Multifractal analysis of atmospheric carbon emissions and OECD industrial production index

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Abstract

Purpose – The purpose of this study aims to analyze the dynamic behavior of the relationship between atmospheric carbon emissions and the Organisation for Economic Co-operation and Development (OECD) industrial production index (IPI) in the short and long term by applying multifractal techniques.

Design/methodology/approach – Multifractal de-trended cross-correlation technique is used for this analysis based on the relevant literature. In addition, it is the most widely used approach to estimate multifractality because it generates robust empirical results against non-stationarities in the time series.

Findings – It is revealed that industrial production causes long and short term environmental costs. The OECD IPI and atmospheric carbon emissions were found to have a strong correlation between the time domain. However, this relationship does not mostly take into account the frequency-based correlations with the tail effects caused by shocks that are effective on the economy. In this study, the long-term dependence of the relationship between the OECD IPI and atmospheric carbon emissions differs from the correlation obtained by linear methods, as the analysis is based on the frequency. The major finding is that the Hurst coefficient is in the range 0.40-0.75 indicating.

Research limitations/implications – In this study, the local singular behavior of the time-series is analyzed to test for the multifractality characteristics of the series. In this context, the scaling exponents and the singularity spectrum are obtained to determine the origins of this multifractality. The multifractal time series are defined as the set of points with a given singularity exponent a where this exponent a is illustrated as a fractal with fractal dimension $f(\alpha)$. Therefore, the multifractality term indicates the existence of fluctuations, which are non-uniform and more importantly, their relative frequencies are also scale-dependent.

Practical implications – The results provide information based on the fluctuation in IPI, which determines the main conjuncture of the economy. An optimal strategy for shaping the consequences of climate change resulting from industrial production activities will not only need to be quite comprehensive and global in scale but also policies will need to be applicable to the national and local conditions of the given nation and adaptable to the needs of the country.

JEL classification – Q58, E21, E32

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Social implications – The results provide information for the analysis of the environmental cost of climate change depending on the magnitude of the impact on the total supply. In addition to environmental problems, climate change leads to economic problems, and hence, policy instruments are introduced to fight against the adverse effects of it.

Originality/value – This study may be of practical and technical importance in regional climate change forecasting, extreme carbon emission regulations and industrial production resource management in the world economy. Hence, the major contribution of this study is to introduce an approach to sustainability for the analysis of the environmental cost of growth in the supply side economy.

Keywords Industrial production index, Climate change, Multifractal detrended cross-correlation, Environmental Kuznets curve

Paper type Research paper

1. Introduction
The purpose of this study is to analyze the dynamic behavior of the relationship between carbon emissions and the industrial production index (IPI) in the short and long term. In this work, the local singular behavior of the time-series is analyzed to test for the multifractality characteristics of these series, namely, carbon emissions and the IPI. In this context, the scaling exponents and the singularity spectrum are obtained to determine the origins of this multifractality. The multifractal time series are defined as the set of points with a given singularity exponent α where this exponent α is illustrated as a fractal with fractal dimension $f(\alpha)$. Therefore, the multifractality term indicates the existence of fluctuations, which are non-uniform and more importantly, their relative frequencies are also scale-dependent. This means that there will be more heterogeneous fluctuations when the exponent α becomes wider.

The organization of this work is as follows: In Section 1, the effects of climate change on the industrial production process in the global economy is explained in relation to the financial and economic sections of key international agreements such as the Kyoto Protocol and Paris Agreement. The three major periods considering the evolution of carbon pricing policies are explained with the rationale behind it. The reason for defining climate change as a "market failure" is discussed based on the environmental Kuznets curve (EKC) and Pareto efficient market approach (Fama, 1970, 1991). The concept of "externalities," which enters the environmental cost scenarios via atmospheric carbon emission is briefly explained. Sections 2 and 3 describe the data, descriptive test statistics and applied methodology, i.e. multifractal detrended fluctuation analysis function (MF-DFA) is presented. In addition, the five major steps for the MF-DFA estimation process are defined based on the literature. Section 4 describes policy recommendations and contributions are made based on our empirical findings and Section 5 presents concluding remarks.

2. Literature review on climate change in relation to industrial production
2.1 Climate change
Recently, it is observed in the literature that studies on the adverse effects of climate change, analysis and measurement of minimum requirements have been drawn attention. The main reason for this is that extreme meteorological conditions, natural disasters, destruction in the ecosystem, shortage of water and loss of some species, which are becoming common in various parts of the world, cause an intensive growth in concerns about climate change. However, one of the most considerable factors, which increases the intent of preventing climate change, is its economic impacts. If the current situation in global warming continues, it is anticipated that there would be heavy economic and ecological outcomes, which will occur in the near future. On the other hand, it is observed that different regions of the world

are affected from climate change in the different ways. The most harmful effects of climate change have been observed in emerging countries rather than in the advanced countries. Because of their industrialization process, emerging countries are considered as the initial responsible actors for climate change (World Bank, 2018).

It should be noted that climate change is a global challenge and for this reason, it should not be considered a problem that could be addressed to only a specific group of countries. On the contrary, this situation requires a collective effort and coordination at the international level. Hence, climate change has been considered an issue in the global agenda of the world economy, as the early 1990s. The United Nations Framework Convention on Climate Change was established in 1992. Afterward, the Kyoto Protocol in 1997, taking necessary measures to mitigate emission level, also provides adequate support in financial, capacity-building and technology themes to developing countries. In addition, the Paris Agreement[1], which constitutes the foundation of climate change policies for the post-2020 period, was adopted as a result of the dialogues that accepted by the end of 2015 with respect to the revision of emerging countries. The key characteristic that differentiates the Paris Agreement from the former agreements is that the obligation of lowering greenhouse gas (GHG) emissions formerly attributed only to advanced countries, has become universal throughout all countries (European Bank for Reconstruction and Development (EBRD), 2011).

There are three major periods considering the evolution of carbon pricing policies. In the first period 1990-2005, advanced countries have launched the carbon tax implementation for the first time and they have taken the preliminary actions in this aspect. For instance, carbon pricing strategies have been implemented in the Nordic countries in the early 1990s via taxation policies. In addition, one of the very first implementations of the emission trading schemes (ETS) was established in the USA in the same period and the schemes load an upper limit on sulfur dioxide (SO_2) emissions. In the second period 2005-2011, the Kyoto Protocol has been widely accepted and the EU ETS was established. In this way, there have been various types of GHG emissions in the scope of the Scheme. In the third period starting from 2012 to the present, the validity of the Kyoto Protocol has weakened, and new carbon pricing tools have emerged at international, national, regional or city levels in the world economies encouraged by the enthusiasm of the Paris Agreement.

It is a fact that the sections of international agreements in relation to the economic and financial issues have always been the most arguable terms during the international negotiations because of the conflict of interest among advanced and emerging countries (Carbon Brief, 2018). In the past, under these agreements, the emissions trading system and policy instruments have been involved as an essential factor to fight against climate change. On the other hand, considering the fact that the financial crises have heavily exhausted the economies, it has become a need to enforce policies to fight climate change with efficient, responsive and innovational approaches. In this context, the fight against climate change, which is a universal issue in terms of the effects, needs to be reinforced not only by environmental policies but also in diverse domains by alternative policy instruments.

2.2 Climate change and the environmental Kuznets curve
Climate change is defined as "market failure" in the relevant literature. To be more precise, social benefits cannot be maximized without minimizing the social costs for the whole parts of the community. In such a circumstance, it is possible to point out that the markets are not "Pareto-efficient." If a Pareto-efficient market is considered, all costs and benefits are involved in the production or consumption decisions of households and organizations. If not, there might be either overproduction or underproduction of goods and services. This situation prevents social well-being from being maximized. Inevitably, there would be a

need for state intervention. In such an event, the concept of "externalities" will enter the environmental cost scenarios[2]. If the economy is not at a Pareto-efficient level because of the existence of externalities; costs and benefits related to the production, consumption and investment decisions of households and organizations could not be expressed completely within the transactions. In this context, market mechanisms turn into insufficient leading to deterioration in the market mechanism. For this reason, when there is an externality within the market, then a value that cannot be reflected in the prices of goods and services will arise (Buchanan and Stubblebine, 1962). In this respect, Uludağ (2019, 2016-2018) claims that human-induced climate change leads to adverse externalities on the essential scale.

In economic theory, the relationship between growth and environmental costs was first introduced by Kuznets (1955). The approach known as EKC in literature and defined as EKC has become an important tool for analyzing the negative externality of growth on the environment (Ike *et al.*, 2019; Özokcu and Özdemir, 2017; Aydın and Esen, 2017; Erdogan *et al.*, 2015; Kocak, 2014; Chen and Chen, 2015; Galeotti *et al.*, 2009; Dinda, 2004). The variables used in the analyses based on this approach are carbon dioxide emission and national GDP. Annual data were generally used in these studies. However, considering that GDP is an income variable, the fact that it is composed of different components may prevent the environmental cost of production in the economy from being clearly seen. In this context, IPI is used as the main indicator of production and the source of growth in this study. Because of the high frequency of the data used, a multifractal approach is applied. An important feature of this approach is the elimination of time-dependent dependence on the frequency domain. In this respect, long-term dependence among the variables are discussed and the intervals at which this dependence emerged are analyzed.

2.3 Shape of the environmental Kuznets curve
Analysis of the interaction of economic growth and environmental factors on costs is important in the literature. In this respect, the EKC is widely used to understand the interaction between economic indicators and negative externalities of growth. The EKC hypothesis indicates that as a starting point, considering the lower levels of income per capita, income distribution will be skewed toward higher income levels. In this way, the level of inequality in national incomes will be high. Hence, when the income level moves up, skewness will be reduced. Therefore, the level of income inequality becomes lower. Based on this hypothesis, the shape of the EKC provides information about these interactions and the maturity level of the economy. When the case of an inverted U-shaped EKC exists, then the environmental recovery would in time takes place as the economy grows. In this way, environmental sustainability is achieved (Bhattarai *et al.*, 2009). The most common and observed shapes of the EKC may be in the form of quadratic function, i.e. U-shaped and inverted U-shaped (Bhattarai *et al.*, 2009) or in the form of cubic functions, i.e. N-shaped and W-shaped (Álvarez-Herranz and Balsalobre-Lorente, 2016; Allard *et al.*, 2018) (Figure 1).

Sarkodie and Strezov (2018) propose an environmental sustainability curve based on the shape of EKC. It is a fact that the economic development of countries leads to an increasing energy demand in various forms. The output of such an increasing growth in the economy causes "environmental degradation" and vice versa. There is one significant contradicting case, which is of China with exceptional economic indicators in relation to this approach. According to the empirical evidence provided by He and Yao (2017), China's figures contradict the EKC hypothesis, where China, at its recent level of economic development, should have experienced a decrease in CO_2 emissions with progress to shift a cleaner environment. However, this is yet to occur in China. There is some mixed evidence in the literature considering the Organisation for Economic Co-operation and Development
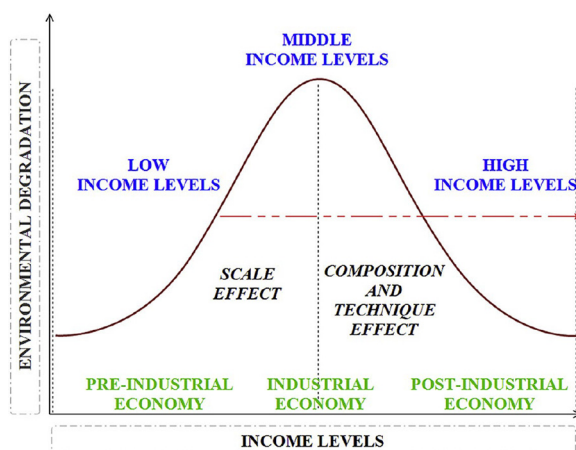
Source: Sarkodie and Strezov (2018)

(OECD) countries (Bilgili *et al.*, 2016; Alvarez-Herranz *et al.*, 2017). Churchill *et al.* (2018) argue that the potential reason for the mixed evidence maybe because of the usage of panel data with long time series and the degree of overlap among countries. To minimize environmental degradation, countries should establish a strategy to determine the policy implications toward renewable energy mix (solar, wind, etc.), which totally depends on the geographic location and economic maturity of these countries (Churchill *et al.*, 2018, pp. 390-391). The IPI can measure the economic maturity level of a country.

2.4 Climate change and industrial production index
IPI is used as an indicator of elementary production in the economy. Industrial production indices determine the fundamental trends of the economy, depending on the connection of production back and forth with other sectors (Shafik and Bandyopadhyay, 1992; Holtz-Eakin and Selden, 1995; Sterpu *et al.*, 2018; Shapiro and Walker, 2018). It is assumed that the increase or decrease of this variable is based on climate change and its impact on carbon emissions and prices. Depending on the increase in the IPI, the increase in carbon prices is an indication that the growth trend is faced with the alternative cost of climate change. The increase in the actual production index on the source of the increase in carbon prices means that the social cost of emerging growth pillars is rising (OECD, 2015).

3. The data and methodology
In the literature, it is generally accepted that the return series show a normal distribution characteristic (Bachelier, 1900); the pricing behavior carries the characteristics of "random walk" and also supports the existence of "efficient market hypothesis." This hypothesis has been widely used in various asset pricing modeling approaches. However, it is argued that return series are not normally distributed, rather they are subject to fractal distribution. Especially, for trade specialists and investors, volatility is the strategic variable for understanding market microstructure. This is because they need accurate volatility forecasts in relation to various undertakings such as derivatives pricing, value-at-risk measurement, portfolio analysis and managerial decision-making processes.

3.1 Data

In this work, atmospheric carbon emissions and OECD IPI data are used to analyze the short and long term relationship of these series based on multifractal detrended cross-correlation methodology. The atmospheric carbon emissions data are taken from the USA Government's Earth System Research Laboratory, Global Monitoring Division and data is based on trends in atmospheric carbon dioxide[3], which is the longest continuous time series since 1958. The growth rates of carbon dioxide are indicated in Figure 2.

IPI is the one for the OECD world IPI data and it is taken from OECD statistics for the period 1971-2018. The monthly logarithmic first differences (log return series) are generated for both of the data to start the estimation process as explained in the following sections.

The descriptive statistics of the two series, i.e. the logarithmic IPI (logipi) and the logarithmic carbon emissions (logcarbon) are shown in Table I, and the graph of the return series are presented with histogram at Figures 3 and 4, respectively.

It is a fact that the negative skewness value of the IPI (logipi) being equal to (-1.6023) in the time period under consideration provides information that the stagnation trend or contraction in production volume in the world economy is more dominant than growth. It can be stated that in this period, monthly shrinkage rates in the trends toward the recession of the economy are higher than the growth rates. Indeed, the positive kurtosis value of logipi, which is greater than (3) and, being equal to (11.103), supports this situation. The positive skewness value of the carbon emissions (logcarbon) being equal to (0.078) in the period under consideration has a tendency for the increase in carbon amount to decrease. Although there is a slowdown in the production of the world economy in this period, the continuing trend of increasing carbon emissions provides information on the use of frequency-based approaches. Similarly, as the kurtosis value of logcarbon is greater than 3, it reveals that the positive changes are larger.
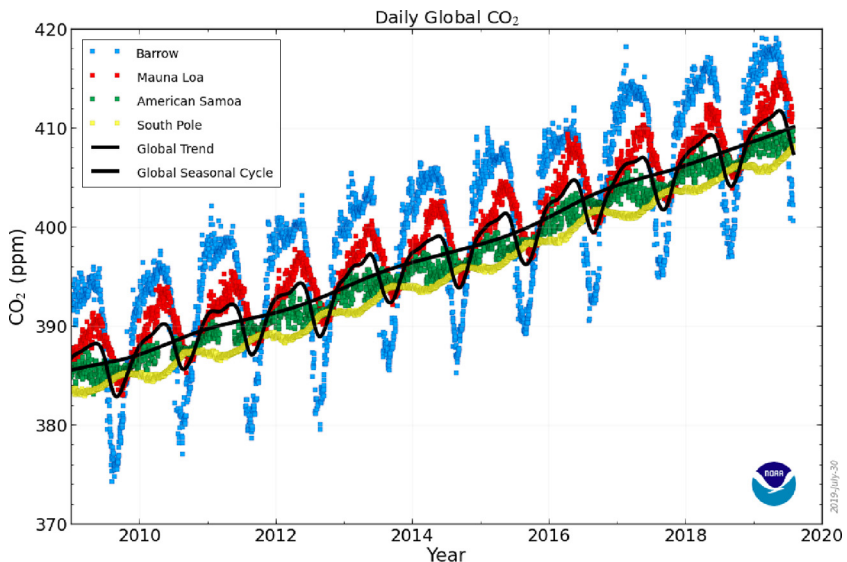

Figure 2.
Growth rate of CO_2

Source: https://datahub.io/core/co2-ppm/view/1

The augmented dickey fuller (ADF) unit root test results are shown in Tables II and III, respectively. Considering the test results, both of the series are not normally distributed, which is similar to the common feature of most of the time series. This can be seen from the Jarque–Bera test statistics and ADF unit root test results (null hypothesis: the variable has a unit root) for variables logipi and logcarbon, respectively.

Before starting the multifractal detrended fluctuation analysis (FA), it is not only enough to execute traditional unit root tests but also it is necessary to conduct additional non-linear unit root tests, namely, Fourier Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test, Fourier generalized least squares (GLS) test and Fourier ADF test. This is because traditional unit root tests do not provide robust results in the case of structural breaks and the existence of nonlinearity (Güriş, 2017, pp. 2-3).

Becker *et al.* (2004, 2006) recommend implementing unit root tests based on a Fourier series expansion to estimate the unknown number of breaks[4]. Enders and Lee (2012) propose a new unit root test by using a Fourier function to improve the power of a Dickey Fuller type of estimation framework. In addition, Rodrigues and Taylor (2012) introduce

Description	Industrial production index (logipi)	Carbon emissions (logcarbon)
Mean	0.0016	0.0004
Median	0.0021	0.0004
Maximum	0.0200	0.0031
Minimum	−0.0385	−0.0018
Std. dev	0.0060	0.0008
Skewness	−1.6023	0.0780
Kurtosis	11.103	3.1385
Jarque–Bera	1657.933	0.950706
Probability	0.000000	0.621666
Sum	0.889197	0.211978
Sum sq. dev	0.019110	0.000343
Observations	524	524

Table I.
Descriptive statistics
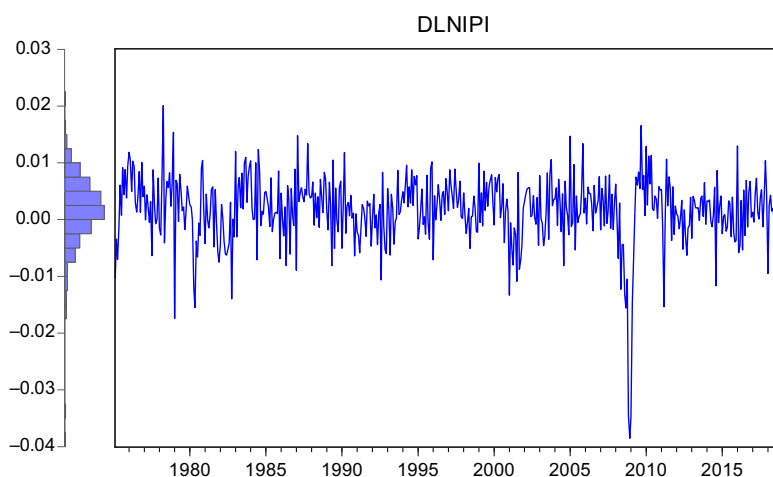of IPI (logipi) and
carbon emissions
(logcarbon)

Figure 3.
Return series of IPI
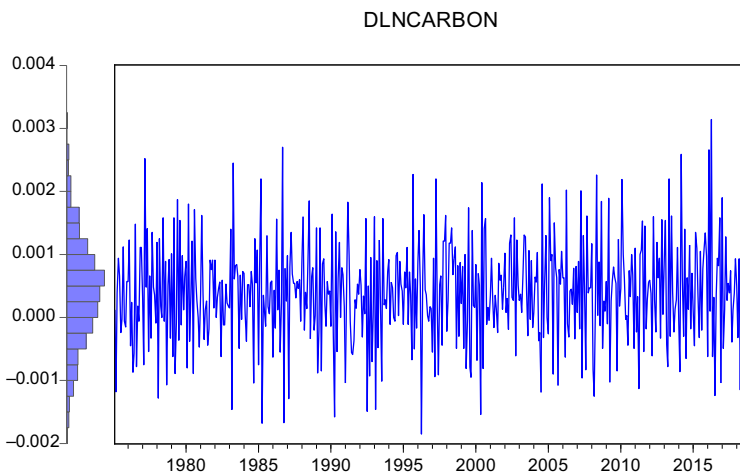
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Figure 4.
Return series of
carbon emissions

ADF tests	Industrial production index (logipi)
With constant	
t-statistic	−5.5444
Prob	0.0000***
With constant and trend	
t-statistic	−5.6576
Prob	0.0000***
Without constant and trend	
t-statistic	−4.5470
Prob	0.0000***
Note: ***Significant at 1% confidence interval	

Table II.
ADF test results for
IPI (logipi)

ADF tests	Carbon emissions (logcarbon)
With constant	
t-statistic	−21.4923
Prob	0.0000***
With constant and trend	
t-statistic	−21.6818
Prob	0.0000***
Without constant and trend	
t-statistic	−2.4495
Prob	0.0140
Note: ***Significant at 1% confidence interval	

Table III.
ADF test results for
atmospheric carbon
emissions
(logcarbon)

another unit root test, namely, local GLS detrended unit root test (Fourier GLS test), which relies on the flexible Fourier form.

Becker *et al.* (2006) argue that the Fourier frequency parameter (κ) could be 1-5 at the critical value table. The authors state that the Fourier frequency parameter (κ) can take the values 1 or 2 for the consistent macroeconomic data, which is shown in Figure 5. It is a fact that the Fourier form of approximation can capture the behavior of a deterministic trend function of unknown form. This is the case even if the function itself is nonstationary (Becker *et al.*, 2004; Harvey *et al.*, 2008).

These unit root tests are applied for the data, i.e. IPI (logipi) and atmospheric carbon emissions (logcarbon) with the constant model, constant and trend model, respectively. Test results are shown in Tables IV and V.

Based on the test results of Fourier ADF, Fourier GLS and Fourier langrange multiplier (LM), the series do not contain Fourier unit root at different frequencies. Fourier KPSS test results support this information in terms of stationarity. The results of all the unit root tests are important for our study regarding the fact that the Kuznets curve provides the information that different behaviors may be at different frequencies. Therefore, the different shapes of the Kuznets curve can be observed according to the frequency and time domain of the time series discussed. In this respect, the theory should be tested considering such differences for the sample data. When the frequency structures in the series are considered, the multifractal detrended cross-correlation approach is applied for analyzing the relationship of the two data at different frequencies.

3.2 Methodology
The fractal theory was, firstly, proposed by Mandelbrot (1963) and has steadily become a new trend to study financial markets in recent years and afterwards the fractal market hypothesis proposed by Peters (1994) has developed a precise presentation of fractal theory in financial
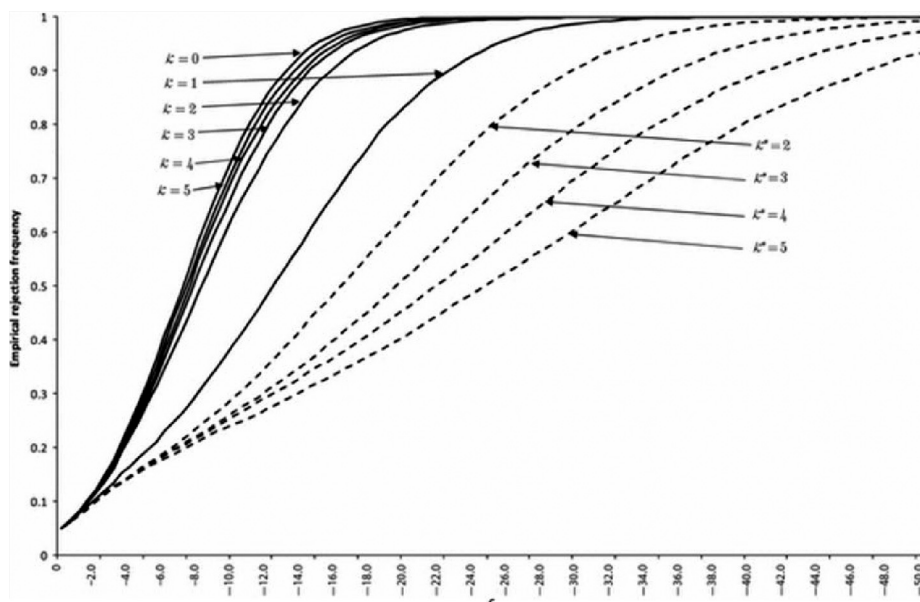

Source: Rodrigues and Taylor (2012)

Figure 5.
The flexible Fourier form

Unit root test type	Industrial production index (logipi) – constant model	Atmospheric carbon emissions (logcarbon) – constant model
Fourier ADF test (Enders and Lee, 2012, p. 197)	ADF-stat = −6.5662** Fourier = 1.0000 Lag = 12.0000	ADF-stat = −7.5142** Fourier = 1.0000 Lag = 12.0000
Fourier GLS test (Rodrigues and Taylor, 2012, p. 742)	GLS-stat = −3.0297** Fourier = 1.0000 Lag = 11.0000	GLS-stat = −4.4917* Fourier = 1.0000 Lag = 12.0000
Fourier KPSS test (Becker et al., 2006, p. 389)	KPSS-stat = 0.3782* Fourier = 2.0000	KPSS-stat = 0.0309* Fourier = 1.0000

Table IV.
Fourier ADF, Fourier GLS and Fourier KPSS test results-with constant model

Notes: Critical value (*) 1% and (**) 5% are −3.637 and −3.017, respectively. Sources: The calculated figures for the unit root tests in Tables IV and V are interpreted based on the critical values, which are taken from the above-mentioned articles, namely; Fourier ADF test (Enders and Lee, 2012, p. 197), Fourier LM test (Enders and Lee, 2012, p. 582), Fourier GLS test (Rodrigues and Taylor, 2012, p. 742) and Fourier KPSS test (Becker et al., 2006, p. 389)

IUnit root test type	IIndustrial production index (logipi) constant and trend model	IAtmospheric carbon emissions (logcarbon) constant and trend model
Fourier ADF test (Enders and Lee, 2012, p. 197)	ADF-stat = −6.6381* Fourier = 3.0000 Lag = 12.0000	ADF-stat = −7.6393* Fourier = 3.0000 Lag = 12.0000
Fourier LM test (Enders and Lee, 2012, p. 582)	LM-stat = −6.0494* Fourier = 1.0000 Lag = 11.0000	LM-stat = −7.6366* Fourier = 3.0000 Lag = 12.0000
Fourier GLS test (Rodrigues and Taylor, 2012, p. 742)	GLS-stat = −4.7745* Fourier = 1.0000 Lag = 11.0000	GLS-stat = −6.7590* Fourier = 2.0000 Lag = 12.0000
Fourier KPSS test (Becker, Enders and Lee, 2006, p. 389)	KPSS-stat = 0.0694* Fourier = 3.0000	KPSS-stat = 0.0124* Fourier = 2.0000

Table V.
Fourier ADF, Fourier GLS, Fourier LM and Fourier KPSS test results-with constant model

Note: Critical Value (*) 1% and (**) 5% are −3.637 and −3.017, respectively

markets. In this work, the local singular behavior of the time-series is analyzed to test for the multifractality characteristics of the series. This methodology is designed basically to study the correlation and multifractal characteristics of two nonstationary series.

There are various empirical studies on the existence of multifractality and long-range correlations in the global financial markets based on the theory of single fractal and multifractal methodologies. Hence, financial time series are particularly multifaceted and have mostly nonlinear characteristics. Considering the huge amount of work on multifractality for both advanced and emerging markets; the main works can be cited as follows: Holley and Waymire (1992), Frisch and Parisi (1985), Mandelbrot (1963, 1969, 1982, 1989, 2001a, 2001b, 2001c), and Evertsz and Mandelbrot (1992), Falconer (1994), Arbeiter and Patzschke (1996), Mantegna and Stanley (1995), Fisher et al. (1997), Calvet et al. (1997), Barral and Mandelbrot (2002), Lobato and Velasco (2000), Ossiander and Waymire (2000), Bacry et al. (2001), Riedi (2002), Calvet and Fisher

(2001, 2002, 2004), Lux (2004), Liu *et al.* (2008), Lux (2008), Ureche-Rangau and de Morthays (2009), Idier (2011), Leövey and Lux (2012), Bacry *et al.* (2012), Calvet *et al.* (2013), Liu and Lux (2013), Chen *et al.* (2013) and Leövey (2013). It should be noted that multifractality is not only simply used for analyzing the volatility but also it is useful for testing the chaotic and fractal characteristics of markets, which could be seen as an indicator of the financial crisis (Caraiani, 2012, p. 1).

In our case, the multifractal detrended cross-correlation approach is applied to determine MF-DFA by decomposing the two-time series. MF-DFA method makes it possible to inspect higher-dimensional fractal and multifractal characteristics concealed within the observed time series. In this context, the scaling exponents and the singularity spectrum are obtained to determine the origins of multifractality.

The multifractal time series are defined as the set of points with a given singularity exponent α where this exponent α is illustrated as a fractal with fractal dimension f(α). Therefore, the multifractality term indicates the existence of fluctuations, which are "non-uniform" and more importantly, their relative frequencies are also "scale-dependent." This means that there will be more heterogeneous fluctuations when the exponent α becomes wider. Hence, exponent α is important to understand the encoding of the spectrum and also to analyze the average irregularity and the intermittency of the signal in the series. MF-DFA is the most widely used approach to estimate the singularity spectrum because it generates robust empirical results against non-stationarities or trends in the data.

There are five major steps for the calculation of multifractal detrended FA as follows (Kantelhardt *et al.*, 2002):

(1) Firstly, we calculate the profile of the time series, namely, Y(j). In this stage, standard FA is made based on the random walk theory to determine the fluctuations in each segment of the data (Bunde and Havlin, 1994). It should be noted that when the fluctuation exponent α is identical with the Hurst exponent H, then this means that the series will have the mono-fractal characteristic. The fluctuation exponent α values that can be calculated by standard FA is limited to $0 < \alpha < 1$. The same rules should also be applied for Hurst exponent, H;

(2) Secondly, we divide the calculated profile of Y(j) into Ns = int(N/s) to obtain the non-overlapping segments of equal length s. The results of FA become statistically unreliable for scales s larger than one-tenth of the length of the data. For this reason, FA should be limited by s < N/10 to prevent any inconvenience (Kantelhardt, 2008, 2015-2016). In this way, 2Ns segments are obtained simultaneously;

(3) Thirdly, we compute the local trend for each 2Ns segments based on the least-square fit of the profile of Y(j), respectively. Afterward, the variance of each segment is determined to analyze the trends. Here, typical results for detrended fluctuation analysis (DFA) can be that of the same long-term correlated, short-term correlated and uncorrelated data for each segment. DFA is obviously based on monotonous trends in a detrending procedure. This is achieved by calculating a polynomial trend $y_{v,s}^m(j)$ within each segment ν by the estimation of least-square fitting and also subtracting this trend from the original Y(j) profile, which means detrending. There are different approaches used in the literature (Gu and Zhou, 2006) for fitting procedures such as linear, quadratic, cubic or higher-order polynomials, and the corresponding methods are, thus called MF-DFA1, MF-DFA2, MF-DFA3, . . .;

(4) Fourthly, we obtain the q-th order fluctuation function for the average overall segments. A multifractal analysis is conducted to examine the key characteristics of fractals under different scales based on the q. According to the relevant literature, the selection ranges

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of q is important for computing accurate multifractal characteristics. It should be noted that the generalized q dependent fluctuation functions Fq(s) depend on the time scale s for different values of q. In addition, Fq(s) depends on the order m. By definition, Fq(s) is only defined for $s \geq m + 2$; and

(5) Finally, at the fifth stage; we determine the scaling behavior of the fluctuation functions by analyzing log-log plots Fq(s) vs s for each value of q. Hence, considering the positive values of q, h(q) expresses the scaling behavior of the segments with big fluctuations. In contrast, considering the negative values of q, h(q) expresses the scaling behavior of the segments with minor fluctuations[5]. The Hurst exponent was, firstly, proposed by Hurst (1951) for implementing in fractal analysis in the literature. From now on, the Hurst exponent (H) is one of the well-known statistical measures, which is used to categorize time series in various research fields. The Hurst exponent contributes to generating a scale for analyzing the long memory features and fractality of a time series. H value can be in a range of between 0 and 1. According to the Hurst exponent value, time series can be analyzed in three major categories as follows: the first category is based on the assumption that H = 0.5 meaning that the time series behaves randomly. In the second category, $0 < H < 0.5$ illustrates that the time series is not stable. In the third category, $0.5 < H < 1$ indicates the existence of long memory in the time series. The mean-reverting nature of the time series increases when the Hurst exponent approaches to zero. On the other hand, the strength of the trend increases when the Hurst exponent approaches one. This situation can be interpreted as meaning that the higher the H value is, the stronger the trend becomes. In this respect, the fact that most of the financial and economic series follows the case of H = 0.5 illustrates the existence of a random series while H > 0.5 indicates a trend reinforcing financial time series. Considering the fact that the Hurst exponent provides a scale for predictability, it is possible to use this value for improving the data selection process before forecasting. In this context, time series with higher Hurst exponents can be identified before building a model, which enables better forecasting for prediction.

4. Empirical findings and discussion on the policy instruments for climate change in relation to industrial production

All our empirical analysis is executed by using the R program, i.e. MF-DFA[6] package, 2019. Our empirical findings regarding the fluctuation function show that the scaling properties of the observed time series at the two data sets present a long-range correlation, showing a long-term persistence of the previous state. In other words, the relationship between atmospheric carbon emissions and IPI shows different memory characteristics in different frequency ranges, which are shown in Figure 6. There is a long-range correlation including both small fluctuations and big fluctuations in the observed period for both of the time series. Also, there is a fat tail distribution considering both of the return series. This situation is the major reason for the formation of multifractality. There is a strong q-dependence of H(q), which indicates the strong multifractal characteristics in carbon emissions and IPI data. In addition, the positive Δf values demonstrate that the relationship between these two data set may have a locally increasing trend. Considering the Hurst exponent (in the range of 0.40-0.75) and the multifractal strength of these time series data, there is a long-range correlation between small and big fluctuations shaping the multifractal characteristics of these observed time series data.

These findings confirm the EKC approach for the short and long term. From this point of view, it can be stated that environmentally-oriented policies reveal a successful tendency in terms of production. However, it was found that the increase in production will increase the

Fluctuation function F for q = 2

Hurst exponent

Multifractal spectrum
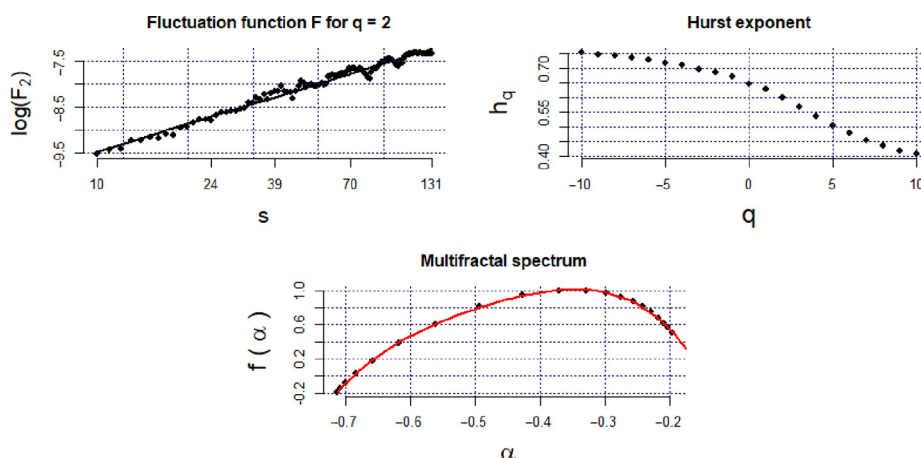
environmental costs in the short term. According to our empirical findings, there may not be any turning point in EKC, instead, there may be different turning points in frequency-based approaches. As a result, it can be stated that the relationship between growth and environmental costs will be in the form of an inverted W, unlike an inverted U-shape i.e. opposed to EKC.

To effectively tackle the problems that may arise as a result of climate change, it will require all countries to make efforts in the common interest. An optimal strategy for shaping the consequences of climate change resulting from industrial production activities will not only need to be quite comprehensive and global in scale but also policies will need to be applicable to the national and local conditions of the given nation and adaptable to the needs of the country. Appendixes 1 and 2 provide an overview of the various policy instruments and time table for carbon pricing that can be implemented in this context, respectively.

5. Concluding remarks

In this paper, the MF-DFA technique is used for the analysis of dynamic behavior of atmospheric carbon emissions and OECD IPI. The empirical findings and test results provide information about the fluctuation in IPI, which determines the main conjuncture of the economy. This study may be of practical and technical importance in regional climate change forecasting, extreme carbon emission regulations and industrial production resource management in the world economy. These results also provide information for the analysis of the environmental cost of the social expenditures, depending on the magnitude of the impact on the total supply.

In this paper, our empirical findings reveal that the industrial production causes long and short term environmental costs. The OECD IPI and atmospheric carbon emissions are found to have a strong correlation between the time domain. However, this relationship does not mostly take into account the frequency-based correlations with the tail effects caused by shocks that are effective on the economy. In addition to the traditional unit root tests, additional unit root tests are applied. The empirical findings of Fourier ADF, Fourier GLS and Fourier LM tests all indicate that the series does not contain Fourier unit root at different frequencies. Fourier KPSS test results support this information in terms of stationarity. In this case, all the unit root test results are important for our study regarding the fact that Kuznets curve provides the information that different behaviors may be at different frequencies. Therefore, different shapes of Kuznets curve

can be observed according to the frequency and time domain of the time series discussed. When the frequency structures in the series are considered, the multifractal detrended cross-correlation approach is applied for analyzing the relationship of the two data at different frequencies to achieve our aim of the study. In this study, the long-term dependence of the relationship between the OECD IPI and atmospheric carbon emissions differs from the correlation obtained by linear methods. The major finding is that the Hurst coefficient is in the range of 0.40-0.75 indicates that the two variables can differ in the frequency domain, depending on their different minimum and maximum current values within the observed period. In addition, our empirical findings confirm the EKC approach for the short and long term.

Notes

1. Within the Paris Agreement, the main goal is decided to restrict the global average temperature increase to under 2°C, and pursuing efforts to 1.5°C before the end of the century, to promote low emission development, to ensure that financial flows will assist emerging countries in fighting the adverse effects of climate change, and finally, to reduce emissions (UNFCCC, 2015). The major role of the emissions trading system in the international climate change framework after 2020 is explained in Article 6 of the Paris Agreement. According to this article, International Emission Trading, Certified Emission Reduction and Emission Reduction Unit will be used by international and domestic markets to fulfill the liabilities of market actors.

2. An externality becomes visible when an economic performer fairly and/or unfairly effects the activities of other economic performers based on her/his production or consumption activities. This means that externalities are dependent on the welfare of some economic performers not only on their own activities but also on activities under the capacity of other economic performers (Tietenberg and Lewis, 2011).

3. Data are reported as a dry air mole fraction defined as the number of molecules of CO_2 divided by the number of all molecules in air, including CO_2 itself, after water vapor has been removed. The mole fraction is expressed as parts per million (ppm). Example: 0.000400 is expressed as 400 ppm.

4. Becker et al. (2006) state that there are some major economic breaks in the literature, such as the 1929 great depression and the oil shocks of the 1970s and the global financial crisis in 2008. However, it took some time to perceive these structural breaks. Fourier forms of unit root tests are preferred in terms of evaluating the breaks in the series as a whole rather than determining the breakage year one by one. It is necessary to make a preliminary test of whether the series contains a trend or to exclude the trend in a non-trend series to increase the power of the test. In such a case, only fixed models are estimated.

5. The MF-DFA approach can only be used for positive generalized Hurst exponents h(q), and it already becomes inaccurate for strongly anticorrelated signals when h(q) is close to zero. In this condition, a modified (MF) DFA technique must be used.

6. This package is used for the MF-DFA, multifractal detrended cross-correlation analysis and the multiscale multifractal analysis. The MFDFA() function proposed in this package was used in Laib et al. (<doi:10.1016/j.chaos.2018.02.024> and <doi:10.1063/1.5022737>). See references for more information. Interested users can find a parallel version of the MFDFA() function on GitHub.

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Appendix 1

Standards, rules and regulations	There should be technological standards to determine the level of reduction in pollution
	There should be performance standards to specify the minimum level requirements to reduce carbon emissions and pollution
Taxes and tariff	There should be a levy imposed to prevent undesirable activities leading to climate change
Cap-and-trade	There should be a system to monitor marketable permits or cap-and-trade systems to limit aggregate emissions. In this way, it is required from each source to hold permits equal to its actual emissions and allow permits to be traded among sources
Voluntary rewards and penalties	There could be an agreement between authorities and one or more parties to achieve green objectives or to improve environmental performance beyond regulatory obligations. To improve the performance, there should be some rewards and/or penalties associated with joining or achieving environmental commitments
Aids and incentives	There may be some tax deductions, supports or aids from a government to an entity for implementing an environmental best practice or performing an action
Public disclosure	There should be public disclosure of environmentally related information. This could be generally from industry to consumers. For instance, labeling programs and rating and certification, etc.
Research and development	There should be an investment in R&D to generate innovation on mitigation to reduce emissions
Non-climate policies	Other policies not specifically directed at emissions reduction but that may have significant climate-related effects

Table AI.
Proposed policy
instruments for
controlling climate
change

Source: Akpan and Akpan (2012)

Appendix 2

Country/region	Starting year	Country/region	Starting year
Finland carbon tax	1990	UK carbon price floor	2013
Poland carbon tax	1990	Shenzhen pilot ETS	2013
Norway carbon tax	1991	Shanghai pilot ETS	2013
Sweden carbon tax	1991	Beijing pilot ETS	2013
Denmark carbon tax	1992	Guangdong pilot ETS	2013
Slovenia carbon tax	1996	Tianjin pilot ETS	2013
Estonia carbon tax	2000	France carbon tax	2014
Latvia carbon tax	2004	Mexico carbon tax	2014
EU ETS	2005	Spain carbon tax	2014
Alberta SGER	2007	Hubei pilot ETS	2014
Switzerland ETS	2008	Chongqing pilot ETS	2014
New Zealand ETS	2008	Korea ETS	2015
Switzerland carbon tax	2008	Portugal carbon tax	2015
Liechtenstein carbon tax	2008	BC GGIRCA	2016
British Columbia carbon tax	2008	Australia ERF safeguard mechanism	2016
RGGI	2009	Fujian pilot ETS	2016
Iceland carbon tax	2010	Washington CaT	2017
Tokyo CaT	2010	Ontario CaT	2017
Ireland carbon tax	2010	Alberta carbon tax	2017
Ukraine carbon tax	2011	Chile carbon tax	2017
Saitama ETS	2011	Colombia carbon tax	2017
California CaT	2012	Massachusetts ETS	2018
Japan carbon tax	2012	Argentina carbon tax	2019
Australia CPM	2012 - 2014	South Africa carbon tax	2019
Québec CaT	2013	Singapore carbon tax	2019
Kazakhstan ETS	2013		

Table AII. Implementation or scheduled time table of carbon pricing

Source: Uludag (2019)

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