The Asymmetric Impact of Informal Economy in the Energy-Economic Growth Nexus in Saudi Arabia

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Abstract: At the macroeconomic level, the question of the informal sector is the most debated. This paper studies the relationship between the informal economy (IFGDP), formal economy (FGDP), total economy (TGDP), and energy consumption (EC) in Saudi Arabia. The Nonlinear Distributed Autoregressive Model (NARDL) is used as an estimation technique on annual data ranging from 1970 to 2017. The empirical results confirm the relationships between variables that are asymmetric. Positive and negative shocks on FGDP, TGDP and IFGDP have positive effects on EC. The results will help policymakers and government officials have a better understanding of the effect of the IFGDP on energy demand and FGDP in Saudi Arabia's development.

Keywords: Informal economy; Energy consumption; Saudi Arabia; Asymmetries.

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1 Introduction and Background

In recent decades, energy consumption and macroeconomic variables are examined in several studies. The relationship between the informal economy and energy consumption has received little attention in theoretical as well as empirical literature, [1], [2], [3], [4], [5]. One of the most important findings is that the IFGDP accounts for a large share of FGDP, especially for developing countries6]. Without considering unrecorded income when investigating the causal link between energy consumption and economic growth, the results may be biased. According to a recent article by [7], 157 countries between 1991 and 2017 were analyzedto determine the size and growth of the IFGDP.For the total sample, the informal economy accounts for 30.9% of GDP. It is estimated that the informal economy in Saudi Arabia makes up about 17% of its formal economy. It is suggested that two-thirds of IFGDP would be spent on the FGDP, [8], [9]. Empirical and theoretical studies indicate that the underground economy reduces real GDP because of the lack of tax revenue. Several studies showed that small informal firms, such as [10] are unproductive, rarely become formal, and pay less than half as much as small formal firms.

Empirical studies examine the relationship between EC, FGDP and the IFGDP are very rare, compared to a vast literature that studies the relationship between energy and growth. A pioneering study by [1] estimates the informal economy in Turkey between 1973 and 2003 using a methodology developed. They are pioneers in the idea that informal economies can be measured by CO2 emissions and energy consumption. Taking into account the size of the informal economy, [2] examines the long-term impact of EC on TFGDP in Turkey during the period 1970-2005. They show that the relationship between TGDP and EC is rejected in the long-term, while EC strongly influences the FGDP. In contrast, FGDP and EC are found to be causally related in the short-term, but TGDP and EC do not appear to have any causal relationship.EC-FGDP nexus therefore supports the conservative hypothesis, implying that energy conservation policies can reduce greenhouse gas emissions without affecting economic growth. IFGDP and production are found to be unstable over time. The later proves the presence of the neutrality hypothesis. Consequently, the implementation of economic policies aimed at reducing the IFGDP cannot serve as a complement to energy conservation programs.

From 1980 to 2009, [11] examines the causal relationship between FGDP and EC in Tunisia in the presence of the IFGDP. The empirical results indicate that there is Granger causality running from EC to FGDP and TGDP. To reduce the number of polluting emissions, the government must use more effective instruments. This analysis suggests that informal economic growth contributes significantly to environmental degradation, which has important policy implications. Between the years 1980-2012, [12] studies the relationship for 159 countries between IFGDP and EC. Their results are reported for several groups of countries based on their informal economies. The IFGDP negatively impacts EC, according to their findings. In emerging countries, for example, the size of the informal sector increased by 1%, resulting in a decrease in energy intensity of about 0.13%. Furthermore, the relationship between IFGDP and EC is U-shaped. In particular, all countries whose IFGDP is less than 20% of their FGDP showed a negative relationship between EC and the IFGDP.

The impact of IFGDP on environmental pollution in African countries from 1991 to 2015 is examined by [4]. They found that the IFGDP and institutional quality are significant contributors to environmental pollution in Africa by using ordinary least squares, fixed effects, and generalized system method of moments. Furthermore, the IFGDP influences institutional quality in the region, which in turn deteriorates the quality of the environment. According to this information, the low level of institutional quality in the region leads to a higher level of IFGDP, and therefore a greater degree of environmental pollution. Recently, [5] examines the relationship between the IFGDP and the ecological footprint for the case of Africa during the 1991-2017 periods. The study finds that both the IFGDP and FGDP have positive and statistically significant impacts on ecological footprints, suggesting that the IFGDP and FGDP contribute to environmental degradation. In similar studies, [13] analyzes data from South Asian countries to study the effect of IFGDP on EC and pollution. The study shows increased EC in Sri Lanka and Pakistan, but decreased EC in India when using the Autoregressive Distributed Lag Model (ARDL). Thus, the Nonlinear ARDL (NARDL) model shows that the IFGDP contributes to the improvement of EC in Pakistan.

Furthermore, we add to the empirical literature in a variety of fields in this context. Despite studies in Saudi Arabia ignoring the role of the IFGDP on EC, this study is the first to examine its effect on EC, [14], [15], [16]. Second, this study is needed since the impact of the IFGDP on EC is neglected. FGDP cannot be used alone to understand the affect of economic activities on EC.

The reason for using Saudi Arabia in this study is as follows: In the Middle East, Saudi Arabia has the largest economy and is the richest Arab nation. By implementing a major public works policy, attracting foreign direct investment, and ensuring a sound banking and financial system, the country has become the largest economy in the region. However, Saudi Arabia suffers from a phenomenon that threatens its economy, which is informal economy. This type of economy constitutes an important part of the GDP volume, since the rate of informal economy in the Kingdom during the period 1991-2017isestimated at 16.28% of the volume of GDP, [6]. Such economic growth is almost entirely based on oil and gas, which has an impact on the country's environmental sustainability.

Following is an outline of the remainder of the paper. The data and methodology are presented in section 2. Section 3 presents the empirical results, and the conclusion and policy recommendations are discussed in the final section.

2 Data and Methodology

2.1 Data

The data includes four variables of the Saudi economy, namely energy consumption (EC), formal gross domestic product (FGDP), total gross domestic product (TGDP) and informal economy

(IFGDP), and covers the period 1970-2017. Data for FGDP and EC are taken from the World Bank database (WDI, 2022). The IFGDP data are taken from the articles of [6] and [17]. The FGDP is expressed in dollars (US constant 2015). The TGDP is the sum of FGDP and IFGDP. EC is expressed in kilograms of oil equivalent per capita.
Figure 1 describes the trajectory of our variables. The graph shows that all variables follow an upward trend and increase during the examined period. FGDP and TGDP show a common trend over the entire period. The difference between TGDP, FGDP and IFGDP seems to have a similar shape as FGDP and TGDP in the time period considered.

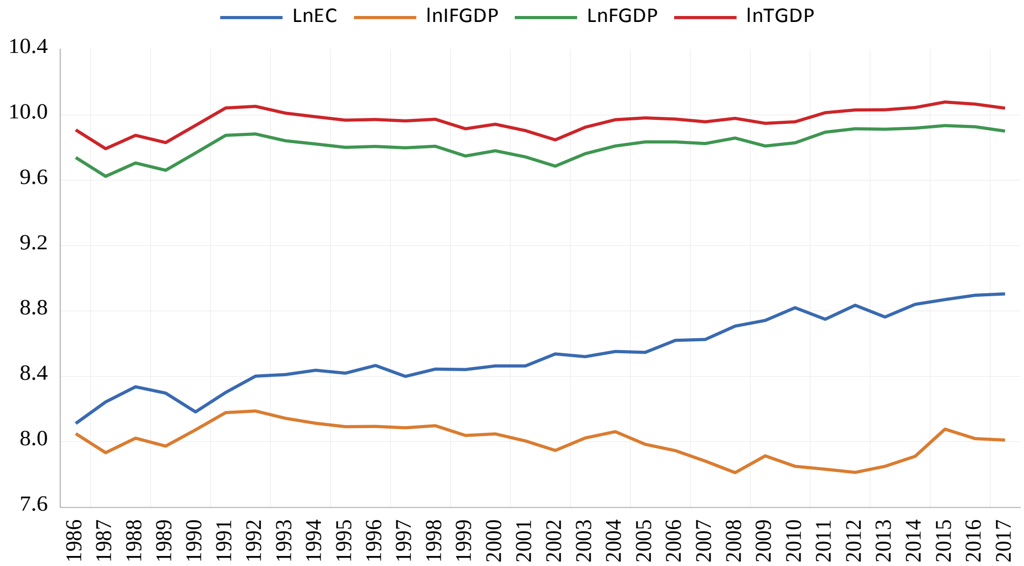

Fig. 1: Energy Consumption, FGDP, TGDP and IFGDP.

Table 1 presents the descriptive statistics and the stochastic properties of the variables used in our study. Based on our results, we show that TGDP and EC have dispersion coefficients of 0.06 and 0.218, respectively. With the exception of energy consumption, all the series have positively asymmetric distributions, which means their lines are longer than those in a normal distribution. The IFGDP and the TGDP show excess kurtosis, indicating that they have fatter tails than a normal distribution. Data variables are normally distributed according to the Jarque-Bera statistic.

Table 1. Summary statistics for the series.

	EC	IFGDP	FGDP	TGDP
Mean	8.541899	8.001219	9.814599	9.966765
Median	8.493103	8.019457	9.816604	9.971686
Maximum	8.904902	8.186980	9.934401	10.07937
Minimum	8.110967	7.810439	9.624406	9.793305
Std. Dev.	0.218137	0.105242	0.079093	0.068511
Skewness	0.088849	-0.261067	-0.471811	-0.585000
Kurtosis	2.091711	2.171914	2.715220	3.039396
Jarque-Bera	1.142087	1.277802	1.295362	1.827270
Probability	0.564936	0.527872	0.523258	0.401064
Sum	273.3408	256.0390	314.0672	318.9365
Sum Sq. Dev.	1.475101	0.343350	0.193926	0.145508
Observations	48	48	48	48

2.2 Methodology

According to previous studies, the ARDL methodology proves insufficient to analyze both long-term and short-term relationships between variables when the dynamics of those variables show nonlinear patterns, [18], [3], [19], [20], [21]. Non-linearity is commonly observed in economic and financial time series for a variety of reasons. Indeed, economic and financial time series are less likely to follow simple linear paths during the period when we conducted our research, because several events complicate them. In fact, The Asian economic crisis of 1997, the oil shocks in 2008, and the global financial crisis of 2008 were among the most important events during the period 1980-2017. It is necessary to develop even more sophisticated models in order to obtain robust results after sudden events cause structural breaks in time series data. In our study, we used [22] nonlinear ARDL model. This model can incorporate long- and short-term asymmetries as well as non-linearity, while simultaneously taking into account the cointegration between variables in the model. Formally, the linear ARDL model has the following form:

$$\Delta EC_t = \sum_{j=1}^{p-1} \theta_j \Delta EC_{t-j} + \sum_{j=0}^{q-1} \phi_j \Delta FGDP_{t-j} + \sum_{j=0}^{q-1} \varphi_j \Delta IFGDP_{t-j} + \sum_{j=0}^{q-1} \gamma_j \Delta TGDP_{t-j} + \alpha + \beta_{EC} EC_{t-1} + \beta_{FGDP} FGDP_{t-1} + \beta_{IFGDP} IFGDP_{t-1} + \beta_{TGDP} TGDP_{t-1} + \eta_t$$

(1)

According to Akaike and Schwarz's information criteria, p and q represent delay orders. The symbol Δ represents the first difference operator.

Based on the simultaneous study of the long- and short-term asymmetry effects of the ARDL model above along with the evaluation of NARDL models for each variable, the following three NARDL models are estimated:

$$\Delta EC_t = \sum_{j=1}^{p-1}\theta_j \Delta EC_{t-j} + \sum_{j=0}^{q-1}(\eta_i^+ \Delta FGDP_{t-j}^+ + \eta_i^- \Delta FGDP_{t-j}^-) + \alpha + \beta_{EC}EC_{t-1} + \beta_{FGDP}^+ FGDP_{t-j}^+ + \beta_{FGDP}^- FGDP_{t-j}^- + \varepsilon_t \quad (2)$$

$$\Delta EC_t = \sum_{j=1}^{p-1}\theta_j \Delta EC_{t-j} + \sum_{j=0}^{q-1}(\rho_i^+ \Delta TGDP_{t-j}^+ + \rho_i^- \Delta TGDP_{t-j}^-) + \alpha + \beta_{EC}EC_{t-1} + \beta_{TGDP}^+ TGDP_{t-j}^+ + \beta_{TGDP}^- TGDP_{t-j}^- + \varepsilon_t \quad (3)$$

$$\Delta EC_t = \sum_{j=1}^{p-1}\theta_j \Delta EC_{t-j} + \sum_{j=0}^{q-1}(\pi_i^+ \Delta IFGDP_{t-j}^+ + \pi_i^- \Delta IFGDP_{t-j}^-) + \alpha + \beta_{EC}EC_{t-1} + \beta_{IFGDP}^+ IFGDP_{t-j}^+ + \beta_{IFGDP}^- IFGDP_{t-j}^- + \varepsilon_t \quad (4)$$

Positive and negative partial sums are denoted by (+) and (-) in Eqs (2)-(4) and are calculated as follows:

$$\mathrm{FGDP}_t^+ = \sum_{j=1}^{t}\Delta FGDP_j^+ = \sum_{j=1}^{t}\max(0, \Delta FGDP_j) \text{ and}$$

$$\mathrm{FGDP}_t^- = \sum_{j=1}^{t}\Delta FGDP_j^- = \sum_{j=1}^{t}\min(\Delta FGDP_j, 0);$$

$$\mathrm{TGDP}_t^+ = \sum_{j=1}^{t}\Delta TGDP_j^+ = \sum_{j=1}^{t}\max(0, \Delta TGDP_j) \text{ and}$$

$$\mathrm{TGDP}_t^- = \sum_{j=1}^{t}\Delta TGDP_j^- = \sum_{j=1}^{t}\min(\Delta TGDP_j, 0);\ \mathrm{IFGDP}_t^+ = \sum_{j=1}^{t}\Delta IFGDP_j^+ = \sum_{j=1}^{t}\max(0, \Delta IFGDP_j) \text{ and}$$

$$\mathrm{IFGDP}_t^- = \sum_{j=1}^{t}\Delta IFGDP_j^- = \sum_{j=1}^{t}\min(\Delta IFGDP_j, 0);$$

For every determinant of energy consumption, positive and negative coefficients are calculated similarly. For example, the long-term positive and negative coefficients for FGDP are calculated as $\delta_{FGDP}^+ = -\frac{\beta_{FGDP}^+}{\beta_{EC}}$ and $\delta_{FGDP}^- = -\frac{\beta_{FGDP}^-}{\beta_{EC}}$,respectively. Using Wald statistics, we test the long- and short-term asymmetry of the NARDL models in equations (2)-(3). We use a Wald statistic test for long-term asymmetry in energy consumption for each determinant Y (FGDP, TGDP, and IFGDP) with the null hypothesis: $\delta_Y^- = \delta_Y^+$.For short-term symmetry, we use a Wald statistic for null hypotheses as follows: $\eta_i^+ = \eta_i^-$ for $i = 1, 2, ..., q-1$. If the Wald test allows the null hypothesis of long- or short-term symmetry to be accepted for a determinant of energy consumption, linearity is imposed for that particular variable and the associated constrained NARDL model is estimated.

In the event that asymmetries are detected (long-term or short-term), the following formulas are used to calculate the asymmetrical multipliers for each determinant Y(FGDP, TGDP and IFGDP) on changes in EC (positive or negative variations):

$$m_{h,Y}^+ = \sum_{j=0}^{h}\frac{\partial EC_{t+j}}{\partial Y_t^+} \text{ and } m_{h,Y}^- = \sum_{j=0}^{h}\frac{\partial EC_{t+j}}{\partial Y_t^-}$$

Shin et al., [22] showed that $m_{h,Y}^+ \to \delta_Y^+$ and $m_{h,Y}^- \to \delta_Y^-$, knowing that $h \to \infty$.

3 Empirical Results

It is necessary to test for (non) stationarity by using both the ADFand ZA unit root tests, which are more appropriate for nonlinear series if breaks are present in their trajectory. ZA and ADF unit root tests can be found in Table 2 below.

Table 2. Unit Roots tests

Series	ADF		ZA	
	Levels	First difference	Levels	First difference
EC	-5.145***	_	-10.655***	_
FGDP	0.235	-6.587***	-2.364	-7.633***
IFGDP	0.128	-2.364**	-3.928	-8.099***
TGDP	0.556	-2.927**	-3.310	-5.365**

Note: The critical values of the ZA(1992) test for 1%, 5%, and 10% significance levels are 5.57, 5.08, and 4.82.

Table 2 shows that all the variables, with the exception of EC, cannot be rejected by the null hypothesis of non-stationarity. These tests reject non-stationarity for all variables of first-difference, indicating that all variables are I(1), except EC. There is a difference between the order of integration of EC compared to other variables since energy consumption is stationary in level (I(0)).As a result of variable stationarity, Johansen's cointegration method cannot be used to test whether the variables have a common long-term relationship since it requires that the variables are integrated equally. It appears that the Johansen cointegration test is not appropriate when there is a difference in the order of integration between the variables. Therefore, in order to test if the variables are cointegrated, we use the NARDL methodology.
Using Wald statistics, the results of the tests for long- and short-term asymmetries are presented in Table 3.There is no evidence that long- and short-term asymmetries exist in FGDP, TGDP, and IFGDP according to Wald statistics. On the long and short term, these results demonstrate a nonlinear and asymmetrical response of energy consumption to FGDP, TGDP, and IFGDP. The long-term relationship between the underlying variablesisconfirmed by the presence of short-and long-term asymmetries. In order to accomplish this, we apply the [22] nonlinear test approach.

Table 3. Wald Test for Short- and Long-term Symmetries

Wald test	FGDP	TGDP	IFGDP
W_{LR}	8.238*	12.781**	3.088***
W_{SR}	10.022*	15.134*	6.158*

Note: The Wald test for short-term symmetry is represented by the WSR.The Wald test for long-term symmetry is represented by the WLR. *, **, and *** indicate rejecting the null hypotheses of short- and long-term symmetry at the levels of significance of 1%, 5%, and 10%, respectively.

According to Table 4, the bounds tests for asymmetric cointegration produced the following results. We use the T(TBDM) statistic developed by [23] as well as the F statistic (SPSS) developed by [24] to investigate whether there is nonlinearity. The calculated F-statistics of [24] and the BDM test t-statistics are greater than the upper critical value, rejecting the null hypothesis that there is no asymmetric cointegration. This is more evident in the FGDP, the TGDP, and the IFGDP. For the Saudi economy, it may be better to introduce a measure of IFGDP in the analysis of EC and economic growth over the long and short term. According to the empirical findings, the EC, FGDP, TGDP, and IFGDP have long-term asymmetric relationships.

Table 4. Bound Testing for Asymmetric Cointegration

	FGDP	TGDP	IFGDP
F_{PSS}	25.366*	30.562*	27.304*
T_{BDM}	-4.358*	-6.254*	-3.774***
χ^2_{Normal}	3.012	1.981	4.011
χ^2_{ARCH}	0.224	0.337	0.207
χ^2_{RESET}	0.501	0.286	0.422
χ^2_{SERIAL}	1.336	0.885	0.905

Pesaran et al., (2001)			Banerjee et al., (1998)	
Significance level	LCB I(0)	UCB I(1)	Significance level	Critical values
1%	3.271	5.365	1%	-4.713
5%	2.636	3.551	5%	-4.035
10%	2.331	3.224	10%	-3.678

Note: * and *** denote significance at the 1% and 10% levels, respectively.

Following the results in Table 3, which confirm the existence of the short- and long-term asymmetric relationships between EC and its determinants in Saudi Arabia, we estimate the NARDL models given in equations (2)-(3) to verify the asymmetric effect of FGDP, TGDP and IFGDP on long-term as well as short-term energy consumption. Using the three models above, we can estimate the NARDL in Table 5. As a potential determinant of EC, we consider FGDP in the first model. In the next models, we replace the FGDP by the TGDP, and then we investigate its impact on the EC using the IFGDP. Based on the empirical results, all three models considered have negative lagged dependent variables that are statistically significant, which confirms the model's stability condition.

Table 5. NARDL estimation results

	FGDP			TGDP			IFGDP	
Variables	Coefficient	*t*-Statistic	Variables	Coefficient	*t*-Statistic	Variables	Coefficient	*t*-Statistic
Constant	1.351***	7.022	Constant	1.982***	8.011	Constant	2.367***	5.667
$FGDP^{+}_{t-1}$	0.258***	5.697	$TGDP^{+}_{t-1}$	0.492***	6.354	$IFGDP^{+}_{t-1}$	0.265***	6.384
$FGDP^{-}_{t-1}$	0.189*	1.801	$TGDP^{-}_{t-1}$	0.365***	6.064	$IFGDP^{-}_{t-1}$	0.198**	2.088
$\Delta FGDP^{+}_{t}$	–	–	$\Delta TGDP^{+}_{t}$	–	–	$\Delta IFGDP^{+}_{t}$	0.169*	1.762
$\Delta FGDP^{+}_{t-1}$	-0.656***	6.022	$\Delta TGDP^{+}_{t-1}$	-0.305***	5.055	$\Delta IFGDP^{+}_{t-1}$	-0.681***	7.881
$\Delta FGDP^{+}_{t-2}$	-0.662***	5.984	$\Delta TGDP^{+}_{t-2}$	-0.368***	4.964	$\Delta IFGDP^{+}_{t-2}$	-0.627**	2.681
$\Delta FGDP^{-}_{t}$	-0.684***	4.224	$\Delta TGDP^{-}_{t}$	-0.299**	2.337	$\Delta IFGDP^{-}_{t}$	–	–
$\Delta FGDP^{-}_{t-1}$	-0.506**	2.354	$\Delta TGDP^{-}_{t-1}$	-0.247***	5.972	$\Delta IFGDP^{-}_{t-1}$	–	–

Note: A positive partial sum is represented by a superscript "+", whereas a negative partial sum is represented by a superscript "-". ***, **, and *denote significance at the 1%, 5% and 10% levels.

EC is positively affected by positive (negative) shocks to the FGDP, TGDP, and IFGDP, in the long term. EC is more influenced by these variables' increases than their decreases. Using the NARDL, the independent variables are decomposed into positive and negative partial sums. Increased EC results from positive changes in FGDP, TGDP, and IFGDP, in the long term. On the other hand, a decrease in FGDP, TGDP, and IFGDP will result in a decrease in EC, in the long term.

In Table 5, a 1% change in FGDP leads to an increase in EC by 0.258% for the dependent variable EC. In contrast, the EC increases by 0.189% when FGDP's partial function changes negatively. With a change of 1%, the positive changes in the cumulative function of FGDP and the negative changes in the partial function of FGDP decrease EC by 0.645%, in the short term. Also, the cumulative function also increases EC by 0.492% for a 1% change in long-term TGDP. Additionally, for a 1% change in TGDP, EC increases by 0.365% if there is a negative change in the cumulative function. In the short term, however, for a 1% change in TGDP, negative and positive changes in the cumulative function of TGDP reduce EC by 0.305% and 0.299%, respectively. It is predicted that the cumulative function of IFGDP increases EC by 0.26 % for a 1% change in IFGDP in the long-term. In contrast, a decrease in IFGDP's partial function increases EC by 0.198%. A 1% change in IFGDP, however, decreases EC by 0.681% and 0.627% for positive and negative changes in IFGDP's cumulative functions, respectively.

The validation of our estimated model as well as the results obtained from the short- and long-term relationship requires the verification of a set of hypotheses, namely error correlation, heteroscedasticity, normality, specification and coefficient stability. Indeed, the four tests presented in Table 5 show that the probability of the statistic for each test is greater than 5%. This means that the null hypothesis is accepted in all these tests. The errors are therefore not autocorrelated, homoscedastic, their distribution follows a normal law and our model is well specified. In addition, the stability of the coefficients of our ARDL model is validated through the CUSUM and CUSUMSQ tests, since the curve does not go out of the corridor in these two tests (Figures 2-4). Finally, based on the results of the five tests performed, we can confirm the robustness of our estimated NARDL model.

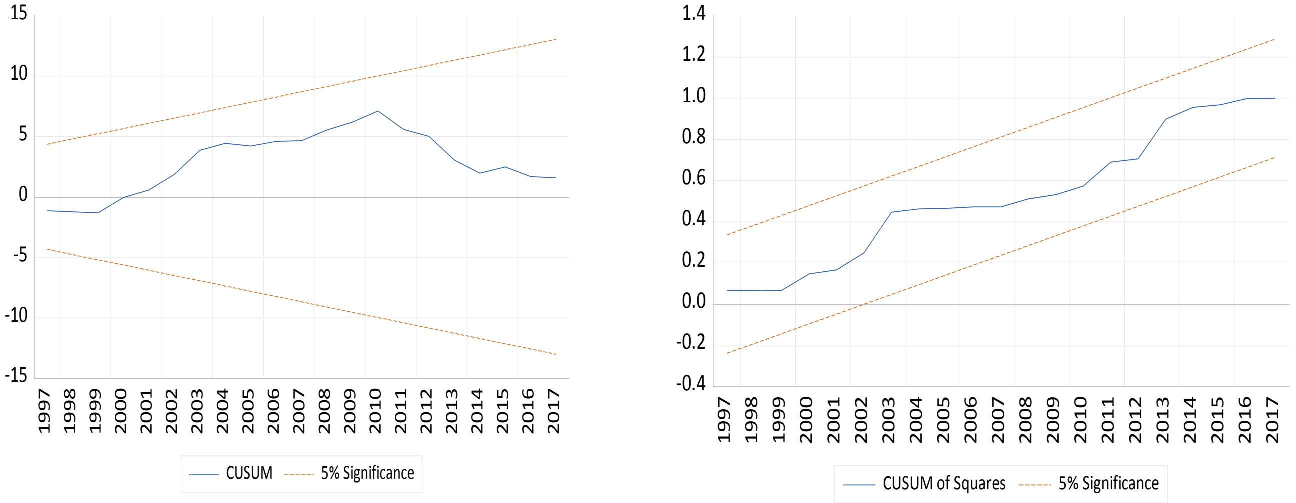

Fig. 2: CUSUM and CUSUM of Square for Formal GDP.

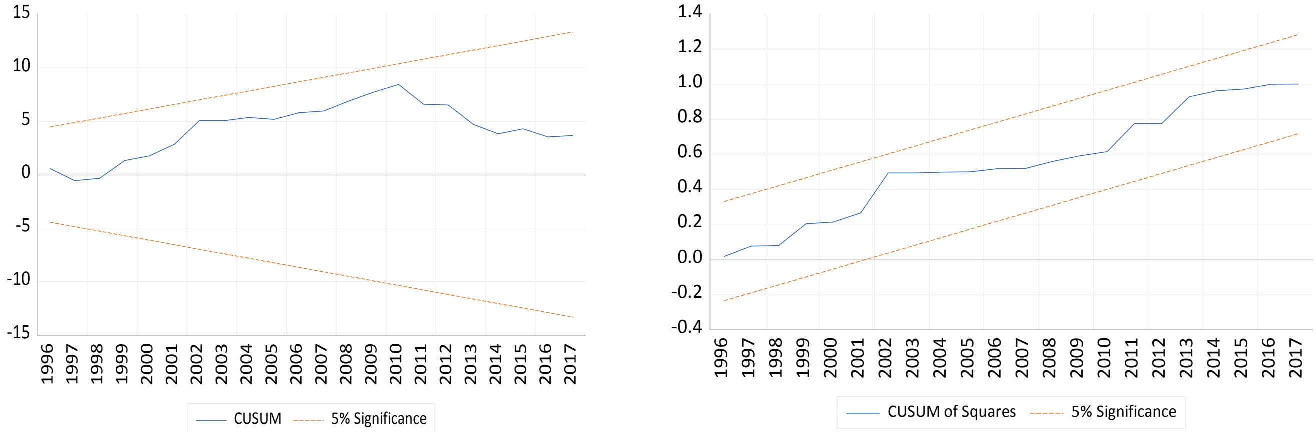

Fig. 3: CUSUM and CUSUM of Square for Informal GDP.

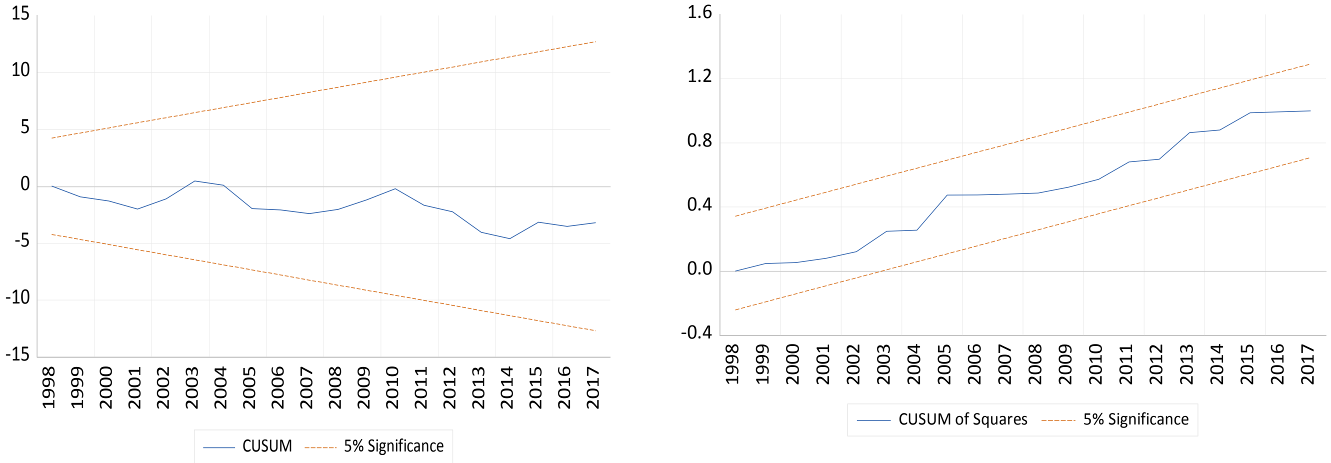

Fig. 4: CUSUM and CUSUM of Square for Total GDP.

Table 5. Robustness test

Statistics	FGDP	TGDP	IFGDP
Breusch-Godfrey	0.467	0.525	0.398
ARCH	0.189	0.357	0.584
Jarque-Bera	0.654	0.544	0.365
Ramsey	0.288	0.354	0.521
CUSUM	Stable	Stable	Stable
CUSUMsq	Stable	Stable	Stable

The NARDL model also presents the long-term asymmetric response of EC in Saudi Arabia to positive and negative variations of its determinants, respectively, after analyzing the long- and short-term impacts of FGDP, TGDP, and IFGDP on EC. Table 6 presents the long-term skew parameters for the three estimated models. According to Table 4, Saudi Arabia's FGDP, TGDP, and IFGDP affect EC in the long term. Specifically, a 1% decrease in FGDP, TGDP, and IFGDP raise energy consumption by 2.35%, 2.52%, and 1.60% in our estimated models, respectively. In other words, official GDP, real GDP and the EU increase energy consumption by 2.35%, 2.52% and 1.60% when they increase by 1%. In contrast, our estimated models estimate EC to be reduced by 0.36%, 0.43%, and 1.01% for a 1% decrease in FGDP, TGDP, and IFGDP, respectively.

Table 6. Long-term parameters.

FGDP		TGDP		IFGDP	
Coefficients	Statistics	Coefficients	Statistics	Coefficients	Statistics
β^+_{FGDP}	2.354***	β^+_{TGDP}	2.521***	β^+_{IFGDP}	1.609***
β^-_{FGDP}	0.365**	β^-_{TGDP}	0.434**	β^-_{IFGDP}	1.011**

β^+_{FGDP}, β^-_{FGDP}, β^+_{TGDP}, β^-_{TGDP}, β^+_{IFGDP} and β^-_{IFGDP} represent estimated long-term asymmetric coefficients associated with the change in FGDP, TGDP, and IFGDP, respectively. ***, **, *denote significance at the 1%, 5% and 10% levels.

Following a positive and negative unitary shock destabilizing the economy, figures 5 to 7 illustrate the trajectory of asymmetric adjustments to a new long-term equilibrium. Up to an 80-period horizon, the green and red dotted lines show how energy consumption responds to a positive and negative unitary shock. Positive and negative unit shocks are represented by a blue curve that represents the asymmetry line. In the blue area, we can see the 95% confidence interval for the asymmetry curve. Using these figures, it is possible to predict how EC will respond to an exogenous shock, either positive or negative.

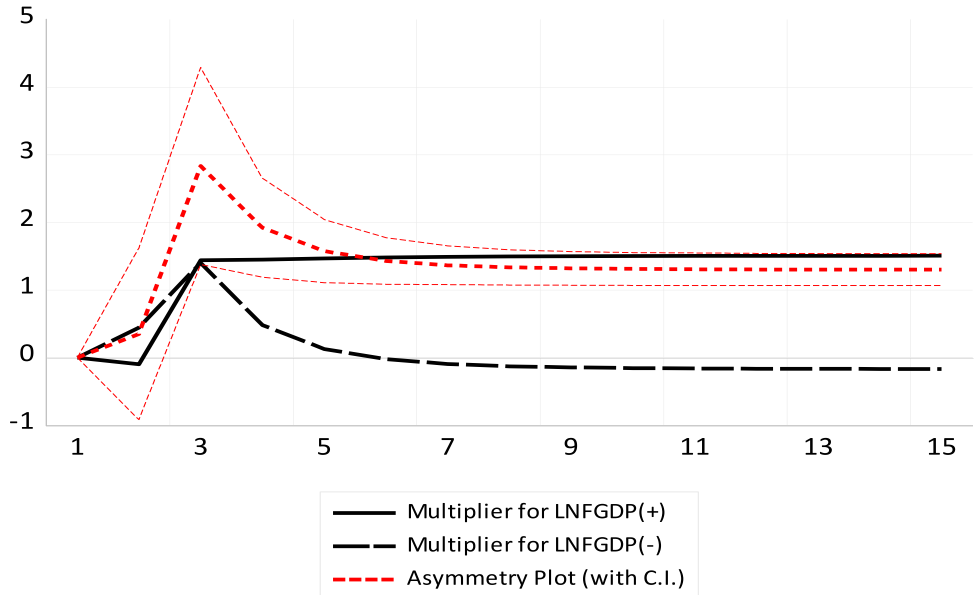

Fig. 5: Multipliers for Formal GDP Model.

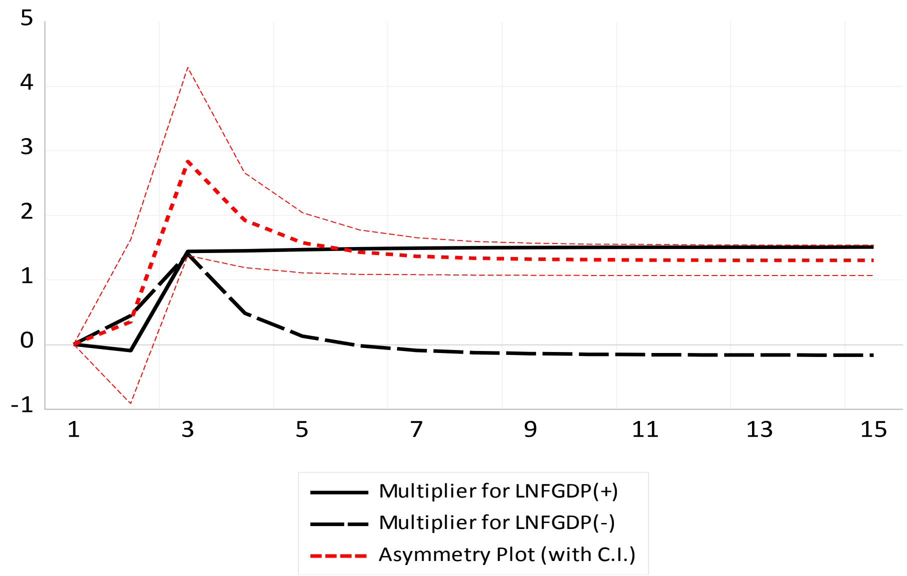

Fig. 6: Multipliers for Informal GDP Model.

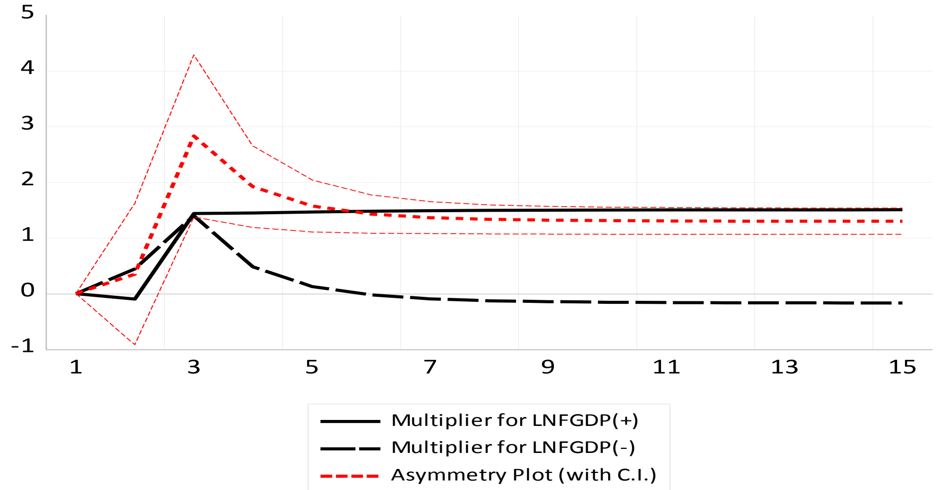

Fig. 7: Multipliers for Total GDP Model.

Indeed, for authorities and decision-makers, it is crucial to have an accurate forecast of future EC. In this way, the Saudi authorities can take the necessary precautions to prevent a disruption of energy supply that would both deteriorate household life quality and disrupt the production process. Alternatively, policymakers could control the EC by monitoring its determinants and adopting the necessary policies to limit its negative effects on the environment, such as CO2 emissions and air pollution, associated with EC. Figure 5 shows the cumulative multipliers for EC and FGDP. It is evident from the graph that EC is positively associated with FGDP, and that negative shocks dominate positive shocks in FGDP.A comparison of figures 6 and 7 shows that the dynamic multiples trail similar trajectories regardless of the economic variables introduced into the model among TGDP and IFGDP. For the first two years, positive unit shocks were more effective than negative unit shocks, and then negative shocks were greater than positive unit shocks in affecting EC. In response to unitary positive and negative shocks in TGDP and IFGDP, the asymmetry curve follows a similar pattern, starting with a significant negative reaction in EC. The negative feedback reaches its peak after about three quarters, and the new equilibrium path for EC follows about six quarters.

4 Conclusion

In this article, we study the relationship between the IFGDP and EC in Saudi Arabia. The study uses annual frequency data for the period 1970-2017. Furthermore, FGDP, IFGDP, and TGDP were examined in relation to EC in Saudi Arabia. This study investigates the long- and short-term effects of FGDP, IFGDP, and TGDP on EC in Saudi Arabia using the nonlinear autoregressive distributed lag model developed by [22].

Based on the empirical results, the variables studied exhibit an asymmetric cointegration relationship. Specifically, the results reveal that in the long term, positive changes in FGDP, TGDP and the IFGDP lead to higher EC. Moreover, negative changes in the FGDP, TGDP and IFGDP reduce EC in Saudi Arabia in the long term. Based on the short-term analysis, the increase in FGDP, TGDP, and IFGDP reduces the short-term EC in Saudi Arabia. We need to adopt new strategies that contribute to the action plan while also respecting sustainable development goals. It is pertinent to Saudi Arabia's OPEC energy policy to address this challenge.

From a policy perspective, this result further suggests that Saudi Arabian policymakers can adopt effective policies to control long- and short-term energy consumption through the informal economy channel, in the sense that the fight against the informal economy is not a priority for the Saudi economy. Instead, in 2016, Mohammed Bin Salman announced Vision 2030. The main objective of the Vision 2030 plan is to ensure the Kingdom's transition to a new model of economic development, more liberal and more open to the world, creating jobs and wealth. In terms of energy, the Kingdom must substantially reduce its domestic consumption. Arabia is, in fact, one of the largest world consumers of black gold for domestic purposes (nearly 3 billion barrels, or +6% per year since 1940). With this in mind, the transition to renewable and clean energies is a priority. The Saudi energy target for 2030 is based on the production of more than 58.7 GW of renewable energy mainly combining solar and wind power. To meet this challenge - and also to meet the expected increase of more than 300% in electricity consumption by 2030 - the city of Riyadh has undertaken to make this sector more attractive and more open to foreign investors, particularly with privatizations and abolishing monopolies. This is, in our opinion, a better solution because Saudi Arabia has good hydroelectric potential, and this resource is not yet fully exploited. Another effort in Saudi Arabia seems to be made in the hydrocarbon industry. Foreign and domestic investment in this sector has enabled Saudi Arabia to more than double its production of natural gas, one of the main energy resources used by households and businesses. Indeed, the production of natural gas is a good channel to increase economic growth as these exports accounted for about 12% of the country's GDP in 2016.

Future research can still improve upon the findings despite the significant methodological and policy contributions. Itissuccessfully demonstrated that energy consumption/formal GDP, energy consumption/total GDP, and energy consumption/informal GDP are non-linear relationships. In the next research, we will analyze the specific turning points of all the non-linear relationships.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.