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Renewable energy consumption-economic growth nexus in G7 countries: New evidence from a nonlinear ARDL approach

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Abstract

The paper investigates the nonlinear pass-through from economic growth to renewable energy consumptionby applying a Nonlinear Auto-Regressive Distributed Lag model (NARDL) for G7 countries. This study covers the period of 1955Q1-2015Q4. The recent approach allows for empirical tests of short-run and long-run asymmetric responses of renewable energy consumption to positive and negative shocks stemming from economic growth. The results reveal that renewable energy consumption responds asymmetrically to economic growth in the long-run for France, Japan, Italy and the UK. However, we find no evidence for a long-run equilibrium between renewable energy consumption and economic growth in Germany, Canada and the US.

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1. Introduction

In the wake of energy conservation policies which have been discussed and implemented over the last decade. The relationship between economic activity and energy consumption in general and renewable energy consumption in particular is of great importance for policymakers in the international debate on global warming. This relationship has been broadly examined in many empirical studies but no agreement has been reached so far. As often argued in the literature, energy consumption is generally a crucial component in economic growth, directly or indirectly, since it is an important input factor of production (Belke et al. 2011).[1] Hence, a negative shock reducing the overall level of production also causes a decrease in energy consumption. This could result in a long-run relationship between energy consumption and economic growth and is especially true for economies which are said to be ‘energy dependent’.

It appears to be of particular importance in this context if this kind of relationship exists between economic activity and renewable component of energy consumption. Renewable energy is expected to be the fastest growing world energy resource (International Energy Outlook, 2010). Besides a general public interest in cleaner and alternative energy resources, this expected increase in renewable energy consumption can be attributed to several government policies such as renewable energy production tax credits, installation rebates for renewable energy systems, renewable energy portfolio standards, and the creation of markets for renewable energy certificates (Kaygusuz 2007, Sovacool 2009, Apergis and Payne 2012). Due to the importance of renewable energy, it is crucial to examine the underlying dynamics between renewable energy consumption and economic growth. However, while there is a tremendous number of studies on energy consumption and economic growth in the literature (Ozturk 2010, Payne 2010), studies focusing on renewable energy consumption have only recently emerged (Apergis and Payne 2012, Tugcu et al. 2012). We aim to make a further attempt to close this gap in the literature by addressing a potential shortcoming of previous studies.

Previous empirical studies have either assumed linearity in the context of cointegration long-run relationship between renewable energy consumption and economic growth or provided evidence in favor of nonlinearity relying on asymmetric Granger causality testing (Destek, 2016). However, these studies do not explicitly account for the possibility of nonlinearity in the cointegration system. This could result from an asymmetric reaction to positive and negative shocks and could be accommodated by the application of various types of regime-switching models. One way to do so relies in solely allowing for nonlinearity in the error correction mechanism by the application of either a threshold ECM proposed by Balke and Fomby (1997), a Markov-Switching ECM of Psaradakis et al. (2004) or a smooth transition regression ECM developed by Kapetanios et al. (2006). However, a general caveat of this kind of models is the common assumption that the underlying cointegrating relationship is represented by a linear combination of the nonstationary variables. But this might be excessively too restrictive since for the same reasons claimed for the error correction mechanism, the long-run cointegration relationship itself could be subject to asymmetry or nonlinearity.

Therefore, one main contribution of this study is the consideration of a combination of nonlinearities in the long-run relationship and in the error correction design by the application of Nonlinear Auto-Regressive Distributed Lag model (NARDL) proposed by Shin et al. (2014). In comparison to standard cointegration approaches, this method allows time series to have different orders of integration which provides a flexible tool for the analysis of joint long-run and short-run asymmetries. Based on this approach, we test for the existence of a stable long-

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[1] See Shahbaz et al. (2012) for an excellent overview of the growth, the conservation, the feedback and the neutrality hypothesis related to the relationship between energy consumption and economic growth.

run relationship between renewable energy consumption and economic growth for G7 economies over the period of 1995Q1-2016Q4. In addition, we also derive asymmetric cumulative dynamic multipliers that allow us to distinguish the asymmetric adjustment patterns resulting from positive and negative economic growth shocks on renewable energy consumption. Our findings reveal that renewable energy consumption responds asymmetrically to economic growth shocks for France, Japan, Italy and the UK.

The remainder of the present paper is structured as follows. Section-2 provides a brief review of the most relevant literature. Section-3 gives an overview of our data set and our empirical methodology while Section-4 presents and discusses our findings. Section-5 concludes with policy implications.

2. Literature Review

This section is designed to give a brief overview of previous empirical studies regarding the so-called renewable energy consumption-economic growth nexus in order to identify the gap in the literature we want to address.[2] The link between energy consumption and economic growth has been widely studied while only the latest studies focus on renewable energy consumption. The first kind of studies has analyzed the link between economic growth and energy consumption by separating energy sources into renewable and non-renewable components. In doing so, Apergis and Payne (2012) have examined the relationship between renewable and non-renewable energy consumption and economic growth for a panel of 80 countries by applying a panel cointegration framework. Their empirical analysis provides the evidence of a long-run relationship by considering cross-sectional dependence. Salim et al. (2014) have re-examined this relationship by allowing for structural breaks. Tugcu et al. (2012), Pao and Fu (2013), Dogan (2015) and Inglesi-Lotz (2016) have also contributed to this strand of the literature by confirming the corresponding long-run relationship for G7 economies, for Brazil, for Turkey, and for OECD countries, respectively.

The second kind of studies solely focused on the relationship between renewable energy consumption and economic growth relying on several panel cointegration tests of the first generation which are constructed under the assumption of independence between the cross-section units. This kind of studies has been conducted for several regions around the globe confirming the finding of a long-run relationship: for OECD countries (Apergis and Payne, 2010a; Kula, 2014), for Europe (Menegaki, 2011), for Eurasia (Apergis and Payne, 2010b), for Central America (Apergis and Payne, 2011a), for emerging markets economies (Apergis and Payne, 2011b), for Africa (Ben Aissa et al. 2014) and for a large panel of 69 countries around the globe (Ben Jebli and Ben Youssef, 2015). Mohammadi and Amin (2015) and Bhattacharya et al. (2016) as the third kind of studies were the first to account for the potential of cross-sectional dependence in the relationship between renewable energy consumption and economic growth by the application of Pesaran's (2007) CIPS test.

Finally, the only studies, which have allowed for the potential of an asymmetric relationship, have been adapted by Alper and Oguz (2016) and Destek (2016). First of all, they have studied the relationship between renewable energy consumption and economic growth for seven Eastern European countries and for six emerging markets economies, respectively. They applied asymmetric Granger causality tests. Their results show a feedback effect between renewable energy consumption and economic growth.

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[2] See e.g. Omri et al. (2015) for further details.

However, to the best of our knowledge, there exists no study which has explicitly considered the possibility of nonlinearity in the cointegration system. Therefore, we contribute to the existing literature by addressing this shortcoming and considering the combination of nonlinearities in the long-run relationship and error correction framework. In doing so, we make use of the NARDL model proposed by Shin et al. (2014) which offers a flexible tool for the analysis of joint long-run and short-run asymmetries. We argue that examining the relationship between the variables in a nonlinear setting is of immense importance. For, instance it allows to detect the hidden cointegration in time series if positive and negative components of a series are cointegrated (Granger and Yoon, 2002). Therefore, to examine the energy consumption and economic growth nexus, we apply the linear and non-linear approaches that allow testing for long-run and short-run asymmetries. However, in the presence of asymmetries, the dynamic multipliers quantify the respective responses of the renewable energy consumption to positive and negative changes in economic growth based on positive and negative partial sum decompositions.

3. Data and Econometric Methodology

3.1 Data

The present study covers the period of 1995-2015. The data for real GDP per capita (constant 2010 US$) is obtained from World Development Indicators (CD-ROM, 2017). The renewable energy consumption (kWh per capita) data is borrowed from BP Statistical Review of World Energy 2017 (http://www.bp.com/statisticalreview)[3]. We have also applied the quadratic match-sum method to transform annual data into quarter frequency following Shahbaz et al. (2017). The quadratic match-sum approach solves the issue of seasonality during the process of data transformation.

3.2 Econometric Methodology

3.2.1 The Non-linear Unit Root Test

Firstly, we take into consideration the nonlinear behavior under the alternative assumption by applying the Harvey et al. (2008) linearity test. This test has better size control and offers substantial power gains over the Harvey and Leybourne, (2007) test. Afterwards, for accepting or rejecting the null hypothesis of time series linearity, we employ unit root tests. The Lagrange Multiplier (LM) unit root test allowing for structural breaks (Lee and Strazicich, 2003, 2013) is applied if a variable shows linear behavior otherwise we use a nonlinear unit root test. In order to perform unit root tests for nonlinear series, we rely on the Kruse (2011) test which is based on the Kapetanios et al. (2003) approach. The authors suggest a unit root test vs. the alternative of a globally stationary Exponential Smooth Transition Auto-Regression (ESTAR) model:

$$y_t = \beta y_{t-1} + \phi y_{t-1} + F(\phi,\ y_{t-1}) + \varepsilon_t \qquad (1)$$

where ε_t is $iid(0,\sigma^2)$ and $F(\phi,\ y_{t-1})$ is the transition function which has an exponential form:

$$F(\phi,\ y_{t-1}) = 1 - \exp\{-\theta(y_{t-1} - c)^2\} \qquad (2)$$

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[3] We use electricity generation from wind, hydro, solar, geothermal and bio energy sources.

where it is assumed by the authors that $\beta = 0$ and $c = 0$. Therefore, the model becomes as follows:

$$\Delta y_t = \phi y_{t-1}(1-\exp\{-\theta y_{t-1}^2))\} + \varepsilon_t \tag{3}$$

As an extension to their model, Kruse (2011) considered that the zero location parameter c in the exponential transition function is too restrictive. This is why he dropped this assumption and considered the following modified ADF model:

$$y_t = \beta y_{t-1} + \phi y_{t-1}(1-\exp\{-\theta(y_{t-1}-c)^2\} + \varepsilon_t \tag{4}$$

As in Kapetanios et al. (2003), the author applied the first-order Taylor approximation of the smooth transition function around $\theta = 0$ and then he proceeds with the following test regression:

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \delta_3 y_{t-1} + \mu_t \tag{5}$$

On the other side, when we fail to reject the linearity hypothesis, we employ the LM unit root tests with structural breaks proposed by Lee and Strazicich (2003, 2013). They provide a Lagrange Multiplier (LM) test with breaks in the intercept and trend which avoid the problems of bias and spurious regression. The LM unit root test allows for one and two structural breaks in the intercept (models A and AA) as well as one and two structural breaks in the intercept and trend (models C and CC). In accordance with the LM principle, the break minimum LM unit root test can be characterized as follows:

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1} + u_t \tag{6}$$

where $\tilde{S}_{t-1} = y_t - \tilde{\psi}_x - Z_t \tilde{\delta}, t = 2,...,T, \tilde{\delta}$ are coefficients in the regression of Δy_t on ΔZ_t, $\tilde{\psi}_x$ is given by $y_1 - Z_1 \tilde{\delta}$. If the time series has a unit root, then $\phi_t = 0$ which is the null hypothesis tested vs. the alternative $\phi_t < 0$ by using the t-statistic. The LM unit root determines endogenously the location of the break (T_B) by searching for all possible break points characterized by a minimum unit-root *t*-test statistic:

$$LM_\rho = \underset{\lambda}{Inf}\, \tilde{\rho}(\lambda) \tag{7}$$

$$LM_\tau = \underset{\lambda}{Inf}\, \tilde{\tau}(\lambda) \tag{8}$$

where $\lambda = T_B / T$, two-break LM unit-root test statistic can be estimated in the same way as the one break model.

3.2.2 Non-linear ARDL Cointegration Approach

We estimate the following equation in our study:

$$REC_t = \alpha + \beta EG_t + \varepsilon_t \qquad (9)$$

where REC_t and EG_t are renewable energy consumption and economic growth respectively expressed in natural logarithmic form and ε_t is an error term. In order to examine both long-run and short-run asymmetries between underlying variables, we use the new nonlinear autoregressive distributed lag (NARDL) approach suggested by Shin et al. (2014)[4]. The asymmetric cointegrating relationship can be written as follows:

$$REC_t = \beta^+ EG_t^+ + \beta^- EG_t^- + \mu_t \qquad (10)$$

where EG_t is natural log of economic growth defined such that $EG_t = EG_0 + EG_t^+ + EG_t^-$, where EG_0 is the initial value and where EG_t^+ and EG_t^- are partial sum processes of positive and negative shocks in EG_t defined by:

$EG_t^+ = \sum_{j=1}^{t} \Delta EG_j^+ = \sum_{j=1}^{t} max(\Delta EG_j, 0)$ and $EG_t^- = \sum_{j=1}^{t} \Delta EG_j^- = \sum_{j=1}^{t} min(\Delta EG_j, 0)$
β^+ and β^- are the the associated asymmetric long-run parameters. The extension of the ARDL model proposed by Shin et al. (2014) yields the following asymmetric error correction model:

$$\Delta REC_t = \vartheta + \rho REC_{t-1} + \beta^+ EG_{t-1}^+ + \beta^- EG_{t-1}^- + \sum_{i=1}^{p-1} \gamma_i REC_{t-i} + \sum_{i=0}^{q-1} (\varphi_i^+ \Delta EG_{t-i}^+ + \varphi_i^- \Delta EG_{t-i}^-) + \epsilon_t \qquad (11)$$

where the symbols p and q denote the respective lag orders for REC_t and EG_t, respectively. When both null hypotheses of short-run and long-run symmetry cannot be rejected, equation-(11) reduces to the standard linear ECM model. The NARDL model, expressed by equation-(11), has several advantages. Firstly, it can be estimated by standard OLS since we can decompose the regressor in its positive and negative partial sums. Secondly, we can test the long-run relationship between the levels of REC_t, $EG_t^+$and EG_t^- (*i.e.* $\rho = \beta^+ = \beta^- = 0$) by using the F_{PSS} statistics suggested by Pesaran et al. (2001) and Shin et al. (2014). The t_{BDEG} test advanced by Banerjee et al. (1998) tests the null hypothesis that $\rho = 0$ against the alternative $\rho < 0$. The bounds test procedure can yield a valid inference regardless of whether the regressors are stationary, nonstationary or mutually cointegrated. We can then compute the asymmetric long-run coefficients as follows: $L_{EG^+} = \hat{\beta}^+/\rho$ and $L_{EG^-} = \hat{\beta}^-/\rho$. Thirdly, we can use the standard Wald test to examine the long-run symmetry $\beta = \beta^+ = \beta^-$ and short-run symmetry which can take either of two forms: $\varphi_i^+ = \varphi_i^-$ for all $i = 1, \dots, q-1$ or $\sum_{i=0}^{q-1} \varphi_i^+ = \sum_{i=0}^{q-1} \varphi_i^-$. Finally, the asymmetric dynamic multiplier effects of a unit change of EG_t^+ and EG_t^- respectively on REC_t can be expressed as follows:

$EG_h^+ = \sum_{j=0}^{h} \frac{\partial REC_{t+j}}{\partial EG_t^+}$ and $EG_h^- = \sum_{j=0}^{h} \frac{\partial REC_{t+j}}{\partial EG_t^-}$ for $h = 0,1,2 \dots$
As $h \to \infty$, then $EG_h^+ \to L_{EG^+}$ and $EG_h^- \to L_{EG^-}$.

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[4] The model is an extension of the linear ARDL proposed by Pesaran et al. (2001).

To test the short-run symmetry, we use the Wald test, and if the symmetry is not rejected, then equation-(11) simplifies to NARDL with long-run asymmetry:

$$\Delta REC_t = \vartheta + \rho REC_{t-1} + \beta^+ EG_{t-1}^+ + \beta^- EG_{t-1}^- + \sum_{i=1}^{p-1} \gamma_i REC_{t-i} + \sum_{i=0}^{q-1} \varphi_i \Delta EG_{t-i} + \epsilon_t \tag{12}$$

If long-run symmetry is not rejected, then equation-(11) simplifies to a NARDL with short-run asymmetry:

$$\Delta REC_t = \vartheta + \rho REC_{t-1} + \beta EG_{t-1} + \sum_{i=1}^{p-1} \gamma_i REC_{t-i} + \sum_{i=0}^{q-1} (\varphi_i^+ \Delta EG_{t-i}^+ + \varphi_i^- \Delta EG_{t-i}^-) + \epsilon_t \tag{13}$$

4. Empirical Findings

We firstly applied the Harvey et al. (2008) linearity test for testing the null hypothesis of linearity against the alternative of a non-linear model. This step provides objective guidelines for choosing the appropriate unit root test. Indeed, conventional unit-root procedures (like Dickey-Fuller (DF), Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP)) have low power when nonlinearity in the data is ignored. The results of the linearity test are shown in Table-1. The null hypothesis of linearity is rejected for all series. As a result, all the time series variables follow a nonlinear behavior. There is evidence to suggest that these variables can be characterized by a nonlinear path over the time. We apply, therefore, the Kruse (2011) test. The results of nonlinear unit root analysis are presented in Table-2. The analysis indicates that 10 of the time series can be considered to be integrated of order one highlighting that any shock has a permanent effect in underlying variable.

Table-1: Linearity Unit Root Analysis

Countries		Statistics	Prob. value	Result
France	REC	24.679	0.000	Non Linear
	GDP	7.653	0.064	Non Linear
Germany	REC	9.157	0.039	Non Linear
	GDP	18.465	0.001	Non Linear
Japan	REC	14.324	0.002	Non Linear
	GDP	13.270	0.001	Non Linear
Italy	REC	28.143	0.000	Non Linear
	GDP	15.568	0.007	Non Linear
Canada	REC	9.861	0.071	Non Linear
	GDP	23.486	0.000	Non Linear
UK	REC	8.851	0.049	Non Linear
	GDP	36.674	0.000	Non Linear
USA	REC	26.863	0.000	Non Linear
	GDP	33.397	0.000	Non Linear

Note: The 1%, 5%, and 10% critical values for Harvey et al. (2008) test are respectively 7.779, 9.488, and 13.277.

Further, we applied linear autoregressive distributed lag (ARDL) and non-linear autoregressive distributed lag (NARDL) models to investigate the short-run and long-run relationship between energy consumption and economic growth for G-7 countries. With the purpose of selecting the best fitting models, we perform the Wald tests to identify the existence of short-run (W_{SR}) and long-run (W_{LR}) symmetries[5]. The results are reported in Table-3 indicating that the null

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[5] The optimal number of lags for the two models is selected by using the SIC criterion.

hypothesis of short-run and long-run symmetry is rejected at the usual levels. In case of France, Italy and UK the null hypothesis of long-run symmetry is rejected at 1% level of significance, while the null of short-run symmetry cannot be rejected. These findings suggest that NARDL with long-run asymmetry is a suitable model to describe the dynamic interaction between renewable energy consumption and economic growth in these countries. These empirical evidences support the views that NARDL proposed by Shin et al. (2014) is best suited to describe the dynamic interactions between renewable energy consumption and economic growth than a linear symmetric specification. On the other hand, a linear ARDL model is best specified in case of Germany, Canada and the USA.

Table-2: ESTAR Unit Root Analysis

Countries	Variables	KSS	Result
France	REC	-4.459	Stationary
	GDP	-1.938	Non stationary
Germany	REC	-1.841	Non stationary
	GDP	-2.436	Non stationary
Japan	REC	-3.856	Stationary
	GDP	-2.269	Non stationary
Italy	REC	-0.129	Non stationary
	GDP	-4.578	Stationary
Canada	REC	-1.869	Non stationary
	GDP	-2.147	Non stationary
UK	REC	-1.562	Non stationary
	GDP	-2.978	Stationary
USA	REC	-1.562	Non stationary
	GDP	-1.329	Non stationary

Note: The 1%, 5%, and 10% critical values, for Kruse. (2011) test, are respectively -3.48, -2.93, and -2.66.

Table-3: Wald Tests for Short-and-Long-Run Symmetry

Country	Long-run W_{LR}	Short-run W_{SR}	Selected Specification
France	8.774 *** [0.003]	0.351 [0.554]	NARDL with LR asymmetry
Germany	0.6809 [0.410]	0.2242 [0.636]	Symmetric ARDL
Japan	7.05*** [0.008]	2.79 * [0.096]	NARDL with LR and SR asymmetry
Italy	6.242*** [0.013]	0.1725 [0.678]	NARDL with LR asymmetry
Canada	0.707 [0.401]	1.299 [0.256]	Symmetric ARDL
UK	20.312*** [0.000]	1.068 [0.303]	NARDL with LR asymmetry
USA	2.095 [0.149]	0.007 [0.933]	Symmetric ARDL

Note: The symbols*, ** and *** denote significance at 10%, 5%, and 1% levels, respectively.

The estimated short and long-run coefficients are reported in Table-4. We observe at first glance that the coefficients of economic growth are positive and significant in most of the cases. The short-run parameter (ΔGDP_t) indicate that 1% change in renewable energy consumption over the short-run will change economic growth by 1.17% in Germany, 0.74% in Japan, 0.45% in Canada and 0.8% in the USA. A change in the previous quarter (i.e. at lag = 1) will significantly decrease the level of economic growth in Germany, Canada[6] and the USA (as coefficients are -0.881, -0.184 and -0.493), respectively. However, in case of Japan both the positive and negative changes in economic growth will decrease the level of renewable energy consumption.

In the long-run a positive change in economic growth ($L_{GDP^{+}}$) has a positive and significant impact on renewable energy consumption in case of France, Japan and Italy. It has a negative and significant impact on renewable energy consumption in UK. This indicates that these countries have more renewable energy consumptions as per 1% increase into their output growth. On the other hand, negative shocks to economic growth are also positively associated with renewable energy consumption in all countries where long term relation exists. For instance, coefficients of ($L_{GDP^{-}}$) are 4.890, 4.826, 2.091 and 8.027 for France, Japan, Italy and UK, respectively. The magnitude of the positive effects of a negative shock to economic growth ($L_{GDP^{-}}$) on renewable energy consumptions is greater than the effect of positive shocks ($L_{GDP^{+}}$) on economic growth. This indicates that a heavy use of alternative resources such as renewable energy during the economic slowdown can significantly increase the level of renewable energy consumption in their countries[7]. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services.

There are both human and natural sources of CO_2 emissions. The natural sources include decomposition, ocean release and respiration while the human sources of emissions come from the activities such as industrial production, deforestation as well as the consumption of fossil fuels like coil, natural gas and oil which have major contributions in economic growth. The environmental Kuznets curve implies that economies grow and environmental degradation deepens and we infer that environmental degradation recedes while using renewable sources. The renewable sources are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. As earlier documented by Quéré et al. (2013) that human sources of carbon (CO_2) emissions are much smaller than natural sources of emissions. But the human activities have upset the natural balance that existed for thousand years before the human influence. Intuitively, we expect that an optimal level of economic growth can be achieved while efficiently use of renewable resources given a certain level of carbon dioxide emissions. Further, these findings are enriched through dynamic multiplier adjustment of renewable energy consumption to unitary variation of economic growth. The graphs in (Figure-1) confirm the existence of positive relation between economic growth and renewable energy consumption. The effect of a negative shock in economic growth is found to dominate that of a positive shock in all countries. However, in case of Japan renewable energy consumption responds asymmetrically to positive and negative changes in economic growth.

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[6] This result pointed out that the renewable energy average cost (the economies of scale) deceases with its volume. Compared to G7 countries, Canada has a high share of renewables in their energy supply. 17.3% of Canada's energy comes from renewables.

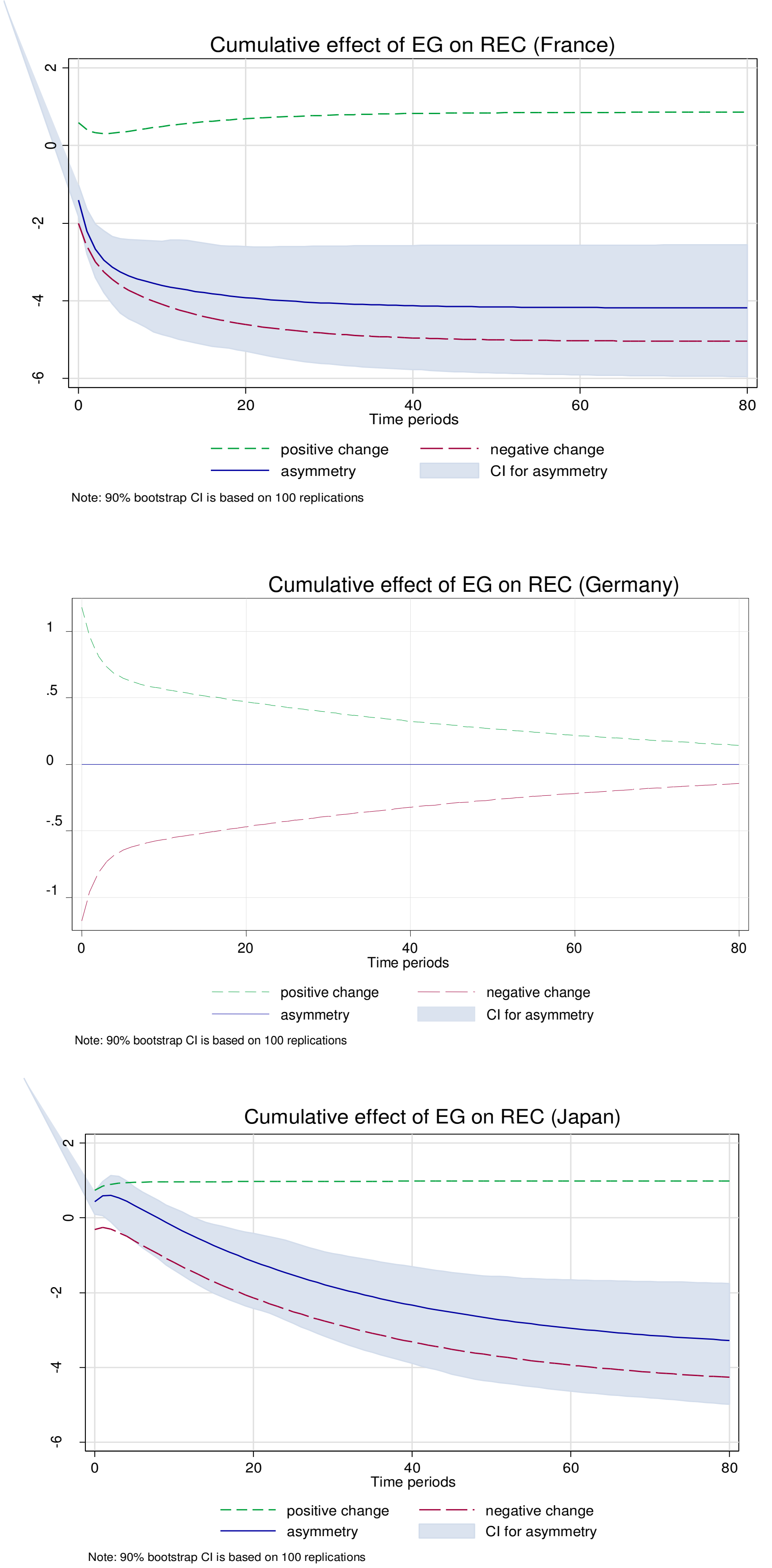
[7] This is in line with the typical idea that oil prices play a determinant role in determining the attractiveness of renewable energy sources. Previous research has investigated the relationship between oil prices and renewable energies during the crises periods (characterized by a negative correlation between GDP growth and real oil price increases). They find a positive and statistically significant relationship between oil prices and renewables share prices (Henriques and Sadorsky, 2008). Bondia et al. (2016) provide evidence that oil prices affect renewable energy consumption in the short-run. Moreover, Reboredo et al. (2017) deduce that such a relationship emerges in the long-run.

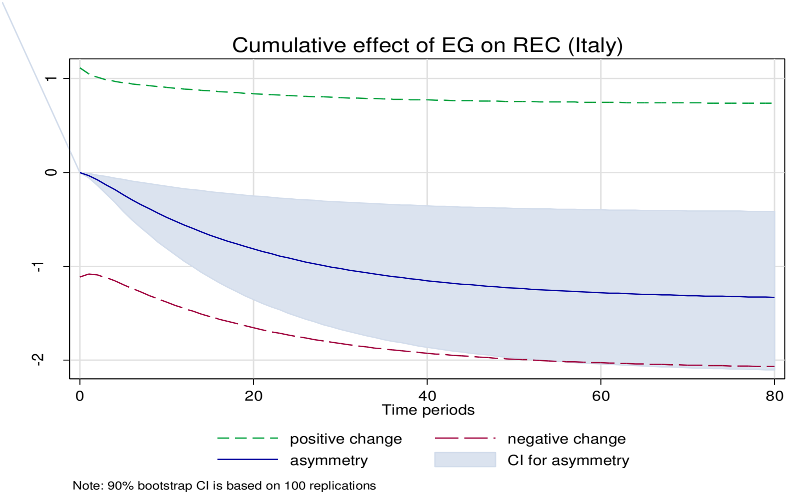
Table-4: The Pass-through of Economic Growth to Renewable Energy Consumption

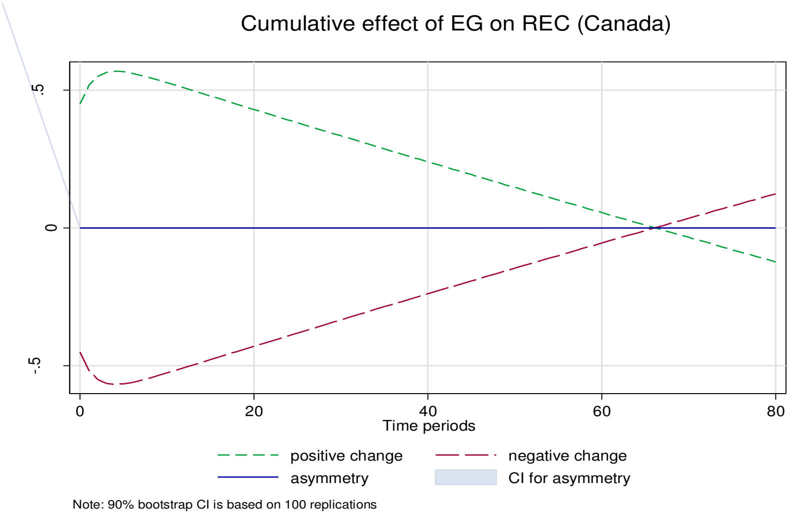
France		Germany		Japan		Italy		Canada		UK		US	
NARDL with LR asymmetry		Symmetric ARDL		NARDL with LR and SR asymmetry		NARDL with LR asymmetry		Symmetric ARDL		NARDL with LR asymmetry		Symmetric ARDL	
Constant	0.176** (0.069)	Constant	0.047* (0.028)	Constant	0.073 (0.027)	Constant	0.129*** (0.018)	Constant	0.008 (0.022)	Constant	0.329*** (0.029)	Constant	0.007 (0.020)
REC_{t-1}	-0.030** (0.012)	REC_{t-1}	-0.010* (0.006)	REC_{t-1}	-0.015*** (0.06)	REC_{t-1}	-0.023*** (0.003)	REC_{t-1}	-0.001 (0.032)	REC_{t-1}	-0.048*** (0.005)	REC_{t-1}	-0.001 (0.003)
GDP_{t-1}^{+}	0.027** (0.013)	GDP_{t-1}	0.004*** (0.008)	GDP_{t-1}^{+}	0.015** (0.06)	GDP_{t-1}^{+}	0.017*** (0.004)	GDP_{t-1}	-0.004 (0.024)	GDP_{t-1}^{+}	-0.055*** (0.014)	GDP_{t-1}	-0.001 (0.001)
GDP_{t-1}^{-}	0.148** (0.078)	ΔREC_{t-1}	0.567*** (0.054)	GDP_{t-1}^{-}	0.071*** (0.027)	GDP_{t-1}^{-}	0.049*** (0.016)	ΔREC_{t-1}	0.565*** (0.055)	GDP_{t-1}^{-}	0.389*** (0.109)	ΔREC_{t-1}	0.565*** (0.055)
ΔREC_{t-1}	0.506*** (0.057)	ΔGDP_{t}	1.177*** (0.204)	ΔREC_{t-1}	0.499*** (0.056)	ΔREC_{t-1}	0.475*** (0.053)	ΔGDP_{t}	0.450*** (0.073)	ΔREC_{t-1}	0.208*** (0.014)	ΔGDP_{t}	0.809*** (0.057)
		ΔGDP_{t-1}	-0.881 (0.210)	ΔGDP_{t}	0.743*** (0.129)			ΔGDP_{t-1}	-0.184** (0.078)			ΔGDP_{t-1}	-0.493*** (0.071)
				ΔGDP_{t}^{-}	0.307* (0.156)								
				ΔGDP_{t-1}^{+}	-0.272** (0.137)								
				ΔGDP_{t-1}^{-}	-0.268* (0.159)								
$L_{GDP^{+}}$	0.881***	L_{GDP}	-0.048	$L_{GDP^{+}}$	0.993***	$L_{GDP^{+}}$	0.731 ***	L_{GDP}	-5.594	$L_{GDP^{+}}$	-1.134***	L_{GDP}	-1.390
$L_{GDP^{-}}$	4.890***			$L_{GDP^{-}}$	4.628***	$L_{GDP^{-}}$	2.091***			$L_{GDP^{-}}$	8.027***		
AIC	-1539.724	AIC	-1375.584	AIC	-1550.375	AIC	-1698.081	AIC	-1817.008	AIC	-716.3958	AIC	-1934.538
SIC	-1508.474	*SIC*	-1354.750	*SIC*	-1519.125	*SIC*	-1673.775	*SIC*	-1796.174	*SIC*	-694.9576	*SIC*	-1913.705
ARCH	227.591	*ARCH*	231.079	*ARCH*	232.432	*ARCH*	237.794	*ARCH*	235.730	*ARCH*	139.643	*ARCH*	234.904

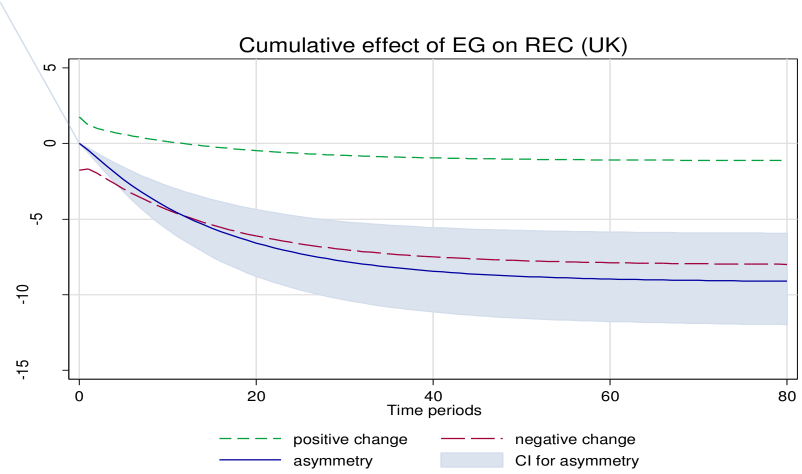
Notes: This table reports the estimation results of the best-suited NARDL specifications for the pass-through of the economic growth to renewable energy consumption. The Schwarz Info Criteria (*SIC*) is *used* to *select* the *optimal lag length*. L_{GDP} indicates the long-run coefficient between renewable energy consumption and the economic growth. $L_{GDP^{+}}$ and $L_{GDP^{-}}$ are the asymmetric positive and negative long-run coefficients. Standard deviations are in parenthesis. ARCH refers to the empirical statistics of the Engle (1982) test for conditional heteroscedasticity applied to 12 lags. $*$, $**$ and $***$ denote the significance at the 10%, 5% and 1% levels, respectively.

Figure-1: Dynamic Multipliers (Cumulative Effect of ECG on REC)

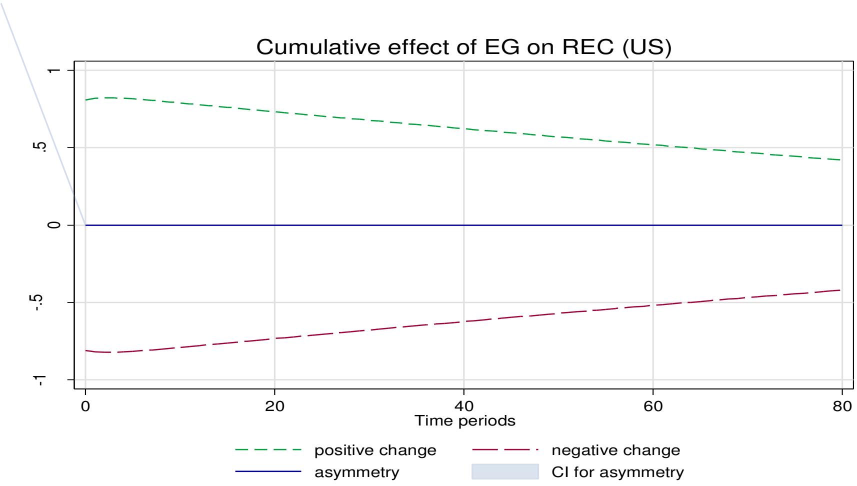



Cumulative effect of EG on REC (Italy)
1
0
-1
-2
0
20
40
60
80
Time periods
positive change
negative change
asymmetry
CI for asymmetry
Note: 90% bootstrap CI is based on 100 replications


Cumulative effect of EG on REC (Canada)
.5
0
-.5
0
20
40
60
80
Time periods
positive change
negative change
asymmetry
CI for asymmetry
Note: 90% bootstrap CI is based on 100 replications



Note: 90% bootstrap CI is based on 100 replications



Note: 90% bootstrap CI is based on 100 replications

5. Conclusion and Policy Implications

In this study, the nonlinear pass-through from economic growth to renewable energy consumption is examined by applying a Nonlinear Auto-Regressive Distributed Lag model (NARDL) for G7 countries. This recent approach allows to quantify the short-run and long-run asymmetric responses of renewable energy consumption to positive and negative shocks stemming from economic growth. The empirical results reveal that renewable energy consumption responds asymmetrically to economic growth shocks in the long-run in four economies (France, Japan, Italy and the UK). The magnitude of the positive effects of negative shocks to economic growth on energy consumptions is greater than the effect of positive shocks to economic growth in each country. This points out that the heavy use of alternative resources during the economic slowdown can significantly increase the level of renewable energy consumption in these countries. We therefore argue that any study aiming to examine renewable energy consumption cannot be conducted without taking into consideration the asymmetric relationship with regard to economic growth that can be caused by the complexity of economic systems.

Our findings have important implications for environmental policy modeling such as to achieve the natural balances (e.g., balance between the human and natural sources of carbon dioxide emissions). The investment in renewable energies is considered as a strategic solution for introducing accessible, safe and sustainable energy in all these countries which allows a sustainable development in the long-run. However, these countries remain highly dependent on oil resources which highlights the importance to reorient funds to renewable energy producers in order to increase the share of renewable energy in the total energy. The human capital is also a key factor that allows for providing efficient, reliable and cost-effective solutions to promote access to renewable energy. Furthermore, innovation is able to build up skills based on the expertise and know-how of pioneer countries to ensure the transfer of skills and knowledge for the long-term creation of renewable energy markets. An additional room for improvement is the diffusion of the renewable energy technology that helps to preserve the environment. Finally, we suggest that the use of renewable sources can reduce environmental degradation and depletion of non-renewable sources. As the renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services.

References

1. Alper, A. and Oguz, O. (2016). The role of renewable energy consumption in economic growth: Evidence from asymmetric causality. *Renewable and Sustainable Energy Reviews*, 60: 953-959.
2. Apergis, N. and Payne, J.E. (2010a). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy*, 38: 656-660.
3. Apergis, N. and Payne, J.E. (2010b). Renewable energy consumption and growth in Eurasia. *Energy Economics*, 32: 1421-1426.
4. Apergis, N. and Payne, J.E. (2011a). The renewable energy consumption-growth nexus in Central America. *Applied Energy*, 88: 343-347.
5. Apergis, N. and Payne, J.E. (2011b). Renewable and non-renewable electricity consumption-growth nexus: Evidence from emerging market economies. *Applied Energy*, 88: 5226-5230.
6. Apergis, N. and Payne, J.E. (2012). Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. *Energy Economics*, 34: 733-738.
7. Balke, N.S. and Fomby, T.B. (1997). Threshold cointegration. *International Economic Review*, 38: 627-645.
8. Banerjee, A., Dolado, J. and Mestre, R. (1998). Error-correction mechanism tests for cointegration in a single-equation framework. *Journal of Time Series Analysis*, 19: 267-283.
9. Belke, A., Dobnik, F. and Dreger, C. (2011). Energy consumption and economic growth: New insights into the cointegration relationship. *Energy Economics*, 33(5): 782-789.
10. Ben Aissa, M.S., Ben Jebli, M. and Ben Youssef, S. (2014). Output, renewable energy consumption and trade in Africa. *Energy Policy*, 66: 11-18.
11. Ben Jebli, M. and Ben Youssef, S. (2015). Output, renewable and non-renewable energy consumption and international trade: Evidence from a panel of 69 countries. *Renewable Energy*, 83: 799-808.
12. Bhattacharya, M., Paramati, S.R., Ozturk, I. and Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, 162: 733-741.
13. Bondia, R.; Ghosh, S.; Kanjilal, K. (2016). International crude oil prices and the stock prices of clean energy and technology companies: Evidence from non-linear cointegration tests with unknown structural breaks. *Energy*, 101, 558–565.

14. Destek, M.A. (2016). Renewable energy consumption and economic growth in newly industrialized countries: Evidence from asymmetric causality test. *Renewable Energy*, 95: 478-484.
15. Dogan, E. (2015). The relationship between economic growth and electricity consumption from renewable and non-renewable sources: A study of Turkey. *Renewable and Sustainable Energy Reviews*, 52: 534-546.
16. Henriques, I.; Sadorsky, P. (2008). Oil prices and the stock prices of alternative energy companies. *Energy Economics*, 30, 998–1010.
17. Inglesi-Lotz, R. (2016). The impact of renewable energy consumption to economic growth: A panel data application. *Energy Economics*, 53: 58-63.
18. Kapetanios, G., Shin, Y. and Snell, A. (2006). Testing for cointegration in nonlinear smooth transition error correction models. *Econometric Theory*, 22: 279-303.
19. Kaygusuz, K. (2007). Energy for sustainable development: Key issues and challenges.*Energy Sources, Part B: Economics, Planning, and Policy*, 2: 73-83.
20. Kula, F. (2014). The long-run relationship between renewable electricity consumption and GDP: Evidence from panel data. *Energy Sources, Part B: Economics, Planning, and Policy*, 9: 156-160.
21. Le Quéré, C., Andres, R. J., Boden, T., Conway, T., Houghton, R. A., House, J. I. and Andrew, R. M. (2013). *The global carbon budget 1959–2011*, Earth System Science. Data, 5, 165–185.
22. Menegaki, A.N. (2011). Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy Economics*, 33: 257-263.
23. Mohammadi, H. and Amin, M.D. (2015). Long-run relation and short-run dynamics in energy consumption-output relationship: International evidence from country panels with different growth rates. *Energy Economics*, 52: 118-126.
24. Omri, A., Ben Mabrouk, N. and Sassi-Tmar, A. (2015). Modeling the causal linkages between nuclear energy, renewable energy and economic growth in developed and developing countries. *Renewable and Sustainable Energy Reviews*, 42: 1012-1022.
25. Ozturk, I. (2010). A literature survey on energy-growth nexus. *Energy Policy*, 38: 340-349.
26. Pao, H.-T. and Fu, H.-C. (2013). Renewable energy,non-renewable energy and economic growth in Brazil. *Renewable and Sustainable Energy Reviews*, 25: 381-392.
27. Payne, J.E. (2010). Survey of the international evidence on the causal relationship between energy consumption and growth. *Journal of Economic Studies*, 37: 53-95.
28. Pesaran, M.H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22: 265-312.
29. Pesaran, M.H., Shin, Y. and Smith, R.J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16: 289-326.
30. Psaradakis, Z., Sola, M. and Spagnolo, F. (2004). On Markov error-correction models with an application to stock prices and dividends. *Journal of Applied Econometrics*,19: 69-88.
31. Reboredo, J.C.; Rivera-Castro, M.A.; Ugolini, A. (2017). Wavelet-based test of co-movement and causality between oil and renewable energy stock prices. *Energy Economics*, 61, 241–252
32. Salim, R.A. Hassan, K. and Shafiei, S. (2014). Renewable and non-renewable energy consumption and economic activities: Further evidence from OECD countries. *Energy Economics*, 44: 350–360.
33. Shahbaz, M., Zeshan, M. and Afza, T. (2012). Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and Granger causality tests. *Economic Modelling*, 29: 2310-2319.

34. Shahbaz, M., Hoang, T. H. V., Mahalik, M. K. and Roubaud, D. (2017). Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. Energy Economics, 63, 199-212.
35. Shin, Y., Yu, B. and Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: *Festschrift in Honor of Peter Schmidt - Econometric Methods and Applications*, Ch. 9, 281-314.
36. Sovacool, B.K. (2009). Rejecting renewables: The socio-technical impediments to renewable electricity in the United States. *Energy Policy*, 37: 4500-4513.
37. Tugcu, C.T., Ozturk, I. and Aslan, A. (2012). Renewable and non-renewable energy consumption and economic growth relationship revisited: Evidence from G7 countries. *Energy Economics*, 34: 1942-1950.