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Innovation technology and environmental sustainability in the case of Tunisia

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Abs t r a c t

This study examines the relationship between innovation and environmental sustainability in Tunisia over the 1971-2014 period. For this reason, the autoregressive distributed lag (ARDL) with break-point method and the Granger causality tests are performed. In the current study, the total patent is considered as a measure of innovation. Our outcome goes in the direction of non-acceptance of the Kuznets hypothesis. In addition, the impact of energy consumption on CO_2 emissions is positive. Moreover, even if the effect of technological innovation is directly insignificant, it indirectly contributes to lessen the effect of energy consumption. Furthermore, in the long and short terms, there are feedback links between economic growth and energy consumption, between pollution and both economic growth and energy consumption. In the long and short runs, there is also a one-way impact going from technological innovation variable to energy consumption one while there is no causality between technological innovation on the one hand and economic growth and CO_2 emissions on the other hand. Consequently, policy makers should stimulate innovatively and enhance technologic capacity in Tunisia.

JEL Codes: C12, Q2, Q3, Q4, Q5.

Keywords: "CO_2 emissions", "technological innovation", "economic growth", "energy consumption".

1. Introduction

According to recent literature, several reasons have made innovation a central determinant of environmental sustainability. First, innovation as a factor of technological progress helps countries to reach their production process efficiencies (Gozgor, 2017). Second, technology improvement leads not only to better energy-saving products and green energy use but also to a less fossil fuel consumption which affects positively the ecosystem (Tang and Tan, 2013). Third, technology innovation in energy allows the transition from lower carbon energy to a more sustainable one (Jordaan et al., 2017). Fourth, technological innovation enhances energy efficiency (Dogan 2016). Fifth, technological innovation can permit an ecological production mode (Yu and Du 2018). So, many recent studies are interested in the linkage between technological innovation and CO_2 emissions (Irandoust, 2016; Alvarez-Herranz et al., 2017; Chen and Lei, 2018; Fernández et al., 2018). These publications found contradictory results, while the majority of articles have accepted the hypothesis that technological innovation can reduce the intensity of CO_2 emissions, others have rejected it. This inconclusive literature motivates us to revisit the linkage between technological innovation and environmental improvement.

For this purpose, the main objective of the present study is to examine the technological innovation-environmental sustainability nexus in the case of Tunisia. Contrary to the previous works, the present one is the first to focus on this relationship for Tunisia. In addition, our paper focuses on the validity of the EKC hypothesis by considering technological innovation as an additional determinant for CO_2 emissions. Moreover, we probe into the role of technology innovation to moderate the negative role of energy use and trade on environmental quality in Tunisia.

To achieve this goal, we apply the autoregressive distributed lag (ARDL) with break-point method and the Granger causality tests on Tunisian data in the period stretching from 1971 to 2014.

This report is structered as follows. Section 2 recapitulates a brief literature review. Section 3 portrays material and methods. Section 4 gives the empirical results, and Section 5 incorporates conclusions and policy implications.

2. Literature Review

Some recent studies have focused on the role of technological innovation in environmental improvement. This literature can be focused either on a country or a group of countries.

For example, in the case of a group of countries, Irandoust (2016) focused on the linkage between technological innovation, economic growth, CO_2 emissions, and renewable energy consumption in the case of four Nordic countries over the 1975–2012 period. The Toda and Yamamoto causality test results prove the existence of one-way link going from technological innovation variable to clean energy one and running from this latter to CO_2 emissions in all countries. Moreover, Alvarez-Herranz et al. (2017) were interested in the effect of energy innovation and renewable energy consumption on environmental improvement in the case of 17 OECD countries during the 1990-2012 period. The empirical results demonstrate positive effects of energy innovation and renewable energy on air quality. In addition, Chen and Lei (2018) reviewed the impact of some determinants of CO2 emissions in the case of 30 countries between 1980 and 2014. The results indicate that technological innovation is more important in the case of high emissions countries compared to low emissions ones. Furthermore, Fernández et al. (2018) investigated the role of innovation in decreasing pollution in the case of China, the United States, and others 15 countries from the European Union. The results demonstrate a positive impact of innovation on environment improvement in the case of European countries and United Sates while a negative effect in China. In addition, in the case of 208 countries classified by income level, Fan et al. (2006) studied their CO2 emissions factors over 1975- 2000 period. The empirical results prove a negative effect of technological innovation in the case of Upper-middle income countries while a positive effect in the case of high, low and Lower-middle-income ones. Also, in the case of 80 developed and developing countries, Kumar and Managi (2009) demonstrated that CO2 emissions are affected positively and negatively by technological innovation in developing and developed countries respectively.

In the case of a single country, Yii and Geetha (2017) examined the connection between energy price, electricity consumption, economic growth, CO_2 emissions, and technology innovation in Malaysia during the 1971- 2013 period. The empirical findings prove that technology innovation has a positive effect on environment quality only in the short term. Besides, Fei et al. (2014) looked into the relationship between technological innovation, CO_2 emission, energy, and growth in the case of New Zealand and Norway during 1971-2010 period. The empirical results reveal the existence of unidirectional link running from technological innovation to CO_2 emissions in the short run in both countries while the presence of one-way short-run link only in Norway. Else, Yu and Du (2018) studied the effect of technological innovation on the quality of environment in China over 1997-2015 period. The results indicate that the impact of innovation is more important in the case of high-speed growth provinces compared to low-speed growth ones. Again, Wang et al. (2017) focused on the determinants of CO_2 emissions in the case Xinjiang over the period between 1952 and 2012. The empirical findings show a negative effect of technological innovation on environment quality over the period before reform and opening up development stage (1952-1978) while positive impact on the period from 1978 to 2012 which was characterized by western opening up after reform development stages. Zhao et al. (2013) were also interested in the main determinants of China's power industry CO2 emissions during the period between

1980 and 2010. The Granger causality test results demonstrate the importance of technological innovation in environment improvement.

3. Material and methods

3.1. Model development

In order to capture the impact of innovation technology on CO_2 emissions, we develop the following model.

$$\ln CO2_t = \alpha_1 + \alpha_2 \ln GDP_t + \alpha_3 (\ln GDP)^2{}_t + \alpha_4 \ln TI_t + \alpha_5 \ln CE_t + \alpha_6 \ln TI * \ln CE_t + \varepsilon_t$$

(1)

Where CO2 represents the per capita CO_2 emissions, GDP is the gross domestic product per capita, and TI is the technological innovation, and CE is the energy consumption. The presence of GDP and GDP square in the model 1 permits to check the existence of the Environmental Kuznets Curve (EKC). We also consider the interaction term between the technical innovation and energy consumption $(\ln TI * \ln CE_t)$ as an independent variable.

t is the time in years, ε represents the error term, and $\alpha_i\,(\mathrm{i} = 1,\ldots,6)$ represents the parameters of the model.

3.2 Methodology

In this paper, the linkage among CO2 emissions, economic growth, energy consumption, and technological innovation is performed in three phases. The first phase is dedicated to the analysis of the stationarity of the interesting variables. The objective of the second phase is to estimate the above-mentioned relationship by using the ARDL approach. The last phase focuses on the Granger Causality test between the variables.

Firstly, we use different generations of time series unit root tests. The first generation ignores the existence of breaks in time-series. In the present study, we perform the Phillips-Perron (PP), the Augmented Dickey-Fuller (ADF), and the Dickey-Fuller GLS (DF-GLS) tests. The second generation integrates the existence of one, two and multiple breaks in time series.

In this case, we perform the Zivot-Andrews (1992) and Clemente-Montañés-Reyes (1998) unit root tests with one and two break points respectively.

Secondly, we use the linear autoregressive distributed lag (ARDL) with breaks approach (Pesaran et al., 2001) to inspect the linkage between CO_2 emissions and innovation. We use the ARDL approach for different reasons. First, we can estimate the short-run and long-run effects jointly. Second, we can resolve the endogeneity problem of the variables. Third, we can test the cointegration of data which are I(0) and/or I(1) integrated series.

The ARDL model takes the following form:

$$\Delta \ln CO2_t = \beta_0 + \sum_{j=1}^{l_1} \beta_{1j} \Delta \ln CO2_{t-j} + \sum_{j=0}^{l_2} \beta_{2j} \Delta \ln GDP_{t-j} + \sum_{j=0}^{l_3} \beta_{3j} \Delta (\ln GDP)^2{}_{t-j} + \sum_{j=0}^{l_4} \beta_{4j} \Delta \ln TI_{t-j} + \sum_{j=0}^{l_5} \beta_{5j} \Delta \ln CE_{t-j} + \sum_{j=0}^{l_6} \beta_{6j} \Delta \ln TI * \ln CE_{t-j} + \eta_1 \ln CO2_{t-1} + \eta_2 \ln GDP_{t-1} + \eta_3 (\ln GDP)^2{}_{t-1} + \eta_4 \ln TI_{t-1} + \eta_5 \ln CE_{t-1} + \eta_6 \ln TI * \ln CE_{t-1} + \eta_7 break_t + \varepsilon_t$$

(2)

Where Δ is the first-difference, β_0 is the constant parameter, $break$ is the break years; $l_1 - l_6$ is the lag length of each variable).

We consider $(H0: \ \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = \eta_6 = 0)$ as a no cointegration hypothesis, and $(H1: \ \eta_1 \neq \eta_2 \neq \eta_3 \neq \eta_4 \neq \eta_5 \neq \eta_6 \neq 0)$ as a cointegration hypothesis.

Three situations can be generated after the estimation of the ARDL model. Firstly, the cointegration situation which is realized when the value of the computed F-statistic is higher than the upper bound value developed by Pesaran et al. (2001). Secondly, the no-cointegration situation which is realized when the lower bound value of Pesaran et al. (2001) is higher than the computed F-statistic. Thirdly, the inconclusive situation is performed elsewhere. Morover, the stability of the ARDL model is tested by using recursive residuals. Furthermore, the validity of the ARDL model is tested by using normality, heteroscedasticity, and serial correlation tests.

Thirdly, the Granger causality test is also examined by estimating the vector error correction model (VECM) as follows:

$$\Delta \ln CO2_t = \phi_0 + \sum_{i=1}^{k} \phi_{1i} \Delta \ln CO2_{t-i} + \sum_{i=1}^{k} \phi_{2i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{k} \phi_{3i} \Delta (\ln GDP)^2{}_{t-i} + \sum_{i=1}^{k} \phi_{4i} \Delta \ln TI_{t-i} + \sum_{i=1}^{k} \phi_{5i} \Delta \ln CE_{t-i} + \alpha_1 ECT_{t-1} + \mu_{1t}$$

(4)

$$\Delta \ln GDP_t = \eta_0 + \sum_{i=1}^{k} \eta_{1i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{k} \eta_{2i} \Delta \ln CO2_{t-i} + \sum_{i=1}^{k} \eta_{3i} \Delta (\ln GDP)^2{}_{t-i} + \sum_{i=1}^{k} \eta_{4i} \Delta \ln TI_{t-i} + \sum_{i=1}^{k} \eta_{5i} \Delta \ln CE_{t-i} + \alpha_2 ECT_{t-1} + \mu_{2t}$$

(5)

$$\Delta (\ln GDP)^2{}_t = \varphi_0 + \sum_{i=1}^{k} \varphi_{1i} \Delta (\ln GDP)^2{}_{t-i} + \sum_{i=1}^{k} \varphi_{2i} \Delta \ln CO2_{t-i} + \sum_{i=1}^{k} \varphi_{3i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{k} \varphi_{4i} \Delta \ln TI_{t-i} + \sum_{i=1}^{k} \varphi_{5i} \Delta \ln CE_{t-i} + \alpha_3 ECT_{t-1} + \mu_{3t}$$

(6)

$$\Delta \ln TI_t = \zeta_0 + \sum_{i=1}^{k} \zeta_{1i} \Delta \ln TI_{t-i} + \sum_{i=1}^{k} \zeta_{2i} \Delta \ln CO2_{t-i} + \sum_{i=1}^{k} \zeta_{3i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{k} \zeta_{4i} \Delta (\ln GDP)^2{}_{t-i} + \sum_{i=1}^{k} \zeta_{5i} \Delta \ln CE_{t-i} + \alpha_2 ECT_{t-1} + \mu_{2t}$$

(7)

$$\Delta \ln TI_t = \vartheta_0 + \sum_{i=1}^{k} \vartheta_{1i} \Delta \ln TI_{t-i} + \sum_{i=1}^{k} \vartheta_{2i} \Delta \ln CO2_{t-i} + \sum_{i=1}^{k} \vartheta_{3i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{k} \vartheta_{4i} \Delta (\ln GDP)^2{}_{t-i} + \sum_{i=1}^{k} \vartheta_{5i} \Delta \ln CE_{t-i} + \alpha_2 ECT_{t-1} + \mu_{2t}$$

(8)

ECT_{t-1} is the lagged error correction terms; μ is the error terms. ϕ, η, φ, ζ and ϑ are the parameters; Δ denotes the first difference; k denotes the lagged length determined by the Schwarz data criteria (SIC).

The statistical significance of the ECT_{t-1} term is used to test the long-run causality among variables. The significance of the Wald test for the lags of each additional variable in equation 4 to equation 8 is used to test the short-run causality.

3.3 Data

In this study, we consider the period from 1971 to 2014 in which the data from all study variables are available. The latter used in the current study incorporate, per capita gross domestic product in 2010 in US dollars, per capita CO_2 emissions (in metric tons per capita), total patent as a measure of technological innovation, and energy consumption (in kg of oil equivalent per capita). All the above-mentioned variables are collected from the World Bank Indicators.

Table 1 Summary statistics

	CO2	GDP	TI	CE
Maximum	2.599	4271.327	680	966.334
Minimum	0.814	1356.581	103	320.077
Mean	1.769	2650.416	273.093	649.549
Standard deviation	0.497	863.906	166.996	189.562
Coefficient of variation	0.280	0.325	0.611	0.291

Table 1 sum up some descriptive statistics for the previous variables. The highest variability is registered for the variable technological innovation which recorded the highest coefficient of variation (0.611). On the contrary, trade is the most stable variable with a low coefficient of variation (0.183).

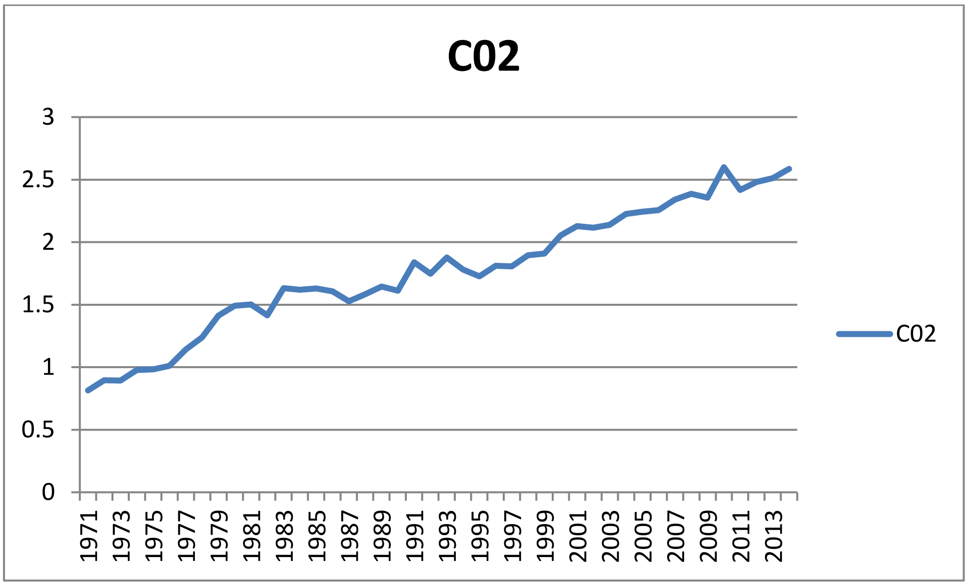


Figure 1. Evolution of CO_2 emissions

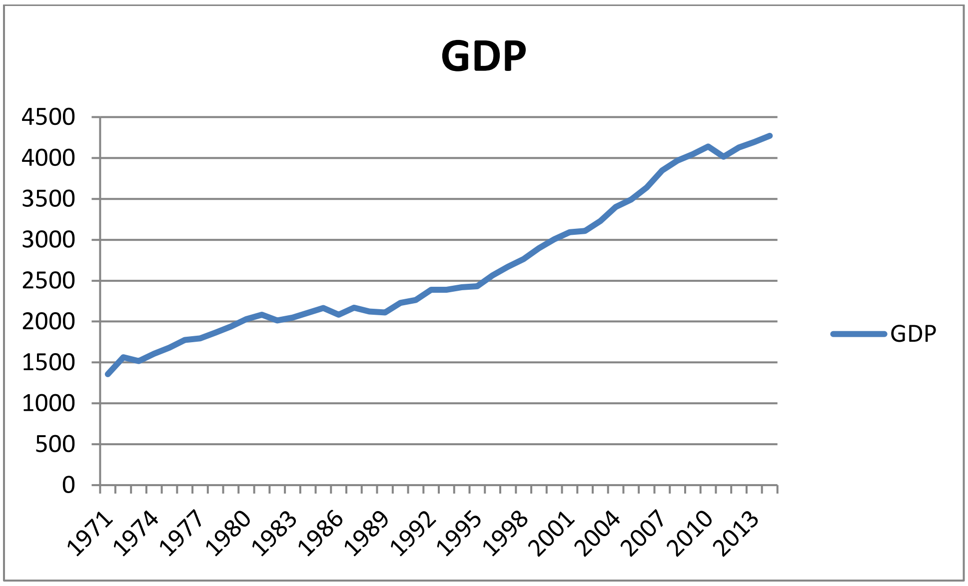


Figure 2. Evolution of gross domestic product

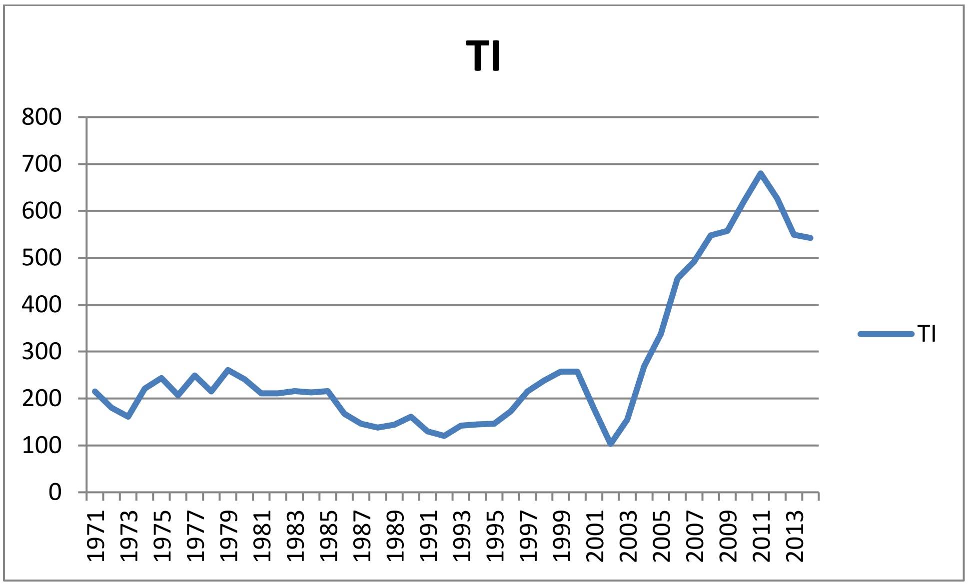


Figure 3. Evolution of technological innovation

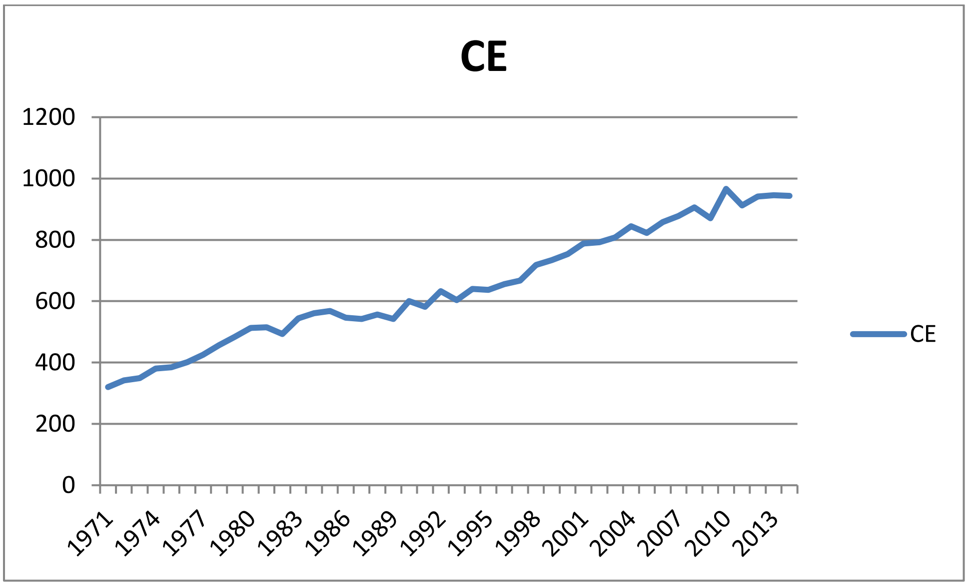


Figure 4. Evolution of energy consumption

Figures 1, 2, 3, and 4 illustrate the evolution CO_2, gross domestic product, technological innovation and energy consumption respectively. We have shown similar trends for all variables except for the technological innovation variable, which was stagnant over the 1971-2003 period and then showed an upward trend between 2003 and 2011.

4. Results and discussions

4.1 Integration process

The results of traditional tests (table 2) indicate that no series are integrated of order two. This conclusion is confirmed by Zivot-Andrews and Clemente, Montanes, Reyes unit Unit Root tests (tables 3 and 4).

Table 2. Result for Unit Root tests

Variables	Augmented Dickey–Fuller test statistic		Phillips–Perron test statistic		Dickey Fuller-GLS Test statistic	
	intercept	Intercept and trend	intercept	Intercept and trend	intercept	Intercept and trend
$\ln CO2$	-2.483	-2.777	-2.722*	-2.735	0.678	-1.271
$\ln GDP$	-2.171	-2.409	-1.209	-2.534	1.602	-2.760
$(\ln GDP)^2$	-0.896	-2.067	-0.913	-2.184	1.513	-2.455
$\ln TI$	-1.374	-1.897	-0.973	-1.744	-1.374	-1.897
$\ln CE$	-1.525	-2.346	-2.403	-2.992	1.029	-1.271
$\Delta \ln CO2$	-8.334***	-8.758***	-8.180***	-8.758***	-1.931*	-8.511***
$\Delta \ln GDP$	-9.240***	-9.057***	-8.817***	-8.660***	-2.736***	-3.808***
$\Delta(\ln GDP)^2$	-8.873***	-8.722***	-8.516***	-8.390***	-3.167***	-4.603***
$\Delta \ln TI$	-2.897***	-4.537***	-4.744***	-4.488***	-4.068***	-4.537***
$\Delta \ln CE$	-10.265***	-10.980***	-9.844***	-10.824***	-3.165***	-10.793***

*** 1% symbolizes the significance at 1 % level. ** symbolizes the significance at 5%. * symbolizes the significance at 10%.

Table 3. Zivot-Andrews Unit Root test with break point

variables	Zivot-Andrews Unit Root test					
	intercept	Break year	trend	Break year	Intercept and trend	Break year
$\ln CO2$	-4.283	1978	-4.011	1981	-4.211	1979
$\ln GDP$	-4.310	1986	-4.026	1992	-4.451	1986
$(\ln GDP)^2$	-4.274	1986	-4.049	1992	-4.344	1986
$\ln TI$	-4.355	2006	-4.380	2004	-4.532	2000
$\ln CE$	-2.532	1986	-2.979	1979	-2.882	1986
$\Delta \ln CO2$	-10.131	1981	-9.184	1988	-10.926	1981
$\Delta \ln GDP$	-10.379	1996	-9.379	2008	-10.577	1990
$\Delta(\ln GDP)^2$	-10.016	1996	-9.092	2008	-10.092	1990
$\Delta \ln TI$	-7.299	2004	-7.511	1978	-7.569	1979
$\Delta \ln CE$	-12.216	1981	-11.509	1987	-12.463	1990

*** 1% symbolizes the significance at 1 % level. * symbolizes the significance at 10%.

Table 4. Unit root tests (Clemente, Montanes, Reyes (1998)) with two breaks points

Variables	Additive outlier	Innovative outlier
$\ln CO2$	-3.847 (1980 , 2001)	-4.793(1975 , 1997)
$\ln GDP$	-3.466(1993 , 2004)	-3.692(1988 , 1995)
$(\ln GDP)^2$	-3.430(1993 , 2004)	-3.479(1988 , 1995)
$\ln TI$	-4.376(1990 , 2007)	-3.252(1987 , 2004)
$\ln CE$	-3.808(1980 , 1998)	-4.230(1989 , 1996)

$\Delta \ln CO2$	-11.332**(1980 , 1985)	-11.161**(1975 , 1997)
$\Delta \ln GDP$	-9.770**(1978 , 1986)	-11.255**(1980 , 1988)
$\Delta (\ln GDP)^2$	-9.375**(1978 , 1986)	-10.735** (1980 , 1988)
$\Delta \ln TI$	-4.872**(1976 , 2001)	-6.447** (1974 , 1978)
$\Delta \ln CE$	-6.427**(1980 , 1985)	-13.432** (1981 , 1986)

** symbolizes the significance at 5%. The values in parenthesis symbolize the break year.

4.2 ARDL cointegration process

The results of the cointegration tests in the case of the linear ARDL approach (see table 5) demonstrate the rejection of the no cointegration hypothesis since the computed F-statistic is higher than the highest limit value.

Table 5
Bound test cointegration results.

Model	$\ln CO2_t = f(\ln GDP_t, (\ln GDP)^2{}_t, \ln TI_t, \ln CE_t, \ln TI * \ln CE_t)$
Bound test F-statistic	5.321***
Significance	1%
LowerI(0) Bound	3.41
Upper I(1) Bound	4.60

*** 1% symbolizes the significance at 1 % level.

4.3 Short-run and long-run results

Table 6
Long and short-run estimates. Selected Model: ARDL (1, 0, 1, 1,0,0)

Variables	Coefficient.	Standard.error	T- Statistic	p-Values
Long-run analysis				
Constant	0.120	0.022	5.452	0.000
$\ln GDP$	0.197***	0.058	3.400	0.001
$(\ln GDP)^2$	-0.194	0.148	-1.308	0.199
$\ln TI$	0.053	0.034	0.542	0.132
$\ln CE$	0.106***	0.027	3.931	0.000
$\ln TI * \ln CE$	-0.003**	0.001	-2.046	0.048
$BREAK$	-0.502***	0.122	-4.091	0.000
short-run analysis				
$\ln GDP$	0.333***	0.063	5.256	0.000
$(\ln GDP)^2$	-0.222	0.156	-1.423	0.163
$\ln TI$	0.022	0.016	1.412	0.167
$\ln CE$	0.318	0.155	2.046	0.048
$\ln TI * \ln CE$	-0.003**	0.001	-2.218	0.033
$BREAK$	-0.872***	0.176	-4.944	0.000
ECT(-1)	-0.260***	0.091	-2.842	0.007
R2	0.984			
Adjusted R2	0.980			
F-statistic	267.355***			0.000
Diagnostic tests				
Serial corrrlation.	0.654			0.526

Normality	1.958	0.375
Heteroscedasticity	1.643	0.149

*** 1% symbolizes the significance at 1 % level. ** symbolizes the significance at 5%. * symbolizes the significance at 10%.

The short and long-run ARDL estimation is presented in table 6.

In the short and long run, the GDP is positively related to CO2 emissions. 1% improvement in economic growth helps to enhance CO2 emissions by 0.333 and 0.197 in the short term and long term respectively. However, the effect of GDP square on environment quality is insignificant. Consequently, the EKC hypothesis is not validated since Tunisian economic output is under the threshold level needed to reach the environmental sustainability.

This affirmation is in agreement with the conclusions of Ben Jebli and Ben Youssef (2015), Fodha and Zaghdoud (2010), and Abid (2015) in the case of Tunisia. This result is contrary to the affirmations of Ahmad et al. (2016) and Yii and Geetha (2017) in the case of Croatia and Malaysia respectively.

In the short and long terms, the impact of technological innovation on CO_2 emissions is insignificant. This means that innovation does not permit environmental sustainability in the case of the Tunisian economy. This result can be explained by different reasons. First, the small and medium-sized enterprises that make up the majority of Tunisian firms (90%) are unable to develop the necessary research and development activities. Second, innovation in Tunisia is mainly the fact of the state although Tunisia's share of R & D as a percentage of GDP is too small (0.7%) to reduce CO2 emissions. Third, cooperation between universities and firms are still very limited in Tunisia.

In the short and long run, the energy consumption is positively combined to the CO_2 emissions. 1% increase in energy category consumption helps to increase CO_2 emissions by 0.318 and 0.106 in the short and long terms respectively. This result is not surprising since in

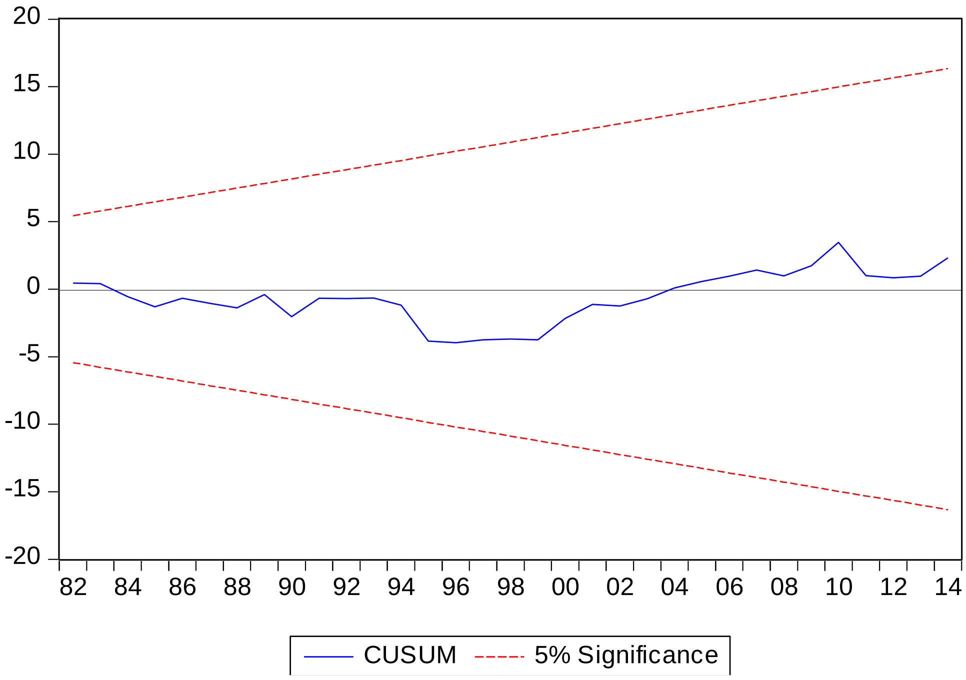
Tunisia the share of non-renewable energy is of the order of 97%. According to PNUD, energy is the main contributor to CO2 emissions in Tunisia in total emissions in 2012. This affirmation is in agreement with the conclusions of Ben Mbarek et al. (2018), Farhani and Otzurk (2015), and Farhani et al. (2014) in the case of Tunisia. This result is contrary to the affirmations of Amri (2017) and Antonakakis et al. (2017).

In the short and long run, the interaction term between energy consumption and technological innovation is negative. This means that technological innovation can moderate the negative effect of energy consumption on the environmental quality.

The results of normality, heteroskedasticity, and serial correlation tests are presented in the bottom of the above-mentioned table.

The speed of adjustment is equal to 26 % per year. The residual diagnostic tests indicate that the normality of residuals is accepted. There is also no autoregressive heteroscedasticity and no serial correlation of residuals.

Furthermore, the stability of the coefficients is confirmed. Indeed, the plots recursive residuals statistics (see fig. 4 and fig. 5) are within the limits of 5% significance.



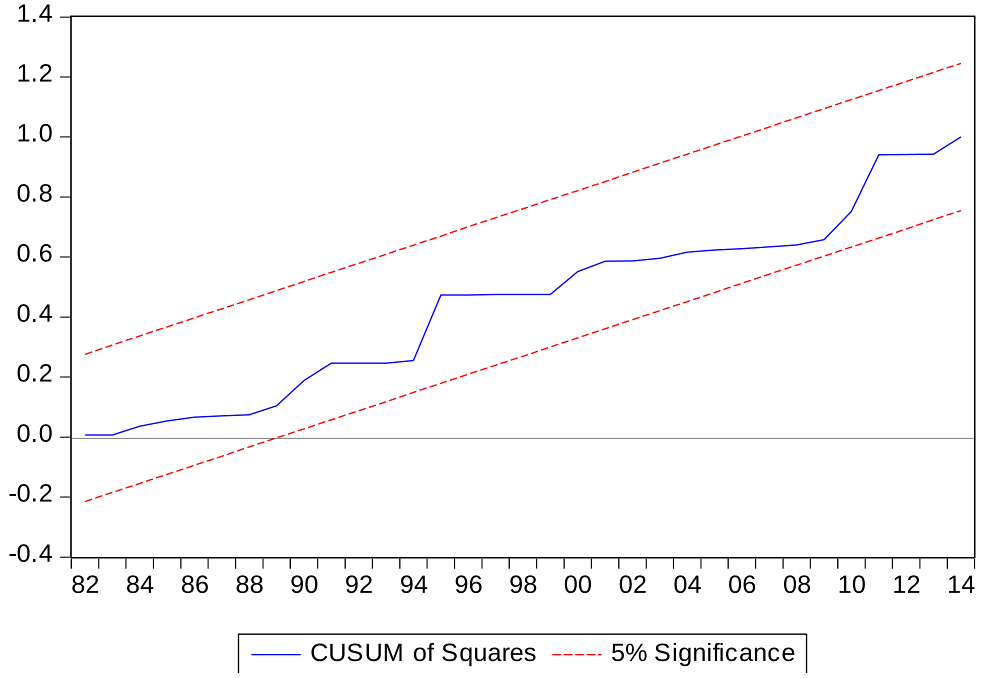


Fig. 4. CUSUM of recursive residual and CUSUM of squares plot of recursive residual.

4.4 Granger causality results

Table 7

Results of Granger causality tests.

Dependent variable	Short-run					Long-run
	$\Delta \ln CO2$	$\Delta \ln GDP$	$\Delta \ln(GDP)^2$	$\Delta \ln TI$	$\Delta \ln CE$	ECT(-1)
$\Delta \ln CO2$	-	0.187(0.001)***	0.018 (0.137)	0.045(0.222)	0.103(0.027)**	-0.133(0.021)**
$\Delta \ln GDP$	0.134 (0.016)	-	0.054(0.007)***	0.145(0.301)	0.145(0.001)	-0.380(0.033)***
$\Delta(\ln GDP)^2$	0.276 (0.117)	0.054(0.002)***	-	0.233(0.101)	0.713(0.763)	2.453(0.533)
$\Delta \ln TI$	0.530 (0.433)	0.144(0.432)	0.407(0.128)	-	0.467(0.122)	3.136(0.332)
$\Delta \ln CE$	0.419 (0.008)***	0.463(0.022)**	0.717 (0.123)	0.573(0.003)***	-	-0. 391(0.002)***

Values in parentheses in indicate the p-Values and values in brackets are t-statistics. *** 1% symbolizes the significance at 1 % level. ** symbolizes the significance at 5%. * symbolizes the significance at 10%.

The Granger causality result is illustrated in table 7.

First of all, we examine the long-term causality link by observing the ECT parameters. The presence of long-term causality between variables is checked if the value of the ECT parameter is significant and belongs to the interval between -1 and 0.

In this case, the results indicate the presence of a feedback causality link between and CO_2 emissions and economic growth, between energy consumption and both CO_2 emissions and GDP. In addition, there is a no causality link between technology innovation and economic growth, and there is no causality between technology innovation and CO_2 emissions.

The existence of the feedback linkage among energy consumption and economic growth demonstrate that both variables are interrelated in Tunisia, in both short and long term. On one hand, the increase of energy consumption can help to enhance the economic growth. On the other hand, the increase of economic growth in Tunisia can improve the use of energy consumption. This agreement is in line with the result of Tang and Tan (2013).

The feedback linkage among energy consumption and CO_2 emissions prove its interdependent in the short and long terms. It means that energy consumption affects positively CO_2 emissions and vice –versa. This agreement is in line with the result of Ben Mbarek et Al. (2017).

The bidirectional linkage among GDP and CO2 emissions means that both variables are jointly related. This result is in line with that of Ben Yii and Geetha (2017).

The absence of causality link between CO2 emissions and innovation technology indicated that both variables are independent. This is likely to happen because the share of R & D in Tunisian GDP is low and does not exceed 7%. Our result is in contradiction of that of Ben Yii and Geetha (2017).

There is a one-way link starting from technology innovation variable to economic growth one. It implies that the use of technology innovation ameliorates the economic growth in Tunisia. This result is in line with that of Tang and Tan (2013).

There is a one–way link going from technological innovation and energy consumption. This outcome confirms the result of Tang and Tan (2013).

5. Conclusion and policy implications

In this paper, we are interested in the relationship between CO_2 emissions and technological innovation in Tunisia from 1971 to 2014. To reach this goal, we use the ARDL approach with break and the granger causality test.

The outcome of the ARDL approach indicates that the EKC hypothesis is not validated in the case of Tunisia. Moreover, there is a positive impact of energy consumption on the CO_2 emissions, in the short and long runs. In addition, the impact of innovation on pollution is directly insignificant but indirectly significant by moderating the positive impact of energy consumption on CO_2 emissions.

The results of the VECM Granger causality test demonstrate two-linkage between CO_2 emissions and economic growth, between economic growth and energy consumption and between CO_2 emissions and energy consumption in the long and short terms. There is also a one-way impact moving from technological innovation energy to energy consumption in long and short-term. Moreover, there is no causality among technological innovation and CO_2 emissions in the short and long terms.

There are different results and implications that can be inferred from this research.

Firstly, the energy consumption and economic growth are interrelated. Therefore, decision-makers should increase Tunisian GDP in order to reach the threshold level allowing environmental improvement. In this context, better performance in terms of R & D and innovation is essential by adopting cleaner technologies in all sectors of the economy.

Secondly, energy consumption has a positive contribution to CO_2 emissions. This indicates that the energy strategy adopted by Tunisia should be modified to permit more environmental quality. Tunisia should enhance its share of renewable energy to allow more technological advance. In this context, the most difficult barrier to overcome is the high cost of these energies. Furthermore, the efforts of the public authorities must be strengthened by the participation of the private sector in this effort.

Thirdly, technological innovation has an insignificant impact on the improvement of the environment. Tunisia should, therefore, adopt a new environmental strategy aimed at improving innovation in the country. As a first step, Tunisia must encourage the development of research and development activities at the enterprise level through fiscal and financial incentives. Second, it should improve the governance of research and development institutes. Third, it should encourage public-private research and improve cooperation between universities and firms.

Fourthly, the interaction between innovative technology and energy consumption can help to reduce CO_2 emissions. Consequently, Tunisia should focus on the adoption of energy innovative technologies to moderate the negative effect of non-renewable energy consumption.

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