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ICT, total factor productivity, and carbon dioxide emissions in Tunisia

Fethi Amri[a,*], Younes Ben Zaied[b], Bechir Ben Lahouel[c]

[a] University of Carthage, Faculty of Economic Sciences and Management of Nabeul, LR18ES48, ENVIE Research Laboratory, Road Hammamet, Mrezgua, Nabeul 8000, Tunisia
[b] ISTEC Paris Business School, 128 Quai de Jemmapes, 75010, Paris, France
[c] IPAG Business School, Paris, France

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ABSTRACT

This paper examines the linkage between carbon dioxide (CO_2) emissions, total factor productivity (TFP) as a measure of income, and information and communication technologies (ICT) in Tunisia from 1975 to 2014. To empirically investigate this relationship, the autoregressive distributed delay (ARDL) with the break point method is specified and estimated. The results demonstrate the rejection of the Environmental Kuznets Curve (EKC) hypothesis by obtaining a higher value of the long-term total factor productivity (TFP) coefficient compared the short term one. Moreover, the result indicates an insignificant impact of ICT on CO_2 emissions as a measure of pollution. As a result, Tunisian policy makers should not only enhance their total factor productivity but also expand their information and communication technology.

1. Introduction

Sustainable development, initially introduced by the Brundtland commission report (1987),[1] in preparing the Earth Summit Rio (1992), is defined as economic development that strives to meet the needs of the current generation without compromising the ability to meet future generation's needs. Consequently, reducing climate change impacts and forecasting adequately global warming represent the most important issues of sustainable development and are two basic United-Nations millenary goals for development. It is, worldwide, commonly recognized for policy makers and academic researchers that global warming and climate change are, generally, caused by CO_2 emissions and other pollution indicators such as SO_2, SPM and nitrogen oxide. Therefore, investigating deeply the determinants of CO_2 emissions is the only useful tool for an ideal and optimal climate change mitigation policy.

From a theoretical point of view, scholars used the Environmental Kuznets Curve (EKC) concept to explain the environmental-economic nexus. Grossman and Krueger (1991) are the first who used the EKC concept in estimating the relationship between CO_2 emissions and economic growth. They demonstrated that income per capita may affect positively CO_2 emissions in linear form but its quadratic form has a negative impact on CO_2 emissions, and they validated EKC assumptions. Indeed, the economic growth expansion generates more pollutant environment before a threshold level of income; after that, an additional amelioration of economic growth helps to ameliorate the environmental quality. This hypothesis can be tested by comparing the short-run and the long-run impact of GDP on CO_2 emissions. The EKC is accepted if the coefficient of the income indicator, in the long-run, is lower than the short-run one. Moreover, this hypothesis can be tested by integrating into the same model the GDP and the square of GDP. In this case, the EKC is verified if the coefficient of GDP is positive and the coefficient of the square of GDP is negative.

Following Grossman and Krueger (1991), several papers were undertaken using different dataset and different pollution indicators (SO_2, SPM, nitrogen oxide …) to carry out empirical results which allow testing EKC assumptions. However, conflicting empirical results are allowed from the literature. Some papers proves the validity of the EKC assumption (Alam et al., 2016; Apergis, 2016; Apergis and Ozturk, 2015; Jalil and Mahmud, 2009; Li et al., 2016).

In contrary, another group of papers reject its validity (Ben Jebli and Ben Youssef, 2015; Fodha and Zaghdoud, 2010; Kang et al., 2016; Ben Jebli et al., 2016; Al-mulali et al., 2015; Alam et al., 2016; Antonakakis et al., 2017; Amri, 2017; Adu and Denkyirah, 2018; Apergis, 2016; Ozturk and Al-Mulali, 2015).

These contradictory results of the EKC hypothesis not only concern papers that focused on a group of countries but also papers that focused on the case of a single country. These papers use both panel and time

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* Corresponding author.
E-mail address: fethiamri.fsegn@gmail.com (F. Amri).

[1] The Brundtland (1987) report “Our common Future” proposed the first universal definition of sustainable development. This definition was approved by the Earth summit participant in Rio in (1992).

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series data.

By using time series data describing only one country, the studies of Baek (2015), Jalil and Mahmud (2009), and Alam et al. (2016) concluded for the validity of the EKC assumption. However, several papers like Pao et al. (2011), Ozturk and Al-Mulali (2015), Apergis (2016), Amri (2017), Al-mulali et al., (2015), Fodha and Zaghdoud (2010), and Ben Jebli and Ben Youssef (2015) reject the validity of EKC assumption.

By using data describing a Panel of countries, the mentioned hypothesis is confirmed by Apergis and Payne (2010), Apergis and Ozturk (2015), Apergis (2016), and Li et al. (2016), and rejected by Adu and Denkyirah (2018,) Antonakakis et al. (2017), Ben Jebli et al. (2016), and Kang et al. (2016).

Empirical literature on the EKC assumption gives rise, as mentioned above, to a controversy about its validity. These polemical results regarding the validity of EKC hypothesis can be explained by many reasons. Technically, the difference in the additional or control variables integrated to complete the curve equation is the principal cause of the contradictory conclusions. The majority of papers augmented the EKC equation by energy consumption (Alam et al., 2016; Amri, 2017; Antonakakis et al., 2017; Apergis and Payne, 2010; Baek, 2015; Jalil and Mahmud, 2009; Ozturk and Al-Mulali, 2015; Pao et al., 2011), by trade (Adu and Denkyirah, 2018; Al-Mulali et al., 2016; Ben Jebli et al., 2016; Kang et al., 2016), by population (Adu and Denkyirah, 2018; Alam et al., 2016; Li et al., 2016), urbanization (Li et al., 2016)), and by corruption as an institutional variable (Apergis and Ozturk, 2015; Ozturk and Al-Mulali, 2015). However, only few papers investigated the impact of Information and communication technologies (ICT) on CO_2 emissions (Higón et al., 2017; Zhang and Liu, 2015).

The literature on the impact of ICT on CO_2 emissions can be classified into two categories (i.e. a linear and a nonlinear impact). In a linear framework, Zhang and Liu (2015) estimated a panel data model based on Chinese regional dataset from 2000 to 2010 to show a positive connection between the adoption of ICT in the industrial sector and the reduction of CO_2 emissions. They also show that the positive impact is variable between the different regions. For instance, they estimated a small impact in the eastern region compared to the central region. However, this impact is not significant in the western region. Moreover, Lee and Brahmasrene (2014), by using a sample of ASEAN countries and by exploiting a panel cointegration technique, demonstrated a positive impact of ICT on CO_2 emissions in ASEAN countries from 1991 to 2009. Asongu (2018), recently, concluded for the same positive impact of ICT in reduction CO_2 emissions. In addition, using a panel data of forty-four Sub-Saharan African countries and GMM estimated method, Asongu et al. (2017) show that ICT can be employed to dampen the potentially negative effect of environmental pollution on human development. Recently, Asongu et al. (2018) examine how increasing ICT penetration in sub-Saharan Africa (SSA) can contribute towards environmental sustainability by decreasing CO_2 emissions. Using panel data of SSA for the period 2000–2012, they conclude for the absence of a significant relationship between ICT and CO_2 emissions. They also find that increasing mobile phone penetration alone has a net negative effect on CO_2 emissions from liquid fuel consumption.

The second category proves a nonlinear positive effect. For example, Higón et al. (2017) demonstrate an inverted U-shape relationship between ICT and CO_2 emissions for a sample of developed and developing countries.

This paper differs from the previous literature. It is pioneer in using total factor productivity (TFP) as a measure of economic activities rather than GDP. According to Ladu and Meleddu (2014), total factor productivity is a measure of growth instead of Gross domestic product. Furthermore, the paper is the first, to the best of our knowledge, that examines the validity of the Environmental Kuznets Curve (EKC) hypothesis using (TFP) as proxy of economic activities and ICT as an additional variable, for the Tunisian case.

The rest of the paper is organized as follows. The second section describes the empirical methodology and the used dataset to test the EKC hypothesis. Section 3 presents and discusses the estimated results. The conclusions and policy implications are presented in the last section.

2. Empirical methodology and data set description

2.1. Data and their proprieties

The empirical investigation aims at testing the validity of the EKC assumption for the relationship between economic activities (TFP), CO_2 emissions and the investment in ICT, for the case of Tunisia. To do so, we collected a novel dataset describing our key variables for a long period of time going from 1975 to 2014. The choice of the period of time is imposed by the data availability constraint. The dependent variable CO_2 emissions, which measures the environmental pollution, is expressed in metric tons. This variable is collected from the World Bank Indicators (WBI database). However, data on total factor productivity (TFP), which is used as proxy of economic activity, is collected from the Federal Reserve Economic Data source and is expressed in constant prices.

The sum of mobile and fixed telephone subscription data per 100 habitants, as a proxy of ICT, is also collected from the World Bank indicators data base. In order to describe variables evolution, we plot their line graphs in Figs. 1, 2 and 3. These figures provide a visual evolution of our key variables.

As we can see from Figs. 1, 2 and 3, the variables evolution is heterogeneous and different trends characterized the key variables. Indeed, an upward trend characterized CO_2 emissions. This can be explained by the accelerated economic activities of Tunisia during the last four decades which generally generated an undesirable output. However, as we can see from Fig. 2, stagnation characterized the total factor productivity (TFP) variable. Finally, the information and communication technologies (ICT) variable is characterized by an accelerated upward trend since 2003 after its stagnation between 1975 and 2002.

Table 1 provides some descriptive statistics of the mentioned variables. As we can clearly see, ICT have the highest coefficient of variation (1.42), reflecting its high and rapid variability during the last four decades. The total factor productivity (TFP) has, in contrast, the lowest coefficient of variation (0.052) which reflects its stagnation and relative stability between 1975 and 2014.

Using these datasets, we will investigate the validity of the EKC assumptions for the Tunisian case, when TFP is used as a proxy of economic activity and the EKC equation is augmented by ICT. The model as well as the empirical methodology is developed in the next section.

2.2. Model and empirical methodology

The EKC hypothesis is tested and examined by integrating the TFP, and ICT as determinants of CO_2 emissions. In its linear framework, the EKC model can be expressed as follow:

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln TFP_t + \beta_2 \ln ICT_t + \varepsilon_t \tag{1}$$

Where TFP denotes the total factor productivity, CO_2 denotes the

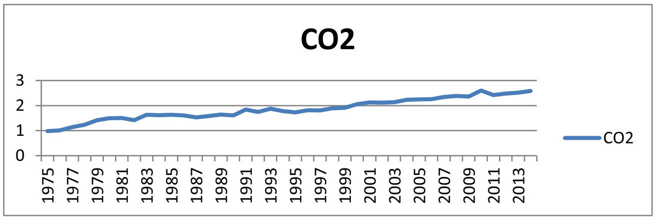

Fig. 1. Evolution of CO_2 emissions.

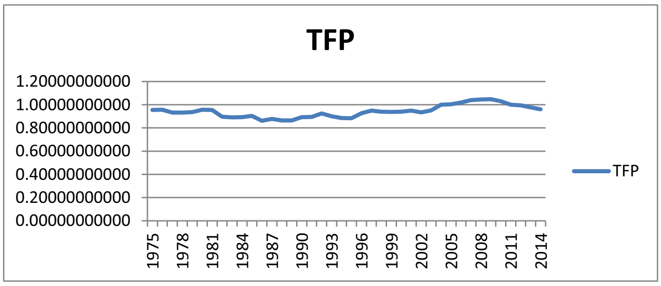

Fig. 2. Evolution of total factor productivity (TFP).

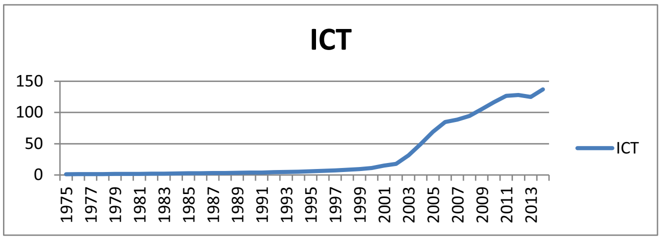

Fig. 3. Evolution of information and communication technologies (ICT).

Table 1
Descriptive statistics.

Statistics	CO_2 emissions	TFP	ICTs
Maximum	2.599	1.047	137.02
Minimum	0.981	0.861	1.16
Mean	1.856	0.942	32.33
Standard error	0.431	0.05	46.15
Coefficient of variation	0.232	0.052	1.42

Note: Variables are collected from the WDI and the Federal Reserve Economic Data source. The Tunisian data are collected for the period between 1975 and 2014.

dioxide carbon emissions, ICT denotes the information and communication technologies, and ε is the error term.

The EKC is validated, therefore, if we get a long run TFP parameter lower than the short run one.

We use the Autoregressive Distributed Lag (ARDL) approach which is developed by Pesaran et al. (2001)) to test the validity of EKC hypothesis. The mentioned approach can be applied only for variables that are integrated of order 1 or zero (I(0) or I (1)) and not for variables which are integrated of order two (I (2)).

In order to respect the ARDL approach requirements, we use both unit roots approach; the traditional unit root tests (Phillips-Perron (PP),Augmented Dickey-Fuller (ADF), Dickey-Fuller GLS (DF-GLS)), and the unit root tests with one structural break (Zivot and Andrews (1992)).

Following Eq. (1), the ARDL approach modeling can be presented as follow:

$$
\begin{aligned}
&\Delta \ln \mathrm{CO2}_t \\
&\quad = \alpha_0 + \sum_{i=1}^{r_1} \alpha_{1i} \Delta \ln \mathrm{CO2}_{t-i} + \sum_{i=0}^{r_2} \alpha_{2i} \Delta \ln \mathrm{TFP}_{t-i} + + \sum_{i=0}^{r_3} \alpha_{3i} \Delta \ln \mathrm{ICT}_{t-i} + \\
&+ \beta_1 \ln \mathrm{CO2}_{t-1} + \beta_2 \ln \mathrm{TFP}_{t-1} + + \beta_3 \ln \mathrm{ICT}_{t-1} + \beta_6 \mathit{break}_t + \omega_t
\end{aligned} \tag{2}
$$

ω is the error term, Δ is the first difference operator, *break* represents the dummy variable used to account for structural break in the data;r_1, r_2 and r_3 are the number of lags associated with each variable in first difference.

We adopted for the lag selection method the Akaike Information Criteria (AIC). It is always used to select the optimal lag order of each variable in first difference and is recognized as robust.

Once the ARDL model is specified, we turn now to the cointegration test within the ARDL model. Three steps are implemented to test for long-run equilibrium relationship between ICT, CO_2 and TFP.

The first step is to estimate the ARDL model by the ordinary least square method. The second step is to calculate the F-Statistic associated to the null hypothesis of no cointegration ($H0: \ \beta_1 = \beta_2 = \beta_3 = 0$) against the alternative hypothesis of cointegration ($H0: \ \beta_1 \neq \beta_2 \neq \beta_3 \neq 0$). The third step is to compare the calculated F-Statistic with the two critical bound values given by Pesaran et al. (2001). There are three possible cases.

The first case is to obtain an F-Statistic lower than lower upper critical value. In this case, there is no cointegration. The second case is to obtain an F-Statistic between the upper and the lower critical values. There is an inconclusive case.

The third case is to obtain an F-Statistic higher than upper critical value. In this case, there is a cointegration linkage between variables.

In the case of the realization of this last situation, the coefficients of the short-term are deduced from the following equation:

$$
\begin{aligned}
&\Delta \ln \mathrm{CO2}_t \\
&\quad = \gamma_0 + \sum_{i=1}^{m_1} \gamma_{1i} \Delta \ln \mathrm{CO2}_{t-i} + \sum_{i=0}^{m_2} \gamma_{2i} \Delta \ln \mathrm{TFP}_{t-i} + \sum_{i=0}^{m_3} \gamma_{3i} \Delta \ln \mathrm{ICT}_{t-i} + \theta \\
&\quad \mathrm{ECT}_{t-1} + \xi \mathit{break}_t + u_t
\end{aligned} \tag{3}
$$

u is the error term, Δ is the first difference operator, *break* represents the dummy variable, $m_1 - m_3$ are the number of lags for each variable in first difference selected by Akaike Information Criteria (AIC), $\gamma_{1i} - \gamma_{3i}$ are the short-run parameters for each variable, and ECT_{t-1} is the error correction term.

Concerning the long-term coefficients, they are given by the parameters $\beta_1 - \beta_3$ of Eq. (2).

We control the stability of the ARDL model by using the cumulative sum of recursive residuals test (CUSUM) and the cumulative sum of square of recursive residuals test (CUSUMQ). Furthermore, the validity of the ARDL model is controlled by using serial correlation, heteroscedasticity, and normality tests.

3. Results discussion

As we used the ARDL approach, the first step of its estimation procedure is to define the order integration of all variables. The result of traditional unit root tests which is figured in Table 2 clearly show that our variables are I(0) and I (1). The latter conclusion is confirmed by Zivot and Andrews (1992) unit root test with break point (Table 3).

Following the outcome of both unit roots tests, we can clearly see that the specification and the estimation of the ARDL model is possible. Thus, without ambiguity, we can use the ARDL model to test the EKC hypothesis.

Table 2
Results of traditional unit root tests.

Variables	Dickey Fuller-GLS		Augmented Dickey–Fuller		Phillips–Perron	
	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept
lnCO2	-2.199	0.220	-3.883**	-2.879*	-4.264 ***	-2.561
lnTFP	-1.726	-1.294	-2.011	-1.283	-2.072*	-1.347
lnICT	-1.963	-0.006	-2.120	-0.152	-1.692	0.378
Δ ln CO2	-8.098***	-7.626***	-7.948***	-7.541***	-7.903***	-7.446***
Δ ln TFP	-5.640***	-5.652***	-5.522***	-5.576***	-5.490***	-5.551***
Δ ln ICT	-3.722*	-2.614**	-4.635***	-2.650*	-3.678**	-2.681*

*** Denotes the significance at 1% level.

** Denotes the significance at 5%.

* Denotes the significance at 10%.

Table 3
Results of Zivot-Andrews unit root test.

Variables	Trend	Break date	Intercept	Beak date	Intercept and trend	Break date
lnCO2	-5.921***	1981	-4.057	1994	-4.995*	1981
lnTFP	-2.536	1983	-3.276	1982	-3.171	1982
lnICT	-2.957	1994	-7.705***	2003	-5.276**	2003
Δ ln CO2	-10.043***	1983	-9.652 ***	1982	-10.272***	1988
Δ ln TFP	-5.562***	2007	-6.350***	2008	-6.767***	2004
Δ ln ICT	-4. 679**	2004	-4.948**	2006	-5.666***	2003

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

Table 4
Result of bound cointegration test.

Model to estimate	$lnCO2_t = f(lnTFP_t, lnICT_t)$
F-statistic	6.372***
I(0)value	5.15
I(1)value	6.36

*** Denotes the significance at 1% level

3.1. ARDL cointegration process

The second step of the estimation procedure is to test the possibility of a cointegration relationship between the key variables. To do so, we use the dummy variable (break) reported by Zivot and Andrews (1992) unit root test. This recovered break point coincides with the start of adoption of the structural adjustment in Tunisia.

The result in Table 4 revealed that there is a cointegration relationship between total factor productivity, CO_2 emissions, and ICT since F-statistic (6.372) is higher than the upper critical bound value given by Pesaran et al. (2001).

3.2. Short-run and long-run results

The estimated results of ARDL model is presented and reported in Table 5. As we can clearly see from Table 5, the short-term TFP coefficient value is lower than its long-term value. Thus, the EKC hypothesis is not verified for the Tunisian case. The latter conclusion means that Tunisia has not yet reached the threshold level of total factor productivity that allows the EKC assumption to be verified. Indeed, it is clear that the actual level of TFP in Tunisia is insufficient to improve and protect the environment.

Table 5
Results of long and short-run analysis ARDL(1, 0, 0)

Variables	Coefficient.	Standard error	T-statistic	*p*-Values
Long-run analysis				
Constant	0.379**	0.150	2.516	0.016
lnTFP	0.121***	0.033	3.638	0.000
lnICT	-0.162	0.923	-0.176	0.861
BREAK	-0.233***	0.084	-2.748	0.009
Short-run analysis				
lnTFP	0.034*	0.019	1.799	0.080
lnICT	-0.045	0.268	-1.170	0.865
BREAK	-0.345***	0.096	-3.599	0.001
ECT(−1)	-0.281***	0.096	-2.908	0.006
R2	0.960			
Adjusted R2	0.957			
F-statistic	283.719***			0.000
Diagnostic tests				
Serial correlation	0.344			0.711
Normality	0.655			0.720
Heteroscedasticity	1.122			0.353

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

From a policy point of view, if Tunisia want to improve its environment, it is necessary to improve total factor productivity which is basically a measure of innovation and technical change in the economy. Given the lower expenditure on research and development in Tunisia compared to other MENA countries, the insufficient level of TFP is not a surprising result. The World Bank statistics and report on development shows that Tunisian expenditure in scientific research and development has never exceeded the 0,668% from the GDP between 2002 and 2015 (World Bank indicators).

The results presented in Table 5 cannot be interpreted separately from the previous literature especially that focusing in the Tunisian case. Indeed, our results confirmed those of Abid (2015). The later demonstrates the presence of a monotonically increasing linkage between CO_2 emissions and formal, and informal GDP in Tunisia between 1980 and 2009. Also, our result is in line with the finding of Fodha and Zaghdoud (2010) paper, which indicates the existence of a monotonically increasing link between CO_2 emissions and GDP during the period from1961 to 2004. Moreover, our result is in line with the outcome of Ben Jebli and Ben Youssef (2015) paper, which rejects the EKC hypothesis for the case of Tunisia.

Compared to papers done for other context, Our results are in line with Kim et al. (2011), Pao et al. (2011), Arouri et al. (2012), Chandran and Tang (2013), Ozcan (2013), Ozturk and Al-Mulali (2015), Alam et al. (2016), Apergis (2016),Amri (2017),Adu and Denkyirah (2018), Bouznit and Pablo-Romero (2016), Lacheheb et al. (2015), Bölük and Mert (2015), Halicioglu (2009), Kohler (2013), Farhani and Shahbaz (2014), Shafiei and Salim (2014), and Al-Mulali et al. (2016).

In contrast, our results are in contradiction with those of Atici (2009), Apergis and Payne (2009), Jalil and Mahmud (2009), Apergis and Payne (2010), Lean and Smyth (2010), Pao and Tsai (2011a), Pao and Tsai (2011b), Saboori et al. (2016), Shahbaz et al. (2013), Kohler (2013), Robalino-López et al. (2014), Lau et al. (2014), Farhani and Shahbaz, 2014 Shahbaz et al. (2014), Apergis and Ozturk (2015). Ben Jebli et al. (2016), Alam et al. (2016), Apergis (2016), and Li et al. (2016).

The results show an insignficant impact of ICT on CO_2 emissions.. This result can be explained by the delay for the development of ICT in Tunisia compared to other neighbor countries. According to a report of the International Telecommunication Union, Tunisia is ranked 99th out of 167 countries.

The empirical investigations show that our results are in contradiction with the results of Higón et al. (2017) which indicates the existence of an inverted U-shaped linkage between the two variables in the case of 26 developed countries and 116 developing countries between 1995 and 2010. It is also in contradiction with the outcome of Zhang and Liu (2015) paper which obtained a negative effect of ICT industry on CO_2 emissions in China for the period between 1995 and 2010.Moreover, compared to recent previous studies for the case of ASEAN and 44 African countries done respectively by Lee and

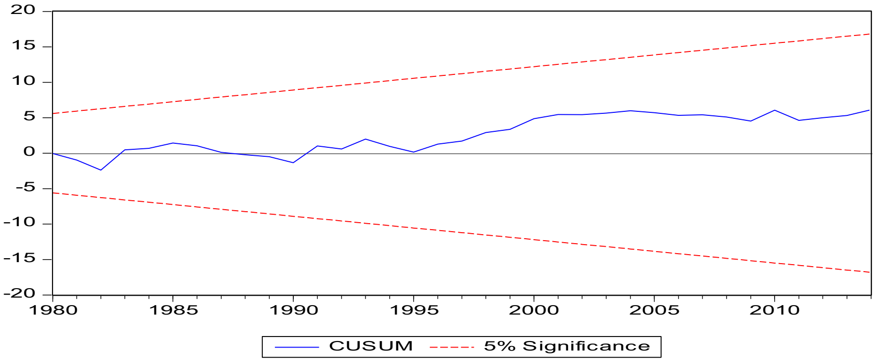

Fig. 4. CUSUM plot.

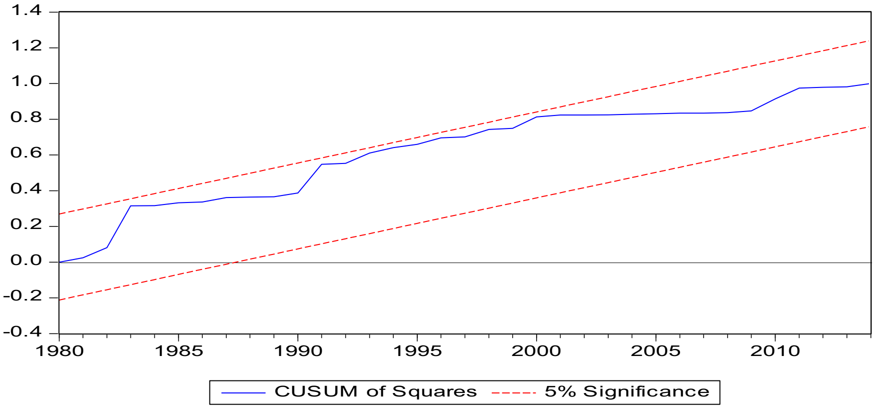

Fig. 5. CUSUMQ plot.

Brahmasrene (2014) and Asongu (2018), our results are in contradiction with these previous findings. Indeed, using a panel of 44 African countries observed between 2000 and 2012, Asongu (2018) shows that ICT have a negative impact on CO_2 emissions. In contrast, Lee and Brahmasrene (2014) show that ICT have a positive impact onCO_2 emissions in ASEAN countries between 1991 and 2009.

Finally, after interpreting the results of the empirical investigation, we turn now to test the validity and stability of the ARDL model used to test the EKC hypothesis for the Tunisian case when TFP is used as indicator of economic activities. As we can see from the different statistics reported in the bottom of Table 5, there is no autoregressive heteroscedasticity and no serial correlation. Moreover, the residuals of the estimated ARDL model are normally distributed. These diagnostic tests clearly confirmed the validity and the stability of the estimated ARDL model. The line graphs presented in Figs. 4 and 5 proved the stability of ARDL model.

4. Conclusion and policy implications

The main purpose of the present paper is to test the EKC hypothesis for the case of Tunisia using time series data between 1980 and 2012. The paper contributes empirically to the literature by considering total factor productivity (TFP) as a measure of economic activities and ICT as an additional variable that augmented the EKC equation.

The empirical investigations developed in this paper draw several finding and policy recommendations. Firstly, the long-run TFP parameter is higher than short run one which implies the reject of EKC hypothesis for Tunisia. It implies that the level of total factor productivity reached in Tunisia cannot permit the environmental improvement. For this, Tunisian makers should enhance the research and development activities and technological capacity of the country in order to improve total factor productivity.

Secondly, The ARDL results indicate an insignificant impact of ICT variable on CO_2 emissions. This indicates that the level of ICT in Tunisia has not enabled the country to decrease emissions. Consequently, Tunisia should use and develop more ICT in order to decrease CO_2 emissions. In this case, Tunisia should concentrate in the more pollutant sectors (building, transport, and industry). For example, in industry sector, ICT can not only improve energy efficiency but also optimize resource utilization in industrial production processes. In transport sector, ICT technologies implementation can help to increase the efficiency of transport. In building sector, ICT can help to save energy and to optimize the use of natural resources.

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Fethi Amri is Assistant Professor of Applied Econometrics, Statistics and Microeconomics, Ministry of Higher Education and Scientific Research, Carthage University, Faculty of Economic Sciences and Management of Nabeul, Tunisia.. Fethi Amri holds a Ph.D in Economics (applied econometrics) from the Faculty of Economic Sciences and Management of Tunis, El Manar University, Tunisia. He has published numerous papers in international refereed journals such as *Region et developpement, Renewable and Sustainable Energy Review, Environmental Science and Pollution Research, Quality & Quantity, and Energy.*

Younes Ben Zaied is currently Full Professor of Economics at ISTEC-Paris School of Business & Marketing (Paris, France), Research Associate at the EconomiX research Lab at the University of Paris nanterre (Nanterre, France) and full time researcher at ESSEC Business School center of academic Excellence (Cergy, France). Younes Ben Zaied holds a Ph.D in Economics (applied econometrics) from the University of Rennes 1 (Rennes, France) (2014). He worked for IESEG School of Management (Paris), University of Rennes 1, University of Le Havre, University of Paris-Sorbonne-Cité and University of Paris Nanterre. He has published numerous papers in international refereed journals such as *Applied Economics, Environmental Modeling and Assessment, Journal of Economic Integration, Climatic Change, Environmental Economics, Journal of Quantitative Economics, and Journal of the Knowledge Economy.*

Bechir Ben Lahouel is currently full professor of Management at IPAG-Paris Business School (Paris, France), research associate at ESSEC business school in Paris. Prof. Ben Lahouel holds a Ph.D in Management science from the University de La Corse in France (2011). He worked for the ESSEC Business School (Paris), Corse University, Creteil University and IPAG business school. He has published several papers in international refereed journals such as Journal of Cleaner Production, European Business Review, Environmental Economics and Policy Studies.