Economics Bulletin

Volume 40, Issue 3

The impact of total factor productivity on energy consumption and CO2 emissions in G20 countries

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Abstract

This study investigates the nexus among total factor productivity, energy consumption and CO2 emissions in G20 countries for time series data from 1971 to 2017 by employing time-varying causality test. By and large, we have found nonlinear causality among the variables. Specifically, the direction from TFP to CO2 is demonstrated for Argentina, France, South Korea, UK and USA. In addition, bidirectional interconnectedness is displayed for four countries (Italy, Japan, Saudi Arabia and Turkey). Furthermore, the one-way relationship between TFP and EC differs among the countries. The causality from EC to TFP is obtained for Brazil, South Africa and Turkey, the vice versa linkage is confirmed for Argentina, Russia, UK and USA, and we have two two-way causalities for Italy and Japan. Lastly, we dissected the validity of the Environmental Kuznets curve hypothesis between TFP to CO2. Our outcomes insinuate the validity of the Environmental Kuznets curve for Turkey, the inverted-U shaped for Argentina and Saudi Arabia, N-shaped for France, Italy and South Africa and inverted-U shaped curve for Japan, UK and USA. In view of the results, some crucial policy implications could be suggested, such as that the impact of TFP policies influenced the EC and CO2.

We would like to thank John P Conley (Editor) for the detailed and constructive comments made on our manuscript. Also, we would like to thank the journal's anonymous reviewers for their valuable comments. Any remaining errors are the authors' responsibility.
Citation: Panayiotis Tzeremes, (2020) "The impact of total factor productivity on energy consumption and CO2 emissions in G20 countries", *Economics Bulletin*, Volume 40, Issue 3, pages 2179-2192
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Submitted: April 30, 2019. **Published:** August 08, 2020.

1. Introduction

In the last three decades, the interrelation among economic growth, energy consumption and emissions has been a hot topic for academics and practitioners as it serves as an effective early warning signal for governments. Because of the social consequences of this topic, an increasing number of researchers have conducted deep studies using larger data sets from numerous countries with stout econometric methods. There is no doubt, then, that topic is a consequential aspect of academic research, but what we learn from each study depends on how the researchers approached the problem and the techniques they applied. Some patterns offer more insight than others. Succinctly speaking and according to literature review, we can classify the studies into three streams. In the first one, energy and environmental economists have analyzed the economic growth and environmental pollution nexus in the framework of the environmental Kuznets curve (EKC) hypothesis, which assumes an inverted U-shaped relationship between environmental pollution and economic development and draws its roots from the pioneering study by Grossman and Krueger (1995). The EKC postulates that as income increases, environmental pollution rises, until some threshold level of per capita income is reached beyond which pollution starts declining (Li et al., 2007; Tzeremes, 2018, 2019). Hence, the early stages of economic growth are expected to bring about an increase in degradation and pollution. This is when countries are struggling to achieve high growth, but ignore the cause and effects of the economic activities, specifically the deterioration of the environment. However, a reversal of this trend is expected beyond a certain level of income per capita, thus the high-income level countries are usually classified as lower polluters when compared to developing countries. In the second stream, the nexus of energy consumption and economic growth has stimulated research curiosity with the pioneering study by Kraft and Kraft (1978). Herein, energy, as a crucial input in the production of many commodities, represents the backbone of the world's industrial development. Hence, more energy consumption leads to more economic development while simultaneously employing energy in a more efficient way requires a higher economic development level as well (Ang, 2007). Therefore, the direction of causality cannot be determined a priori. Lastly, a third research stream investigating the linkages among energy consumption, economic growth and environmental pollution, has emerged as a result of the combination of the energy-growth and environment-growth nexuses (Soytas and Sari, 2009; Ozcan et al., 2020).

Based on this premise, our inquiry adopts the last stream but from a different angle. More precisely, for all the foregoing strands, the majority of researchers have used economic growth in order to estimate the models (Ozturk, 2010; Payne, 2010), bar a few exceptions, some authors employ growth models (Gozgor et al., 2018), production function (Halicioglu and Ketenci, 2018; Tugcu and Topcu, 2018) or Total Factor Productivity-TFP (Tugcu and Tiwari, 2016; Haider and Ganaie, 2017). Our study uses TFP in order to investigate the impact of TFP on energy consumption (EC) and CO_2 in G20 countries spanning the period 1971 to 2017 via the (nonlinear) time-varying causality test as proposed by Ajmi et al. (2015). Economic growth can be explained by the neoclassical and the endogenous growth model. On the one hand, the neoclassical model stimulates economic growth by capital stocks and population growth. Furthermore, capital stocks and population growth imply decreasing returns to scale and their influence on economic growth becomes slightly balanced in the long run. Hence, exogenous TFP plays an important role on economic growth due to the fact that it indicates the level of technological development (Solow, 1956). On the other hand, TFP via the technological change determine a vital role on economic growth adopted by the endogenous growth theories (Lucas, 1989; Romer, 1986). Consequently, both theories agree on the conclusion that TFP boost the performance of sustainable economic growth in the long run.

Having a bird's eye view of existing literature[1], a number of researches explored the links between economic growth, energy consumption and CO_2 emissions involving a variety of empirical findings. Despite the plethora of researches conducted in this realm, the current work is distinguished from the existing body of understanding in several substantial directions, to the best of our knowledge. First, unlike previous researches, this work explores for the first time the linkages among TFP, energy consumption and CO_2 emissions for G20 countries. Second, no single attempt has been known to investigate the interaction among TFP, energy consumption and CO_2 emissions by using nonlinear techniques, and third, we examine the validity of the traditional EKC hypothesis (between TFP and CO_2) for each country.

The remainder of this paper is organized as follows: Section 2 describes the sample and methodology model, and Section 3 the discussion of the empirical test and of the findings. This is followed by the final conclusions and the discussion of the implications of the results in Section 4.

2. Data and Methodology

2.1 Data and pretests

Our probe investigates the linkage between the index TFP and the variables CO_2 and EC through a time-varying Granger causality test in the G20 countries[2] over the period 1971-2017. The TFP dataset has been extracted from the Penn World Table-v9.1 (Feenstra et al., 2015) and EC (kg of oil equivalent per capita) and CO_2 emissions (metric tons per capita) have been derived from World Bank, World Development Indicators[3].

Firstly, we will determine the stationarity, employing unit root tests. We perform three tests, namely: Elliott et al. 1996, Dickey–Fuller generalized least squares (DF-GLS) and Phillips and Perron, 1988 (PP), for the purpose of determining the maximum order of integration between the variables.

2.2 Time-varying vector autoregressive model

Since its description (Sims, 1980), vector autoregressive (VAR) modelling has been successfully applied to the analysis of multivariate time series, focusing on the identification of complex relationships among several time series. The parameters of VAR models can be easily interpreted and they provide a simple identification of Granger causality (Granger, 1969). In particular, deeming a s-dimensional vector autoregressive (VAR) pattern of order k, Granger (1969) developed the well-known Granger causality test. Having an unprecedented influence on the scientific discipline, the traditional Granger causality test can be written in its general form as:

$$P_t = \mathrm{q} + L_1 P_{t-1} + L_2 P_{t-2} + \cdots + L_k P_{t-k} + m_t \qquad (1)$$

in equation (1) $P_t = [P_{1t}, P_{2t}, \ldots P_{st}]$, $q\ and\ L_i (i = 1,2, \ldots k)$ are coefficient matrices implemented by

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[1] We found only three studies for G20 countries (Lee, 2013; Yao et al., 2015 and Luo et al., 2017)

[2] Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Korea, South Africa, Turkey, United Kingdom (UK) and United States of America (USA). Moreover, the time period for Germany and Russia is 1991-2017.

[3] The data can be downloaded from: https://datacatalog.worldbank.org/ Moreover, Carbon emissions per capita are measured as the total amount of carbon dioxide emitted by the country as a consequence of all relevant human (production and consumption) activities, divided by the population of the country.

$$q = \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_s \end{bmatrix}, \qquad L_i = \begin{bmatrix} l_{11i} & l_{21i} & \cdots & l_{s1i} \\ l_{12i} & l_{22i} & \cdots & l_{s2i} \\ \vdots & \vdots & \vdots & \vdots \\ l_{1si} & l_{2si} & \cdots & l_{ssi} \end{bmatrix}$$

and m_t denotes an error vector of random variables with zero mean and a covariance matrix Σ calculated by

$$\sum = \begin{bmatrix} \sigma_{11}^2 & \sigma_{21} & \cdots & \sigma_{s1} \\ \sigma_{12} & \sigma_{22}^2 & \cdots & \sigma_{s2} \\ \vdots & \vdots & \vdots & \vdots \\ \sigma_{1s} & \sigma_{2s} & \cdots & \sigma_{ss}^2 \end{bmatrix}$$

the aforementioned VAR model is valid in cases that the autocorrelations and cross-correlations are constant over time. Hence, there are limitations owing to the fact that the system dynamics in real datasets document changes depending on external factors (such as natural disasters, economic crises, new technologies, etc.).

In order to eliminate these limitations Sato et al. (2007) developed a time-varying vector autoregressive framework (or dynamic VAR as called) that has a time-smooth variation as a contribution. They applied this time-varying vector autoregressive framework by adopting a theoretical model of locally stationary procedure proposed by Dahlhaus et al. (1999). The dynamic VAR can be reproduced in the following form:

$$w_{t,T} = d(t/T) + \sum_{l=1}^{k} C_l\,(t/T) w_{t-l,T} + u_{t,T}, \tag{2}$$

where $w_{t,T}$ and $d(t/T)$ are two variables (TFP, EC and CO_2) of our analysis in order to check the causality as a pair, $C_l(t/T)$ is the autoregressive coefficients and $u_{t,T}$ is the error vector of the Equation (2). Ajmi et al. (2015) remodeled Expression (2) by proposing the M- and B-splines functions.[4] In particular, the new time-varying vector autoregressive pattern calculates the splines through a multiple linear regression framework by the Equation (2). Hence, the new time-varying framework takes the below form:

$$v_t = \sum_{n=0}^{H} c_n\, j_n(t) + \sum_{k=1}^{O} M_n^l j_n(t)\, v_{t-l} + a_t \tag{3}$$

c_n display the vectors and M_n^l illustrate the B-splines coefficients. Another vital characteristic of Ajmi et al. (2015) is the concept of the examination of Granger causality. Implementing the Wald test on the coefficients, we can capture the validity of the time-varying Granger causality. To clarify, having two variables, we can estimate the existence of time-varying Granger causality when the coefficients are equal to zero (or not). Moreover, when the B-spline is significant (or not) for each coefficient, this in turn means that the time-varying causality is time-varying or constant. The principal restriction of employing this pattern is that it demands the reckoning of many coefficients. Therefore, because of the lessened number of observations, we had to accede a bivariate DVAR of order 1. Consequently, we set a dynamic VAR of order $n = 1, k = 3$ and $lag = 1$ for a VAR model with two variables and we check the causality for each pair (see Sato et al., 2007; Ajmi et al., 2015).

[4] M- and B-splines functions are nominated by Eilers and Marx (1996).

3. Empirical Results and Discussions

The outcomes of the unit roots tests at the level as well as at the first difference are tabulated in Table 1. To examine the variability of the variable we employed DF-GLS and PP unit root test. By probing those unit root tests, we can conclude that some of the variables, TFP, EC and CO_2 have unit root at level with intercept and trend but at first difference all variables are stationary or integrated at order I(1). Then, we also conduct the Zivot and Andrews (ZA) unit root break with single unknown break effect. The estimated results are shown in Table 2. We can find that none of the series rejects the null hypothesis of there being a unit root with structural break. In the next step of our long-run cointegration analysis, we used the Johansen's (1990) cointegration technique. The test provides two likelihood based tests for the presence of a cointegrating vector, which is the Trace and the Maximum-Eigen values tests as shown in Table 3. The estimated results show that both statistics reject the null hypothesis of no cointegration of the estimation at 1% and 5% significance level.

Concerning the findings of the causalities, we will start our analysis from the classical Granger causality test (Equation (1)). The results are reported in Table 4. Particularly, watching the relationship between EC and CO_2, we can observe only one unidirectional causality running from the CO_2 to EC (for Mexico) and five countries (France, Italy, Turkey, UK and USA) with the vice versa linkage. When we notice the nexus between CO_2 and TFP, four countries (Australia, Mexico, Russia and South Africa) reveal one-way linkage from CO_2 to TFP and South Korea, UK and USA disclose the opposite causality. Lastly, the interconnectedness for the pair of TFP and EC divulge three countries (Canada, India and South Africa) with unidirectional causality running from the EC to TFP and also three (Russia, UK and USA) with the opposite relationship. Moreover, we can notice that the majority of the results indicate the neutrality hypothesis among the variables for the countries and surprisingly we do not have bidirectional relationship. Regarding the dynamic Granger causality (Equations (2)), Table 5 depicts the results. For the first pair of variables (EC and CO_2), we can observe only one one-way causality running from the CO_2 to EC (for India) and two cases of bidirectional linkage (for France and Russia). When it comes to CO_2 and TFP nexus, France, Saudi Arabia and Turkey show unidirectional relationship from CO_2 to TFP and two countries (Argentina and South Korea) the contrary direction. Furthermore, Italy shows two-way interconnectedness for that pair of variables. Finally, with respect to TFP and EC nexus, one-way dynamic causalities running from the EC to TFP are indicated for Brazil, Japan and Turkey, whilst the opposite causality is obtained for Argentina, Australia, Russia and UK. Lastly, Italy and USA show bidirectional causality.

Table 6 illustrates the findings for the time-varying Granger causality framework, delineated in Equation (3). Dissecting the first pair of variables (EC and CO_2), Argentina, Turkey (albeit weak, statistically significant at the 10% level) and USA reveal unidirectional causality running from EC to CO_2. This sign is also an expected result and an indication that these countries still have a large dependence on fossil-based energy sources, such as oil and coal.

Table 1 Unit root tests results

	DF-GLS test						Pperron test					
	Level			1st diff.			Level			1st diff.		
Countries	CO_2	EC	TFP	CO_2	EC	TFP	CO_2	EC	TFP	CO_2	EC	TFP
Argentina	-1.08[6]	-1.10[6]	-1.47[4]	-3.50[1]***	-3.54[2]***	-2.07[2]**	-7.92[3]	-7.73[3]	-9.25[3]	-31.50[3]***	-39.04[3]***	-29.78[3]***
Australia	0.89[5]	-1.54[4]	-2.40[4]	-3.72[2]***	-3.81[2]***	-2.64[2]***	-3.23[3]	-6.81[3]	-9.50[3]	-45.29[3]***	-52.53[3]***	-38.59[3]***
Brazil	-1.58[3]	-1.60[4]	-2.50[4]	-3.69[2]***	-2.18[3]***	-2.22[2]***	-11.09[3]	-9.27[3]	-13.70[3]	-27.99[3]***	-36.46[3]***	-27.92[3]***
Canada	-2.95[3]*	-1.12[4]	-2.72[3]	-2.84[3]***	-2.94[2]***	-2.91[2]***	-11.15[3]	-13.71[3]	-8.56[3]	-33.04[3]***	-25.78[3]***	-47.93[3]***
China	-1.39[4]	-1.73[4]	-1.47[4]	-3.00[2]***	-2.10[3]**	-2.52[2]**	-5.36[3]	-2.11[3]	-6.52[3]	-21.48[3]**	-24.27[3]**	-29.71[3]***
France	-2.03[3]	-1.49[4]	-1.37[3]	-2.16[2]**	-2.08[3]**	-1.99[3]**	-11.12[3]	-1.53[3]	-6.89[3]	-52.43[3]***	-45.34[3]***	-29.75[3]***
Germany	-1.78[3]	-1.29[4]	-3.49[2]**	-2.11[2]**	-2.74[3]***	-2.50[2]**	-22.66[3]***	-23.39[3]***	-2.71[3]	-31.36[3]***	-33.26[3]***	-17.72[3]*
India	-2.87[2]	-1.25[4]	-1.12[5]	-2.29[3]**	-3.81[1]***	-3.92[2]***	-8.33[3]	-0.88[3]	-2.64[3]	-45.98[3]***	-45.88[3]***	-28.92[3]***
Indonesia	-1.39[3]	-1.59[3]	-1.22[4]	-3.00[1]***	-2.86[2]***	-2.80[3]***	-15.49[3]	-4.32[3]	-8.06[3]	-33.71[3]***	-40.88[3]***	-21.92[3]**
Italy	-1.59[3]	-1.91[3]	-0.96[4]	-2.10[3]**	-2.05[3]**	-2.42[3]**	4.59[3]	3.36[3]	-5.46[3]	-39.45[3]***	-46.81[3]***	-36.45[3]***
Japan	-1.50[3]	-1.23[3]	-0.93[4]	-2.58[3]**	-2.80[2]***	-3.71[2]***	-10.05[3]	-1.57[3]	-5.35[3]	-39.50[3]***	-42.38[3]***	-40.90[3]***
Mexico	-1.52[3]	-1.23[3]	-3.01[3]*	-2.20[3]**	-3.38[2]***	-2.94[3]***	-5.95[3]	-5.75[3]	-6.98[3]	-54.77[3]***	-34.78[3]***	-24.14[3]**
Russia	0.61[5]	-1.37[4]	-0.51[5]	-2.71[3]***	-3.76[2]***	-2.56[3]**	-4.9[3]	-6.11[3]	-3.62[3]	-19.56[3]**	-16.42[3]*	-18.81[3]**
Saudi Arabia	-1.90[3]	-1.73[3]	-1.30[3]	-2.37[3]**	-3.29[2]***	-3.11[3]***	-19.09[3]	-5.32[3]	-4.51[3]	-42.40[3]***	-34.09[3]***	-39.98[3]***
South Korea	-0.95[4]	-1.37[4]	-0.93[4]	-2.20[3]**	-3.49[2]***	-3.88[2]***	-1.91[3]	-0.24[3]	-6.59[3]	-44.94[3]***	-44.10[3]***	-40.10[3]***
South Africa	-1.78[3]	-1.62[3]	-1.96[3]	-2.74[3]***	-2.78[3]***	-2.33[3]**	-8.71[3]	-7.79[3]	-8.65[3]	-42.97[3]***	-43.25[3]***	-25.66[3]***
Turkey	-1.10[4]	-1.69[3]	-1.43[3]	-3.44[2]***	-2.20[3]**	-3.56[1]***	-16.82[3]	-21.6[3]**	-20.65[3]**	-37.51[3]***	-37.25[3]***	-39.49[3]***
UK	-2.26[3]	-3.31[3]**	-0.88[4]	-2.20[3]**	-2.07[3]**	-2.55[3]**	-7.56[3]	-0.06[3]	-3.41[3]	-59.93[3]***	-53.04[3]***	-28.79[3]***
USA	-2.14[3]	-1.50[3]	-1.47[4]	-2.39[3]**	-3.43[2]***	-2.64[2]***	-8.37[3]	-10.01[3]	-13.70[3]	-28.49[3]***	-29.58[3]***	-29.65[3]***

Notes: ***, ** and * denote significant at 1%, 5% and 10% level. Numbers in square brackets are selected lags.

Table 2 Findings of the ZA unit root test with a structural break

Country	Variable	Level	Break	1st diff.	Break	Country	Variable	Level	Break	1st diff.	Break
Argentina	lnTFP	-3.19	1991	-5.75***	1996	Japan	lnTFP	-4.18	1988	-6.67***	1980
	lnEC	-3.74	1988	-7.09***	2002		lnEC	-2.94	1994	-7.83***	1983
	$lnCO_2$	-4.14	2004	-6.18***	2002		$lnCO_2$	-4.94*	1988	-7.42***	1987
Australia	lnTFP	-2.78	1984	-7.43***	2011	Mexico	lnTFP	-3.35	1983	-4.90**	1980
	lnEC	-3.62	2007	-8.25***	1988		lnEC	-4.55	1978	-6.53***	1981
	$lnCO_2$	-2.86	2009	-7.35***	2011		$lnCO_2$	-4.63	1983	-9.56***	1982
Brazil	lnTFP	-3.03	1994	-4.92**	1996	Russia	lnTFP	-4.69	1996	-6.52***	1998
	lnEC	-3.88	1990	-6.53***	1978		lnEC	-4.72*	1995	-4.82**	1995
	$lnCO_2$	-3.29	1981	-5.51***	1978		$lnCO_2$	-4.95*	1995	-4.89**	1998
Canada	lnTFP	-4.11	1999	-7.72***	1993	Saudi Arabia	lnTFP	-4.82*	1982	-7.06***	1974
	lnEC	-4.27	2003	-5.19***	1983		lnEC	-6.54***	1978	-7.06***	1981
	$lnCO_2$	-3.72	1997	-6.39***	1991		$lnCO_2$	-5.02*	1995	-7.67***	1998
China	lnTFP	-3.26	1996	-5.31**	1999	South Korea	lnTFP	-3.91	1986	-7.41***	1975
	lnEC	-3.31	1997	-4.89**	2001		lnEC	-3.63	1990	-7.53***	1985
	$lnCO_2$	-3.39	1997	-5.45**	2001		$lnCO_2$	-4.24	1993	-7.94***	1997
France	lnTFP	-4.53	1997	-5.71***	2002	South Africa	lnTFP	-2.83	2001	-4.99**	1992
	lnEC	-4.62	2003	-8.19***	1983		lnEC	-4.16	1989	-6.84***	1984
	$lnCO_2$	-3.94	1981	-8.64***	1994		$lnCO_2$	-3.78	1990	-6.66***	2002
Germany	lnTFP	-3.25	1991	-4.85***	2012	Turkey	lnTFP	-4.34	1998	-7.31***	1999
	lnEC	-6.39***	2008	-8.87***	2006		lnEC	-4.21	1986	-6.79***	1977
	$lnCO_2$	-6.89***	2008	-7.44***	1994		$lnCO_2$	-4.38	1985	-6.67***	1977
India	lnTFP	-2.79	1984	-5.54***	1975	UK	lnTFP	-3.18	1999	-4.82**	1992
	lnEC	-4.06	2001	-7.16***	2003		lnEC	-3.33	2003	-9.03***	1984
	$lnCO_2$	-3.53	2001	-7.01***	1996		$lnCO_2$	-4.56	2009	-9.99***	1984
Indonesia	lnTFP	-6.63***	1998	-5.44***	2003	USA	lnTFP	-9.54***	1973	-10.12***	1972
	lnEC	-5.98***	1990	-7.35***	1985		lnEC	-2.89	1987	-5.56***	1983
	$lnCO_2$	-3.79	1977	-7.26***	2012		$lnCO_2$	-2.65	1996	-5.48***	1982

Italy	lnTFP	-3.40	1998	-6.29***	1980
	lnEC	-3.03	2007	-7.48***	2007
	$lnCO_2$	-3.77	2007	-6.91***	2007

Notes: Break denotes the time of the structure change. ***, **, and * significant at the 1, 5, and 10 levels, respectively

Table 3 Findings of Johansen's cointegration tests

	Trace statistic (λ_{trace})			Maximum eigenvalue statistics (λ_{max})		
Country	r=0	r≤1	r≤2	r=0	r≤1	r≤2
Argentina	44.03***	17.23**	12.52**	31.42***	14.52**	13.71**
Australia	42.16***	25.03***	12.35**	12.13**	14.91**	15.82**
Brazil	33.11**	18.19**	15.30**	22.90**	14.89**	15.52**
Canada	33.55**	17.71**	10.00**	21.83**	14.91**	10.13**
China	36.06**	22.28**	13.83**	23.78**	18.45**	13.66**
France	49.15***	19.46**	14.13**	29.69***	15.33**	14.42**
Germany	41.79***	17.84**	15.41**	23.95**	14.43**	15.16**
India	34.64**	19.69**	12.60**	24.94**	17.09**	12.91**
Indonesia	72.53***	18.44**	15.98**	56.09***	15.46**	15.43**
Italy	38.76***	20.78**	16.77**	22.98**	15.01**	16.83**
Japan	19.02***	9.02**	17.75**	18.01**	9.02**	18.44**
Mexico	34.19**	18.81**	11.78**	23.38**	15.02**	11.96**
Russia	31.86**	18.63**	15.04**	22.23**	14.59**	15.54**
Saudi Arabia	42.13***	14.64**	16.85**	28.75***	16.49**	17.73**
South Korea	62.86***	12.44**	13.74**	24.36**	19.63**	16.02**
South Africa	65.12***	12.58**	12.46**	28.54**	17.19**	12.11**
Turkey	86.32***	17.08**	16.47**	59.73***	15.36**	15.23**
UK	48.08***	21.59**	15.73**	24.35**	15.21**	16.43**
USA	77.23***	19.16**	19.49**	15.12**	9.12**	18.94**

Notes: ** and *** indicate 5% and 1% levels of significance, respectively and r is cointegration rank

Moreover, France, India and Russia divulge a two-way relationship for that pair. This reciprocal nexus is not surprising for these countries, the proportion of the nonrenewable sources is high and air pollution plays a vital role. Furthermore, another possible clarification for this nexus is that energy mix is dominated by fossil fuels with the resultant effect of CO_2 emissions. In addition, this outcome indicates that increased energy consumption will lead to environmental degradation with negative effects on the atmosphere and a potential rise of CO_2 emissions provoke an increase in energy consumption. The governments can modify the traditional energy sources (such as fossil fuels) with energy conservation technologies – renewable energy sources (inter alia solar panels, wind power and hydro power plant) or they can substitute it with clean renewable systems for higher environmental quality. If we closely examine it, the linkage from TFP to CO_2 is demonstrated for Argentina, France, South Korea, UK and USA. It implies that more productivity leads to more carbon emissions when relying on fossil fuels for the production of goods. Based on these outcomes, we unveil that in these countries, productivity is a main cause of CO_2 emissions over the specified period. In addition, bidirectional interconnectedness is displayed for four countries (Italy, Japan, Saudi Arabia and Turkey). The feedback signs imply that as economic development increases governments will have environmental problems and the opposite. This indicate that rising scales of air pollution can be activated by the positive relationship between natural resources and economic activities. Lastly, the one-way relationship between TFP and EC differs among the countries. For example, the causality from EC to TFP is obtained for Brazil, South Africa and Turkey, the vice versa linkage is confirmed for Argentina, Russia, UK and USA, and we have two pairs of two-way causalities for Italy and Japan.

Table 4 Traditional Granger causality test results

	H: CO_2 to EC	H: CO_2 to TFP	H: EC to CO_2	H: EC to TFP	H: TFP to CO_2	H: TFP to EC
Argentina	0.605	0.412	0.546	0.31	0.784	0.317
Australia	0.46	0.079*	0.373	0.37	0.562	0.618
Brazil	0.544	0.869	0.998	0.624	0.827	0.955
Canada	0.473	0.286	0.63	0.049**	0.161	0.136
China	0.15	0.342	0.193	0.313	0.616	0.604
France	0.806	0.515	0.072*	0.566	0.433	0.116
Germany	0.344	0.765	0.926	0.811	0.313	0.187
India	0.359	0.137	0.512	0.058*	0.243	0.401
Indonesia	0.399	0.821	0.678	0.712	0.277	0.829
Italy	0.582	0.561	0.1*	0.465	0.666	0.781
Japan	0.74	0.152	0.129	0.172	0.687	0.352
Mexico	0.15**	0.085*	0.802	0.342	0.992	0.268
Russia	0.114	0.1*	0.509	0.212	0.402	0.058*
Saudi Arabia	0.167	0.273	0.922	0.62	0.146	0.939
South Korea	0.2	0.122	0.846	0.232	0.093*	0.266
South Africa	0.28	0.038**	0.283	0.045**	0.936	0.413
Turkey	0.523	0.895	0.05**	0.878	0.927	0.636
UK	0.177	0.373	0.04**	0.539	0.005***	0.004***
USA	0.109	0.131	0.02**	0.423	0.01***	0.01***

Notes: Values in tables are the p-values. ***, ** and * denote significant at 1%, 5% and 10% level. The number of lags used to implement the test is equal to one.

Table 5 Dynamic Granger causality test results

	H: CO_2 to EC	H: CO_2 to TFP	H: EC to CO_2	H: EC to TFP	H: TFP to CO_2	H: TFP to EC
Argentina	0.506	0.433	0.391	0.398	0.061*	0.015**
Australia	0.18	0.961	0.514	0.841	0.66	0.075*
Brazil	0.765	0.183	0.282	0.039**	0.121	0.284
Canada	0.994	0.58	0.798	0.964	0.766	0.661
China	0.652	0.339	0.261	0.292	0.578	0.59
France	0.02**	0.1*	0.037**	0.695	0.611	0.42
Germany	0.945	0.152	0.946	0.259	0.851	0.63
India	0.015**	0.577	0.155	0.788	0.825	0.235
Indonesia	0.494	0.303	0.349	0.784	0.248	0.795
Italy	0.275	0.017**	0.214	0.007***	0.034**	0.055*
Japan	0.661	0.203	0.242	0.00***	0.193	0.128
Mexico	0.424	0..645	0.811	0.399	0.686	0.365
Russia	0.016**	0.125	0.031**	0.227	0.706	0.034**
Saudi Arabia	0.334	0.081*	0.314	0.574	0.685	0.234
South Korea	0.917	0.853	0.858	0.887	0.043**	0.493
South Africa	0.396	0.593	0.552	0.356	0.966	0.927
Turkey	0.535	0.024**	0.233	0.035**	0.583	0.655
UK	0.618	0.329	0.824	0.119	0.247	0.033**
USA	0.761	0.13	0.443	0.089*	0.331	0.023**

Notes: Values in tables are the p-values. ***, ** and * denote significant at 1%, 5% and 10% level. The number of lags used to implement the test is equal to one.

This two-way linkage between productivity and energy consumption insinuates that a possible rise of TFP will exert the same influence on EC and vice versa. Moreover, economic development can be achieved by increasing a country's energy consumption levels (and the vice versa) for the aforementioned Italy and Japan. This means, absorption of more natural resources (inter alia, water, land, energy and soil) from the production process due to the rising of economic activities. Our results are in line with those reached by Ang, 2007; Esso, 2010; Lee, (2013); Yao et al., (2015); Luo et al., (2017).

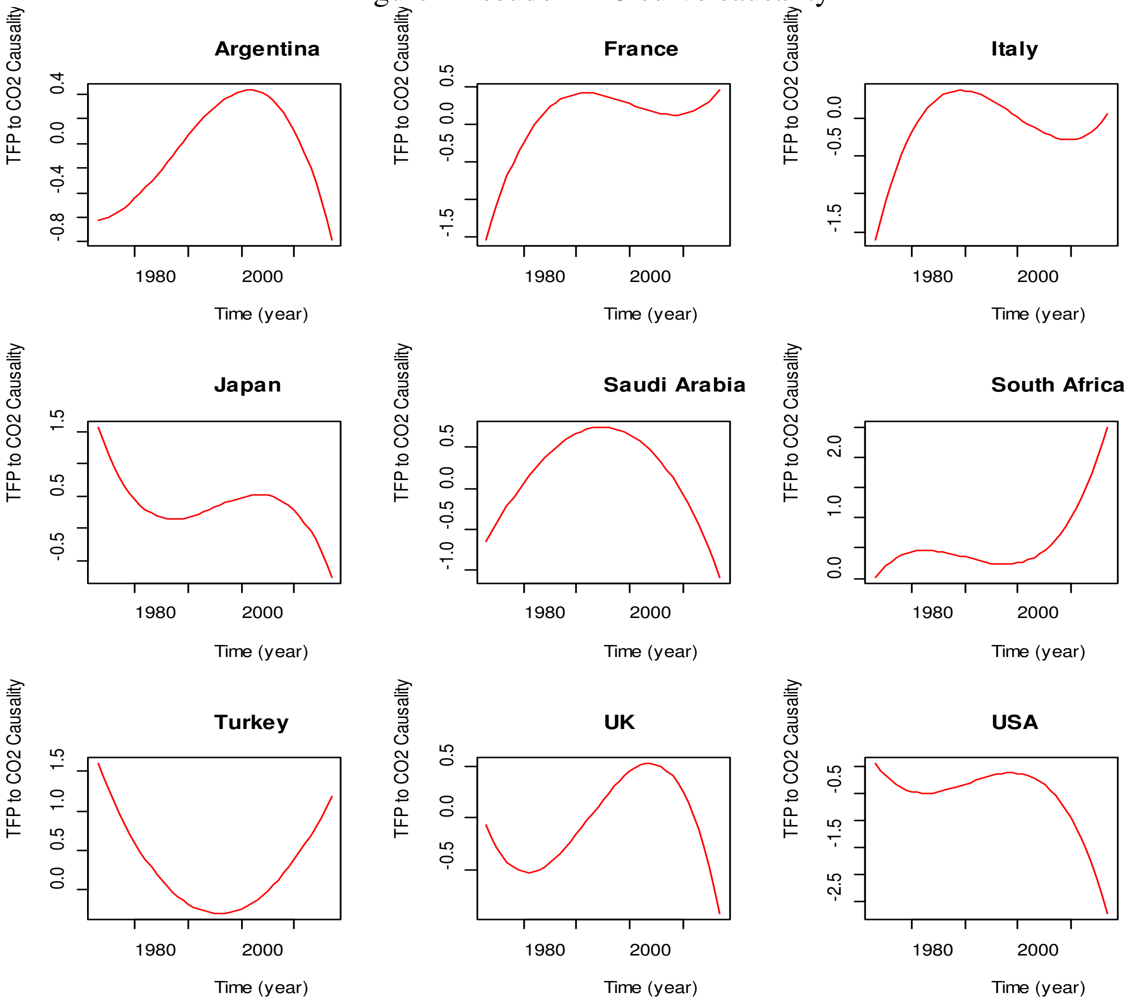
The final step in the analysis is to enable visualization and, hence, greater ability to see the validity of the traditional EKC hypothesis, so we follow the Ajmi et al.'s (2015) method, and we carry out the "curve causality" procedure. The authors were the first who displayed the EKC as a chart. They applied only the significant time-varying causality running from economic growth to air pollution. For our purpose, we will use the significant time-varying causality running from TFP to CO_2. As we can clearly observe from Table 4, we have 9 countries (Argentina, France, Italy, Japan, Saudi Arabia, South Korea, Turkey, UK and USA). Figure 1 layouts the causality curves for the significant countries with that phenomenon. Especially, figure 1 layouts the plots of the "curve causality", and as it is shown, our outcomes support the validity of the traditional EKC for one country (Turkey), the inverted-U shaped for Argentina and Saudi Arabia and N-shaped and inverted-U shaped curve for the rest of the countries. Starting from the latter sign, N-shaped curve (France, Italy and South Africa) implies that as TFP develops, CO_2 emissions first increase, then decline after the left turning point and they finally rise when they arrive at the right turning point. Moreover, this outcome shows that TFP has a positive significant effect on CO_2 emissions in the long run. With respect to inverted-N shaped for Japan, UK and USA, it endorses that as TFP develops, CO_2 emissions first decrease, then increase after the left turning point and finally decline when they arrive at the right turning point. Additionally, this outcome shows that TFP has a negative significant effect on CO_2 emissions in the long run. Regarding the inverted-U shaped for Argentina and Saudi Arabia, it postulates that as TFP raises, CO_2 emissions decline, until some threshold level of TFP is reached after which pollution starts decreasing. This condition implies that environmental quality can be characterized as a luxury good since it is preferred after a critical TFP is attained. Additionally, the existence of three factors (scale, composition and technique effects) can elucidate the existence of the inverted-U shaped curve. All of them emerging during the development process (Grossman and Kruger, 1995). The U-shaped curve indicates that CO_2 emissions in Turkey are now raising with the development of TFP.

Table 6 Time-varying Granger causality test results

	H: CO_2 to EC	H: CO_2 to TFP	H: EC to CO_2	H: EC to TFP	H: TFP to CO_2	H: TFP to EC
Argentina	0.622	0.479	0.042**	0.423	0.1*	0.021**
Australia	0.164	0.525	0.662	0.925	0.801	0.141
Brazil	0.87	0.28	0.417	0.077*	0.212	0.433
Canada	0.92	0.566	0.878	0.674	0.698	0.552
China	0.505	0.444	0.137	0.39	0.616	0.751
France	0.037**	0.184	0.039**	0.836	0.035**	0.354
Germany	0.981	0.246	0.969	0.34	0.837	0.613
India	0.033**	0.172	0.085*	0.473	0.845	0.317
Indonesia	0.578	0.318	0.477	0.731	0.31	0.87
Italy	0.412	0.019**	0.299	0.005***	0.066*	0.097*
Japan	0.81	0.073*	0.18	0.00***	0.1*	0.049**
Mexico	0.438	0.552	0.901	0.28	0.817	0.425
Russia	0.031**	0.169	0.061*	0.347	0.684	0.056*
Saudi Arabia	0.354	0.1*	0.345	0.728	0.016**	0.367
South Korea	0.932	0.893	0.937	0.818	0.019**	0.376
South Africa	0.392	0.118	0.419	0.1*	0.992	0.84
Turkey	0.647	0.046**	0.074*	0.058*	0.064*	0.744
UK	0.714	0.485	0.594	0.172	0.01***	0.001***
USA	0.559	0.261	0.032**	0.235	0.01***	0.01***

Notes: Values in tables are the p-values. ***, ** and * denote significant at 1%, 5% and 10% level. The number of lags used to implement the test is equal to one.

Figure 1 Pseudo-EKC curve causality



4. Concluding remarks

At the time of writing, we know of no other study that has attempted to investigate the impact of TFP on EC and CO_2 in G20 countries spanning the period 1971 to 2017 via the time-varying causality test. In this respect, this study makes a unique contribution: by exploring for the first time the linkages among TFP, energy consumption and CO_2 emissions for G20 countries. Second, no single attempt has been known to investigate the interaction among TFP, energy consumption and CO_2 emissions by using nonlinear technique, and third, we examine the validity of the traditional EKC hypothesis for each country. In our result, we have found nonlinear causality between the trivariate models. Specifically, for the nexus EC and CO_2, Argentina, Turkey and USA reveal unidirectional causality running from EC to CO_2. Moreover, France, India and Russia divulge a two-way relationship for that pair. If we closely examine it, the linkage from TFP to CO_2 is demonstrated for Argentina, France, South Korea, UK and USA. In addition, bidirectional interconnectedness is displayed for four countries (Italy, Japan, Saudi Arabia and Turkey). Furthermore, the one-way relationship between TFP and EC differs among the countries. For example, the causality from EC to TFP is obtained for Brazil, South Africa and Turkey, the vice versa linkage is confirmed for Argentina, Russia, UK and USA, and we have two pairs of two-way causalities for Italy and Japan. Lastly, we dissected the validity of the traditional EKC hypothesis between TFP to CO_2. Our outcomes insinuate the validity of the traditional EKC for Turkey, the inverted-U shaped for Argentina and Saudi Arabia, N-shaped for France, Italy and South Africa and inverted-U shaped curve for Japan, UK and USA.

Based on these empirics, we can see that it is implied that the impact of TFP policies influenced the EC and CO_2 probably with more accuracy than economic growth. When we observe the findings of the current study, it is pertinent to take pragmatic steps necessary to strengthen the environmental regulations in G20 countries. Thus, it is on this premise that the following few substantial policy implications are asserted on the basis of the empirical results from the current research which is enlightened in the subsequent passages: For the G20 economies, the maintenance of productivity without causing environmental degeneration is one of the big challenges to achieve and if the situation persists, the increased pollution activated by productivity will pose a great threat to global environment. So there is a need to enhance regulatory policies that trigger the use of non-renewable energy and in this way increase energy efficiency and the share of renewable sources in energy mix. Furthermore, the development of renewable energy in G20 members is absolutely essential to limit emissions of CO_2 as renewable energy is considered as less polluting compared to conventional coal based energy.

All sectors allied with energy sections (such as industry, residential, commercial, electric power and transportation sectors) need to play a joint role in designing and implementing necessary measures to boost green environment. Additionally, more actions should be introduced, such as environmentally-friendly transport in replacement of motorized transport, and more projects on the development of environmentally-friendly technologies, especially those in relation to the energy sector, should be sponsored by the G20 governments. In G20 countries, there is a need to control emissions as these countries account for more than half of the global emissions and they are still expanding their activities, so policies in favor of sustainable environment are needed in these countries. Moreover, energy seems to have effects on both TFP and environmental quality while it is also affected by them. Therefore, energy conservation policy cannot be applied without causing adverse effects on growth process. However, in this situation, a rising energy demand is likely to create more environmental pressure resulting from human activities. As far as this is concerned, alternative energy sources (renewable) come to the forefront to compromise between TFP and environment as they will lessen both the detrimental effects of TFP on the environment and energy consumption. The intensity of TFP long-run impacts is powerful for most countries. It implicates that the policymakers should attach more importance to TFP in terms of CO_2 emissions, mitigation policies and EC policies. It is further implied that high levels of CO_2 emissions may induce the policymakers to suggest policies to promote renewable sources. These empirical findings can guide policymakers to give core consideration to the TFP policies about EC and emission mitigation.

References

Ajmi, A. N., Hammoudeh, S., Nguyen, D. K., & Sato, J. R. (2015) "On the relationships between CO_2 emissions, energy consumption and income: the importance of time variation." *Energy Economics* **49**, 629-638.

Ang, J. B. (2007) "CO_2 emissions, energy consumption, and output in France." *Energy policy* **35,** 4772-4778.

Dahlhaus, R., Neumann, M. H., & Von Sachs, R. (1999) "Nonlinear wavelet estimation of time-varying autoregressive processes." *Bernoulli* **5**, 873-906.

Eilers, P. H., & Marx, B. D. (1996) "Flexible smoothing with B-splines and penalties." *Statistical science*, **11**, 89-102.

Elliott G, Rothenberg TJ, Stock JH. (1996) "Efficient tests for an autoregressive unit root." *Econometrica* **64,** 813‑836.

Feenstra, R. C., Inklaar, R., Timmer, M.P. (2015) "The Next Generation of the Penn World Table" *American Economic Review* **105**, 3150-3182, available for download at www.ggdc.net/pwt.
Gozgor, G., Lau, C. K. M., & Lu, Z. (2018) "Energy consumption and economic growth: New evidence from the OECD countries." *Energy* **153,** 27-34.
Granger, C. W. (1969) "Investigating causal relations by econometric models and cross-spectral methods." *Econometrica* **37**, 424-438.
Grossman, G. and A. Krueger (1995) "Economic growth and the environment." *The Quarterly Journal of Economics* **110,** 353–377.
Haider, S., & Ganaie, A. A. (2017) "Does energy efficiency enhance total factor productivity in case of India?." *OPEC Energy Review* **41,** 153-163.
Halicioglu, F., & Ketenci, N. (2018) "Output, renewable and non-renewable energy production, and international trade: Evidence from EU-15 countries." *Energy* **159,** 995-1002.
Jacques Loesse, E. S. S. O. (2010) "The Energy Consumption-Growth Nexus in Seven Sub-Saharan African Countries". *Economics Bulletin* **30,** 1191-1209.
Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. *Oxford Bulletin of Economics and statistics*, **52**, 169-210.
Kraft, J. and A. Kraft (1978) "On the relationship between energy and GNP." *Journal of Energy and Development* **3**, 401–403.
Lee, J. W. (2013) "The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth." *Energy Policy* **55,** 483-489.
Li, H., Grijalva, T., & Berrens, R. P. (2007) "Economic growth and environmental quality: a meta-analysis of environmental Kuznets curve studies." *Economics Bulletin* **17,** 1-11.
Lucas, R. E. (1989). On the mechanics of economic development. *NBER Working Paper*, (R1176).
Luo, G., Weng, J. H., Zhang, Q., & Hao, Y. (2017) "A reexamination of the existence of environmental Kuznets curve for CO_2 emissions: evidence from G20 countries." *Natural Hazards* **85**, 1023-1042.
Ozcan, B., Tzeremes, P. G., & Tzeremes, N. G. (2020). Energy consumption, economic growth and environmental degradation in OECD countries. *Economic Modelling*, **84**, 203-213.
Ozturk, I. (2010) "A literature survey on energy–growth nexus." *Energy policy* **38,** 340-349.
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.
Phillips, P. C., & Perron, P. (1988) "Testing for a unit root in time series regression." *Biometrika* **75**, 335-346.
Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of political economy*, **94**, 1002-1037.
Sato, J. R., Morettin, P. A., Arantes, P. R., & Amaro Jr, E. (2007) "Wavelet based time-varying vector autoregressive modelling." *Computational Statistics & Data Analysis* **51**, 5847-5866.
Sims, C. A. (1980). Macroeconomics and reality. *Econometrica: journal of the Econometric Society*, 1-48.
Solow, R. M. (1956) "A contribution to the theory of economic growth." *The quarterly journal of economics* **70,** 65-94.

Soytas, U. and R. Sari (2009) "Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member." *Ecological Economics* **68**, 1667–1675.

Tugcu, C. T., & Tiwari, A. K. (2016) "Does renewable and/or non-renewable energy consumption matter for total factor productivity (TFP) growth? Evidence from the BRICS." *Renewable and Sustainable Energy Reviews*, **65,** 610-616.

Tugcu, C. T., & Topcu, M. (2018) "Total, renewable and non-renewable energy consumption and economic growth: Revisiting the issue with an asymmetric point of view." *Energy* **152,** 64-74.

Tzeremes, P. (2018) "Time-varying causality between energy consumption, CO_2 emissions, and economic growth: evidence from US states." *Environmental Science and Pollution Research* **25**, 6044-6060.

Tzeremes, P. (2019). Does the Environmental Kuznets Curve Exist in the Chinese Regions?. *Global Economic Review*, **48**, 363-377.

Yao, C., Feng, K., & Hubacek, K. (2015) "Driving forces of CO_2 emissions in the G20 countries: An index decomposition analysis from 1971 to 2010." *Ecological informatics* **26**, 93-100.

Zivot, E., & Andrews, D. W. K. (2002). Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *Journal of business & economic statistics*, **20**, 25-44.