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Research paper

Which type of energy drove industrial growth in the US from 2000 to 2018 ?

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HIGHLIGHTS

- Investigates the effects of energy consumption on industrial production (IP) for the US over the period 2000:M01–2018:M02.
- Employs the nonlinear autoregressive distributed lag approach.
- Yields that there exist asymmetric relationships between different types of energy and IP.
- Discusses theoretical and practical implications.

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ABSTRACT

This paper investigates the impacts of non-renewable consumption (NRE) and renewable energy consumption (RE) on industrial production (IP) in the US using monthly data from 2000:01 to 2018:02. To do so, the paper employs the nonlinear autoregressive distributed lag (NARDL) approach to examine asymmetric relationships, thus contributing to the past literature methodologically. The findings show that both non-renewable and renewable energy drive industrial growth in the US and that a certain asymmetric behaviour can be concluded: the impact of an increase in NRE on IP is greater than that of a decrease in NRE on IP, while the influence of an increase in RE on IP seems to be less than that of a decrease in RE on IP.

1. Introduction

In 2014, as per World Bank (2018), fossil fuel energy remained the dominant contributor in the world's energy consumption mix with 81% of total energy consumption. This figure demonstrates the world's dependency on fossil fuels, such as coal, oil, and natural gas, even in recent times and despite all the environmental consequences of their use as well as the countries' commitments to transitioning to low carbon energy supply mixes. This dependency and its persistence through the years raises numerous concerns for the future of the energy sector but also the global socioeconomic and environmental conditions. Firstly, Chapman (2014) raises again the issue of future depletion of fossil energy sources; issue that was raised before in the literature (see Hubbert's peak) but due to technological advancements, exploration of more geographical locations with natural resources, and pricing adjustments, this point is not reached *yet*. Following that, another concern is that sustainability of energy security, defined as "*the uninterrupted availability of energy sources at an affordable price*" (International Energy Agency (IEA) 2018). Thus, uncertainty in energy may lead to serious economic consequences since the economic production as well as securing appropriate living standards in the population depend highly on the usage of energy. Finally, the combustion of fossil fuels is the main contributor to greenhouse gas emissions that lead to climate change. Because of air pollution exposure, it is estimated that in 2012 approximately seven million people died – one in eight of total global deaths – in the world (World Health Organization, 2018). Moreover, the world's average temperature has increased about 2.0 degrees Fahrenheit/1.1 degrees Celsius since the late 19th century, and the year 2016 was the warmest year on record to date (National Aeronautics and Space Administration (NASA) 2018a). NASA (2018b) reveals negative outcomes of climate change. Accordingly, as results of climate change, (i) temperatures will go on rising, (ii) frost-free season will augment, (iii) precipitation patterns will suffer a change, (iv) more droughts and heat waves will occur, and (v) hurricanes will be stronger.

These concerns have resulted in a slight shift in energy policy making towards adoption and promotion of clean, renewable energy sources (biomass, hydroelectric, geothermal, solar and wind) (Bilgili et al., 2016; Bulut, 2017; Diemuodeke and Briggs,

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2018). As Fang (2011) denotes, policy's expectations from this shift are dual: on the one side, mitigate greenhouse gas emissions and contribute towards a solution to climate change, and secondly, make sure access to energy is provided widely and the economic production process receives energy as a major factor of production.

The US energy mix is another example of great dependency on fossil fuels, regardless of all the concerns. Approximately 60% of its electricity generation is from fossil fuels while 20% from nuclear power and 17% from renewables, in 2017 (Energy Information Administration (EIA), 2018a).

Empirical literature on the renewable energy-economic growth nexus for the US (see e.g., Ewing et al., 2007; Payne, 2009, 2011; Bowden and Payne, 2010; Menyah and Wolde-Rufael, 2010; Yildirim et al., 2012; Bilgili, 2015; Aslan, 2016; Bilgili et al., 2017; Troster et al., 2018; Bilgili et al., 2019) is not new, but a consensus has not been reached (as is the case with generally the energy-growth nexus). For instance, while Ewing et al. (2007), Payne (2011), Bilgili (2015), Aslan (2016), Bilgili et al. (2017), Troster et al. (2018), and Bilgili et al. (2019) yield strong evidence about the positive effects of renewable energy consumption on economic growth, the others find no and/or weak evidence for the related relationship. Besides, studies by Payne (2010), Omri (2014), Csereklyei et al. (2016) and Dogan and Seker (2016) have provided comprehensive and all-inclusive databases of empirical studies in the literature. More specifically, with regards to the different impacts of renewable energy vis-à-vis non-renewable energy, Inglesi-Lotz and Dogan (2018) found that "increases in non-renewable energy consumption intensify pollution while the opposite holds for renewable energy" adding that a unidirectional causality was found running from "emissions, income, trade and non-renewable energies towards renewable energies; from non-renewable energy to emissions; and from emissions and non-renewable energies to trade" for ten sub-Saharan African countries. Other examples of studies showed that increases in renewable energy improve economic growth in a group of emerging economies (Apergis and Payne, 2011a), OECD countries (Apergis and Payne, 2010a; Inglesi-Lotz, 2016; Salim et al., 2014), Eurasian countries (Apergis and Payne, 2010b), Central America (Apergis and Payne, 2011b), top renewable energy countries (Bhattacharya et al., 2016), and a panel of 80 countries (Apergis and Payne, 2012a, 2012b). Besides, some studies explored that renewable energy consumption has little or no effect on economic growth in European countries (Menegaki, 2011), OECD countries (Kula, 2014), and emerging countries (Ozcan and Ozturk, 2019).

This paper investigates whether renewable energy was a contributing factor towards the growth in industrial production in US, in contrast to non-renewable energy by using monthly data from January 2000 to February 2018. The majority of the studies in the literature has made a strong assumption that the relationship between renewable energy consumption and economic growth is characterized as linear and symmetric. This paper differs in that it employs a nonlinear cointegration approach: nonlinear autoregressive distributed lag (NARDL) method developed by Shin et al. (2014). In addition, this paper distinguishes between renewable and non-renewable energy consumption, appreciating the different dynamics of the two when it comes to their use in the industrial production as well as market structures.

The rest of the paper is organized as follows: Section 2 discusses the theoretical framework, econometric methodology and dataset employed. Section 3 presents the empirical results, while Section 4 concludes the paper by providing some policy implications.

2. Methodology and data

To investigate the particular effects of non-renewable and renewable energy consumption on industrial production in the US, the paper regresses industrial production on non-renewable and renewable energy consumption. This model is described as:

$$\mathrm{lnIP_t} = \beta_0 + \beta_1 \mathrm{lnNRE_t} + \beta_2 \mathrm{lnRE_t} + \varepsilon_t \tag{1}$$

where ln, IP, NRE, RE, and ε stand for natural logarithm, industrial production index (2002 = 100), total non-renewable/fossil energy consumption (in Trillion Btu), total renewable energy consumption (in Trillion Btu), and error term, respectively. The choice of the econometric methodology to capture asymmetric behaviours require a relatively big sample of data. Hence, the decision was to work with monthly data; that does not come without its disadvantages. To estimate a structural model using a Cobb–Douglas production function, data on capital, labour, and technology would be needed but are not released in a monthly frequency.

Before examining the asymmetric cointegration relationship in the model, this paper investigates the order of integration of the variables in the model. The paper employs three unit root tests, namely ADF test of Dickey and Fuller (1981), PP test of Phillips and Perron (1988), and KPSS test of Kwiatkowski et al. (1992), to investigate the order of integration of the variables. While ADF and PP methods test for the null hypothesis of the presence of a unit root, the null hypothesis of KPSS implies a stationary variable.

Shin et al. (2014) produce the NARDL approach by specifying that previous empirical works on cointegration mostly assume a linear symmetric long-run relationship between variables. Their approach lets researchers investigate asymmetric relationships between variables. The NARDL approach can be employed irrespective of whether the regressors are I(0), I(1) or mutually cointegrated just like the ARDL approach.

Prior to producing the full demonstration of the NARDL model, they present the following asymmetric long-run regression:

$$\mathrm{y_t} = \beta^+ \mathrm{x_t^+} + \beta^- \mathrm{x_t^-} + \mathrm{u_t} \tag{2}$$

$$\Delta \mathrm{x_t} = \mathrm{v_t} \tag{3}$$

where $\mathrm{y_t}$ and $\mathrm{x_t}$ are dependent and independent variables, respectively. Besides, $\mathrm{x_t}$ is dissociated as $\mathrm{x_t} = \mathrm{x_0} + \mathrm{x_t^+} + \mathrm{x_t^-}$ where $\mathrm{x_t^+}$ and $\mathrm{x_t^-}$ denote partial sum process of positive and negative changes in $\mathrm{x_t}$:

$$\mathrm{x_t^+} = \sum_{\mathrm{j=1}}^{\mathrm{t}} \Delta \mathrm{x_j^+} = \sum_{\mathrm{j=1}}^{\mathrm{t}} \max\left(\Delta \mathrm{x_j}, 0\right) \tag{4}$$

$$\mathrm{x_t^-} = \sum_{\mathrm{j=1}}^{\mathrm{t}} \Delta \mathrm{x_i^-} = \sum_{\mathrm{j=1}}^{\mathrm{t}} \min\left(\Delta \mathrm{x_j}, 0\right) \tag{5}$$

Shin et al. (2014) extend the ARDL approach of Pesaran and Shin (1999) and Pesaran et al. (2001) and produce a dynamic framework to investigate asymmetries between variables. They consider the following NARDL (p,q) model:

$$\mathrm{y_t} = \sum_{\mathrm{j=1}}^{\mathrm{p}} \phi_{\mathrm{j}} \mathrm{y_{t-j}} + \sum_{\mathrm{j=0}}^{\mathrm{q}} \left(\theta_{\mathrm{j}}^+ \mathrm{x_{t-j}^+} + \theta_{\mathrm{j}}^- \mathrm{x_{t-j}^-}\right) + \varepsilon_t \tag{6}$$

where $\mathrm{x_t}$ is a kx1 vector of multiple regressors described as $\mathrm{x_t} = \mathrm{x_0} + \mathrm{x_t^+} + \mathrm{x_t^-}$, ϕj stands for the autoregressive parameter, θ_{j}^+ and θ_{j}^- stand for the asymmetric distributed lag parameters, and ε_t is the error term.

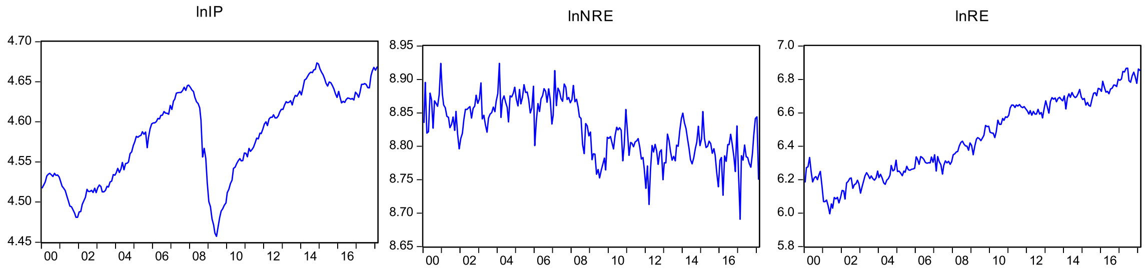

Fig. 1. Time plots of the variables in the empirical model.
Source: Federal Reserve (2018); EIA (2018b).

Following Pesaran et al. (2001), Eq. (6) can be rewritten in the error correction form as Eq. (7)

$$\Delta y_t = p y_{t-1} + \theta^+ x^+_{t-1} + \theta^- x^-_{t-1} + \sum_{j=1}^{p-1} \gamma_j \Delta y_{t-j} + \sum_{j=0}^{q-1} \left(\varphi_j^+ \Delta x^+_{t-j} + \varphi_j^- \Delta x^-_{t-j}\right) + \varepsilon_t \qquad (7)$$

where $\beta^+ = -\theta^+/p$ and $\beta^- = -\theta^-/p$ are the related asymmetric long-run parameters. The application of the NARDL approach consists of three stages. First, the null hypothesis of a symmetric long-run relationship $\left(H_0 : \beta^+ = \beta^-\right)$ is tested using the Wald statistic. Second, F_{III} statistic is used to test the null hypothesis of no cointegration stated as $H_0 : p = \theta^+ = \theta^-$. Finally, if one explores an asymmetric cointegration relationship between variables, then he/she can estimate asymmetric long-run parameters.

The data are in monthly frequency for the period 2000:01 to 2018:02, seasonally adjusted, and in their natural logarithm form. Industrial production index data are obtained from Federal Reserve (2018) while energy consumption data are extracted from EIA (2018b).

From Fig. 1, it can be observed that renewable energy consumption as well as industrial production exhibit increasing trends in the period studied, in contrast with non-renewable energy consumption that shows almost a stationary-type of characteristic, with a slight decreasing trend. These observations might indicate a certain level of substitutability between renewable and non-renewable energy in this period.

3. Findings

Table 1 depicts the results of the ADF, PP and KPSS unit root tests. As is seen, lnIP and lnRE are stationary at first differences according to all unit root tests. On the other hand, lnNRE is stationary at level with regard to PP test and is stationary at first difference according to ADF and KPSS tests. Hence, based on these results, the NARDL approach can be performed to examine the asymmetric cointegration in the model, and if such a relationship exists, and to estimate asymmetric long-run parameters.

Panel A of Table 2 indicates that the null hypothesis of symmetry can be rejected at 5% significance level. This finding implies the employment of the NARDL model instead of the ARDL model. Panel B of Table 2 reports whether there exists a cointegration relationship among variables in the model. Accordingly, the null hypothesis of no cointegration is rejected at 1% significance level, implying there is a cointegration relationship in the model. Hence, long-run parameters can be estimated by employing the NARDL approach. Panel C of Table 2 reports the long-run parameters.

The previous section explained how long-run coefficients are calculated. Accordingly, the long-run coefficients of $\ln NRE^+$ and $\ln NRE^-$ are 2.053 (−0.115/−0.056) and 1.321 (−0.074/−0.056), respectively. Moreover, the long-run coefficients of $\ln RE^+$ and $\ln RE^-$ are 0.446 (−0.025/−0.056) and 1.160 (−0.065/−0.056), respectively.

Table 1
Results of unit root tests (ADF, PP, KPSS)[a].

Variable		ADF	PP	KPSS
lnIP	Level	−1.944	−1.431	1.046[a]
	1st difference	−3.904[a]	−12.979[a]	0.052
lnNRE	Level	−2.534	−4.487[a]	1.308[a]
	1st difference	−16.378[a]	−28.657[a]	0.090
lnRE	Level	0.089	−0.132	1.858[a]
	1st difference	−13.497[a]	−19.409[a]	0.098

Notes:
[a] Indicates 1% statistical significance.

Accordingly, 1% increase in non-renewable energy consumption leads to 2.053% increase in industrial production index while 1% decrease in non-renewable energy consumption results in 1.321% decrease in industrial production index. Besides, 1% increase in renewable energy consumption results in 0.446% increase in industrial production index while 1% decrease in renewable energy consumption leads to 1.160% decrease in industrial production index.

Finally, the stability of the parameters in the long-run NARDL model is tested by CUSUM and CUSUM-Q tests suggested by Brown et al. (1975). CUSUM and CUSUM-Q statistics are based on cumulative residuals and cumulative squares of residuals, respectively. As the residuals and the squares of the residuals remain in the critical bounds of the 5% significance level, the estimated long-run parameters seem to be stable over the period 2000:01–2018:02 (see Fig. 2).

4. Conclusion

World's heavy dependence on non-renewable energy sources result in serious concerns and problems all over the world, namely exhaustion of non-renewable sources in the future, energy security, and environmental problems. As a result of these major concerns and problems, (i) policy makers have paid attention to renewable energy sources in the last decades and (ii) investments in renewable energy technologies which have increased specifically since 2004 led to a rapid decline in the cost of renewable energy technologies (Diemuodeke and Briggs, 2018; Kocaarslan and Soytas, 2019). Then, many papers in the energy literature focused on the relationship between renewable energy and economic growth and the theoretical and empirical literature on this field began to expand.

This paper has investigated the impacts of non-renewable and renewable energy consumption on industrial production in the US using monthly data from 2000:01 to 2018:02. After performing unit root tests to determine the order of integration of the

Table 2
NARDL cointegration test.

Panel A: Testing the presence of asymmetry						
Test statistic	3.756[b]		Prob. value		0.025	
Panel B: Testing the presence of cointegration						
F_{III} test statistic	Critical values[c]					
	1%		5%		10%	
9.913[a]	I(0) 5.15	I(1) 6.36	I(0) 3.79	I(1) 4.85	I(0) 3.17	I(1) 4.14
Panel C: Long-run parameters						
Variable	Coefficient		Std. error		Prob. value	
Constant	0.298[a]		0.078		0.000	
$\ln IP_{t-1}$	−0.056[a]		0.018		0.002	
$\ln NRE^{+}_{t-1}$	0.115[a]		0.024		0.000	
$\ln NRE^{-}_{t-1}$	0.074[a]		0.022		0.001	
$\ln RE^{+}_{t-1}$	0.025[b]		0.011		0.031	
$\ln RE^{-}_{t-1}$	0.065[a]		0.013		0.000	
Panel D: Diagnostic test results[d]						
$R^2 = 0.67$, $\overline{R}^2 = 0.57$, F-ist = 6.522 (0.000), $\chi^2_{BG} = 0.657$ (0.520), $\chi^2_{WH} = 1.165$ (0.244)						

[a] Indicates 1% statistical significance.
[b] Indicates 5% statistical significance.
[c] Critical value are obtained from Pesaran et al. (2001).
[d] χ^2_{BG} and χ^2_{WH} stand for Breusch–Godfrey LM test statistic for no serial correlation, and White's test statistic for no heteroscedasticity. Values in parentheses show prob. values.

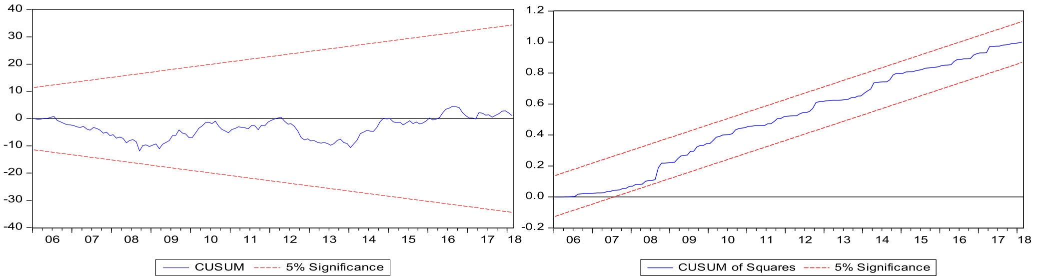

Fig. 2. CUSUM and CUSUM-Q tests.

variables, the paper employed the NARDL approach to examine asymmetric relationships between energy consumption and industrial production. The findings indicated that (i) 1% increase in non-renewable energy consumption led to 2.053% increase in industrial production index, (ii) 1% decrease in non-renewable energy consumption resulted in 1.321% decrease in industrial production index, (iii) 1% increase in renewable energy consumption resulted in 0.446% increase in industrial production index, and (iv) 1% decrease in renewable energy consumption led to 1.160% decrease in industrial production index.

Overall, the empirical findings indicated that non-renewable and renewable energy consumption had long-run asymmetric effects on industrial production in the US because of the different coefficients. Besides, the findings of this paper concurred with those of Ewing et al. (2007), Payne (2011); Bilgili (2015), Aslan (2016), Bilgili et al. (2017), Troster et al. (2018), and Bilgili et al. (2019), which yielded renewable energy consumption had positive effects on economic growth.

These findings have important implications for researchers and policy makers. First, both non-renewable and renewable energy drive economic growth in the US. Second, the effects of increases and decreases in energy consumption may differ from each other in terms of the magnitude of the effects. Therefore, future research may focus on asymmetric relationships between energy consumption and economic growth. Third, the effect of a decrease in non-renewable energy consumption on industrial production seems to be lower than that of an increase in non-renewable energy consumption while the impact of a decrease in renewable energy consumption on industrial production appears to higher than that of an increase in renewable energy consumption.

Even though the paper yields that both non-renewable and renewable energy consumption contribute to industrial growth in the US, the exploitation of fossil energy sources result in serious problems and concerns as was denoted previously. The third implication above means that the negative effect of a decrease in non-renewable energy consumption may be offset by increasing renewable energy consumption along with increases and/or improvements in other important factors of production, such as technology, capital, labour force, human capital, and institutional quality etc. Therefore, this paper remarks that the US economy can decrease non-renewable energy consumption and increase renewable energy consumption without sacrificing economic growth.

As Bilgili et al. (2019) remark, the substitution level of non-renewable energy sources with renewable energy sources was very low in the US until early 2000s. Then, policy makers in the US have implemented many policies to support and encourage the utilization of renewable energy. As a result of this awareness in states and at federal level, renewables have begun to replace non-renewable sources from 2000 to 2018 as was exhibited in Fig. 1. Besides this replacement, renewable energy consumption mix of the US dramatically changed in the 2000s. Table 3 exhibits the shares of renewable energy sources in total renewable energy consumption in the US during the period 2000–2017. As one can

Table 3
Shares of renewable energy sources in total renewable energy consumption in the US (%).
Source: EIA (2018b).

Year	Biomass	Geothermal	Hydroelectric	Solar	Wind
2000	49.28	2.69	46.05	1.04	0.93
2005	49.95	2.90	43.36	0.93	2.85
2010	53.94	2.54	31.08	1.11	11.31
2015	50.84	2.20	24.09	4.42	18.45
2017	44.61	1.91	25.14	7.03	21.31

observe from the table, the US economy has substituted hydroelectric with wind and solar sources in the last years. Accordingly, during the period 2005–2017, the shares of solar and wind energy consumption rised from 0.93% to 7.03% and from 2.85% to 21.31%, respectively. This figure is not surprising when we consider national and federal attention for solar and wind energy in the US, the advantages of solar and wind energy, and the decreases in costs of solar and wind energy. Today, the US government actively stimulates the production of solar and wind energy especially through production tax credit and investment tax credit. Due to these supports, the US is the second largest producer of solar and wind power after China in the world by 2017. The costs of solar and wind energy have remarkably decreased over the last years in the US because of technological developments and investments in solar and wind energy industries. For instance, the cost of solar photovoltaic cell per watt declined from 76.67 USD to 0.74 USD from 1977 to 2013 (Economist, 2013). Besides, average capital costs of wind energy projects declined by 65% in the period 1980–2004 and several studies find that this decrease will probably continue in the future (Lantz et al., 2012).

In the energy economics literature, some papers reveal that renewables have not only direct but also indirect effects on economic growth. Accordingly, renewable energy can positively affect economic growth by improving capital formation and increasing the labour employment of an economy (see e.g., Chien and Hu, 2008; Bilgili et al., 2019, among others). Last but not least, apart from contributing to economic growth, renewable energy has the merit that it can decrease environmental problems. Therefore, based on the empirical findings and the advantages of renewable energy, this paper argues that policy makers should proceed to encourage renewable energy production and consumption in the US. In doing so, they not only can contribute to economic growth of the US economy but also can decrease the problems and concerns stemming from the utilization of fossil energy sources.

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