# The CO2-Growth nexus revisited: A nonparametric analysis for G7 economies over nearly two centuries

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## Abstract

Using a two-century long dataset and some recently popularized nonparametric econometric techniques, this study revisits the nexus between economic growth and carbon dioxide ($CO_2$) emissions for the G7 countries over nearly two centuries. The use of nonparametric modelling is warranted by the fact that long historical time series are often subject to structural breaks and other forms of nonlinearity over the course of time. We employ nonparametric cointegration and causality tests along with the cross-validated Local Linear technique analysis and validate the existence of the environmental Kuznets curve in six of the G7 countries – Canada, France, Germany, Italy, U.K. and the U.S.– and the only exception is Japan. Our empirical analysis also finds $CO_2$ emissions and economic growth to be cointegrated and closely interrelated in the Granger sense. Our results are robust and highlight the nonlinear causal relationship between the two variables.



**JEL Classification**: C14, Q5.

**Keywords:** G7 Countries, Economic Growth, CO2 Emissions, EKC Hypothesis, Nonparametric Econometrics.

## 1. Introduction

Throughout the 20th century, most of the increases in economic growth were fueled by a fossil energy process that generated high carbon dioxide ($CO_2$) emissions. Given the importance of fossil fuels in the world's economy, it seems logical for policy makers to consider that any reductions in $CO_2$ emissions would hamper economic growth and may trigger an economic downturn. However, recent anecdotal evidence has shown that the economies of major countries like the United States can prosper even as emissions fall and that economic growth and pollution need not rise in tandem- the so called "decoupling" phenomenon (Aden, 2016). Successful decoupling is important because it demonstrates the feasibility of the transition to cleaner modes of economic activity without compromising welfare growth[1].

Academic research on economic growth and environmental quality has been concerned with understanding the causal relationship between economic growth and $CO_2$ emissions. Following Kuznets (1955), it has been hypothesized that an Environmental Kuznets Curve (EKC) exists between economic growth and carbon emissions, which implies that once a certain level of income is reached, economic growth will be secured without a proportional increase in pollutants (Shafik and Bandyopadhyay, 1992; Grossman and Krueger, 1995; Stern, 2004). In other words, the EKC hypothesis states that the relationship between economic growth and environmental quality can be expressed in the shape of an inverted-U shaped curve[2].

The relationship between $CO_2$ emissions and economic growth has always been studied in relation to the EKC hypothesis. Most of previous studies have relied on parametric and semiparametric specifications of this relationship and have presumed a priori that the causality runs from economic growth to environmental quality. However, there is not any theoretical justification for this assumption. Other studies assume a linear relationship between growth and carbon emissions without considering structural breaks and other forms of nonlinearity. Rules, regulations (e.g., incentives and penalties), programs and international agreements on energy issues have changed over the last few decades and have affected participation and compliance, thereby introducing abrupt and smooth breaks in this relationship (Barrett and Stavins, 2003; Price, 2005). This consideration

[1] In a study by Price Water Coopers (PwC, 2013), decoupling can be realised by improvements in energy efficiency, energy conservation in homes or changes in the fuel mix towards zero or low-emission fuels. Two types of decoupling can be distinguished: the relative (GDP grows at a faster pace than carbon emissions), and the absolute (GDP grows whereas carbon emissions decrease or stay stable) decoupling (https://www.pwc.nl/nl/assets/documents/pwc-decarbonisation-and-the-economy.pdf).

[2] The literature on this hypothesis has been largely inconclusive. Dinda (2004) and Kijima et al. (2010) provide a review of the theoretical development and empirical studies dealing with the EKC phenomenon.

warrants nonparametric techniques that account for nonlinearities and are also able to reveal hidden structure in the data[3].

In this paper, we contribute to the body of the related literature in a number of ways. First, we strive to determine the direction of causality between economic growth and carbon emissions for the G7 countries, using very long data series. While previous studies have focused on relatively small datasets spanning only a few decades, we use the largest dataset ever employed which spans a period of nearly two centuries. Therefore, the findings of this study are expected to provide useful insights and recommendations that may be viewed as a benchmark for the rest of the world.

Second, we acknowledge the importance of many structural breaks in this relationship over this very long time period, and use novel nonparametric cointegration and causality techniques. One major advantage with the use of nonparametric econometric techniques is that they do not require a specific functional form and make fewer assumptions about the model being estimated than parametric and semiparametric techniques do (see Li and Racine, 2007, for a more detailed discussion). As such, there are serious doubts over the findings of prior studies that have employed linear econometric techniques without regard to breaks to test the causal relationship between economic growth and $CO_2$ emissions[4].

Third, this study contributes to the long debate on the existence of an inverted-U shaped EKC and on the appropriateness of environmental and economic policies. The EKC hypothesis is empirically supported in six out of the seven G7 countries, namely Canada, France, Germany, Italy, U.K. and the U.S., with the exception of Japan.

The remainder of the paper is organized as follows. Section 2 provides a selective literature review. Section 3 presents a preliminary data analysis. Section 4 describes the methodological framework. Section 5 discusses the empirical results. Finally, Section 6 offers some concluding remarks.

[3] Understanding the causal relationship between economic growth and environmental quality for the G7 countries is of paramount importance for economic policy-making, given the increasing awareness of climate change and the degradation of environmental quality in these countries.

[4] Millimet et al. (2003) explore the importance of modelling strategies when estimating the emissions-income relationship and overwhelmingly reject the parametric EKC modelling approach.

## 2. Review of the related literature

This section provides a selective literature review, referring to some of the major studies that have dealt with the relationship between carbon emissions and economic growth. Roberts and Grimes (1997) examine the relationship between $CO_2$ emissions and GDP growth, using parametric modelling and data for 147 countries over a 25-year period (1965-1990), and confirm the EKC hypothesis mainly for high-income countries. They suggest that the emergence of an EKC for $CO_2$ emissions intensity is the result of a relatively small number of wealthy countries becoming more efficient since 1970, while the average for the rest of the world worsens.

Schmalensee et al. (1998) employ a flexible form model for income effects and find clear evidence of an inverted-U curve for high-income countries during the period 1950-2050. de Bruyn et al. (1998) base their study on the “intensity-of-use” analysis in resource economics and estimate a growth model for three different types of emissions in four developed countries (U.K.,U.S., Germany and Netherlands). They conclude that the presumption that economic growth results in improvements in environmental quality is unsupported by evidence in the countries under investigation. Harbaugh et al. (2002) examine the robustness of the evidence for the existence of an inverted U-shaped relationship between national income and pollution by using parametric methods and a panel data set on ambient air pollution in cities worldwide. They conclude that there is little empirical support for such a relationship.

Coondoo and Dinda (2002) and Dinda and Coondoo (2006) use parametric panel data-based cointegration analysis and find that for developed countries such as Europe and North America, the causality runs from carbon emissions to income, whereas the reverse holds (although causality has also been found to be bidirectional) for less developed countries such as Central and South America and Oceania. Turner and Hanley (2011) employ a computable general equilibrium model of the Scottish economy to consider the factors influencing the relationship between $CO_2$ emissions and real GDP and the per capita EKC relationship. They show that when the general equilibrium price elasticity of demand for energy is relatively inelastic, the economy may move onto the downward part of the EKC with $CO_2$ emissions falling as GDP rises. However, when the demand curve for energy is elastic, the economy lies on the upward part of the EKC with energy use and $CO_2$ emissions rising faster than GDP.

Barassi and Spagnolo (2012) investigate the linear and nonlinear relationship between income and carbon emissions from both long-run and short-run perspectives. They find evidence of a feedback in the causality in the mean and the volatility spillovers between carbon emissions and output growth in major industrialized countries over the period 1870-2005. Hamit-Haggar (2012) investigates the causal relationship between greenhouse gas emissions, energy consumption and economic growth for Canadian industrial sectors over the period 1990-2007. The empirical evidence shows that there is a nonlinear relationship between greenhouse gas emissions and economic growth, consistent with the environmental Kuznets curve hypothesis. Ajmi et al. (2015) detect time-varying causalities between emissions and GDP and an inverted N-causality curve which lends no support to the validation of the EKC hypothesis.

Azomahou et al. (2006) examine the empirical relation between $CO_2$ emissions and GDP per capita during the period 1960-1996, using a panel of 100 countries and relying on the nonparametric pool ability test with country-specific effectsof Baltagi et al. (1996). They provide evidence supporting specifications which assume the stability of the relationship between carbon emissions and GDP per capita and also show that their nonparametric specification tests do not reject monotonicity but do reject the polynomial functional form which leads to the environmental Kuznets curve. However, they employ a short sample period of only 36 years and do not test for cointegration or direction of causality. A second paper that has dealt with nonparametric techniques is the one by Taskin and Zaim (2000) who construct environmental efficiency indexes using nonparametric production frontier techniques and subsequently establish an environmental Kuznets relationship for environmental efficiency based on kernel estimation methods. Contrary to those studies, we rely on recent nonparametric methods and use a sample period of almost two centuries that contains a greater number of structural breaks[5].

## 3. Preliminary data analysis

This paper examines the association between economic growth and $CO_2$ emissions for the G7 countries, using historical data for the period 1820-2015. The dataset for Italy and Japan is limited to periods 1860-2015 and 1950-2015, respectively, due to data unavailability. To the best of our knowledge, our dataset is the largest that has ever been used in similar studies. Data on $CO_2$ emissions has been collected from the Carbon Dioxide Information Analysis Centre (CDIAC, http://cdiac.ornl.gov/), while data on real GDP per capita has been obtained from the *Historical Statistics* of the World Economy: 1-2008 AD. In line with previous studies, $CO_2$ emissions have been converted into per capita units and all series are expressed in natural logarithmic form before any empirical analysis (Boden et al., 2010; Shahbaz et al., 2016).

A typical empirical analysis of time-series data employs parametric methods which assume linearity and requires satisfying some basic regression assumptions such as normality, homoscedasticity and no autocorrelation. The (often unsubstantiated) assumption of linearity leads to

[5] Nonparametric techniques have also been used to investigate the causal relationships between energy consumption and economic growth (e.g. Chiou-Wei et al., 2008; Cheng-Lang et al., 2010; Dergiades et al., 2013).

employing techniques having low power while the underlying processes may, in fact, be nonlinear. We provide the descriptive statistics along with the correlation coefficients in Table 1. It is shown that high volatility in carbon emissions and economic growth is more pronounced for the resource-based Canadian economy, compared to the rest of the G7 economies. The Jarque-Berra test statistic rejects the null of normality at the 5% level of significance for both carbon emissions per capita and economic growth (real GDP per capita) for all countries. Ljung-Box Q tests show that there is evidence of autocorrelation up to the 12th order in our series. Figure 1 provides a visual illustration of our series in log level form.

The stability of our model is assessed using the Chen-Hong (2012) test for smooth structural changes. This procedure is a consistent nonparametric test of model stability when there are multiple breaks – both abrupt and smooth – and the number of breaks and corresponding break dates are not known. This is particularly useful for us as our dataset includes long historical data where structural breaks and other forms of nonlinearity may be plentiful. Table 2 presents the results from the Chen-Hong (2012) test for structural changes. Clearly, the null hypothesis of model stability is rejected at the 5% level for each of the G7 economies. This demonstrates that the relationship between $CO_2$ emissions and economic growth is not stable over time and suffers from abrupt and/or smooth structural breaks and other sources of nonlinearities.

**Table1: Descriptive Statistics and Correlation Analysis (in log level)**

| Country | Var. | Mean | Median | Max. | Min. | Std. Dev. | J.B. | Prob. | Corr. | Q | Prob. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | $\ln C_t$ | -0.17 | 1.82 | 2.87 | -6.40 | 3.31 | 31.46 | 0.00* | 0.87 | 2320.03 | 0.00 |
| | $\ln Y_t$ | 8.20 | 8.18 | 10.24 | 6.44 | 1.13 | 14.49 | 0.00* | | 2200.70 | 0.00 |
| France | $\ln C_t$ | 0.69 | 1.13 | 2.27 | -2.67 | 1.37 | 40.32 | 0.00* | 0.81 | 1964.60 | 0.00 |
| | $\ln Y_t$ | 8.25 | 7.99 | 10.07 | 6.98 | 0.95 | 18.75 | 0.00* | | 2061.11 | 0.00 |
| Germany | $\ln C_t$ | -0.07 | 0.66 | 1.15 | -3.41 | 1.41 | 45.23 | 0.00* | 0.77 | 1926.45 | 0.00 |
| | $\ln Y_t$ | 8.28 | 8.04 | 10.04 | 6.98 | 0.92 | 17.77 | 0.00* | | 1924.82 | 0.00 |
| Italy | $\ln C_t$ | -0.01 | -0.14 | 2.10 | -6.79 | 1.65 | 10.12 | 0.01* | 0.91 | 1170.91 | 0.00 |
| | $\ln Y_t$ | 8.35 | 8.03 | 9.95 | 7.25 | 0.93 | 16.48 | 0.00* | | 1548.29 | 0.00 |
| Japan | $\ln C_t$ | 1.77 | 2.08 | 2.29 | 0.20 | 0.63 | 16.26 | 0.00* | 0.97 | 355.66 | 0.00 |
| | $\ln Y_t$ | 9.29 | 9.54 | 10.12 | 7.56 | 0.77 | 8.81 | 0.01* | | 405.30 | 0.00 |
| U.K. | $\ln C_t$ | 1.88 | 2.20 | 2.47 | 0.51 | 0.61 | 43.77 | 0.00* | 0.77 | 2187.10 | 0.00 |
| | $\ln Y_t$ | 8.48 | 8.42 | 10.17 | 7.24 | 0.82 | 10.42 | 0.01* | | 2149.15 | 0.00 |
| U.S. | $\ln C_t$ | 1.28 | 2.41 | 3.11 | -2.76 | 1.98 | 35.02 | 0.00* | 0.87 | 2254.54 | 0.00 |
| | $\ln Y_t$ | 8.50 | 8.46 | 10.39 | 7.00 | 1.06 | 14.60 | 0.00* | | 2221.37 | 0.00 |

Notes: Var. = Variable; Max. = Maximum; Min. = Minimum; Std. Dev. = Standard Deviation; J.B. = Jarque-Berra normality test; Prob. = Probability; and Corr. = Correlation Coefficient; Q = Ljung-Box Q test * Reject$H_0$: Normality if Prob. <0.05.

The failure of such key assumptions may result in a parametric analysis giving inefficient, inconsistent and unreliable results, virtually invalidating any inferences made (Li and Racine, 2007; Henderson et al., 2008). In addition, as the model suffers from instability due to structural changes, any parametric specification will have to be augmented by an inclusion of dummy variables. However, the actual number of breaks is not known and is not uniform or identical across all G7 economies. Furthermore, it is difficult to model smooth structural changes by including dummy variables and also the inclusion of multiple dummies (to account for multiple breaks) may lead to adverse effects on the asymptotic properties of the parametric methods. Alternatively, parametric estimations of structural changes may involve splitting the data into several sub periods and/or using moving windows in estimation. However, these may require substantial judgment from the researcher and can be computationally demanding.

In contrast, nonparametric econometric methods do not require a priori assumptions of model linearity; instead, the data is allowed to determine the functional form, and thus, nonparametric techniques are able to model nonlinearity effectively. Consequently, there is virtually no better alternative than using nonparametric techniques in our econometric analysis.

**Table 2: Chen-Hong (2012) Test for Smooth Structural Changes (*p*-values)**

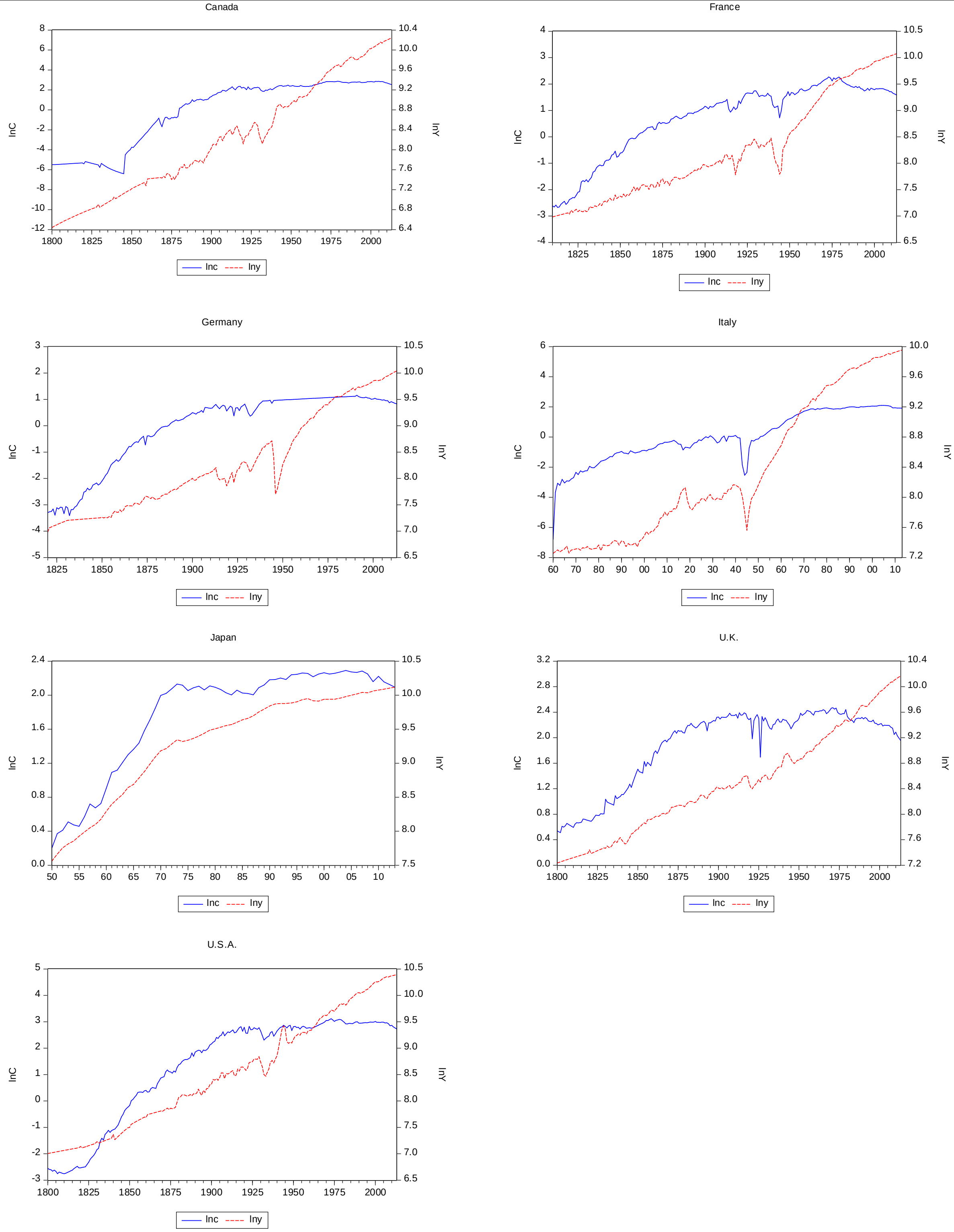
| | Model: $\ln C_t = f(\ln Y_t)$ | |
|---|---|---|
| Country | $\hat{C}$-het | $\hat{H}$-het |
| Canada | 0.000* | 0.000* |
| France | 0.000* | 0.000* |
| Germany | 0.000* | 0.000* |
| Italy | 0.000* | 0.000* |
| Japan | 0.000* | 0.000* |
| U.K. | 0.000* | 0.000* |
| U.S.A | 0.000* | 0.000* |

Notes: $H_0$: Model is stable. $\hat{C}$-het and $\hat{H}$-het represent heteroscedasticity robust version of the generalized Chow and Hausman tests, respectively. *P*-values are generated using bootstrap, *B*=9999. * Reject $H_0$ (stability) at the 5% level of significance.

## 4. Methodological framework

As indicated, this study conducts a bivariate analysis of the long-run equilibrium (cointegration) and the direction of Granger causality between $CO_2$ emissions and economic growth for G7 countries. We start this section by examining the relative merits of nonparametric unit root tests, followed by the nonparametric cointegration, regression analysis and causality tests.

# Figure 1: Time Plots of Model Variables



*4.1 Bierens (1997a) and Breitung (2002)unit root tests*

We investigate the order of integration of logarithmic carbon emissions ($\ln C_t$) and logarithmic economic growth ($\ln Y_t$) by using the nonparametric unit root tests developed by Bierens (1997a) and Breitung (2002). The Bierens (1997a) approach tests the null hypothesis of a unit root with a drift process against the alternative of a nonlinear trend stationarity process. The conventional parametric unit root tests such as the Augmented Dickey-Fuller test may falsely report non-stationarity – that is, they may fail to reject a false null hypothesis, which is known as the type II error – for a variable's series due to the presence of nonlinearities. The Bierens (1997a) approach is able to test for unit roots, while taking into account the presence of such nonlinearities. The null hypothesis considers a time-series variable, say $z(t)$, as a unit root with a drift process. The alternative hypothesis identifies $z(t)$ as a nonlinear trend stationary process where $a < 0$. The test statistic ($\hat{A}m$) used in this paper is denoted by $n(a-1)$.

The robustness of the Bierens (1997a) estimates is examined by conducting the nonparametric Breitung (2002) test for stationarity. Unlike the former procedure, the latter cannot only account for nonlinearity in the series but is also robust to any structural breaks. The null and alternative hypotheses under the Breitung (2002) test are similar to those of the Bierens (1997a) test and can be outlined as follows:

$H_0$: $z(t)$ is a unit root with a drift process.
$H_1$: $z(t)$ is a trend stationary process.

Here, $z(t)$ is detrended as the alternative hypothesis assumes that it is a trend stationary process.

*4.2 Bierens (1997b) and Breitung (2001, 2002) cointegration tests*

If the order of a variable's integration can be established as I(1), we can further test carbon emissions and economic growth for a long-run equilibrium (or cointegration). To accomplish this, we avail of the (nonlinear) Bierens (1997b) and Breitung (2001, 2002) nonparametric cointegration tests. The advantage of nonparametric cointegration testing methods over their parametric counterparts, such as the Johansen (1991) approach, is that the latter may falsely reject the null of no cointegration (type I error) due to the presence of nonlinearities in the underlying process. Under the Bierens (1997b) test, the test statistic is $\lambda_{min}$ and the null hypothesis is written as $r = 0$ against the alternative of $r \geq 1$.

A more improved Breitung (2001, 2002) nonparametric cointegration test is able to detect the presence of a long-run equilibrium in spite of additive outliers – i.e. structural breaks. This makes the Breitung (2001, 2002) procedure more versatile than that of Bierens (1997b). The Breitung (2001, 2002) cointegration procedure comprises right-tailed tests, starting from the null hypothesis: $r = 0$. The cointegration rank $r$ is determined by the first accepted null hypothesis and equals $r = 2$ if the test statistic rejects all of the null hypotheses.

*4.3 Local linear nonparametric regression*

We examine the Environment Kuznets Curve hypothesis by estimating a nonparametric regression equation between the logarithmic carbon emissions and economic growth, denoted as $\ln C_t$ and $\ln Y_t$, respectively. To accomplish this, we use the cross-validated Local Linear (LL) nonparametric regression technique developed by Li and Racine (2004) to observe whether there is an inverted-U shaped relationship between $CO_2$ emissions per capita and GDP per capita. The LL approach is able to estimate unknown data-driven regression functions, i.e. nonlinearity using the least squares cross-validation for the selection of smoothing parameters. Li and Racine (2004) describe thatthe LL nonparametric smoothing, unlike (linear) parametric regression techniques, does not involve estimating parameters (coefficients). Instead, the LL nonparametric method computes the gradient (the slope or first derivative) vector of the fitted model – $\delta$, which is analogous to the parameters (coefficients) in a linear (parametric) model. The $\delta$ is estimated as a vector since it is often non-constant with respect to variations in the particular explanatory variable.

*4.4 Hiemstra and Jones (1994) and Diks and Panchenko (2006) Granger causality test*

Further to testing for nonparametric cointegration, we can proceed to testing the direction of Granger causality in a nonlinear framework. To this end, we implement the two extant bivariate nonparametric tests for Granger causality: namely the Hiemstra and Jones (1994) and Diks and Panchenko (2006) tests – hereafter referred to as HJ and DP, respectively. Similar to the standard or conventional cointegration tests, the parametric Granger causality tests may also falsely report the direction of causality due to nonlinearities being ignored. The two aforementioned nonparametric methods can overcome such shortcomings by accounting for nonlinearities in the causal relationships.

Hiemstra and Jones (1994) propose a nonparametric technique building upon the Baek and Brock (1992) test for conditional independence. In explaining the HJ test, let us first consider two time series variables: $\{X_t\}$ and $\{Y_t\}$. The test for Granger causality involves finding evidence against the following null hypothesis:

$H_0$: $\{X_t\}$ does not Granger cause $\{Y_t\}$

When no model restriction is imposed, such as the assumption of a finite order of the process, it is not possible to condition on the infinite past in a nonparametric approach (Diks and Panchenko, 2006). Therefore, $\{X_t\}$ and $\{Y_t\}$ are defined as a lagged vector of time series as $X_t^{l_X} = X_{t-l_X+1} \dots X_t$and $Y_t^{l_Y} = Y_{t-l_Y+1} \dots Y_t$, whose lag lengths are finite and equal to $l_X$ and $l_Y$, respectively. The test for conditional independence for finite lag lengths can then be specified as:

$$(Y_{t+1}|X_t^{l_X}, Y_t^{l_Y}) \sim Y_{t+1}|Y_t^{l_Y} \tag{1}$$

In a bivariate setting, for $Z_t = Y_t + 1$,$W_t = (X_t^{l_X}, Y_t^{l_Y}, Z_t)$ is an $(l_X + l_Y + 1)$-dimensional vector with an invariant distribution. The null hypothesis, defined as ratios of joint distributions indicates the conditional distribution of $Z$ given that$(X, Y) = (x, y)$ is the same as that of $Z$ given $Y = y$ only. This allows the joint probability distribution $f_{X,Y,Z}(x, y, z)$,when lag lengths $(l_X, l_Y)$ are equal to 1, to be expressed as the following:

$$\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \cdot \frac{f_{Y,Z}(y,z)}{f_Y(y)} \tag{2}$$

for each vector $(x, y, z)$ in the support of $(X, Y, Z)$. Equation (2) resembles $f_{X,Y,Z}(x, y|z) = f_{X,Y}(x|y) = f_{Z,Y}(z, y|z)$, and identifies that $X$ and $Z$ are independent conditionally on $Y = y$, for each fixed value of $y$. The discrepancy between the left- and right-hand sides of equation (2) is measured by calculating the following ratios of correlation integrals.

$$\frac{C_{X,Y,Z}(\varepsilon)}{C_Y(\varepsilon)} = \frac{C_{X,Y}(\varepsilon)}{C_Y(\varepsilon)} \cdot \frac{C_{Y,Z}(\varepsilon)}{C_Y(\varepsilon)} \tag{3}$$

As part of the test for the direction of Granger causality, the sample versions of the correlation integrals in equation (3) are computed and the left-hand- and right-hand-side ratios are tested for statistical equality.

$$C_{W,n}(\varepsilon) = \frac{2}{n(n-1)} \sum \sum I_{ij}^W \tag{4}$$

in which$I_{ij}^W = I(\|W_i - W_j\| \leq \varepsilon)$.

Diks and Panchenko (2005, 2006) argue that the null hypothesis under the HJ test is misspecified, and, thus, it is prone to over-rejection of the null. As a result, Diks and Panchenko (2006) modify the null under the HJ test by multiplying equation (2) with a positive weight function, $g(x, y, z)$. By allowing $g(x, y, z) = f_Y^2(y)$, $q$ can be simplified as:

$$q = E\left[f_{X,Y,Z}(X, Y, Z) f_Y(Y) - f_{X,Y}(X, Y) f_{Y,Z}(Y, Z)\right]. \quad (5)$$

Based on equation (5), the test statistic under the Diks and Panchenko procedure can be formulated as:

$$T_n(\epsilon_n) = \frac{n-1}{n(n-2)} \times \sum_{i=1}^{n} \left(\hat{f}_{X,Y,Z}(X_i, Y_i, Z_i) \hat{f}_Y(Y) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,Z}(Y_i, Z_i)\right) \quad (6)$$

where$\epsilon_n$ is the bandwidth, dependent on the sample size $n$. A sufficiently high optimal bandwidth (depending on the sample size) may be chosen to produce consistent and efficient estimates. Empirical applications usually truncate the bandwidth choice within the bounds [0.5, 1.5], following Diks and Panchenko (2006).

## 5. Empirical results and discussion

As indicated earlier, the econometric analysis commences by determining the unit root properties of carbon emissions and economic growth, using the unit root tests proposed by Bierens (1997a) and Breitung (2002). Nonlinearity may occur in carbon emissions and economic growth due to many factors such as structural reforms, regulatory changes, policy shifts, real and financial shocks, and regional and global imbalances (Baum et al., 2004; Christopoulos and León□Ledesma, 2007). These internal and external shocks may affect time series to different extents. More specifically, carbon emissions mainly depend on macroeconomic factors (e.g. business cycle positions and product market regulations), energy consumption depends on domestic as well as global energy market conditions, and globalization is coupled with trade policies (Terasvirta and Anderson, 1992; Awokuse and Christopoulos, 2009).

Table3 depicts the results of the Bierens (1997a) nonlinear unit root test. These results indicate that in level form, the null of nonstationarity is not rejected at the 5% level for both carbon emissions and economic growth. Carbon emissions and economic growth are found to be stationary after first differencing, i.e. the null hypothesis is rejected at the 5% level, which implies that both variables are integrated of order I(1). The results derived from the Breitung (2002) nonlinear unit root test are similar to those of Bierens (1997a), confirming the robustness of the unit root analysis. As a next step, cointegration and causality testing procedures are applied as carbon emissions and economic growth are shown to be integrated of I(1), even after accounting for the possible presence of nonlinearity.

The results and the corresponding critical values of the Bierens (1997b) cointegration test for the G7 countries are shown in Table 4. The empirical evidence indicates that the null hypothesis of a zero cointegration rank ($r = 0$) is rejected (at the 1% and 5% levels) in favor of the alternative of a cointegration rank of 1 ($r = 1$) in Canada, France, Germany, Italy, U.K. and the U.S., but not in Japan. In addition, the null of a cointegration rank 1 ($r = 1$) against the alternative of a cointegration rank 2 ($r = 2$) is not rejected at the 5% level of significance in the same six countries. It implies the presence of one cointegrating vector, confirming the existence of a cointegration relationship between carbon emissions and economic growth for Canada, France, Germany, Italy, U.K. and the U.S., excluding Japan only.

To test the robustness of the cointegration results, we have applied the Breitung (2001, 2002) cointegration tests. Test statistics, critical values and the relevant simulated $p$-values are shown in Table 5. We show that the empirical findings of the Breitung (2001, 2002) cointegration tests are identical to those of the Bierens (1997b) estimates, confirming the reliability of our cointegration analysis. Going one step forward, we assess the validity of the EKC hypothesis for the G7 economies using the LL nonparametric regression technique. Parametric regression techniques, such as the Ordinary Least Squares (OLS), are only able to verify the EKC hypothesis by adding squared economic growth as an explanatory variable and estimating a linear regression based on this modified specification. While an intuitive approach, it is often prone to misspecification – i.e. the researcher stipulates the quadratic model a priori – as OLS is designed primarily to minimize squared residuals, and thus puts less emphasis on estimating the shape of a particular regression function. As such, the parametric estimations of EKC may be inaccurate and may yield deceptive results. In contrast, the ability of the LL approach to estimate unknown, data-driven regression functions allows for more accurate estimation of the complex nonlinearity of the EKC.

In addition, the gradient components (slope coefficients) are allowed to change over time, which is useful when the data generating process and model relationship may suffer from smooth structural changes. Moreover, the LL approach can generate the regression function as a curve, enabling the researcher to visually gauge the shape of the relationship – inverted-U in this study. This is better than the parametric approach which relies solely on the coefficient estimates and corresponding hypothesis tests and inferences.

**Table 3: Nonparametric Unit Root Test Results**

| Country | $\ln C_t$ | | $\Delta \ln C_t$ | | $\ln Y_t$ | | $\Delta \ln Y_t$ | |
|---|---|---|---|---|---|---|---|---|
| | Bierens | Breitung | Bierens | Breitung | Bierens | Breitung | Bierens | Breitung |
| Canada | 0.874 | 0.020 | -96.855* | 0.001* | -15.754 | 0.014 | -838.369* | 0.000* |
| | (1.000) | (0.900) | (0.000) | (0.000) | (0.390) | (0.700) | (0.000) | (0.000) |
| France | -2.341 | 0.020 | -714.291* | 0.000* | -5.998 | 0.017 | -174.555* | 0.000* |
| | (0.990) | (0.900) | (0.000) | (0.000) | (0.910) | (1.000) | (0.000) | (0.000) |
| Germany | -1.041 | 0.022 | -123.456* | 0.000* | -12.408 | 0.015 | -842.333* | 0.000* |
| | (1.000) | (1.000) | (0.000) | (0.000) | (0.490) | (0.900) | (0.000) | (0.000) |
| Italy | -22.756 | 0.003 | -275.312* | 0.000* | -8.067 | 0.017 | -219.539* | 0.000* |
| | (0.280) | (0.200) | (0.020) | (0.000) | (0.790) | (1.000) | (0.000) | (0.000) |
| Japan | -1.516 | 0.021 | -55.888* | 0.001* | -1.721 | 0.023 | -42.783* | 0.003* |
| | (0.980) | (1.000) | (0.000) | (0.000) | (0.860) | (1.000) | (0.010) | (0.000) |
| U.K. | 0.518 | 0.022 | -101.456* | 0.000* | -9.821 | 0.014 | -479.240* | 0.000* |
| | (0.990) | (1.000) | (0.000) | (0.000) | (0.720) | (0.800) | (0.000) | (0.000) |
| U.S. | 0.719 | 0.024 | -126.469* | 0.000* | -24.169 | 0.013 | -561.779* | 0.000* |
| | (1.000) | (1.000) | (0.000) | (0.000) | (0.130) | (0.900) | (0.000) | (0.000) |

Notes: The parentheses include the *p*-values. The null $H_0$: Series is non-stationary with a drift. The alternative $H_A$: Series is a nonlinear trend stationary process. * Reject $H_0$if the *p*-value is< 0.05.Bierens (1997a): Test statistic = $\hat{A}m$; the *p*-values are simulated for a relevant sample size using 100 replications. The optimal value of *p* is chosen by the Schwarz (1978) Bayesian Criterion. Breitung (2002): the *p*-values are simulated using 10 replications.

**Table 4: Bierens (1997b) Cointegration Analysis**

| | Test Statistic ($\lambda_{min}$) | | | | | | | Significance level | Critical value |
|---|---|---|---|---|---|---|---|---|---|
| | Canada | France | Germany | Italy | Japan | U.K. | U.S. | | |
| Tests of $H_0$: $r$ = 0 against $H_1$: $r$ = 1 | | | | | | | | | |
| $m$ = 2 | 0.001** | 0.000** | 0.003** | 0.001** | 0.020 | 0.004** | 0.000** | 10% | 0.005 |
| $m$ = 3 | 0.072 | 0.410 | 0.107 | 0.089 | 0.020 | 0.005* | 0.000* | 5% | 0.017 |
| Tests of $H_0$: $r$ = 1 against $H_1$: $r$ = 2: | | | | | | | | | |
| $m$ = 2 | 1.414 | 11.858 | 8.642 | 2.124 | | 0.138 | 12.539 | 10% | 0.111 |
| $m$ = 2 | 1.414 | 11.858 | 8.642 | 2.124 | | 0.138 | 12.539 | 5% | 0.054 |
| Rank ($r_0$=?) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | | |

Notes: $r$ is the number of cointegrating vectors. * Reject $H_0$ at the 5% level of significance if test statistic < 5% critical value. ** Reject $H_0$ at the 10% level of significance if the test statistic <10% critical value.

**Table 5: Breitung (2001, 2002) Cointegration Analysis**

| | Country | | | | | | | 5% Crit. val. | 10% Crit. val. |
|---|---|---|---|---|---|---|---|---|---|
| | Canada | France | Germany | Italy | Japan | U.K. | U.S. | | |
| Tests of $H_0$: $r = 0$ against $H_1$: $r = 1$ | | | | | | | | | |
| Test Statistic | 613.85** | 763.49* | 898.40* | 718.55* | 191.61 | 936.36* | 650.67** | 713.30 | 596.20 |
| Simulated *p*-value | 0.085 | 0.029 | 0.015 | 0.041 | 0.907 | 0.010 | 0.066 | | |
| Tests of $H_0$: $r = 1$ against $H_1$: $r = 2$ | | | | | | | | | |
| Test Statistic | 43.97 | 43.59 | 42.06 | 56.17 | | 54.61 | 40.87 | 281.10 | 222.40 |
| Simulated *p*-value | 0.994 | 0.997 | 0.999 | 0.874 | | 0.893 | 1.000 | | |
| Rank ($r_0$=?) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | | |

Notes: *r* is the number of cointegrating vectors. Case: Model with drift. The *p*-values are based on 10,000 replications of the Gaussian random walks for appropriate length, *n*. * Reject $H_0$ if *p*-value < 0.05. ** Reject $H_0$ if *p*-value < 0.10.

Figure 2 provides a visual illustration of the LL nonparametric regression estimates. As can be seen, the relationship between ln$C_t$ and ln$Y_t$ is nonlinear. There is also evidence of an inverted-U shaped relationship between the two variables for Canada, France, Germany, Italy, U.K. and the U.S, excluding Japan. Nevertheless, Japan's $CO_2$ emissions seem to decline slightly with respect to higher income. The regression estimates provide a very good fit as the respective $R^2$ is in excess of 0.90 in all cases. The bandwidths used in the LL estimations are also found to be quite reasonable.

Figure A1 (Appendix) illustrates the gradient component plots of ln$C_t$ with respect to ln$Y_t$ (i.e. the slope or first derivative) and their respective *p*-values. As can be seen, the gradient components of ln$C_t$ with respect to ln$Y_t$ are statistically significant at the 5% level for all G7 economies. After a steep initial increase, each of the gradient components exhibits a continuous downward trend, despite periodic fluctuations in most of the G7 countries, excluding Italy and Japan. More specifically, in Italy, although the gradient component starts at a high level, it gradually declines and exhibits a continuous downward trend. This implies that the rate of $CO_2$ emissions growth in the six G7 economies (except Japan) has declined over the years, a finding that is in line with the EKC hypothesis.

In Japan, however, the gradient component exhibits a slight increasing trend and there are substantial fluctuations around an increasing mean until a high value of ln$Y_t$ (~9.0). Subsequently, it embarks on a downward trend while fluctuating even more. This indicates that Japan's $CO_2$ emissions growth rate has not declined sufficiently before the country reached a very high level of income. This late decline in emissions growth rate is the reason behind the rejection of the EKC hypothesis in Japan. Based on the estimates in Figures 2 and A1, we can validate the presence of an inverted-U shaped relationship between $CO_2$ emissions and economic growth for Canada, France, Germany, Italy, U.K. and the U.S. Although $CO_2$ emissions are observed to decline slightly with respect to high GDP per capita in Japan, a clear and unambiguous inverted-U relationship between the two variables cannot be validated.

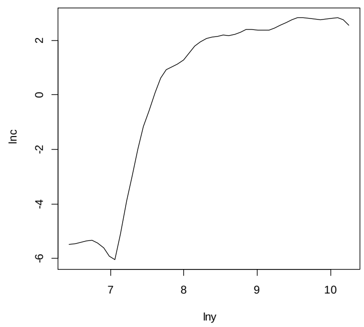
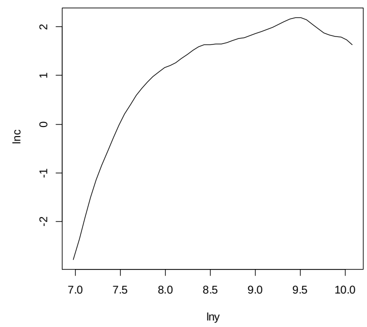
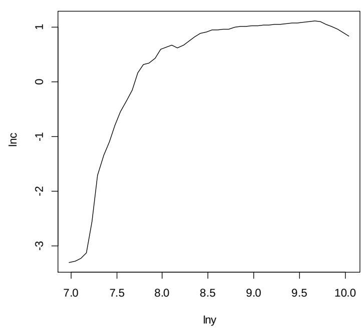
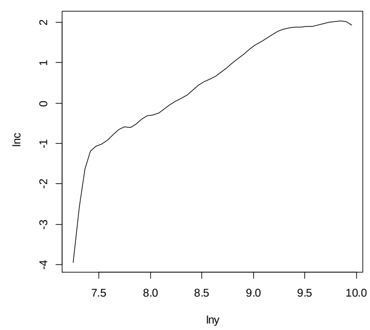
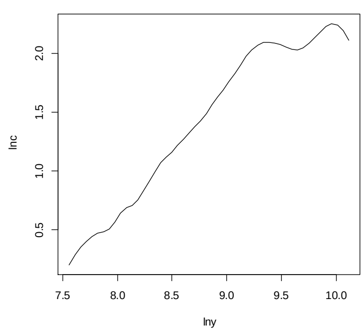
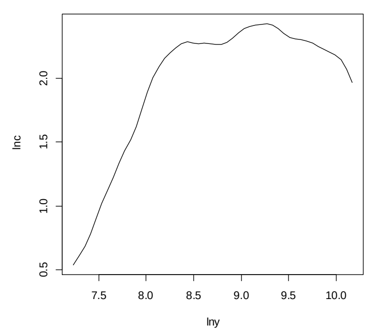
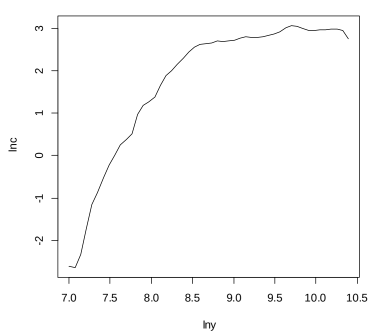
The inverted U-shaped relationship between economic growth and carbon emissions in Canada is consistent with earlier studies (e.g. Galeotti et al., 2009; He and Richard, 2010; Hamit-Haggar, 2012; Apergis, 2016). However, it is inconsistent with the findings by Day and Grafton (2003) who provide evidence against the existence of the EKC hypothesis in Canada. Our results for France are in line with those documented by Iwata et al. (2010), Jobert et al. (2012), Can and Gozgor, (2015), Apergis, (2016) and Mutascu et al. (2016). For the Italian economy, the EKC hypothesis is confirmed by Cialani (2007), Mazzanti et al. (2008), Annicchiarico et al. (2009), and Sica (2014) whereas it is rejected by Apergis (2016). Validation of the EKC hypothesis for the U.K. economy is supported by Ubaidillah (2011), Fosten et al. (2012) and Sephton and Mann (2016), while Aldy (2005), Congregado et al. (2016) and Apergis et al. (2017) provide evidence supporting the EKC hypothesis in the U.S. Our evidence for Japan contradicts the findings by Yaguchi et al. (2007) and Rafindadi (2016) who validate the existence of the environmental Kuznets curve.

The documented presence of cointegration (i.e. long-run equilibrium) between carbon emissions and economic growth as well as the confirmation for the existence of the EKC hypothesis, pave the way for determining the direction of causality between the two variables by applying the Hiemstra-Jones (1994) and Diks-Panchenko (2006) nonparametric causality tests. The results of the Hiemstra-Jones (1994) test are reported in Table 6. We find a positive causality running from carbon emissions to economic growth at the 1% level of significance for all G7 countries except Japan.

This finding is consistent with that of Barassi and Spagnolo (2012) and Hamit-Haggar (2012) who, using parametric econometric techniques, also find that carbon emissions cause economic growth positively and significantly. In contrast, Day and Grafton (2003) report a feedback effect between carbon emissions and economic growth, while Ajmi et al. (2015) report a neutral effect between the two variables and Acaravci and Ozturk (2010) show that neither economic growth causes carbon emissions nor carbon emissions cause economic growth.

The estimated results also demonstrate a positive feedback effect (i.e. bidirectional causality) between carbon emissions and economic growth for the French economy similar to Barassi and Spagnolo (2012). Our evidence for the existence of a positive bidirectional causality between the two variables for Italy is inconsistent with that documented by Barassi and Spagnolo (2012) and Ajmi et al. (2015) who report a unidirectional but positive causality, running from economic growth to carbon emissions.

**Figure 2: Local Linear Nonparametric Regression Plots**

| Canada | $R^2$ | BW | France | $R^2$ | BW |
|---|---|---|---|---|---|
|  | 0.996 | 0.052 |  | 0.991 | 0.086 |
| **Germany** | $R^2$ | BW | **Italy** | $R^2$ | BW |
|  | 0.990 | 0.035 |  | 0.933 | 0.074 |
| **Japan** | $R^2$ | BW | **U.K.** | $R^2$ | BW |
|  | 0.999 | 0.057 |  | 0.987 | 0.072 |
| **U.S.** | $R^2$ | BW | | | |
|  | 0.998 | 0.039 | | | |

Notes: BW refers to Bandwidth. Bandwidth Type: Fixed. Continuous Kernel Type: Second-Order Gaussian.

**Table 6: Hiemstra-Jones (1994) Causality Analysis**

| Countries | Direction | Test Statistic | $p$-values | Bandwidth ($\epsilon_n$) |
|---|---|---|---|---|
| Canada | $\ln C_t \Rightarrow \ln Y_t$ | 2.392* | 0.008 | 1.000 |
| | $\ln Y_t \nRightarrow \ln C_t$ | 0.211 | 0.416 | 1.000 |
| France | $\ln C_t \Rightarrow \ln Y_t$ | 1.505** | 0.066 | 0.700 |
| | $\ln Y_t \Rightarrow \ln C_t$ | 1.369** | 0.085 | 0.900 |
| Germany | $\ln C_t \Rightarrow \ln Y_t$ | 1.760* | 0.039 | 1.000 |
| | $\ln Y_t \nRightarrow \ln C_t$ | -0.294 | 0.615 | 1.000 |
| Italy | $\ln C_t \Rightarrow \ln Y_t$ | 1.437** | 0.075 | 1.000 |
| | $\ln Y_t \Rightarrow \ln C_t$ | 1.820* | 0.034 | 1.000 |
| Japan | $\ln C_t \nRightarrow \ln Y_t$ | 0.931 | 0.175 | 1.000 |
| | $\ln Y_t \nRightarrow \ln C_t$ | -0.965 | 0.832 | 1.000 |
| U.K. | $\ln C_t \Rightarrow \ln Y_t$ | 1.625** | 0.051 | 1.000 |
| | $\ln Y_t \nRightarrow \ln C_t$ | -1.194 | 0.883 | 1.000 |
| U.S. | $\ln C_t \Rightarrow \ln Y_t$ | 2.289* | 0.011 | 1.000 |
| | $\ln Y_t \nRightarrow \ln C_t$ | -0.458 | 0.676 | 1.000 |

Notes: Embedding dimension = 1.$H_0$: No causality in the direction. * Reject $H_0$ if the $p$-value < 0.05.** Reject $H_0$if the $p$-value < 0.10.

We also document the presence of a unidirectional and positive causality running from carbon emissions to economic growth for both the U.S. and U.K. economies. The null hypothesis is not rejected in either direction for Japan. This empirical finding is dissimilar to that of Barassi and Spagnolo (2012) who find that carbon emissions positively cause economic growth in Japan and also to that of Ajmi et al. (2015) who indicate the existence of a unidirectional causality from economic growth to carbon emissions for this country.

**Table 7:Diks-Panchenko (2006) Causality Analysis**

| Country | Direction | Test Statistic ($T_n(\epsilon_n)$) | $p$-value | Bandwidth ($\epsilon_n$) |
|---|---|---|---|---|
| Canada | $\ln C_t \Rightarrow \ln Y_t$ | 2.138* | 0.016 | 0.700 |
| | $\ln Y_t \nRightarrow \ln C_t$ | -1.116 | 0.867 | 0.700 |
| France | $\ln C_t \Rightarrow \ln Y_t$ | 2.306* | 0.010 | 0.500 |
| | $\ln Y_t \Rightarrow \ln C_t$ | 2.303* | 0.010 | 0.500 |
| Germany | $\ln C_t \Rightarrow \ln Y_t$ | 2.042* | 0.020 | 0.500 |
| | $\ln Y_t \nRightarrow \ln C_t$ | 1.281 | 0.100 | 0.500 |
| Italy | $\ln C_t \Rightarrow \ln Y_t$ | 1.882* | 0.029 | 0.500 |
| | $\ln Y_t \Rightarrow \ln C_t$ | 1.936* | 0.026 | 0.500 |
| Japan | $\ln C_t \nRightarrow \ln Y_t$ | 0.716 | 0.236 | 0.500 |
| | $\ln Y_t \nRightarrow \ln C_t$ | 0.651 | 0.257 | 0.500 |
| U.K. | $\ln C_t \Rightarrow \ln Y_t$ | 1.715* | 0.043 | 0.600 |
| | $\ln Y_t \nRightarrow \ln C_t$ | 0.611 | 0.270 | 0.600 |
| U.S. | $\ln C_t \Rightarrow \ln Y_t$ | 2.213* | 0.013 | 0.500 |
| | $\ln Y_t \nRightarrow \ln C_t$ | 0.082 | 0.467 | 0.500 |

Notes: Embedding dimension = 2. $H_0$: No causality in the Direction. * Reject $H_0$ if $p$-value < 0.05.

In order to test the robustness of the causality analysis, we have applied the Diks and Panchenko (2006) causality test and the results are provided in Table 7. We find these results to be more statistically significant, underscoring a unidirectional nonlinear causality running from carbon emissions to economic growth for Canada, Germany, U.K., and the U.S. We document a feedback effect for France and Italy but a neutral effect between the two variables for Japan. The bandwidths used in estimating the HJ and DP test statistics are within the commonly used range of 0.5 to1.5[6]. Further, the HJ and DP estimates are free from estimation biases and can reliably be used for inference[7].

## 6. Concluding Remarks

This study employs nonparametric econometric techniques to analyze the nexus between economic growth and $CO_2$ emissions for the G7 economies over a long period of nearly two centuries. Unlike the parametric and semiparametric methods used in earlier studies, the nonparametric methods employed in this study are more suitable to model the dynamic relationships between $CO_2$ emissions and economic growth due to the structural breaks caused by changes in policies, structural reforms, regulations, external shocks, etc.

As a result, this study makes several unique and substantial contributions to the literature, particularly by using recent and sophisticated econometric techniques that complement each other. The empirical findings show that $CO_2$ emissions and GDP per capita are cointegrated in six out of the seven G7 economies: Canada, France, Germany, Italy, U.K. and the U.S. This means that there is a long run relationship between the two variables for those six countries. The LL regression estimates document an inverted-U shaped relationship between the two variables in the same six economies, substantiating the EKC hypothesis, which implies an improvement in environmental quality after income per capita reaches a certain level.

The Granger causality tests indicate that there is a one-way causality running from $CO_2$ emissions to economic growth for Canada, Germany, U.K. and the U.S., a dual causation between $CO_2$ emissions and economic growth for France and Italy, and no causality between the two variables for Japan. This suggests that the relationship between economic growth and carbon

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[6] The bandwidth is a measure of closeness in the kernel density, matching the distribution in a nonparametric setting. Bandwidths are important in kernel smoothing and can affect the significance (rejection of null) of the tests performed.

[7] As a robustness test, we have re-estimated the causality tests using data for the period 1992-2015. This period is more homogeneous with only minor changes in the production and consumption structures across countries. The *United Nations Framework Convention on Climate Change* event that was opened for signature by 154 nations in 1992, makes the selection of the aforementioned period ideal. The results (available upon request) are virtually identical to our initial results, providing evidence that the causal relationship between $CO_2$ emissions and GDP per capita has been accurately captured using data from the 1800s.

emissions is mixed for the G7 countries, implying that environmental policymaking is not a “one size fits all” approach. Our findings are robust as both cointegration and causality tests results are identical under two different econometric techniques– namely the Bierens (1997b) and Breitung (2001, 2002) cointegration tests and the Hiemstra and Jones (1994) and Diks and Panchenko (2006) Granger causality tests. We highlight the presence of nonlinearity in the causal relations between $CO_2$ emissions and economic growth in six of the G7 economies. This underscores the importance of changes in programs, regulations and legislations in shaping up the environment-growth relationship for the major economies of the world.

The unidirectional relationship running from carbon emissions to economic growth for Canada, Germany, U.K. and U.S. implies that these countries can expand economic growth without much concern about degrading the environment. In the real world, the U.S. economy for example, managed to grow by 13% between 2005 and 2014, while the U.S. energy-related carbon pollution fell by more than 8%[8]. The U.S. economy is becoming more energy efficient, and its energy mix is cleaner and less carbon-intensive than it was a decade ago. The U.K. has achieved absolute decoupling for many air pollutants and carbon emissions, a fact that can be partly explained by shifts in the location of production, with many of the goods and services consumed in this country now being produced in other countries, particularly developing ones[9]. The results further imply that those countries have correctly changed the scale and composition of their sectoral GDP and have the appropriate regulations in place to protect the environment. Consequently, it may be hard for these countries to compromise in multilateral negotiations with developing countries that pollute heavily, such as China and India, as their economic growth is more environment-friendly than that of the other countries.

However, the situation is different for France and Italy which exhibit a bidirectional relationship between carbon emissions and economic growth. For these two countries any attempt to protect the environment implies a reduction in economic growth. In such cases, countries should possess the appropriate sectoral mix, use cleaner energy sources and enforce environmental laws and regulations. They should also improve the efficiency of their resource consumption and adopt new production techniques and product designs.

Japan is the only G7 country that exhibits a neutral effect between carbon emissions and economic growth. This implies that Japan can expand economic growth independently, without having to worry about carbon pollution which would not affect the Japanese environmental quality. Still, Japanese policy makers should strive to improve environmental performance. The Japanese

[8] http://www.eia.gov/environment/emissions/carbon/
[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32101/10-1213-economic-growth.pdf

cities are among the world's least polluted according to the World Health Organization, and Japan prides itself on blue skies[10]. Moreover, Japan, the world's fifth largest emitter of greenhouse gases, plans to slash its greenhouse gas emissions by 26 percent by 2030 from the 2013 levels, compared to 18-20% for the United States and 24% for the European Union. In short, Japan has managed to clean up without sacrificing economic growth by investing in pollution-control technologies and granting local governments latitude to stiffen environmental standards beyond national requirements.

The confirmation of the EKC hypothesis in Canada, France, Germany, Italy, U.K. and the U.S., reveals that economic growth is attainable with minimum cost to environment in the long run. The theory of EKC implies that initially $CO_2$ emissions rise with economic growth, and after reaching a threshold level of real GDP per capita, economic growth improves environmental quality via energy efficiency, technological development and environmental policies, underscoring the importance of critical thresholds. In order to achieve energy efficiency improvements, these countries should focus on their energy mix-usage and more attention should be given to renewable energy sources, not only for maintaining their pace of economic growth but also for preventing further environmental degradation.

The existence of an EKC implies that these six economies already use more advanced technologies than the rest of the world's countries. Although their domestic production has been enhanced, more is needed in terms of increased funding for research and development that will eventually improve technical efficiency and environmental quality. Environmental quality could be further improved by changing behavior towards the use of product labeling and by implementing new carbon emissions tax and trading schemes. These policy insights may be helpful for developing economies in attaining more sustainable economic growth and simultaneously maintaining environmental quality[11].

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[10] http://latitude.blogs.nytimes.com/2013/02/15/japans-pollution-diet/

[11] Japan plans to have nuclear energy account for 20 to 22% of Japan's electricity mix in 2030, compared to 30% percent before the Fukushima nuclear incident. It has set targets for renewable energy at 22-24% of this electricity mix, liquefied natural gas (LND) at 27% and coal at 26%.

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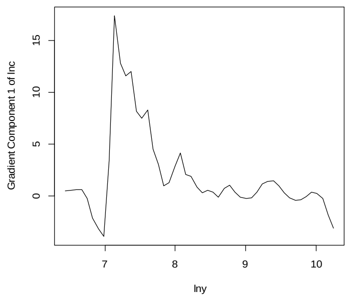
# Appendix

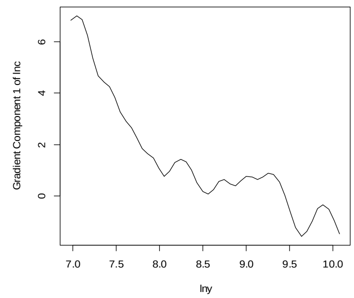
**Figure-A1: Local Linear Nonparametric Regression Gradient Component Plots**

Canada — *p*-value



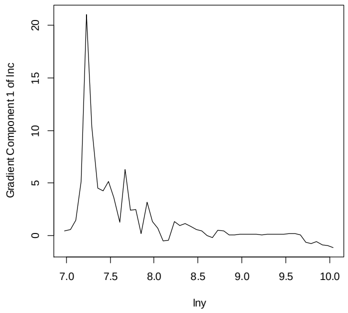

0.000*

France — *p*-value



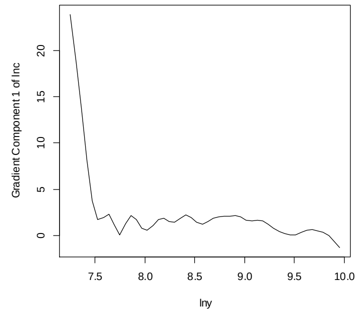

0.000*

Germany — *p*-value



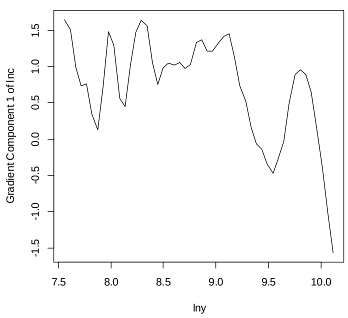

0.000*

Italy — *p*-value



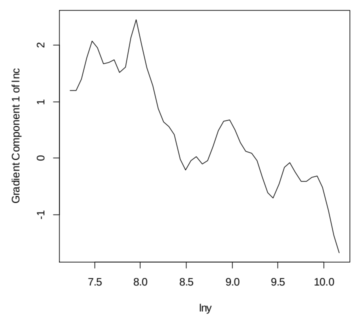

0.000*

Japan — *p*-value



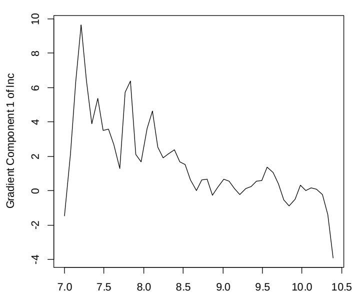

0.000*

U.K. — *p*-value




0.000*

U.S. — *p*-value




0.000*

Notes: $H_0$: Gradient component = 0. The *p*-values are generated using 399 replications. * Reject $H_0$ at the 5% level of significance.