I(1)	-4.46850	0.0005	I(1)
	LEX	-3.18666	0.0247	I(0)	-4.22033	0.0012	I(1)
	LNI	-4.39034	0.0007	I(1)	-4.40421	0.0006	I(1)
	LOP	-3.90083	0.0033	I(1)	-3.88258	0.0035	I(1)
Venez	LED	-5.10415	0.0001	I(1)	-5.15986	0.0000	I(1)
	LEX	-6.97579	0.0000	I(1)	-6.97716	0.0000	I(1)
	LNI	-3.52100	0.0100	I(0)	-3.52528	0.0099	I(1)
	LOP	-3.90083	0.0033	I(1)	-3.88258	0.0035	I(1)
Nigeria	LED	-4.69473	0.0002	I(1)	-4.73312	0.0002	I(1)
	LEX	-4.05865	0.0020	I(1)	-4.05120	0.0020	I(1)
	LNI	-3.56087	0.0089	I(0)	-3.47323	0.0114	I(0)
	LOP	-3.90083	0.0033	I(1)	-3.88258	0.0035	I(1)
Algeria	LED	-5.03059	0.0001	I(1)	-5.03937	0.0001	I(1)
	LEX	-4.19182	0.0013	I(1)	-4.19686	0.0013	I(1)
	LNI	-4.42473	0.0006	I(1)	-4.42822	0.0006	I(1)
	LOP	-3.90083	0.0033	I(1)	-3.88258	0.0035	I(1)

The ADF test is used in determining the stationarity levels of the entire variable and confirmed by the Phillips Perron Tests, all at 5% significance levels.

To present a parsimonious result, we applied the maximum lag-order selected by various information criteria including the Akaike, Schwarz and Hannan-Quinn. The maximum lag selected is 2, but for the want of space, we report the table in the appendix. The full information of the estimated results of the equations comprising of the long- and short-run results, cointegration tests, post estimation/diagnostic, and the asymmetry tests are presented in table 3 accordingly. The full information includes the estimations of the equations (4) and (8a, 8b) for the ARDL and NARDL respectively. The long- and short-run results, the cointegration, the post-estimation/diagnostics, and the asymmetry tests results are reported in panels A-E of the table (3) respectively for each of the selected OPEC economies.

The major aim of the study is to explore the possible presence of non-linearity and asymmetry response of energy demand to exchange rate appreciations and depreciation which is relatively scarce in the literature. Equally, the paper aims to reaffirm the findings of previous studies concerning non-linear income elasticities of energy demand. For clarity and comparison, we began the analysis with the conventional and restrictive linear ARDL model. Just as noted earlier, the restrictive nature of the linear ARDL and the cointegration thereafter will result in what Granger and Yoon (2002) refers to hidden cointegration. To guide against such defects and provide a profound analysis, the non-linear ARDL (NARDL) quickly comes to the rescue. With the capacity of separating variables between partial sums of positive and negative values, one can pinpoint the relative reactions of these economies as it affects their demand for energy in response to movements of the exchange rate and national income. The restrictive and less-robust nature of the conventional ARDL is reinforced by the outcome of its parameters as compared with the NARDL approach (see table 3). Long-run (cointegration) relationships between the variables were established for all the economies using the non-linear method while such could not be established within the linear framework. Equally, the cusum and cusum of square graphs of the linear approach are predominantly unstable, but those obtained from the non-linear approach are all stable across the board, for want of space, we reported only the outputs from the non-linear (NARDL) model. (see fig. 1).

Table 3: Long / Short-run ARDL and NARDL, Diagnostic and Asymmetry Test Results

Iran	Coeff.	ARDL	Std. Error	NARDL	Std. Error
Panel A: Long-run	*Lex*	0.017551	[0.0355]	-	-
	Lni	0.179***	[0.0363]	-	-
	lex$^+$	-	-	-0.01130*	[0.0063]
	lex$^-$	-	-	-0.004478	[0.0300]
	lni$^+$	-	-	0.053***	[0.0177]
	lni$^-$	-	-	0.4815**	[0.2066]
	Lop	0.040789	[0.0354]	-0.0216**	[0.0096]
	C	1.0119**	[0.4515]	0.628***	[0.1801]
Panel B: Long-run	*Δlex*	-0.00857	[0.0058]	-	-
	Δlni		-	-	-
	Δlex$^+$	-	-	-0.0307**	[0.0137]
	Δlex$^-$*(-2)*	-	-	0.01839	[0.0265]
	Δlni$^+$	-	-	0.070960	[0.0504]
	Δlni$^-$	-	-	0.525***	[0.1372]
	Δlop	0.069***	[0.0115]	-	-
	Ect	-0.06***	(0.0146)	-0.082***	(0.0165)
Panel C	**Cointegration Test:**	3.911**		2.4409**	
Panel D:	**Post estimation/Diagnostic Test Results**				
	Adj. R^2	0.61		0.53	
	B-G Serial LM	1.15	(0.3221)	0.128638	(0.879)
	ARCH(1)	0.006824	(0.9344)	0.013494	(0.907)
	R-RESET	0.71403	(0.4013)	0.002782	(0.958)
	CUSUM: S	CUSUM^2:U		CUSUM: S	CUSUM ^{2}:S
Panel E:	**Wald Test for Asymmetry:**	*Lex-W*$_{LR}$:na	*lex-W*$_{SR}$:3.705*	*lni-W*$_{LR}$: 5.025**	*Lni-W*$_{SR}$: 7.77***

Venezuela	Coeff.	ARDL	Std. Error	NARDL	Std. Error
Panel A: Long-run	*Lex*	-0.02***	[0.0071]	-	-
	Lni	0.035819	[0.0690]	-	-
	lex$^+$	-	-	-0.008530	[0.0054]
	lex$^-$	-	-	-0.03600*	[0.0214]
	lni$^+$	-	-	0.0326**	[0.0153]
	lni$^-$	-	-	0.030385	[0.0410]
	Lop	0.177***	[0.0621]	0.019086	[0.0197]
	C	2.978***	[0.6517]	0.756***	[0.2558]
Panel B: Short-run	*Δlex*	-	-	-	-
	Δlni	-	-	-	-
	Δlex$^+$	-	-	-0.003171	[0.0040]
	Δlex$^-$	-	-	-0.111428	[0.0666]
	Δlni$^+$	-	-	0.064886	[0.0944]
	Δlni$^-$	-	-	0.105509	[0.0747]
	Δlop	0.151***	[0.0429]	0.210***	[0.0458]
	ect.	-0.16***	(0.0375)	-0.156***	(0.0000)
Panel C:	**Cointegration Test:**	3.796**		2.4029**	
Panel D:	**Post Estimation/Diagnostic Test Results**				
	Adj. R^2	0.41		0.46	
	B-G Serial LM	1.20(0.3)		0.97(0.3)	
	ARCH	0.59(0.4)		0.49(0.4)	
	R-RESET	0.03(0.8)		0.10(0.7)	
	CUSUM: S	CUSUM^2: S		CUSUM: S	CUSUM ^{2}: S
Panel E:	**Wald Test for Asymmetry:**	*Lex-W*$_{LR}$:na	*lex-W*$_{SR}$:na	*lni-W*$_{LR}$: 9.1***	*Lni-W*$_{SR}$: na

Nigeria	Coeff.	ARDL	Std. Error	NARDL	Std. Error
Panel A: Long-run	*Lex*	-0.38855	[0.4297]	-	-
	Lni	0.367430	[0.1966]	-	-
	lex$^+$	-	-	-0.037***	[0.0133]
	lex$^-$	-	-	-0.1126**	[0.0483]
	lni$^+$	-	-	0.029***	[0.0084]
	lni$^-$	-	-	3.642108	[2.5178]
	Lop	-0.18839	[0.2136]	-0.0166**	[0.0072]
	C	1.21843*	[0.6953]	0.497***	[0.1125]

Panel B: Short-run	*Δlex*	-0.04386	[0.0297]	-	-
	Δlni	-0.13***	[0.0477]	-	-
	Δlex^{+}	-	-	-0.0734**	[0.0313]
	Δlex^{-}	-	-	0.126661	[0.0808]
	Δlni^{+}	-	-	-	-
	Δlni^{-}	-	-	-0.08844*	[0.0471]
	Δlop	0.120***	[0.0129]	0.130***	[0.0146]
	Ect	-0.03***	(0.0124)	-0.489***	(0.0000)
Panel C:	**Cointegration Test:**	Noc		4.365***	
Panel D:	**Post Estimation/Diagnostic Test Results**				
	Adj. R^2	0.74		0.77	
	B-G Serial LM	1.93(0.1)		0.15(0.8)	
	ARCH	0.54(0.4)		0.00(0.9)	
	R-RESET	2.1(0.0)**		2.07(0.1)	
	CUSUM: S	$CUSUM^2$: U		CUSUM: U	$CUSUM^2$: S
Panel E:	**Wald Test for Asymmetry::**	$Lex\text{-}W_{LR}$: 3.312*	$lex\text{-}W_{SR}$: 5.429**	$lni\text{-}W_{LR}$: na	$Lni\text{-}W_{SR}$: na
Algeria	**Coeff.**	**ARDL**	**Std. Error**	**NARDL**	**Std. Error**
Panel A: Long-run	*Lex*	0.206285	[0.2031]	-	-
	Lni	0.446***	[0.0966]	-	-
	lex^{+}	-	-	0.032333	[0.0318]
	lex^{-}	-	-	0.030290	[0.0514]
	lni^{+}	-	-	0.05609*	[0.0305]
	lni^{-}	-	-	0.024139	[0.0451]
	Lop	-0.052973	[0.0885]	-0.003978	[0.0133]
	C	-4.16***	[0.4823]	0.506***	[0.1678]
Panel B: Short-run	*Δlex*	-0.08394	[0.0813]	-	-
	Δlni	0.034246	[0.0919]	-	-
	Δlex^{+}	-	-	0.335***	[0.0726]
	Δlex^{-}	-	-	-0.106556	[0.1284]
	Δlni^{+}	-	-	-0.257***	[0.0740]
	Δlni^{-}	-	-	-	-
	Δlop	-0.12***	[0.0402]	0.014732	[0.0201]
	Ect	-0.11***	(0.0232)	-0.254***	(0.0000)
Panel C:	**Cointegration Test:**	4.493**		2.455**	
Panel D:	**Post Estimation/Diagnostic Test Results**				
	Adj. R^2	0.64		0.574	
	B-G Serial LM	2.4(0.0)*		0.21(0.8)	
	ARCH	0.64(0.7)		0.04(0.8)	
	R-RESET	0.9(0.3)		0.34(0.5)	

	CUSUM: S	$CUSUM^2$: U		CUSUM: S	$CUSUM^2$: S
Panel E:	**Wald Test for Asy:**	$Lex\text{-}W_{LR}$:na	$lex\text{-}W_{SR}$: 2.77***	$lni\text{-}W_{LR}$: na	$Lni\text{-}W_{SR}$: na

Note: *, **, ***, respectively denote 10%, 5% and 1% levels of significance. na depicts no asymmetry, noc implies no cointegration, S / U denote stable and unstable cusum and $cusum^2$ respectively. ARDL and NARDL denote autoregressive distributed lag and non-linear autoregressive distributed lag models respectively. C denotes constant, *Ect* denotes error correction term. Values in brackets [] are standard error values while those in parenthesis () are probability values. The cointegration value for the NARDL was obtained through the Wald test coefficient restrictions with the Null Hypothesis of no cointegration: C(2)=C(3)=C(4)=C(5)=C(6)=C(7)=0 where the null is rejected if the F-Statistic value is significantly different from zero. B-G Serial LM denotes Breusch-Godfrey serial correlation tests, ARCH represents autoregressive conditional hetroscedasticity test, while R-REST denotes Ramsey Reset specification test. $Lex\text{-}W_{LR}$, $lex\text{-}W_{SR}$, $lni\text{-}W_{LR}$, $lni\text{-}W_{SR}$ *denotes Wald Long- and Short-run asymmetry of exchange rate and national income respectively*. The joint null hypothesis of no asymmetry is $-\theta^{+}/p = -\theta^{-}/p$.

Cusum and Cusum² of NARDL

Iran

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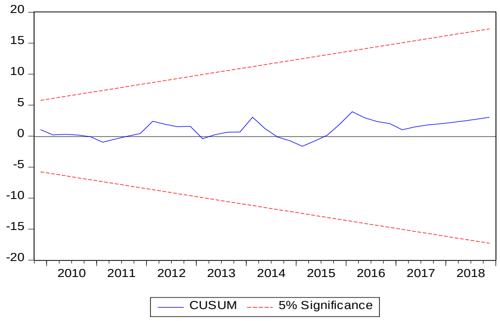
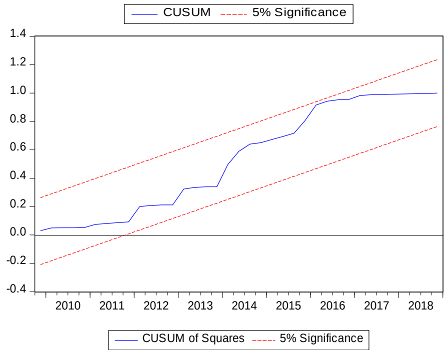
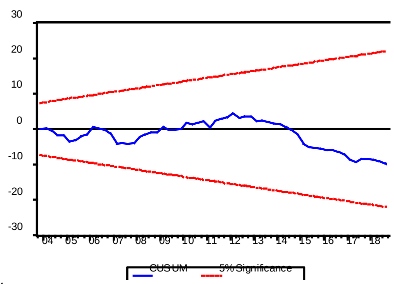
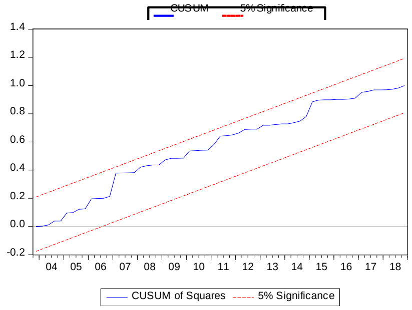


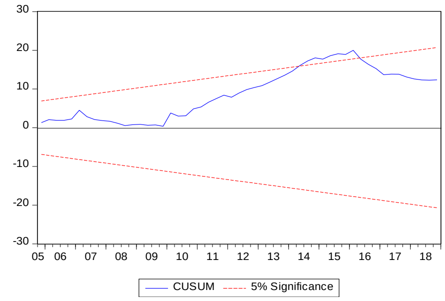


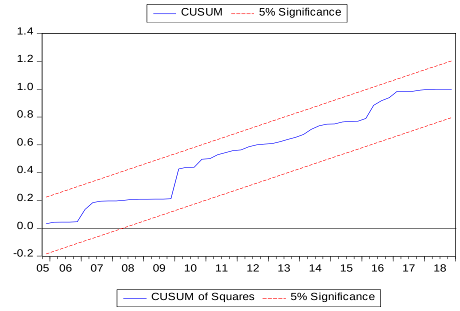
Venezuela



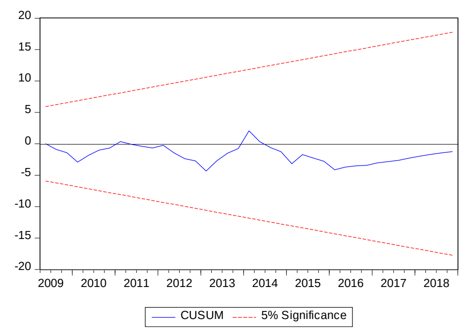


Nigeria





Algeria



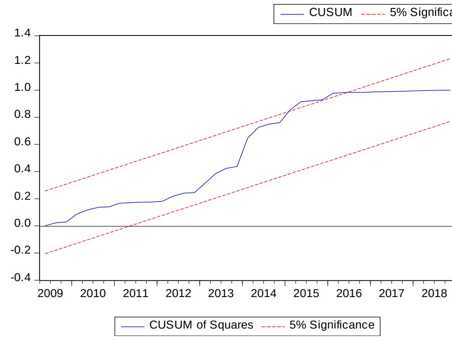


Fig. 1. Cusum and Cusum^2 from NARDL estimations

More findings

In Iran, demand for energy increases significantly in response to exchange rate appreciation both in the long- and short-run. Energy demand in Iran remains unaffected

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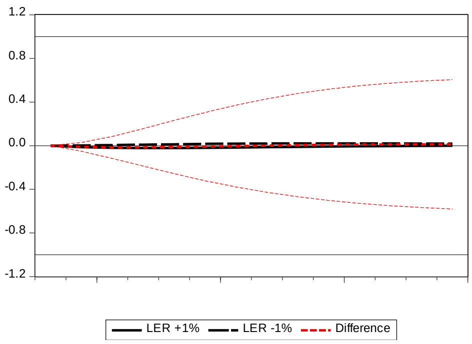
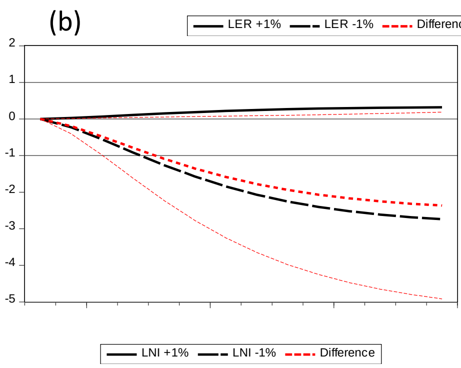
as the local currency depreciates against the US dollar. In reactions to income changes, energy demand in Iranian increases significantly in moments of rising and falling national income. This evidence is in tandem with the findings of most previous studies including that of Liddle et al (2020) and the review by Labandeira et al (2017). In Venezuela and Nigeria, exchange rate depreciation affects the demand for energy negatively. Exchange rate appreciation does not affect energy demand significantly in Venezuela, while in Nigeria; it results in significant reductions in energy demand. With regards to Algeria, energy demand is unaffected by both appreciations and depreciation of the exchange rate in both time dimensions. Much like what obtains in Iran and as recorded in previous studies, energy demands in Venezuela, Nigeria and Algeria increased significantly as these economies witness rising national incomes. The demand for energy remains unchanged in these countries when their national income declines. This highlights the importance of energy in the quest for developmental and industrial activities in the modern economies.

The tests for asymmetry are reported in Panel E of Table 3 for each economy accordingly. The test is conducted through the Wald F test with the null hypothesis of no asymmetry. The null hypothesis can only be rejected only if the probability value of the Wald F-test is significantly greater than zero at the chosen level of significance. The Wald tests for long- and short-run denoted by (W_{LR} and W_{SR}) is calculated through $-\theta+/p = -\theta-/p$. The null hypothesis presumes equality between the coefficients of both partial sums of the variable for long-run strands and short-run frameworks. From the findings in panel E of Table 3, the asymmetry effect of exchange rate on energy demand was only recorded in the short-run in Iran and Algeria without such in the long-run. The exchange rate does not have an asymmetric effect on energy demand in Venezuela both in the short- and long-run. The exception to these pieces of evidence is the case of Nigeria where the exchange rate affects energy demand asymmetrically both in long- and short-run. This revelation highlights the need for country-specific studies to avoid aggregation bias. With respect to income differentials, Iran energy demand is affected asymmetrically both in the long- and short-run as national income changes. In Venezuela, national income has asymmetry effect on energy demand only in the long-run. In Nigeria and Algeria, national income changes do not affect energy demand asymmetrically in both time dimensions. To provide more evidence to these revelations, the dynamic adjustment multiplier graph (fig. 2) reveals the dynamic adjustment pattern and process of energy demand to exchange rate and income movements.

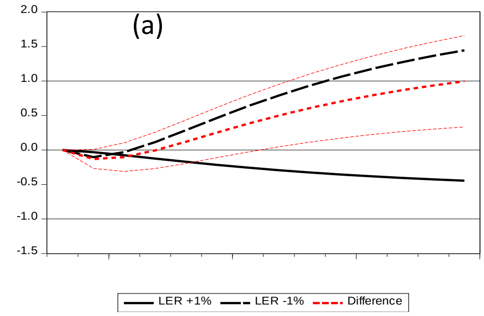
The post estimation/diagnostic tests for each of the economy are presents in panel D accordingly. The post estimations/diagnostic tests conducted include the Breusch-Godfrey serial correlation tests, the ARCH test for heteroscedasticity test, the Ramsy-RESET test for model specification and the CUSUM and CUSUM^2 tests for model stability. Overwhelmingly, all the statistics from the diagnostic tests of the nonlinear (NARDL) approach unlike the linear (ARDL) approach confirm the robustness of the study and this makes it more appropriate for policy prescriptions.

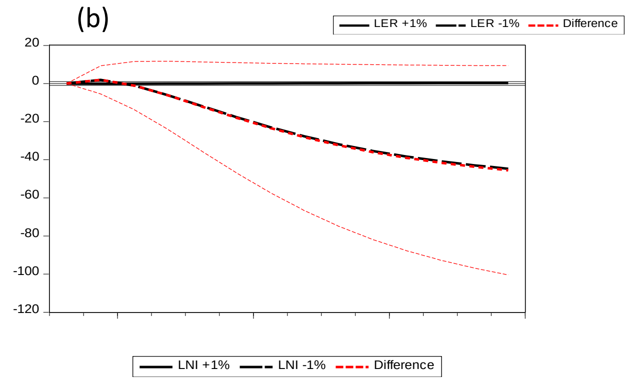
Iran (a)



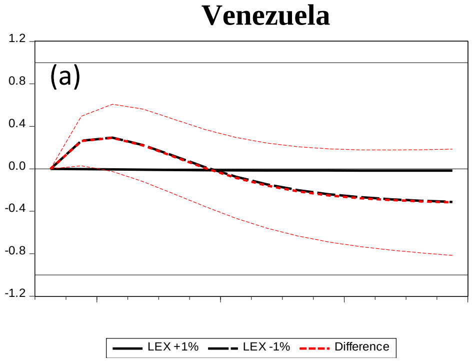


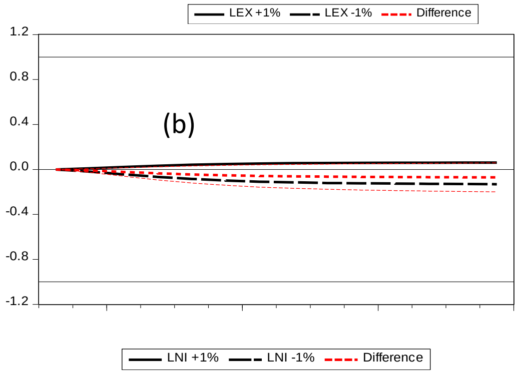
Nigeria





Venezuela





Algeria

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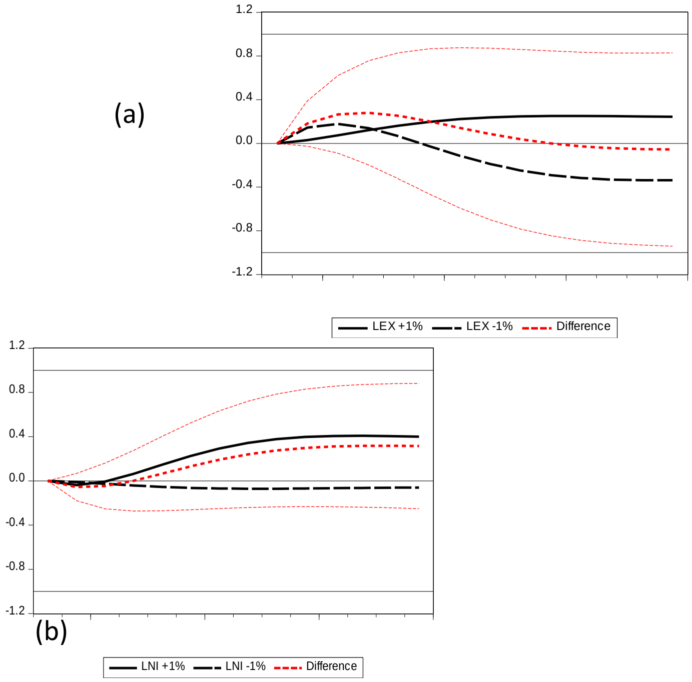

Fig. 2. Dynamic Adjustment Multiplier Graphs

As noted earlier, the NARDL reveals three types of asymmetries, namely; the long-run asymmetry, the short-run asymmetry and the dynamic adjustment asymmetry. The long- and short-run asymmetries earlier captured in panel E of table 3 are calculated with the Wald test using the X^2 distribution of one degree of freedom (Kisswani, 2018; Uche, 2019; Omoke et al., 2020). The dynamic adjustment multiplier graphs presented in figure 2 above capture the underlying asymmetric adjustment process of energy demand to both the exchange rate changes (a) and national income changes (b) for each of the selected OPEC economy. The positive and negative innovative curves show how changes in the movement variable affect the response variable. For the economy of Iran, the graphs reaffirms the absence of asymmetry (graph a) and the presence of asymmetry (graph b) running respectively from exchange rate and income differentials to energy demand. Similar scenario is revealed concerning the Venezuela economy. For the economy of Nigeria, exchange rate affects energy demand asymmetrically, while income shocks effects are symmetry. In Iran, demand for energy adjusts faster to national income positive shocks than negative shocks. In Venezuela, energy demand adjustment processes to both shocks (positive and negative) in national income are of equal proportions. The graph (a) for Nigeria further reveals a faster adjustment of energy demand to exchange negative shock (depreciation) than positive shock (appreciations). For the Algerian economy, energy demand adjustment processes to exchange rate shocks (positive and negative) are equal. The use of the dynamics adjustment multiplier graphs provides more profound guidelines for energy demand policies and related issues in the selected economies.

Conclusions

The study explores the asymmetry effects and dynamic adjustment process of energy demand to exchange rate and income differentials in selected OPEC economies, viz; Iran, Venezuela, Nigeria and Algeria from2000Q1 to 2018Q4). To give empirical details to the stated objectives, we applied a non-liner autoregressive distributed lag model (NARDL) proposed by Shin et al (2014), an enhanced version of the ARDL of Peseran and Shin (1999) and bounds test of Shin et al (2001). The non-linear version (NARDL) decomposes series into its positive and negative partial sums to reveal the specific and separate effects of each on the dependent variable. The motivation for such enquiry is based on the numerous limitations observed in existing knowledge among which includes the non-consideration of the exchange rate in their energy demand specifications, the dissenting and divergent findings and conclusions, the assumptions of linearity, applications of panel data studies and the concentrations in studying mainly the advanced economies. To fill these gaps, the present study incorporated the exchange rate in its energy demand specification within a nonlinear framework to unravel the role of exchange in energy demand specifically for each economy to avoid the heterogeneity bias inherent in panel data estimations. To provide a more robust and comparative analysis, we explored both the linear and non-linear versions of the ARDL model. The non-linear model (NARDL) provides more clear-cut findings than the linear approach based on pieces of evidence from their parameters.

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The empirical estimations highlight the relevance of the exchange rate and the need to incorporate it in energy demand models as most economies depend heavily on external sources for domestic energy supplies. The study reports that exchange rate movements (appreciations and depreciation) affect energy demand asymmetrically in both Nigeria and Algeria but such effects were not found in Iran and Venezuela. Several studies in the past identified asymmetries passing through national income differentials to energy demand, but their focuses were mainly the advanced and the OECD economies. Having identified this lacuna, we explore to identify if such is obtainable in the selected OPEC economies that fall within the bracket of developing economies. With regards to the Iranian and Venezuela's economies, our findings conformed with those previous studies that report asymmetry effects from income changes to energy demand. However, such assertions do not apply to the economies of both Nigeria and Algeria. Further details provided by the dynamic adjustment multiplier graph reveals that energy demand adjustment in Iran is stronger to negative than positive income shocks, while equal adjustments of energy demand to both shocks (income changes) were recorded in Venezuela. On the other streams, energy demand adjustment to exchange rate changes in Nigeria is more responsive to negative (depreciation) than positive (appreciations) shocks. The adjustment dynamics of energy demand to exchange rate changes in Algeria are of equal proportions. Unarguably, these clear-cut revelations from this study aptly highlight the significance of country-specific studies as against aggregated study of panel data. It is only through this means that country specifics and peculiarities can be established. Having revealed these much, future energy demand models and policies should take cognizance of the effects of the exchange rate as its non-inclusion could undermine the effectiveness of energy demand policies majorly in economies that rely heavily on external sources for domestic energy supplies. A critical open task for further investigations is to widen the study scope by separating the exchange rate effects between large and moderate changes. The empirical outcomes of this study will provide reliable guidelines for energy demand policies and ensures proper exchange rate alignment to curtail future welfare losses.

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