Dynamic Relationships among CO2 Emissions, Energy Consumption, Economic Growth, and Economic Complexity in France

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30 March 2016

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Abstract

Environmental degradation is most often brought to the agenda by arousing the attention of scholars, and there has been an increase in the studies on this issue. This paper re-estimates the environmental Kuznets curve in France over the period of 1964–2011. To this end, the unit root test with one structural break and a cointegration analysis with multiple endogenous structural breaks are considered. The impacts of the energy consumption and the economic complexity on CO_2 emissions are also included in dynamic empirical models. First, it is found that the environmental Kuznets curve hypothesis is valid in France in both the short and the long run. Second, the positive impact of energy consumption on CO_2 emissions is also observed in the long run. Third, it is observed that a higher economic complexity suppresses CO_2 emissions in the long run. The evidence suggests important environmental policy implications to suppress CO_2 emissions in France.

Keywords: environmental Kuznets curve; energy consumption; economic complexity; time series modeling; structural breaks; French economy

1. Introduction

Today, one of the issues is that most countries are exposed to environmental degradation, which causes many problems; e.g., it negatively affects health (Iwata et al. 2010). Environmental degradation is most often brought to the agenda by arousing the attention of scholars, and there has been an increase in the studies on this issue. In addition, the world's major institutions are voicing the problems caused by global warming, which is mainly related to environmental degradation. In this context, the relationship between environmental degradation and economic growth is discussed in the available literature (e.g., Ang 2007; Dinda et al. 2000). For this purpose, the environmental Kuznets curve (EKC) hypothesis is used in analyzing the relationship between economic growth and environmental degradation. According to this hypothesis, environmental degradation increases until a country reaches a high (certain) income level. After that, while a decline in environmental degradation occurs, environmental quality increases (Dinda 2004; Iwata et al. 2010; Kearsly and Riddel 2010). With the increasing development of countries, environmental awareness is also expected to increase. When economic structural transformation is observed in this process, technological advancement in the country is also ensured (Yin et al. 2015). In other words, there is an "inverted-U" relationship between environmental degradation and income (Dinda et al. 2000). The inverted-U path, which is an important indicator of environmental quality, is closely related to the output composition of the country (Suri and Chapman 1998).

Twenty different environmental degradation criteria have been used for analyzing the EKC hypothesis (Onafowora and Owoye 2014). However, it can be said that environmental degradations are predominantly represented by CO_2 emissions. CO_2 emissions in the country are known to be driven by different parameters, i.e., social, cultural, economic, and technological factors (Tarancon and Del Rio 2007). However, rather than social and cultural parameters, the relationship between economic and technological parameters and CO_2 emissions are investigated in the literature. A summary of these effects is represented in Figure 1.

[Insert Figure 1]

In the first periods of development, countries carried out extensive activities in the agriculture sector, which hardly contributed to environmental degradation (Kearsly and Riddel 2010). Following this process, countries proceeded to the industrialization stage, which emitted high pollution. Following completion of this process, countries focused on knowledge- and skill-intensive manufacturing (Song et al. 2008). The last stage showed a process that increased the level of environmental quality (Rezek and Rogers 2008). In the process of structural change, new technology that emitted less pollution replaced old technology used in manufacturing (Lau et al. 2014). These processes are the scale (composition), the structural, and the technological (technique) effects, respectively (Tsurumi and Managi 2010; Yin et al. 2015).

On the other hand, research and development (R&D) expenditures were used as a proxy for technological progress and changes in the economic structure (Yin et al. 2015). It was emphasized that as per capita income increased, structural transformation in the economy increased R&D expenses, thus the advancement of technological production. As a consequence of this, a higher level of environmental quality would be achieved (Dinda et al. 2000). However, R&D expenditures were indicative of an entry for the emergence of a product. In this case, since not all R&D expenditures encouraged economic growth, it was not a suitable indicator of successful transformation (Mohnen and Hall 2013). In other words, R&D expenditures were not exactly a convenient parameter to examine the impact of structural change and technological advancement on environmental degradation. Some studies emphasized that technological production processes (technical effect) were closely related with an increase in per capita gross domestic product (GDP) (Dinda et al. 2000; Panayotou 1997). However, a high level of income per capita does not express a strong structure in an economy. For instance, oil exporter countries (e.g., Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates) are at a high level of per capita income, but they cannot be classified in such category.

Indeed, structural changes in an economy affect countries in many aspects. However, technological improvement is the most important among them, and it can be defined as a process that reduces production costs or causes the emergence of new products (Stafforte and Tamberi 2012). Technological improvement is closely related to "capabilities" of a country (e.g., institutional quality, infrastructure quality, rule of law, and property rights) as well as its skills and knowledge accumulation, i.e., productivity of skilled labor and technology level (Hidalgo 2009; Hidalgo and Hausmann 2009; Hidalgo et al. 2007). In this context, developed countries mainly concentrate on the production of goods and services, which require skilled a labor force and high-level technology (Maggioni et al. 2014).

The EKC hypothesis has been heavily tested in developing countries in the literature. In other words, there are a small number of studies to test the validity of the EKC hypothesis in developed countries.[1] For instance, Ang (2007) examined the effects of energy consumption

[1] In addition, there are some studies that include the French data in panel data sets for Organization for Economic Cooperation and Development (OECD) and the European Union (EU) countries to analyze the EKC hypothesis. (see, Al-Mulali and Ozturk 2016; Bilgili et al. 2016; Cho et al. 2014; Jebli et al. 2016; Liu 2005; Richmond and Kaufman 2006).

and output on CO_2 emissions from 1960 to 2000 in France. It was demonstrated that there was a long-running relationship among the variables and that the relationship is quadratic in nature. In addition, it was observed that there is a statistically significant causality that runs from economic growth to both energy consumption and CO_2 emissions in the long run. The significant causal relationship that runs from energy consumption to economic growth is also observed in the short run. Iwata et al. (2010) also tested the validity of the EKC hypothesis in France by controlling the effect of nuclear energy consumption. In the study, the EKC hypothesis was found to be valid and that nuclear energy consumption reduced CO_2 emissions. Ajmi et al. (2015) tested the EKC hypothesis for each G7 country, including France, and they concluded that the EKC hypothesis was not valid for all countries.[2]

Studies mainly use time series techniques to test the validity of a standard EKC hypothesis in developed countries, and CO_2 emissions is generally used as the dependent variable. Independent variables consist of GDP, squared GDP, and energy consumption.[3] However, in studies on EKC hypothesis analysis in developing countries, scholars used additional explanatory variables.[4] Our study has some similarities with these papers. However, our paper uses a totally different explanatory variable to test the validity of the EKC hypothesis for a developed country, France. The explanatory variable in our paper is the *economic complexity index* (ECI), which represents sophisticated, knowledge-based, and skill-based production.

The ECI was first introduced by Hidalgo and Hausmann (2009). Hidalgo (2011) also criticized the aggregated "traditional production approach" to explain the economic growth and development process of a country. According to the traditional production approach, there are two factors (capital and labor force) affecting economic growth and development. However, according to Hidalgo (2011), production not only needs labor and capital but also needs "capabilities." Some of these "capabilities" are nontradable goods and services, consisting of specific infrastructure, labor skills, property rights, regulations, etc. (Hidalgo and Hausmann 2009). ECI is calculated with trade data from the United Nations (UN) Comtrade; thus, the data are only based on the export basket (not all goods produced). This index aims to demonstrate the production characteristics of the economic system by taking into account the capabilities of

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[2] For a recent literature review of the EKC hypothesis, see Al-Mulali and Ozturk (2016).
[3] For exceptional approaches, for instance, see Bento and Mountinho (2016) and He and Richard (2010).
[4] For instance, the capital formation (Soytas and Sari 2009; Zhang and Cheng 2009), the education level (Managi and Jena 2008), the financial development (Javid and Sharif 2016), the foreign direct investments (FDI) (Tang and Tan 2015), the labor force (Soytas and Sari 2009), the population density (Akbostanci et al. 2009; Onafowora and Owoye 2014), the trade openness (Ang 2009; Halicioglu 2009; Jayanthakumaran et al. 2012; Kanjilal and Ghosh 2013; Nasir and Rehman 2011; Onafowora and Owoye 2014), and the urbanization (Managi and Jena 2008; Zhang and Cheng 2009) are used as an additional control variable to analyze the validity of the EKC hypothesis in developing countries.

a country (Hausmann et al. 2011; Minondo and Requena-Silvente 2013). Therefore, the economic complexity is an indicator of sophisticated and knowledge-skill based production of a country (Hartmann et al. 2015). Economic complexity can be defined as the knowledge- and skills-based production structure of a country with an efficient output level. The high value of the index is a sign of the highly sophisticated manufacturing capabilities of the country's production structure (Sweet and Maggio 2015).

At this point, structural changes in the economy should be expected to reduce the CO_2 emissions of a developed country since this process shows a transformation from "energy-intensive economy" to "technology-intensive economy." However, if policy-makers do not implement environmental regulations in this process, positive improvements with regard to environmental quality might not be observed (Tsurimi and Managi 2010). On the other hand, it can be suggested that economic complexity has the capability of representing the scale, the structure, and the technological effects within a holistic approach in the EKC hypothesis. If a country is a poor or a developing country, it should be expected that as economic complexity increases, CO_2 emissions increase up to a certain stage of development. It is possible to observe a decline in CO_2 emissions by ensuring structural transformation and increasing knowledge- and skill-based-technology-intensive manufacturing. From this point of view, in developed countries, economic complexity is expected to reduce CO_2 emissions. Nevertheless, this is closely related to environmental policy implementation (Dinda 2004; Kanjilal and Ghosh 2013).

Furthermore, the ideal example of this case is France since it is one of the countries with the highest economic complexity in the world, and it has managed to achieve structural transformation. This is reflected in the technological patent applications made by the country. For instance, France is one of the leading countries in nanotechnology-based patent applications since 1977 (Colombelli et al. 2014). The country is also one of the most important energy consumers in the world. France was deeply influenced by the oil shocks in the 1970s. Since those years, it has taken several measures to reduce energy dependence. Moreover, France is the EU country with the least CO_2 emissions (Ang 2007; Iwata et al. 2010). The most important underlying cause of that is the carbon tax imposed in the country. Another reason is the implementation of the nuclear program for electricity generation since the 1970s (Ang 2007). When compared with other types of energy resources (e.g., coal, oil, or natural gas), nuclear energy used for electricity generation emits less CO_2 (Iwata et al. 2010).

The main goal of this study is to investigate the relationship between the economic complexity, which has the capability of representing the scale, the structure, and the technological effects, and CO_2 emissions within the context of the EKC hypothesis. The validity of the EKC hypothesis is evaluated in the context of many different variables (e.g., FDI, population density, trade openness, and urbanization). However, there is still no study that analyzes the EKC hypothesis with regard to economic complexity as a measure of economic structure transformation, which has the capability of representing product manufacturing involving technological knowledge. To the best of our knowledge, this is the first study that investigates the relationship between CO_2 emissions, per capita GDP, energy consumption, and economic complexity in the literature. In this context, our study aims to fill this gap in the literature by focusing on the French case for the period 1964–2011.

The rest of the paper is organized as follows. Section 2 explains the data, the empirical model, and the econometric methodology. Section 3 provides the empirical results. Section 4 discusses the empirical results and suggests policy implications. Section 5 presents conclusions.

2. Data, Empirical Model, and Econometric Methodology

2.1. Data

CO_2 emissions (metric ton per capita) are used in France over the period 1964–2011 as the dependent variable. The real GDP per capita (constant 2005 $) and the squared real GDP per capita (constant 2005 $) are considered to capture the linear and nonlinear effects of income, respectively. Energy consumption (kilogram of oil equivalent) per capita is also added to the empirical model. All these variables are used in logarithmic form, and the frequency of the data is annual. The data are obtained from the world development indicators (WDI) of the World Bank.

The data of the economic complexity index (ECI) are obtained from the database of *Atlas of Economic Complexity* by Hausmann et al. (2011). A higher ECI value means a higher economic complexity. The ECI is also modeled in logarithmic form. A summary of the descriptive statistics is also represented in Appendix I.

2.2. Empirical Model

This paper uses a well-known EKC model, i.e., it considers per capita income, squared per capita income, and per capita energy consumption as determinants of the CO_2 emissions (e.g., Ang 2007; Bilgili et al. 2016; Soytas and Sari 2009; Zhang and Cheng 2009). The income effect is captured by the level of real GDP per capita and squared real GDP per capita and the energy effect is measured by energy consumption per capita. This paper also proposes that the economic complexity can also be a significant determinant of CO_2 emissions. Thus, the empirical model for the EKC hypothesis is

$$CO_{2t} = f(RGDP_t^{\alpha 2}, SRGDP_t^{\alpha 3}, ENGC_t^{\alpha 4}, ECI_t^{\alpha 5}) \quad (1)$$

The model in Eq. (1) can be written in the following logarithmic form:

$$logCO_{2t} = \alpha_0 + \alpha_1 logCO_{2t-k} + \alpha_2 logRGDP_{t-k} + \alpha_3 logSRGDP_{t-k} + \alpha_4 logENGC_{t-k} + \alpha_5 logECI_{t-k} + \varepsilon_t \quad (2)$$

In Eq. (2), $logCO_{2t}$ and $logCO_{2t-k}$ are the CO_2 emissions in logarithmic form at time *t* and *t–k*; $logRGDP_{t-k}$ and $logSRGDP_{t-k}$ are the level of real GDP per capita and the squared real GDP per capita in logarithmic form at time *t–k*; $logENGC_{t-k}$ is the energy consumption per capita in logarithmic form at time *t–k*; and $logECI_{t-k}$ is the economic complexity index in logarithmic form at time *t–k*. The error term is represented by ε_t. According to the EKC hypothesis, α_2>0 and elastic, α_3<0, and α_4>0. All these are found to be statistically significant unless there is no valid CO_2 emission function in France. Furthermore, a higher level of energy consumption leads to higher CO_2 emissions (Ang 2007). This paper also suggests that α_5<0 since as a country's export basket becomes more sophisticated (a higher economic complexity), a lower CO_2 emission is observed in a developed country, i.e., France. At this stage, statistically significant (long-run) coefficients need to be obtained.

2.3. Econometric Methodology

The unit root test of Lee and Strazicich (2013) that models one structural break in the series is implemented. After finding a statistically significant unit root in all variables, cointegration analysis is also implemented.

The cointegration test of Maki (2012) that models the structural breaks in the level and regime shifts is considered, and the maximum number of structural breaks is selected as two events. Maki (2012) proposes four different models to analyze the cointegrating (long-run) relationships among variables. Since the results of the unit root test considers the break in the level, *Model 0,* i.e., structural break(s) in the level (intercept) without the time trend, is considered as the benchmark results for the cointegration test methodology of Maki (2012).

The long-run coefficients of the EKC model in Eq. (2) are estimated by the dynamic ordinary least squares (DOLS) by Stock and Watson (1993) with the heteroskedasticity and autocorrelation consistent (HAC) standard errors (Bartlett kernel, Newey–West fixed bandwidth = 4.0000). Two structural-break dates (1983 and 1997) are also added to the long-run estimations. The selection of structural-break dates is based on the results of the cointegration test.

Furthermore, reaching the long-run equilibrium can take time for CO_2 emissions in France. Therefore, the speed of adjustment between short- and long-run CO_2 emissions can also be modeled by the following error correction model (ECM):

$$\Delta logCO_{2t} = \alpha_0 + \sum_{i=1}^{n} \alpha_1 \Delta logCO_{2t-k} + \sum_{i=0}^{n} \alpha_2 \Delta logRGDP_{t-k} + \sum_{i=0}^{n} \alpha_3 \Delta logSRGDP_{t-k} + \sum_{i=0}^{n} \alpha_4 \Delta logENGC_{t-k} + \sum_{i=0}^{n} \alpha_5 \Delta logECI_{t-k} + \alpha_6 \varepsilon_{t-1} + \mu_t \quad (3)$$

In Eq. (3), Δ is the change in the variables, μ_t is the error term, and ε_{t-1} is the lagged error correction term (ECT) that can be obtained from the estimation of Eq. (2), and it indicates the speed of adjustment of disequilibrium between short- and long-run levels of the CO_2 emissions in France. It is expected that α_6<0. In addition, the short-run coefficient is estimated for the ECM that is represented in Eq. (3). Finally, the Granger causality/block exogeneity Wald tests are implemented, and the empirical model for the test procedure can be represented as such:

$$\begin{bmatrix} \Delta logCO_{2t} \\ \Delta logRGDP_t \\ \Delta logSRGDP_t \\ \Delta logENGC_t \\ \Delta logECI_t \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} + \begin{bmatrix} \gamma_{11,1}\gamma_{12,1}\gamma_{13,1}\gamma_{14,1}\gamma_{15,1} \\ \gamma_{21,1}\gamma_{22,1}\gamma_{23,1}\gamma_{24,1}\gamma_{25,1} \\ \gamma_{31,1}\gamma_{32,1}\gamma_{33,1}\gamma_{34,1}\gamma_{35,1} \\ \gamma_{41,1}\gamma_{42,1}\gamma_{43,1}\gamma_{44,1}\gamma_{45,1} \\ \gamma_{51,1}\gamma_{52,1}\gamma_{53,1}\gamma_{54,1}\gamma_{55,1} \end{bmatrix} \begin{bmatrix} \Delta logCO_{2t-1} \\ \Delta logRGDP_{t-1} \\ \Delta logSRGDP_{t-1} \\ \Delta logENGC_{t-1} \\ \Delta logECI_{t-1} \end{bmatrix} + \cdots +$$

$$\begin{bmatrix} \gamma_{11,i}\gamma_{12,i}\gamma_{13,i}\gamma_{14,i}\gamma_{15,i} \\ \gamma_{21,i}\gamma_{22,i}\gamma_{23,i}\gamma_{24,i}\gamma_{25,i} \\ \gamma_{31,i}\gamma_{32,i}\gamma_{33,i}\gamma_{34,i}\gamma_{35,i} \\ \gamma_{41,i}\gamma_{42,i}\gamma_{43,i}\gamma_{44,i}\gamma_{45,i} \\ \gamma_{51,i}\gamma_{52,i}\gamma_{53,i}\gamma_{54,i}\gamma_{55,i} \end{bmatrix} \begin{bmatrix} \Delta logCO_{2t-i} \\ \Delta logRGDP_{t-i} \\ \Delta logSRGDP_{t-i} \\ \Delta logENGC_{t-i} \\ \Delta logECI_{t-i} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \\ \varepsilon_{4,t} \\ \varepsilon_{5,t} \end{bmatrix} \quad (4)$$

In Eq. (4), ECT_{t-1} is the lagged ECT that is estimated from the long-run equilibrium model; $\varepsilon_{1,t}$, $\varepsilon_{2,t}$, $\varepsilon_{3,t}$, $\varepsilon_{4,t}$, and ε_{5t} are defined as a finite covariance matrix with the mean zero, and they are represented by the independent and identically distributed random errors.

3. Empirical Results

The results of the unit root test of Lee and Strazicich (2013), which are considered for the structural break in the level, are reported in Table 1.

[Insert Table 1]

The results in Table 1 indicate that all variables contain a unit root at the 1% statistical significance level, and the first differences of the variables are stationary. Therefore, all variables in the empirical model can be an I(1) process. Therefore, the results are suitable for implementing the cointegration technique. The results of the cointegration test are also reported in Table 2.

[Insert Table 2]

The results of three of four models of the cointegration test in Table 2 show that there is a statistically significant cointegration at the 1% level among log CO_2 Emissions – log GDP Per Capita – log Squared GDP Per Capita – log Energy Consumption – log Economic Complexity. Thus, the short- and long-run coefficients are obtained.

The results of the DOLS estimations for obtaining long-run coefficients are reported in Table 3. As expected, the coefficient of the log real GDP per capita is positive and elastic (12.57); where the coefficient of the squared log real GDP per capita is found as negative and elastic (–1.56). Furthermore, the coefficient of the log energy consumption per capita is also found as positive and inelastic (0.92) as expected. In addition, the coefficients for dummy variables of the structural break dates are statistically significant at the 5% significance level.

[Insert Table 3]

The coefficient of the log economic complexity index (ECI) is also obtained as negative and inelastic (–0.47); thus, as the economic complexity increases, CO_2 emissions decrease. The coefficient of the log ECI is found as statistically significant at the 1% level. Therefore, the results show that one standard deviation increases in the ECI yield a 2.5% decrease (approximately 5.81 metric tons per capita) in CO_2 emissions in France.

The results of the ECM estimation are also reported in Table 4. The coefficients of the lagged log real GDP per capita and the lagged squared log real GDP per capita are found as positive and elastic (32.14) and negative and elastic (–3.54), respectively. Their coefficients are also found as statistically significant at the 1% level. The negative and inelastic coefficients for the lagged log CO_2 emissions per capita (–0.41) and the lagged log energy consumption per capita (0.03) are also observed. The coefficient of the log ECI is also found as 0.148; however, these coefficients are not found as statistically significant in the short run.

[Insert Table 4]

The ECT term of the ECM regression is found as −0.149, and it is statistically significant at the 5% level. The evidence indicates that the CO_2 emissions in France converge to the long-run equilibrium by a 14.9% speed of adjustment through the channels of the real GDP per capita, the squared real GDP per capita, the energy consumption per capita, and the economic complexity. Finally, the results of the Granger causality/block exogeneity Wald tests are reported in Table 5.

[Insert Table 5]

The results show that there is a statistically significant causality ($p<0.01$) that runs from the log real GDP per capita and the squared log real GDP per capita to the log CO_2 emissions in the short run. These findings are in line with the results of the ECM estimations of the short-run coefficients. In addition, the overall chi-square test statistics of the causal relationship for the log CO_2 emissions are also found statistically significant ($p<0.05$). These results are in line with the results of the DOLS estimations of the long-run coefficients. It is observed that the results of the Granger causality/block exogeneity Wald tests imply that the empirical findings both for the short and long run are statistically robust. In addition, it is found that there is a statistically significant ($p<0.05$) causal relationship that runs from the log real GDP per capita and the squared log real GDP per capita to the log energy consumption per capita in the short run. However, the overall chi-square test statistics of the causal relationship for the log energy consumption per capita is obtained as statistically insignificant. Therefore, it is observed that income per capita causes energy consumption, and the causal effect of the income per capita on energy consumption is nonlinear in France over the specified period.

4. Discussion and Policy Implications

The evidence in the paper indicates that income, energy consumption, and the economic complexity are the main determinants of CO_2 emissions, and therefore, the EKC hypothesis is valid in France in the long run. At this point, income is the most important variable in determining CO_2 emissions in France since the income effect is statistically significant both in the short ($p<0.01$) and long run ($p<0.05$). Also, there is an *inverted U* relationship between income and CO_2 emissions in France. In other words, the empirical findings imply that as income increases, the CO_2 emissions also increase until stabilization is reached. CO_2 emissions are then reduced in the long run. It is also observed that energy consumption is positively associated with CO_2 emissions in the long run, as expected. The empirical evidence on the effects of income and energy consumption on CO_2 emissions is in line with previous empirical results in France (Ang 2007; Iwata et al. 2010). In addition, it is also found that a higher economic complexity, i.e., including more sophisticated goods to the export basket, yields lower CO_2 emissions in France in the long run. However, the short-run effect of the economic complexity is not found as statistically significant. To the best of our knowledge, the first empirical results in the literature on the effect of the economic complexity on CO_2 emissions are obtained in the paper. The evidence in the paper implies that it is possible to forecast CO_2 emissions from past levels of per capita income, per capita energy consumption, and the economic complexity.

The evidence suggests that there are some environmental policy implications to suppress CO_2 emissions. First, it is found that a higher per capita income yields a rise in environmental pollutants, but it declines after the turning point. Since France is a developed country (it is on the high income level), as per capita income increases, CO_2 emissions will decrease, systematically. However, it is important to note that policy-makers should focus on providing environment-friendly investments. Second, given that France is a net energy importer, policy implications should be focused on increasing renewable energy consumption. At this stage, investments or tax incentives for renewable energy technologies can be an important policy tool. Similarly, nuclear energy consumption can decrease CO_2 emissions in France.

Third, the evidence in the paper illustrates that the economic complexity significantly reduces CO_2 emissions in France. Indeed, according to Hausmann et al. (2011), the ECI is a more accurate predictor of GDP per capita growth than traditional measures of governance, competitiveness, and human capital. The empirical results in the paper illustrate that the ECI is also important for managing environmental pollutants in France. Therefore, when creating a more sophisticated export basket, French firms and policy-makers should take advantage of lower environmental pollution in the country. On the other hand, producing goods, which creates more CO_2 emissions, can be imported. In addition, these policy implications need a more detailed knowledge of the scale of environmental pollutants in each sector and (maybe each firm, if possible) in the French economy.

5. Conclusion

Climate change is a major problem that the modern world has been never faced, and it is highly related to the increasing environmental degradation at the global level. Although several environmental indicators are tested for their effects on climate change, CO_2 emissions are the most frequently used. Within this context, this paper tries to offer a new variable to analyze environmental degradation, and it investigates the validity of the EKC hypothesis in France for the period 1964–2011 in the context of economic complexity. To this end, the unit root test and the cointegration analysis that captures endogenous structural breaks in time series are implemented. Using the ECM and the DOLS estimation techniques, the short- and long-run coefficients are obtained. Energy consumption is also included in the empirical models.

The evidence in the paper is as follows. First, it is found that the EKC hypothesis is valid in France both in the short and long run. Second, the positive and the inelastic impact of energy consumption on CO_2 emissions is also obtained in the long run. Third, it is observed that a higher economic complexity suppresses CO_2 emissions in the long run, and this evidence is the novel contribution of the paper to the existing empirical literature on the EKC hypothesis. This paper suggests that a higher economic complexity is a significant indicator in decreasing CO_2 emissions.

Future papers on the effects of economic complexity on CO_2 emissions can be examined in other developed and emerging economies with time series tools. Furthermore, the cases of OECD and EU countries can also be analyzed by panel data estimation techniques.

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.

Akbostanci, E., Turut-Asik, S., Tunc, G.I. (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve?. *Energy Policy*, 37 (3): 861–867.

Al-Mulali, U., Ozturk I. (2016). The investigation of environmental Kuznets curve hypothesis in the advanced economies: The role of energy prices. *Renewable and Sustainable Energy Reviews*, 54: 1622–1631.

Ang, J.B. (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy*, 35 (10): 4772–4778.

Ang, J.B. (2009). CO_2 emissions, research, and technology transfer in China. *Ecological Economics*, 68 (10): 2658–2665.

Bento, J.P.C., Moutinho, V. (2016). CO_2 emissions, non-renewable and renewable electricity production, economic growth and international trade in Italy. *Renewable and Sustainable Energy Reviews*, 55: 142–155.

Bilgili, F., Kocak, E., Bulut, U. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: A revisited environmental Kuznets curve approach. *Renewable and Sustainable Energy Reviews*, 54: 838–845.

Cho, C-H., Chu, Y-P., Yang, H-Y. (2014). An environment Kuznets curve for GHG emissions: A panel cointegration analysis. *Energy Sources, Part B: Economics, Planning, and Policy*, 9 (2): 120–129.

Colombelli, A., Krafft, J., Quatraro, F. (2014). The emergence of new technology-based sectors in European regions: A proximity-based analysis of nanotechnology. *Research Policy*, 43 (10): 1681–1696.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics*, 49 (4): 431–455.

Dinda, S., Coondoo, D., Pal, M. (2000). Air quality and economic growth: An empirical study. *Ecological Economics*, 34 (3): 409–423.

Gozgor, G., Can, M. (2016). Export product diversification and the environmental Kuznets curve: Evidence from Turkey. *MPRA Paper*, No. 69761, University Library of Munich.

Halicioglu, F. (2009). An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, 37 (3): 1156–1164.

Hartmann, D., Guevara, M.R., Jara-Figueroa, C., Aristaran, M., Hidalgo, C.A. (2015). Linking economic complexity, institutions and income inequality. *Mimeograph*. http://arxiv.org/ftp/arxiv/papers/1505/1505.07907.pdf.

Hausmann, R., Hidalgo, C.A, Bustos, S., Coscia, M., Chung, S., Jimenez, J., Simoes, A., Yildirim, M. (2011). *The Atlas of Economic Complexity*. Puritan Press: Cambridge, MA.

He, J., Richard, P. (2010). Environmental Kuznets curve for CO_2 in Canada. *Ecological Economics*, 69 (5): 1083–1093.

Hidalgo, C.A. (2009). The dynamics of economic complexity and the product space over a 42 year period. *Harvard University CID Working Paper*, No.189.

Hidalgo, C.A. (2011). *Discovering Southern and East Africa's Industrial Opportunities*. The German Marshall Fund of the United States, Economic Paper Series: Washington, D.C.

Hidalgo, C.A., Hausmann, R. (2009). The building of economic complexity. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 106 (26): 10570–10575.

Hidalgo, C.A., Klinger, B., Barabasi, A.L., Hausmann, R. (2007). The product space conditions the development of nations. *Science,* 317 (5837): 482–487.

Iwata, H., Okada, K., Samreth, S. (2010). Empirical study on the environmental Kuznets curve for CO_2 in France: The role of nuclear energy. *Energy Policy*, 38 (8): 4057–4063.

Javid, M., Sharif, F. (2016). Environmental Kuznets curve and financial development in Pakistan. *Renewable and Sustainable Energy Reviews*, 54: 406–414.

Jayanthakumaran, K., Verma, R., Liu, Y. (2012). CO_2 emissions, energy consumption, trade and income: A comparative analysis of China and India. *Energy Policy*, 42: 450–460.

Jebli, M.B., Youssef, S.B., Ozturk, I. (2016). Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecological Indicators*, 60: 824–831.

Kanjilal, K., Ghosh, S. (2013). Environmental Kuznets's curve for India: Evidence from tests for cointegration with unknown structural breaks. *Energy Policy*, 56: 509–515.

Kearsley, A., Riddel, M. (2010). A further inquiry into the pollution haven hypothesis and the environmental Kuznets curve. *Ecological Economics*, 69 (4): 905–919.

Lau, L-S., Choong, C-K., Eng, Y-K. (2014). Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter? *Energy Policy*, 68: 490–497.

Lee, J., Strazicich, M.C. (2013). Minimum LM unit root test with one structural break. *Economics Bulletin*, 33 (4): 2483–2492.

Liu, X. (2005). Explaining the relationship between CO_2 emissions and national income-the role of energy consumption. *Economic Letters*, 87 (3): 325–328.

Maggioni, D., Lo Turco, A., Gallegati, M. (2014). Does export complexity matter for firms' output volatility? *Universita Politecnica Dellemarche, Dipartimento di Scienze Economiche e Sociali, Quaderni Dı Ricerca*, No. 407.

Maki, D. (2012). Tests for cointegration allowing for an unknown number of breaks. *Economic Modelling*, 29 (5): 2011–2015.

Managi, S., Jena, P.R. (2008). Environmental productivity and Kuznets curve in India. *Ecological Economics*, 65 (2): 432–440.

Minondo, A., Requena-Silvente, F. (2013). Does complexity explain the structure of trade? *Canadian Journal of Economics*, 46 (3): 928–955.

Monhen, P., Hall, B.H. (2013). Innovation and productivity: An update. *Eurasian Business Review*, 3 (1): 47–65.

Nasir, M., Rehman, F.U. (2011). Environmental Kuznets curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy*, 39 (3): 1857–1864.

Onafowora, O.A., Owoye, O. (2014). Bound testing approach to analysis of the environment Kuznets curve hypothesis. *Energy Economics*, 44: 47–62.

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: Turning a black box into a policy tool. *Environment and Development Economics*, 2 (4): 465–484.

Rezek, J.P., Rogers, K. (2008). Decomposing the CO2-income tradeoff: An output distance function approach. *Environment and Development Economics*, 13 (4): 457–473.

Richmond, A.K., Kaufman, R.K. (2006). Is there a turning point in the relationship between income and energy use and/or carbon emissions? *Ecological Economics*, 56 (2): 176–189.

Song, T., Zheng, T., Tong, L. (2008). An empirical test of the environmental Kuznets curve in China: A panel cointegration approach. *China Economic Review*, 19 (3): 381–392.

Soytas, U., Sari, R. (2009). Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecological Economics*, 68 (6): 1667–1675.

Stafforte, S., Tamberi, M. (2012). Italy in the space (of products). *Economia Marche Journal of Applied Economics*, 31 (1): 90–113.

Stock, J., Watson, M.W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica*, 61 (4): 783–820.

Suri, V., Chapman, D. (1998). Economic growth, trade and energy: Implications for the environmental Kuznets curve. *Ecological Economics*, 25 (2): 195–208.

Sweet, C.M., Maggio, D.S.E. (2015). Do stronger intellectual property rights increase innovation? *World Development*, 66: 665–677.

Tang, C.F., Tan B.W. (2015). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy*, 79: 447–454.

Trancon, M.A., Del Rio, P. (2007). CO_2 emissions and intersectoral linkages. The case of Spain. *Energy Policy*, 35 (2): 1100–1116.

Tsurumi, T., Managi, S. (2010) Decomposition of the environmental Kuznets curve: Scale, technique, and composition effects. *Environmental Economics and Policy Studies*, 11 (1): 19–36.

Yin, J., Zheng, M., Chen, J. (2015). The effects of environmental regulation and technical progress on CO_2 Kuznets curve: An evidence from China. *Energy Policy*, 77: 97–108.

Zhang, X–P., Cheng, X–M. (2009). Energy consumption, carbon emission, and economic growth in China. *Ecological Economics*, 68 (10): 2706–2712.

Figure 1
A Summary of the Environmental Kuznets Curve (EKC) Hypothesis

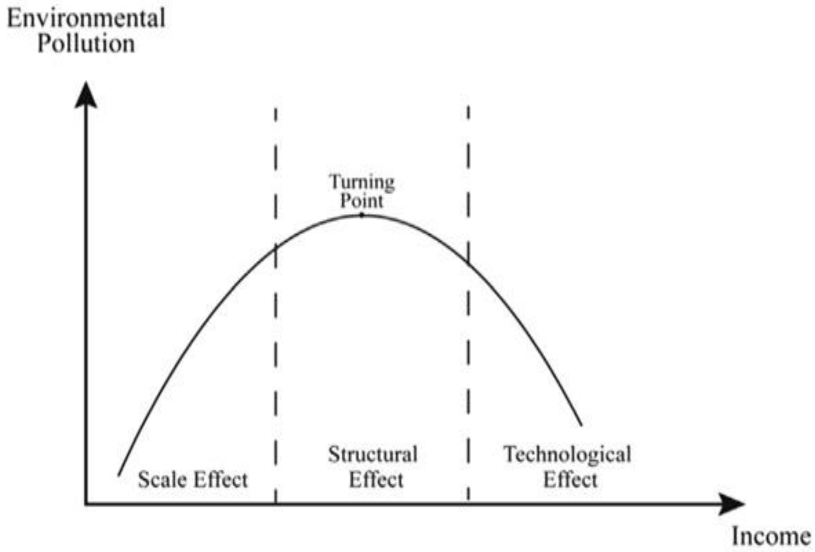

Table 1
Results of the Unit Root Test of Lee and Strazicich (2013)

Variables	LM	CV (1%)	CV (5%)	CV (10%)	Lag	Variables	LM	Break Date
Log Real GDP per Capita	–1.925	–4.239	–3.566	–3.211	1	Δ Log Real GDP per Capita	–5.034***	1975
Log Squared Real GDP per Capita	–1.997	–4.239	–3.566	–3.211	1	Δ Log Squared Real GDP per Capita	–4.976***	1975
Log CO_2 Emissions per Capita	–2.142	–4.239	–3.566	–3.211	0	Δ Log CO_2 Emissions per Capita	–8.165***	1977
Log Energy Consumption per Capita	–2.795	–4.239	–3.566	–3.211	0	Δ Log Energy Consumption per Capita	–7.016***	1972
Log Economic Complexity	–2.282	–4.239	–3.566	–3.211	1	Δ Log Economic Complexity	–11.18***	1976

Notes: The table shows the results of the unit root test of Lee and Strazicich (2013), and the results include the break on level. Null hypothesis: the series have a unit root. The optimal number of lags is selected by the Akaike Information Criteria (AIC). The maximum number of lags is 3. Trimmer rate is defined as 0.10. CV: Critical Values. *** indicates the rejection of the null hypothesis at the 1% significance level.

Table 2
Results of the Cointegration Test of Maki (2012):
CO_2 Emissions – GDP per Capita – Squared GDP per Capita – Energy Consumption – Economic Complexity

Cointegration among Variables	Test Statistics	CV (1%)	CV (5%)	CV (10%)	Break Dates
Model 0	–6.008**	–6.303	–5.839	–5.575	1983, 1997
Model 1	–5.531	–6.556	–6.055	–5.805	1984, 2004
Model 2	–10.02***	–7.756	–7.244	–6.964	1980, 1991
Model 3	–8.570***	–8.167	–7.638	–7.381	1978, 1992

Notes: The table shows the results of four models of the cointegration test of Maki (2012). The null hypothesis: there is no cointegration among the series and the alternative hypothesis is cointegration with *i* breaks. The maximum number of breaks is 3. Trimmer rate is defined as 0.10. CV: Critical Values. Critical values are based on the bootstrapped values of Table 1 in Maki (2012). *** and ** indicate the rejection of the null hypothesis at the 1% and the 5% significance level, respectively.

Table 3
Results of the Dynamic Ordinary Least Squares (DOLS) Estimations for the Long Run Coefficients

Dependent Variable:	Log CO_2 Emissions per Capita
Log Real GDP per Capita	12.57 (6.015)**
Log Squared Real GDP per Capita	–1.563 (0.668)**
Log Energy Consumption per Capita	0.921 (0.304)***
Log Economic Complexity	–0.470 (0.119)***
D1983	–0.052 (0.021)**
D1997	0.038 (0.017)**
Constant Term	–27.30 (12.77)**
Observations	45
Adjusted R^2	0.966
Leads and Lags	(1,1)
Standard Error of Regression	0.013
Durbin–Watson Statistics	2.156
Long Run Variance	0.846
Sum Squared Residuals (SSR)	0.005

Notes: The selection of break dates is based on the Model 0 of cointegration test of Maki (2012). The Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors (Bartlett kernel, Newey-West fixed bandwidth = 4.0000) are in parentheses. *** and ** indicate statistical significance at the 1% and the 5% level, respectively.

Table 4
Results of the Error Correction Model (ECM) Estimations for Short Run Coefficients

Dependent Variable:	ΔLog CO_2 Emissions per Capita
Error Correction Term (ECT)	–0.149 (0.059)**
ΔLagged Log CO_2 Emissions per Capita	–0.413 (0.274)
ΔLagged Log Real GDP per Capita	32.14 (11.55)***
ΔLagged Log Squared Real GDP per Capita	–3.543 (1.298)***
ΔLagged Log Energy Consumption	0.033 (0.331)
ΔLagged Log Economic Complexity	0.148 (0.086)
Observations	48
Adjusted R^2	0.098

Notes: The optimal number of lag length is selected by the Schwarz Information Criteria (SIC). The standard errors are in parentheses. *** and ** indicate the rejection of the null hypothesis at the 1% and the 5% significance level, respectively.

Table 5
Results of the Granger Causality / Block Exogeneity Wald Tests

Dependent Variable:	ΔLog CO_2 Emissions	ΔLog GDP per Capita	ΔLog Squared GDP per Capita	ΔLog Energy Consumption	ΔLog Economic Complexity	Overall Chi–square Statistics
ΔLog CO_2 Emissions:	–	7.736*** [0.0054]	7.445*** [0.0064]	0.010 [0.9189]	2.964 [0.0851]	10.49** [0.0329]
ΔLog GDP per Capita:	0.230 [0.6311]	–	0.484 [0.4864]	0.480 [0.4883]	0.737 [0.3904]	2.037 [0.7289]
ΔLog Squared GDP per Capita:	0.230 [0.6310]	0.353 [0.5523]	–	0.470 [0.4928]	0.742 [0.3888]	1.862 [0.7610]
ΔLog Energy Consumption:	0.646 [0.4214]	4.648** [0.0311]	4.513** [0.0336]	–	1.860 [0.1726]	6.086 [0.1941]
ΔLog Economic Complexity:	0.237 [0.6259]	0.022 [0.8811]	0.008 [0.9250]	0.013 [0.9093]	–	3.886 [0.4216]

Notes: The optimal number of lag length is selected by the Schwarz Information Criteria (SIC). The probability values are in brackets. *** and ** indicate the rejection of the null hypothesis at the 1% and the 5% significance level, respectively.

Appendix I

Descriptive Summary Statistics and the Description of Variables in France: 1964–2011

Variable	Unit	Data Source	Mean	Standard Deviation	Skewness	Kurtosis
Real per Capita GDP (constant 2005$ price)	Logarithmic Form	World Bank, WDI	4.400	0.125	–0.597	2.359
Squared Real per Capita GDP (constant 2005$ price)	Logarithmic Form	World Bank, WDI	19.37	1.094	–0.554	2.296
CO_2 Emissions (metric tons per capita)	Logarithmic Form	World Bank, WDI	0.843	0.075	0.459	2.011
Energy Consumption (kilogram of oil equivalent per capita)	Logarithmic Form	World Bank, WDI	3.542	0.087	–1.269	3.798
Economic Complexity (index)	Logarithmic Form	Hausmann et al. (2011)	0.223	0.053	–0.562	3.415