2. Asymmetry in the Environmental Pollution, Economic Development and Petrol Price Relationship: MRS-VAR and Nonlinear Causality Analyses

Özgür ERSIN[1]
Melike BILDIRICI[2]

Abstract

The paper aims at assessing the nonlinear relations among the carbon dioxide (CO_2) emissions, petrol prices and the level of economic prosperity in USA and UK for the 1861-2012 and 1871-2012 periods. By covering one of the largest samples, the paper achieves its novelty through the utilization of the Markov-switching based VAR and Granger causality methodologies to provide important insights regarding the shape of the Environmental Kuznets Curve. The selection of UK and USA is not only based on the availability of the largest data, but also on selecting countries that have gone through the stages of economic development in the sense of Rostow. In addition, the impact of the petrol prices is introduced to the environment-income relation. With this respect, the paper achieves a link between the literature of the regime-switching based business cycles and the environmental economics. The empirical findings of the paper show that: (i) the asymmetric impacts of the economic growth rates on emissions cannot be rejected both for the expansionary and for the recessionary periods in both countries in addition to the nonlinear effects of petrol prices, (ii) the nonlinear Granger causality results reveal bidirectional effects in both regimes which hold especially for the USA compared to the UK, (iii) the efficiency of the MRS-VAR models in capturing historical recession dates is confirmed since they coincide with major success to those reported by NBER and ECRI, (iv) the difference in persistence and durations of regimes should be taken into consideration. Within a policy perspective, the practical implications of the paper suggest further improvement in policies directed towards the environmental impact of economic growth in addition to petrol prices in different phases of the business cycles. The MRS-VAR findings also reveal practical implications regarding the shape of EKC: considering the size and the significance of the parameters in different regimes, the inverted U shape does not hold for the USA since the positive effects on emissions dominate in both regimes. In the UK, the negative effect is dominant only in regime

[1] *Beykent University, Faculty of Economics and Administrative Sciences, Department of Economics, Ayazaga-Sariyer, Istanbul, Turkey. E-mail: ozgurersin@gmail.com.*
[2] *Yildiz Techical University, Faculty of Economics and Administrative Sciences, Department of Economics, Davutpasa, Istanbul, Turkey. E-mail: melikebildirici@gmail.com.*

2. The paper also discusses the need of caution due to the shift of production from the developed to the far east - creating a derived demand of world's environmental degradation.

Keywords: Environment economics, environmental Kuznets curve, nonlinear causality, CO_2 emissions, petrol prices

JEL Codes: O44, C24, C41, B23, Q41

1. Introduction

An examination of the literature of the environmental and energy economics conceals that the impacts of national production and income on environmental pollution have been subject to differentiated findings. As a result, important size of research focus on the investigation of the existence of turning points of environmental damages. In addition to the existence of turning points or thresholds, investigation of deceleration of environmental degradation, if exists, has been an important area of research. Accordingly, after accomplishing a specific level of development, the worsening of environmental degradation could be inverted. However, a fraction of the literature also suggests that after passing a threshold level of development, this could even result in the acceleration in environmental degradation. An overall evaluation shows that, for almost half of the countries analyzed, though an inverse-U shape relation cannot be rejected, for many countries analyzed[3], the negative influence of production on degradation is far from being overturned[4]. Another noticed characteristic is the dependency to the empirical method utilized. The majority relies on linear econometric models and their panel regression generalizations, which could also include quadratic or cubic transformations of economic prosperity variables to achieve a nonlinear in variables representation with which the existence of turning points could be evaluated. However, this type of polynomial regressions is limited since they fail to be nonlinear in parameters. As a result, many important insights such as the regime-dependent and asymmetric relations among the variables could not be captured.

The study focuses on the analysis of environment-income relationship with nonlinear in parameters models, namely, the MRS-VAR[5] and nonlinear Granger causality methodologies. Regarding the first strand of the literature which aim at differentiation of the variables used, the paper accepts the utilization of CO_2 per capita and GDP per capita (henceforth, p.c. CO_2 and p.c. GDP) analogous to the mainstream selection of variables. Subsequently, this necessity is also justified by the available CO_2 emissions p.c. data which allows the study to broaden its sample to one of the largest datasets available that covers almost two centuries. There are different measures of emissions in the literature and in the data sources. A detailed evaluation of available data is given in the Annex. Depending on the type of emissions measure, differentiated empirical results are possible. To achieve comparability of the findings of this study with the majority of the literature, the study aims at

---

[3] *The inverse-U association among the level of GNP or GDP with environmental pollution is generally accepted as the EKC hypothesis.*

[4] *Within the literature, not only the selection of the variable that represents environmental damages affect these findings, such as sulfur dioxide (SO_2) or carbon dioxide (CO_2) or their per capita (p.c.) levels, the variables representing the level of economic prosperity, for instance the gross domestic (or national) product (i.e. GDP, GNP) or their p.c. levels or their purchasing power parity (PPP) adjusted variants, also have significant alterations in the empirical findings conducted even for the identical countries.*

[5] *Markov Regime Switching Vector Autoregressive, MRS-VAR (Krolzig, 1998).*

utilizing the approach followed by the seminal papers (Grossman and Kruger, 1991; Stern at al., 1996, Stern & Enflo, 2013; Esteve & Tamarit, 2012) by selecting the p.c. CO_2 emissions from fossil fuels in 1000 metric tons.

The novelty of the paper is based on two main contributions. First one is the method of the study: the usage of a dataset that covers such a long period of time with MRS-VAR type regime switching models. Compared to the commonly used nonlinear models including the STAR and TAR models, the MRS-VAR model allows the determination of the asymmetry in the economic development-emissions nexus with various differences. The model allows the dating of the recessionary and expansionary periods in the economy which provide important information regarding the regime dependent relations between the analyzed variables. Further, another important difference of the MRS-VAR model from the STAR and TAR type nonlinear models is, the model could be easily extended to regime-dependent nonlinear Granger causality analysis which allows, instead of a single regime approach as for the Granger approach being an extension of the linear VAR models, causality investigation not only for the overall sample but also for specific regimes such as the expansionary and recessionary regimes. Second source of novelty of the paper is the incorporation of the effects of the crude petrol prices to the Environmental Kuznets Curve (EKC) literature pioneered by Stern & Enflo (2013) and Stern *et al.* (1996). In these pioneering papers of the EKC, the utilization of historically large span of data covering more than one century is a necessity since the EKC relation is a long-run concept that included the historical phases of development. By investigating the emission-income relation through different phases of the business cycles, the paper aims at capturing nonlinear and asymmetric characteristics of such relation by utilizing the nonlinear econometric approaches of Hamilton (1990) and Krolzig (1998). If an overlook of the results of the paper is to be presented, in contrast to the EKC relation that assumes an inverted U shape with a single threshold or turning point or their two turning point extensions in the literature, the nonlinear dynamics of the relation is continuously altered depending on the phases of the business cycle thus the relation is asymmetric in the sense of a two regime environment. Further, in contrast to linear Granger causality results, the nonlinear Granger causality results reveal regime dependent direction of causality.

Given the above discussion, the aim of the paper is to investigate the nonlinear and regime dependent relations between the p.c. CO_2 emissions and p.c. GDP in the course of business cycles in the USA and UK with an emphasis on the petrol prices in addition to the use of one of the largest datasets available[6]. The motivation of the inclusion of the petrol prices to the relation is as follows. As shown by Hamilton (1990) and Krolzig (1998), petrol prices are a strong force that could trigger the recessionary regimes. Additionally, petrol is an important source of environmental degradation as a result of being a non-renewable fossil-based fuel which is known to have strong impact on the environmental pollution. For this purpose, the study is among the first studies that examines the nonlinear causality between the emissions, petrol prices and economic development with MRS-VAR models to investigate the behavior followed by the variables in distinct regimes that follow Markov chains.

---

[6] *The inclusion of petrol prices is also a necessity for the environment – income relation since though the fossil fuels have been an important factor of energy and production in addition to being consumed at larger amounts as the GDP levels accelerate historically, the dependency to fossil fuels have also been known to possess important implications on the environment. In addition, Hamilton (1990), Krolzig (1998) underlined the impact of petrol prices on the triggering of recessionary and crises periods, for details, see: Bildirici and Ersin (2017 and 2018b).*

In this paper, the selection of the sample is based on aiming at obtaining comparable empirical findings and further contributions by benefiting from the MRS-VAR nonlinear models as detailed above. One important finding is that following the seminal paper of Grossman & Krueger (1991), a large amount of studies aim at benefiting from the utilization quadratic and cubic transformation of the income variables*, i.e.* benefiting from nonlinear in variables models. Once estimated, a quadratic (cubic) model could be evaluated to calculate the turning point (points) to investigate the inverted U shape relation as being postulated by the EKC. Further, the approach is augmented to the analysis of historically large samples that is also in the spirit of the EKC curve that puts forth the relation to be related to the stages of economic development that is expected to cover historically long periods[7]. Within this approach, Stern *et al.* (1996) emphasize the causal associations between the emissions and income levels, while Stern & Enflo (2013) underline the inclusion of the energy consumption (EC) to the relation within a long period of sample of data. Another seminal paper is Esteve & Tamarit (2012), who further emphasize the selection of nonlinear techniques over linear counterparts in environment-income relation and the advantages of nonlinear techniques over their linear counterparts. Compared to the nonlinear in variables models, the MRS-VAR approach utilized in the study allows a significant difference. Instead of assuming one historically measurable level of GDP p.c. or one significant point in time, the MRS-VAR model allows the regime-switching being governed with a probabilistic state variable that allows regime changes through the whole sample. Therefore, the regime changes, if statistically cannot be rejected, aim at the investigation of regime-dependent relations in the emissions-income relation. Further, instead of the determination of a single or double threshold or turning points of GDP p.c. and/or economic growth rates, the method used in the study allows nonlinear dependencies throughout the whole period[8]. Compared to the Esteve & Tamarit (2012) and Stern & Enflo (2013), the inclusion of petrol prices is a necessity within the business-cycle context. The incorporation of petrol prices and investigating their effects on the business cycle and emissions is a necessity to provide a link between the MRS-VAR type investigation of business cycles (Hamilton, 1990; Krolzig & Toro, 2005) with the environmental economics literature that underlines the requirement of large sample sizes (Esteve & Tamarit, 2012; Stern & Enflo, 2013)[9]. Further, as shown by Unruh & Moomaw (1998), the historical dependence between macroeconomic factors and the environment is subject to trajectory changes which cannot be induced into a single or couple of points in history. The historical dependence of the GDP and CO_2 is striking since both of these series are subject to trajectory changes towards new attractors (Unruh & Moomaw, 1998). As shown by Hamilton (1990) and Krolzig (1998), the petrol price shocks

[7] *Supplementary advantage of the MRS-VAR methodology is its extendibility to nonlinear Granger causality to investigate regime specific relations in addition to the overall causal representations.*

[8] *Petrol prices have been shown to contribute to the business cycles by Hamilton (1990) and Krolzig (1998). The study also deviates by following the MS-VAR approach.*

[9] *As of our literature search, Fosten et al. (2012) also follows a historical perspective similar to Stern & Enflo (2013) by evaluating a dataset that starts from 1830's for UK. They follow the non-linear threshold cointegration methodology to evaluate the emissions (CO_2 and SO_2) and income relationship. Our study deviates by incorporating the effects of petrol prices whose impact cannot be neglected on both economic growth cycles not to mention its effect on the environment itself. One important point that is made is that instead of petrol consumption in the economy, due to availability of data, the variations in petrol prices had to be included in the study. The main reason is the unavailability of such data to our knowledge for such a long period of time.*

in the history cause trajectory changes caused by wars, economic crises, changing production techniques, acceleration and deceleration of trade and capital movements etc. once such a historically long period of data is under the investigation. Further, these trajectory changes that trigger discontinuity in the single parameter estimates could also hold for the impact of the GDP p.c. levels on the emissions. By the inclusion of the petrol prices to the relation, the study has also a shortcoming since instead of its prices; the consumption of petrol could be more effective on the emissions. One simple explanation is the unavailability of such a long data for the petrol consumption. However, the reasoning is based on the business-cycle generating effects of the petrol prices. Therefore, the standpoint of the paper is that the petrol prices and the cycles triggered by the petrol price changes have important effects on petrol consumption and therefore on emissions in addition to its effects on business cycles. The main hypothesis to be tested is whether an upsurge (a reduction) in petrol prices could have caused to a deterioration (inclination) in environmental degradation since it could generate a recessionary (expansionary) economic growth regime, *i.e.* decreased (increased) CO_2 emissions in such regimes. Further, historically, the swings in petrol prices have been observed to affect the economic performance. As an example, decreasing petrol prices could stimulate the economic performance by lowering the costs of production, which at the same time puts extra pressure on the environment through increasing emissions[10]. Overall, in addition to its effects on the business cycles, petroleum and fossil fuels themselves are among the key sources of CO_2 releases in the world.

In view of the discussion given above, the novelty of the paper is the investigation of the environment-income relation with MRS-VAR and MRS-VAR based Granger causality analysis that not only allow the dating of recessionary and expansionary regimes, but also the nonlinear relation between the analyzed variables. As a result, the study has three aims. First is to evaluate the nonlinear causal connections among the growth rates of GDP p.c. and CO_2 p.c. in UK and USA for a long span of data. Second is, the petrol prices are included as a third variable to incorporate the Markov switching based business cycle literature with the EKC literature[11]. Third is, the determination of the regime datings and regime-dependent nonlinear causal relations between the analyzed variables to evaluate if the environment-income-petrol price relation is subject to continuous regime changes and nonlinearity instead of the single or double turning points assumed in the literature. Further, since the dataset covers a large span of data which includes many important factors such as world wars, economic crises such as the petrol shocks in the petrol crises in 1970's, the division of the sample space into two or more sub-samples or regimes which include expansionary and

[10] *For a detailed discussion of petrol prices, readers are referred to the Bildirici & Ersin (2013) who suggest the STAR-neural networks-GARCH approach over the GARCH and STAR counterparts to overcome the difficulty in forecasting the volatility in petrol prices.*

[11] *This perspective is also in spirit of Hamilton (1990) that influenced many studies. It should also be noted that in this approach, petrol prices could also be assumed to be a control variable instead of an endogenous variable though the investigation of the effects of such large economies on the petrol price itself deserves attendance. Nevertheless, though the UK's petrol production is comparatively much lower than the USA's, as a major economy with one of the largest GDP's in the Europe, through crude petrol demand of UK, the effects of UK on petrol prices will also be statistically investigated. It should also be noted that though the UK is not among the top petrol producing countries and though UK's petroleum industry could be considered as being dependent to crude petrol imports, the UK is home to many important petroleum companies such as the BP and Shell in addition to being home to well-known refineries including the ExxonMobil and Chevron in addition to Shell.*

recessionary periods is a necessity. With this purpose, the MRS-VAR and MRS-VAR Granger causality approaches will be evaluated for one of the longest datasets available corresponding to 1861-2012 and 1871-2012 periods for UK and USA[12]. Our findings could be summarized as follows. The GDP p.c., emissions p.c. and the petrol price relationships are subject to regime switching characterized with two distinct regimes, i.e. recessionary regimes including the periods of economic crises and expansionary regimes for both UK and USA. For both countries, the MRS-VAR model is efficient in capturing the recessionary period datings being very close to the official datings of the NBER and ECRI. Compared to linear approach, the MRS-VAR based Granger causality results reveal nonlinear causal relations between the analyzed variables for the sample of countries in investigation. Further, in line with the aims of the study, the petrol prices not only have strong nonlinear effects in the creation of business cycles but also on the emission growth rates which are expected to be under the influence of economic production regimes.

The structure of the paper is as follows. In Part 2, the literature will be investigated with an emphasis on the emissions and GDP p.c. relation and the motive behind proposing Markov switching type models to investigate such relation. The MRS-VAR and the MRS-VAR based nonlinear extension of the Granger causality is evaluated in Part 3. The empirical findings regarding the datings of the recessionary regimes, the nonlinearity in the EKC relation and the comparison of the nonlinear and linear causality tests are given in Part 4. Part 5 consists of the discussions and conclusions. Lastly, as noted in the introduction section and as to be underlined in the literature section, the selection of emissions and income variables deserve special attendance especially for our study that aims at utilizing such a long period of sample. As a result, a more detailed explanation of the variables is given in the Annex section.

2. Literature Review

The literature that addresses the relationships amid the economic development and environment intensifies on the effects of GDP on various pollutants such as the CO_2 to test whether the strengthening of pollution is statistically significant as the level of economic progress escalates or whether this type of relationship reverses after attaining a certain threshold. Grossman & Krueger (1991) provides a throughout investigation for environmental impacts of economic activity for 42 countries and they show that pollution increases at low GDP p.c. levels and decreases at higher GDP levels. By using a dataset that corresponds to 137 countries for the 1971-1991 period, Tucker (1995) examines the CO_2 emission and GDP p.c. relation. Even though petrol prices are not added to the relationship, Tucker (1995) notes that the deceleration of emissions in certain periods such as the 1970's should be related to the sharp increases in petrol prices that leads the cost of energy to rise. Unruh & Moomaw (1998) investigates the "income indeterminacy" of the CO_2 emissions in the literature. Their empirical analyses derive the conclusion of applying nonlinear approaches to achieve the throughout explanation of country level pollution, a finding that results from the distinct pattern shifts due to historic events discovery of the hole in the ozone layer, the scientific declaration of the role of CFC gases and petrol price shocks. However, Unruh & Moomaw (1998) point at the importance of petrol shocks which provide an impetus to change the CO_2 emission trajectories.

[12] *Within this approach, the study also aims at being one of the first papers to link the petrol price-economic growth business cycle literature with the environment-economic development literature.*

Further, the majority of studies focus on the evaluation of the EKC hypothesis focus on linear in parameter and nonlinear in variables models. In the seminal paper, Stern et. al. (1996) discuss the restrictions faced by empirical studies aiming at the calculation of turning points in terms of EKC. According to Stern *et al.* (1996), the first problem is the avoidance of simultaneity, *i.e.* assuming the causality flows in one direction from GDP to emissions only, the second is historical alteration of trade and intensification of it and their effects on environment, and the third is the availability and quality of data (Stern *et al.*, 1996, p. 1155). It should be noted that Stern *et al.* (1996) is the earliest, as of our knowledge, paper that suggest the utilization of datasets covering long historical periods due the necessity of the EKC type relation to be tested, since such relation requires countries that had been through various stages of economic growth including industrialization periods, world wars and economic crises. Even though this is the case, combined with the "indeterminacy" critique of Unruh & Moomaw (1998), papers including Stern *et al.* (1996) and Grossman & Kruger (1991) could be considered as linear econometric approaches which focus on the estimation of possible single or couple turning points assuming unidirectional causality flowing from economic prosperity to emissions while underlining the need for further econometric advances to analyze such relationship[13]. Further, there are factors such as the non-normal distribution of world GDP considering that a large fraction of the world is underdeveloped. According to their findings, considering the fact that the continuing deforestation and development of the developing economies and their contribution to the world emissions, analysis of turning points could be misleading (Stern *et al.*, 1996, p. 1157). As a more recent study, Richmond & Kaufmann (2006) investigate the possibility of an inverse-U type effects of energy consumption (EC) and GDP on CO_2 and they also conclude with doubts regarding the existence of turning points in addition to questioning whether the relationship could be continuously positive instead. Such conclusion could also be taken as misleading if the relation between the analyzed variables could be continuously changing within a nonlinear framework due to regime-dependency. Such regime changes could be a function of a threshold variable and its distance to a certain estimate of a threshold (such as those in the TAR and the STAR models) or being a function of an unobservable Markov chain. With such nonlinear approaches, the cycles could be affectively modelled instead of manipulating the dataset by taking their squares and cubes.

A large fraction of recent literature inspects the income-emission relation with more advanced linear econometric methodologies. The recent linear approaches focus on the following techniques: Granger causality, vector autoregression (VAR) models, Johansen cointegration, Engle and Granger cointegration, structural VAR (SVAR), autoregressive distributed lag (ARDL) and panel cointegration. Further, many important papers also aim at incorporating additional variables. Ghosh (2010) applies the ARDL bounds testing accompanied with Johansen–Juselius maximum likelihood procedure to inspect the carbon emissions-economic growth relation by including the energy supply-demand gap and its role for India. Alam et al. (2012) examine the association among economic prosperity, EC, CO_2 and a fourth factor, electricity usage with ARDL and Johansen cointegration tests[14]. Ang

[13] *Nevertheless, the simultaneity problem could be controlled with causality analysis which should be nonlinear and regime dependent since the GDP and therefore the emissions data is subject to regime changes. On the other hand, linear causality analysis avoids the importance of regime-dependent behavior which is also under the influence of economic crises, petrol shocks, wars and policy changes if a large span of data is to be analyzed.*

[14] *Their results designate causality from EC to economic growth without feedback along with the most significant causal links being accepted among development and CO_2.*

(2007) emphasizes the causality between the EC, pollutant gases and national output in France with vector error correction (VEC) models of cointegration. Zhang & Cheng (2009) also employ Toda-Yamamoto tests (TY) accompanied with VEC models to examine the causality among EC, GDP and CO_2 in China for 1960–2007 and their findings are in favor of two one-way causal associations for the long run, from GDP to EC and from EC to CO_2. Wang et al. (2011) examines the pollution and income relationship again with an additional variable, the EC for China[15]. Sanjari & Delangizan (2010) also utilize the VEC and TY tests with a conclusion of causal associations that flow from p.c. GDP towards CO_2 for Iran. Menyah & Wolde-Rufael (2010) validate that simultaneity could be rejected in the opposite way, i.e. not from the GDP to CO_2 but the reverse in addition to two unique causal links from EC to GDP and CO_2 for which the feedback hypothesis is rejected.

Similar to our study, a certain fraction of studies also direct concerns towards the usage of quadratic and cubic terms of GDP to obtain the thresholds or turning points. An important finding is shown by Fodha & Zaghdoud (2010) suggesting that great care is required for assessing the econometric models with two or higher orders[16]. Arouri et al. (2012) inspects the EKC for the MENA countries and their findings exhibit positive effects of EC on CO_2 while the second order terms to achieve the EKC representation is also criticized. Jalil & Mahmud (2009) examine the foreign trade, emissions, growth relation for China with ARDL models with quadratic terms of GDP. Pao & Tsai (2010) is another study that incorporates quadratic terms of p.c. GDP estimate the effects of GDP and EC on emissions for BRIC countries with panel regressions. In their study, homogeneity of the panel is open to questioning in light of the assessment provided for the parameters estimated for the panel and nation specific regressions once investigated. Similarly, Bildirici and Ersin (2018a, b) discuss the shortcomings of indeterminacy in the linear models and to model the complexity of nonlinearity, Bildirici and Ersin (2018a) suggest STARDL model and Bildirici and Ersin (2018b) suggest MS-VAR augmented neural networks models to investigate the CO_2 emissions and economic growth relation in the former and the CO2, growth, petrol relation in the latter for the UK and the USA.

One point that cannot be disregarded is that though studies focus on the usage of quadratic or cubic terms to overcome the shortcomings of the linear techniques, they still tend to avoid the nonlinearity inherent in the processes followed by the series under consideration. Further, the p.c. GDP is known to be nonlinear in different phases of the business cycle. This has important outcomes. In general, the precise epoch of the regime change is unidentified. Further, there is no assurance that the association between GDP and the hazardous gases will take place concurrently with equivalent magnitudes (Fallahi, 2011; Bildirici, 2013). Hamilton (2005) demonstrates that among very important factors, the variables investigated could behave asymmetrically during economic downturns. Further, the petrol crises, the financial crises and sudden shifts in government policies could result in dramatic breaks in

---

[15] They discuss that the significant causality among all of the analyzed variables suggests that emissions in China would not be reduced in recent future since this type of environmental policy would put strong burdens on the country's economic growth rates (Wang et al., 2011, 4870).

[16] To this end, Fodha & Zaghdoud (2010) fit linear models with quadratic and cubic terms of p.c. GDP to a dataset of Tunisia to assess the shape of the EKC and note that the relationship diverges from the inverse-U towards an N-shaped EKC with two turning points, which, if checked with caution, being too close in addition to being unexpectedly low. They conclude that, the CO2-income relationship is in fact a monotonically increasing curve rather than an inverse-U relationship.

the path followed by economic variables (Hamilton, 2005, 2)[17]. By attaining an inference with respect to the regime probabilities, which is conditional on the information set, the possible nonlinear relations between economic and emission variables could easily be investigated.

As discussed above, the stages of business cycles and/or fluctuations in economic growth and regime dependence could have significant impact on emissions. Furthermore, in particular dates, the behavior of the petrol price, economic prosperity and CO_2 might have changed. Above all, crude petrol price is under the influence of many anomalies, which include its drastic shifts resulting from the fluctuations in the financial markets, political factors, OPEC decisions and investor sentiments since the crude petrol is a financial asset traded in spot and future markets (Yu *et al.*, 2008 ; Bildirici & Ersin, 2014)[18]. Most importantly, the connection amid the petrol and economic growth rates is altered especially after the wars and crises which also holds for the relation of CO_2 emissions to these variables[19]. Therefore, it is a necessity to take nonlinearity and the phases of the business cycles into account if the aim to analyze a large span of data consisting of almost two centuries. Similar large sample approaches include Stern & Kander (2013), Stanley *et al.* (2012) and Stern & Enflo (2013) which highlight problems that could be encountered the sample is small, especially for the emissions[20].

As a result of the above-mentioned necessity of nonlinearity, selected number of studies shifted their focus to nonlinear in parameters models to explore the environment-income relation which are intensified around the STAR and TAR models[21]. Yavuz & Yilanci (2013) followed a univariate approach of TAR-unit root tests to investigate possible convergence in CO_2 emissions in G7 countries. Aslanidis & Iranzo (2009) assesses emissions and income p.c. with panel STAR for a set of non-OECD countries for a sample of 1971-1997. Ersin (2016) examines the asymmetric effects of GDP on CO_2 with heterogeneous panel STAR models for selected OECD countries and results are in favor of strong deviations from the EKC hypothesis. With the use of linear and nonlinear STAR causality approaches for Korea, Kim *et al.* (2010) show that the results for the nonlinear variants suggest bi-directional causal

---

[17] *One approach is to utilize the hidden Markov chain (HMC) (Bildirici, 2013). HMC modeling targets at attaining a multiple-regime architecture as an alternative to linear approaches. In the HMC approach, no prior assumptions have been made regarding the shifts in the regime probabilities which have been determined by a stochastic Markov chain (MC). For the estimation of the MRS, the expectation maximization (EM) algorithm and the Hamilton filter, readers are referred to Hamilton (2005). ML estimator (i.e. max. likelihood) estimation is also possible, see Hamilton (1990) and Krolzig (1998). MRS approach provides tools including the dating of the business cycles by the use of an unobserved discrete-state MC to achieve endogenously switching regimes between different regression spaces or autoregressive processes (Krolzig & Toro, 2005).*

[18] *Further, the volatility of petrol prices is also subject to nonlinearity and regime-switches that could impact these relations (Bildirici & Ersin, 2014).*

[19] *Hamilton (2003) states that the dates for which this alteration is in effect. These include the 1956 Suez crisis, 1973 (also is the Arab-Israel War), 1978 Iranian revolution, 1980 Iraq-Iran war, 1990 Persian Gulf war and 2007-2008 Great Recession during which drastic shifts in petrol prices had global impacts (Hamilton, 2003).*

[20] *Stern & Kander (2010) inspect the relations between energy, gross output, labor and capital data in Sweden with a sample of 150 years. Stern & Enflo (2013) apply Granger causality and cointegration to same time period and expose the sensitivity of the econometric tools to sample size, selected variables and the control variables.*

[21] *Acronyms of threshold autoregressive and smooth transition autoregressive.*

effects in contrast to their linear counterparts. Bildirici and Ersin (2017) propose the STARDL model[22] which allows modeling of asymmetric relations in addition to cointegration between CO_2 and GDP for USA. Their results suggest significant impact of economic development on CO_2 and given the transition being governed with CO_2 growth rates, the results deviate from the EKC hypothesis[23].

To our knowledge, a shorter list of studies focus on Markov regime switching models (MRS) to investigate the regime dependent relations between the pollutants and economic growth (Benz & Trück, 2006, 2009; Chesney & Taschini, 2012; Chevallier, 2011; Park & Hong, 2013). The approach followed in this study is also differentiated in terms of the modeling and determination of nonlinear causality[24] which could either be bidirectional or unidirectional in specific regimes or in all regimes. With the use of the MRS-VAR approach, regime-dependent causality, the determination of regime durations, regime datings are the additional contributions. Further, the analysis aims at providing a comparative perspective by analyzing USA and UK simultaneously.

3. Empirical Methodology

The study consists of several steps. The empirical methodology consists of two different approaches based on two different fields. These two different fields are MRS-VAR and causality. The approaches will then be obtained by merging these different fields to yield two different techniques: MRS-VAR, MRS-VAR Granger causality to investigate the characteristics under distinct regimes. As a result, MRS-VAR modeling is preferred to determine economic regime changes through MC. The direction of causality is determined for different regimes with MRS-VAR causality approach.

3.1. MRS-VAR Models

Hamilton (1990) provides a nonlinear approach based on MC for estimating nonlinear relations. The MRS-AR[25] and their generalization to VAR models to achieve the MRS-VAR model could be studied following the seminal papers of Hamilton (1990), Krolzig (1998) and

---

[22] *Smooth Transition Autoregressive Distributed Lag.*

[23] *In the study, a second best STARDL model is also modeled with economic growth rates as being the transition variable in the spirit of EKC. Bildirici and Ersin (2018) and our current study follows differentiated approaches since instead of a two-variable approach, the effects of petrol prices are also included; all variables are assumed as endogenous instead of modeling emissions only and instead of smooth regime transitions, regime switches are governed with an unobservable MC process. Further differences include modeling UK instead of USA only and the proposal of nonlinear MRS-VAR based Granger causality.*

[24] Causality, if not statistically rejected, could be regime-dependent or could exist for all of the regimes analyzed simultaneously. In all cases, as long as causality cannot be rejected for a certain regime, the overall rejection of causality with linear Granger causality, one could overlook the important causal effects which exist for a certain regime. Therefore, the linear causality analysis is subject to doubts if variables under investigation follow nonlinear processes. As shown by MRS-VAR models could also be extended to MRS-Granger causality to investigate the environmental pollution and energy consumption relation. Bildirici (2013) and Fallahi (2011) are among the pioneering studies of this approach to extend the MRS-VAR to MRS-Granger causality.

[25] *Markov Regime Switching Autoregressive.*

Krolzig & Toro (2005). MRS models are also commonly applied in the energy literature[26]. Various studies conducted by Krolzig investigated MRS-VAR and MRS-VEC[27] to study the business cycles (Clements & Krolzig, 2002; Krolzig, 1998; Krolzig *et al.*, 2000; Krolzig & Toro, 2005). Additionally, Bildirici (2013) and Fallahi (2011) propose the MRS-VAR and MRS Granger causality approach. Following Krolzig & Toro (2005), the MRSIAH(*r*)-VAR(*p*) model is defined as[28]

$$\mathbf{Y_t} = \mu^{(s_t)} + \sum_{i=0}^{i} \omega_i^{(s_t)} \mathbf{X_t} + \varepsilon_t^{(s_t)} \tag{1}$$

where: $\varepsilon_t^{(s_t)} \sim N\left(0, \delta_{s_t}^2\right)$ assumed to follow normal distribution. $\omega_i^{(s_t)}$ is the parameter vector in s_t regimes and $\mathbf{X_t}$ is the input matrix consists of $\mathbf{X_t} = \left(dly_{t-1}, dly_{t-2}, ..., dly_{t-p}, dlco2_{t-1}, dlco2_{t-2}, ..., dlco2_{t-p}, dlp_{t-1}, dlp_{t-2}, ..., dlp_{t-p}\right)$, lagged variables of $\mathbf{Y_t}$ which consists of $dly_t, dlco2_t$ and dlp_t, the GDP p.c. growth rate, the CO_2 emissions growth rate and the petrol price growth rate for the study. $\delta_{s_t}^2$ shows the variance of the residuals in each regime (Krolzig, 1998). $\mu^{(s_t)}$ is the regime-dependent mean, $P = \left\{p_{ij}\right\}$ is the transition probability set where *j,i*=1,2,…,*r* and $P_{ij} = \Pr\left[s_t = j \middle| s_{t-1} = i\right]$; s_t =1,2,…,*r* represents a discrete variable and *r* is the number of regimes and s_t is governed by the MC (Krolzig, 1998),

$$P_r\left[s_t \middle| \left(s_{t-1}\right)_{i=1}^{\infty}, \left(Y_{t-1}\right)_{i=1}^{\infty}\right] = P_r\left\{s_t \middle| s_{t-1}; \Omega\right\}, \tag{2}$$

P_r defines the conditional probability of s_t on s_{t-1} where *r* is the number of regimes. The conditional probability of y_t does not depend on s_{t-1}, as a result, $P(\mathbf{Y_t} | \mathbf{Y_{t-1}}, \mathbf{s_t}) = P(\mathbf{Y_t} | \mathbf{Y_{t-1}})$ (Clements & Krolzig, 2002). s_t is assumed to have the irreducibility and ergodicity property. For a two-regime model, the matrix defining the transition between each regime is stated as[29],

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \tag{3}$$

with the unconditional probability distribution of for p_{ij},

$$p_{ij} = \mathrm{P}\left(s_t = j \middle| s_{t-1} = i\right) \tag{4}$$

---

[26] *Cologni & Manera, (2008), Holmes & Wang (2003) and Bildirici et al. (2009) are among the applications of MRS-AR and MRS-VAR to investigate the effects of the petrol prices on EC.*

[27] *MRS Vector Autoregressive models allow cointegration modeling within MRS-VAR framework.*

[28] *Following their methodology, MRSIAH(r)-VAR(p) stands for Markov Regime Switching Intercept Autoregressive Heteroskedasticity-Vector Autoregressive with r and p showing the number of regimes and lag length in VAR vectors, respectively.*

[29] *The MC is always ergodic and irreducible and an absorbing state does not exist and the ergodicity and irreducibility assumptions are essential to achieve the theoretical properties (Clements & Krolzig, 2002; Krolzig, 1998; Krolzig et al., 2000; Krolzig & Toro, 2005).*

Since the MC satisfies the irreducibility and ergodicity property and as shown by Hamilton (1990), for a two-state MC with p_{ij},

$$P(s_t=1)=\frac{1-p_{22}}{2-p_{11}-p_{22}}, P(s_t=2)=\frac{1-p_{11}}{2-p_{11}-p_{22}} \tag{5}$$

each of which define the regime probabilities. MRS, MRS-AR and MRS-VAR models could be estimated with the EM and ML algorithms[30] and following Hamilton (1990), the EM algorithm has been the dominant approach followed in the literature[31].

3.2. MRS-VAR Nonlinear Granger Causality

Study follows Fallahi (2011) and Bildirici (2013) who obtain the conditions to relate Granger causality relations for the MRSIA(*r*)-VAR(*p*) by generalizing the linear causality approach to MRS. Their practice necessitates the calculation of the MRSIA(*r*)-VAR(*p*) or a MRSIAH(*p*)-VAR(*r*) (Bildirici, 2013). With the use of the statistical significance of the parameters in each vector, the regime specific causality between the variables are evaluated. The model is given as:

$$\begin{bmatrix} dly_t \\ dlco2_t \\ dlp_t \end{bmatrix} = \begin{bmatrix} \mu_{1(st)} \\ \mu_{2(st)} \\ \mu_{3(st)} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \phi_{11}^{(j)}st & \phi_{12}^{(j)}st & \phi_{13}^{(j)}st \\ \phi_{21}^{(j)}st & \phi_{22}^{(j)}st & \phi_{23}^{(j)}st \\ \phi_{31}^{(j)}st & \phi_{32}^{(j)}st & \phi_{33}^{(j)}st \end{bmatrix} \begin{bmatrix} dly_{t-j} \\ dlco2_{t-j} \\ dlp_{t-j} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,st} \\ \varepsilon_{2,st} \\ \varepsilon_{3,st} \end{bmatrix} \tag{6}$$

As a typical, in the vector where dly_t is the endogenous variable, either $dlco2_t$ or dlp_t or both Granger-cause dly_t in the *j*th regime as long as $\phi_{12}^{(j)}$ or $\phi_{13}^{(j)}$ or both are statistically significant. As a result, the MRS-VAR causality test reduces to the following null hypotheses $H_0:\phi_{12}^{(j)}=0$, $H_0:\phi_{13}^{(k)}=0$ (Fallahi, 2011; Bildirici, 2013).

4. Dataset and the Empirical Results

4.1. Data

As noted in the introduction and in the literature section, the selection of the variables could result in differentiated empirical findings. Therefore, the study aims the use of the emission variable utilized by the majority of the literature focusing on a similar historical perspective for comparative purposes. A detailed evaluation of the available datasets are discussed in the Annex section. To obtain a large span of data, this study utilizes annual data for the UK and the USA. The per capita CO_2 data for both countries are taken from the Gapminder database which collects the emissions data from CDIAC database[32]. In the database, the

[30] *Expectation Maximization and Maximum Likelihood, respectively.*

[31] *In the EM algorithm, parameters of the model are assumed to be under the influence of an unobserved stochastic variable. The algorithm is achieved with following an iterative procedure for t= 1,2,...,T, under the assumption that* $\xi_{it-1}=P_r\left[s_{t-1}=i\middle|\Omega_{t-1};\theta\right]$ *. For the EM algorithm, see Hamilton (1990).*

[32] *CDIAC, Carbon Dioxide Information Analysis Center and its database is available at <http://cdiac.ess-dive.lbl.gov> (Accessed on Nov 2017).*

per capita CO_2 emissions is measured as being from fossil fuels in 1000 metric tons and cover the 1831-2012 period in the 2016 version of the database as the analysis is conducted. However, as discussed in the introduction section, the inspection of the CO_2 per capita data for the USA revealed that the distributional aspects of the data as a time series was very restrictive up to 1871 for the USA due to the rolling estimates for empty observations. The per capita GDP is taken from the Maddison project 2013 database for the USA and for the UK. The Maddison Project 2013 dataset reports yearly data starting from 1800 to 2012 reported in international Geary–Khamis dollars (GK$) in 1990 constant prices. The crude petrol prices are obtained from the British Petrol (BP) Statistical Review of World Energy database stated in US dollars per barrel in current US$. In the BP database, the data starts from 1861 and is collected by BP as: *the 1861-1944 period was stated as being the yearly average per barrel prices, the 1945-1983 period was obtained from the Arabian Light per barrel posted at Ras Tanura and lastly, the 1984-2012 period was noted as the Brent as of date* (BP, 2017). The US Energy Information Administration (EIA) would be another source which reports both the Brent and WTI crude petrol prices, however, their dataset covers the post 1986 period. As a result of the above-mentioned characteristics, and in order to obtain one of the longest available datasets, the analyses in the paper covers the 1871-2012 period and the 1861-2012 period for the USA and for the UK, respectively. The variables are subject to natural logarithms and the per capita GDP, the crude petrol prices and per capita CO_2 emissions are denoted as ly_t , lp_t and $lco2_t$ after logarithmic transformations. The first differences of the variables are denoted as dly_t, dlp_t and $dlco2_t$ which also correspond to the yearly growth rates of the respective variables.

4.2. Empirical Results

The study will focus on the following steps in the empirical section.

1. Investigation of stationarity.

2. Johansen cointegration tests, if variables are integrated of the same order *d* so that they follow I(*d*) processes. In case of the acceptance of no cointegration, the causality tests could still be conducted.

3. After testing for the appropriate architecture of the MRS-VAR model with LL an LR tests, the dating obtained from the MRS-VAR model is evaluated if the crisis years are capture accurately. In addition to the LL and LR tests, if the dating produced by the model coincides with the crisis dates, the model will be accepted.

4. If the Johansen test fails to produce a cointegrated vector, the innovations of the series are used for MS-Granger-Causality. Within this approach, the direction of causality is determined.

4.2.1 Unit Root and Johansen Cointegration Results

At step 1, the variables are examined with the ERS unit root test (Elliott, Rothenberg, & Stock, 1996; Ng & Perron, 2001). The results are reported in Table 1. Accordingly, all variables, i.e. lyt , lpt and lco2t follow I(1) processes and become stationary once they are first differenced. At step 2, linear cointegration between lyt , lpt and lco2t are evaluated and the Johansen test results are reported. The Johansen cointegration test aims at testing the null of no cointegration against linear cointegration of order 1 and the test is iterative for higher orders. The results indicate that the null of no cointegration cannot be rejected. As a result, to achieve the MRS-Granger causality, MRS-VAR models will be estimated.

Table 1

ERS Unit Root and Johansen Cointegration Test Results

Unit Root Tests: UK				
Variables:	Mza	MZt	MSB	MPT
ly_t	-4.52103	-1.41844	0.31374	5.58787
dly_t	-30.4653	-3.78951	0.12439	1.15637
$lco2_t$	-3.21392	-1.23610	0.38461	7.59019
$dlco2_t$	-33.9298	-4.08820	0.12049	0.81449
Unit Root Tests: USA				
ly_t	-2.4006	-0.51088	0.41356	5.62078
dly_t	-61.5797	-5.53101	0.08982	0.43994
$lco2_t$	0.53150	1.87574	3.52916	709.259
$dlco2_t$	-69.9184	-5.90481	0.08445	0.36786
Unit root tests for petrol prices †				
lp_t	12.2986	10.0387	0.81624	153.562
dlp_t	-13.9093	-2.99015	0.15501	6.31020
Asymptotic critical values				
1%	-13.80	-2.58	0.174	1.78
5%	-8.10	-1.98	0.233	3.17
10%	-5.70	-1.62	0.275	4.45
Johansen Cointegration Test				
UK			USA	
For r=0, τ = 25.62; for r≤ 1, τ = 9.46, for r≤ 2 τ =0.014			For r=0, τ=25.18, for r≤ 1, τ=10.05, for r≤ 2, τ=1.23	

Notes. † lp_t shows the logarithms of petrol prices and the petrol price series will be utilized for both of the models for USA and UK. τ represents the trace statistic. Critical values for the Johansen cointegration tests at 5% significance level are 29.79, 15.49 and 3.84, respectively.

4.2.2. MRS-VAR Results

For the MRSIAH(*r*)-VAR(*p*) models, the optimum number of regimes (*r*) is selected with sequential Chi-square tests and the optimum number of lag length (*p*) is selected with AIC information criteria. Accordingly, the chosen *r* is 2 representing the recessionary and expansionary regimes for both of the countries analyzed. The optimum *p* is selected as 8 for the UK and as 5 for the USA[33]. The results suggest that in terms of durations of each regime, the expansionary regime (Regime 2) dominates the recessionary regime (Regime 1) so that the expansionary periods correspond to a larger part of the sample space as expected[34]. At the first stage, the business cycle datings will be shortly evaluated. At the second stage, the estimated models will be examined.

[33] *Following Krolzig (1998), a linear VAR is tested under the null against a 2 state MRS-VAR. The test is repeated for a set of MRS-VAR architecture that allow the regime specific intercept (MRSI-VAR) or autoregressive parameters (MRSIA-VAR) or variances (MRSIAH-VAR) simultaneously. MRSIAH-VAR is selected as the optimum model since the calculated LR test statistic is the largest, compared to the critical χ^2. The results are not included to save space but are available upon request.*

[34] *The probability matrix of transitions approves the stationarity of each regime. As shown by (Hamilton, 1990, 2005), ergodic transition probabilities matrices ensure covariance-stationarity.*

4.2.2.1. Business Cycle Characteristics

The MRSIAH-VAR models allow the dating of the recessionary and expansionary periods for each country which define the business cycles in UK and USA. The results are reported in Table 2a and 2b for UK and USA, respectively. For comparative purposes, the official recession dates reported by NBER for USA and by ECRI for UK are also listed. Since the data covers a larger period than is reported by the ECRI historically, the Wikipedia recession dates are used to fill the empty spaces on the table for roughly the pre-1950's for UK. The crisis dating results of the model for the UK track fairly well the crisis dates given by Wikipedia and the ECRI (see Table 2a). In Table 2b, the crisis dating results obtained by the MRSIAH-VAR model for the USA match efficiently to the official recession dates. The results also approve the ability of the MRS-VAR models to capture the recessionary periods for each country.

Table 2a

Analysis of Recession and Crises Dates for UK, 1861-2012 Period

Wikipedia Dating		MRS	ECRI
Long DEP	1873-96	1871:1 -1873:1	*na*
		1883:1 - 1886:1	
		1892:1 - 1893:1	
1919-21, DEP	1919-21	1919:1 - 1921:1	*na*
Great DEP	1930-1931	1931:1 - 1933:1	*na*
1956, R	1956 Q2-Q3	1956:1 - 1956:1	1957:02-1958:4*
1961, R	1961 Q3-Q4	1960:10-1962.1	1962:3**
Mid-1970's, R	1973Q3 – 1974Q1 and 1975Q2-Q3	1974:1 - 1975:1	1974:09-1975:08
Early 1980's, R	1980:1 – 1981:1	1979:1 - 1982:1	1979:06-1981:05
Late 2000's, R	2008Q2- 2009Q3	2009:1 - 2010:1	2008:05-2010:01
Double trough R	2011Q4 2012Q2	2012:01-2012:07	2011:5**

*Notes. R and DEP denote Recession and Depression, respectively. ECRI is the Economic Cycle Research Institute business cycle periods. *In ECRI reports, dating for UK start just after the finishing of 1956 recession. Here, the reported first dating, 1957:02-1958:4 does not represent the crisis date; instead, it is the peak and trough dates after the 1956 recession. ** Trough date is reported only. Source: ECRI, [https://www.businesscycle.com/download/report/3675] (01.15.2015)*

Table 2b

Analysis of Recession and Crises Dates for USA, 1871-2012 Period

NBER Dating and Historical Crises		MRS	NBER Dating and Historical Crises		MRS	ECRI*
The Long D and the P of 1873	Oct 1873 –Mar 1879	1880:1-1881:1	1926–27, R	Oct 1926 – Nov 1927	1926:1-1926:1	*na*
1882–85, R	Mar 1882 – May 1885	1883:1-1883:1	Great DEP	Aug 1929 –Mar 1933	1929:1-1932:1	*na*
1887–88, R	Mar 1887 – April 1888	1888:1-1888:1	1937–1938, R	May 1937 – June 1938	1938:1-1938:1	*na*
1890–91, R	July 1890 – May 1891	1889:1-1890:1	1945, R	Feb–Oct 1945	1945:1-1945:1	*na*
1893 Panic	Jan 1893 – June 1894	1892:1-1895:1	1949, R	Nov 1948 – Oct 1949	1948:1-1949:1	1948:11-1949:10
1896 Panic	Dec 1895 – June 1897	-	1953, R	July 1953 – May 1954	1953:1-1954:1	1953:07-1954:05
1899–1900, R	June 1899 – Dec 1900	-	1958, R	Aug 1957 –April 1958	1957:1-1958:1	1957:08-1958:04
1902–04, R	Sep 1902 –Aug 1904	1903:1-1904:1	1960–61, R	Apr 1960 –Feb 1961	1960:1-1961:1	1960:04-1961:02
1907, P	May 1907 – June 1908	1908:1-1909:1	1969–70, R	Dec 1969 – Nov 1970	1970:1-1971:1	1969:12-1970:11
1910–1911, P	Jan 1910 – Jan 1912	-	1973–75, R	Nov 1973 – Mar 1975	1974:-1976:1	1973:11-1976:03
1913–1914, R	Jan 1913–Dec 1914	1914:1-1914:1	1980, R	Jan–July 1980	1980:1-1980:1	1980:01-1980:07 1980:07-1982:11
Post WWI, R	Aug 1918 – March 1919	1918:1-1918:1	Early 1990s, R	July 1990 –Mar 1991	1991:1-1992:1	1990:07-1991:03
1920–21, DEP	Jan 1920 – July 1921	1920:1-1921:1	Early 2000s, R	March 2001–Nov 2001	2001:1-2002:1	2001:03-2001:11
1923–24, R	May 1923 – June 1924	-	Great R	Dec 2007 – June 2009	2008:1-2010:1	2007:12-2009:06

*Notes. NBER is the National Bureau of Economic Research. *In ECRI reports, dating for USA start after WW II. In the NBER dates, R, P and DEP denote Recession, Panic and Depression, respectively. Sources: NBER, ECRI and authors' own calculations obtained with MRS-VAR models.*

4.2.2.2. MRS-VAR Estimation and MS-Granger Causality Results

The results of the MRSIAH(2)-VAR(8) model for the UK are given in Table 3. The average duration of the recessionary regime (regime 1) is 2.14 years and the expansionary regime is more persistent, for which the average duration is 5.57 years. As a result, the recessionary regimes are dominated by the expansionary regimes in UK. The conditions suggest presence of asymmetry and persistence of the expansions for the UK[1].

The estimated two regime MRSIAH(2)-VAR(8) model has two regimes with three vectors of dly_t, $dlco2_t$ and dlp_t, for which the lag order in each vector is 8, selected with AIC information criterion. Furthermore, it should be noted that the variables dly_t, $dlco2_t$ and dlp_t are innovations of p.c. GDP, p.c. CO_2 and petrol prices since they are in log-first differences. In the first vector of regime 1(dly_t vector), the majority of the parameters are statistically significant. As a result, in regime 1 (recessionary regime), the effects of petrol price and p.c. CO_2 innovations on p.c. GDP growth rates cannot be rejected. In regime 2, among the modeled parameters, the parameter of the first lag of CO_2 emission innovations has significant impacts on p.c. GDP, while the effect of petrol price innovations cannot be accepted.

The second vector in each regime is $dlco2_t$, the innovations of p.c. CO_2. In regime 1, if the parameter estimates and the statistical significance of the parameters are examined, the accumulated effect[2] of GDP on CO_2 is positive. As a result, innovations of both p.c. GDP and petrol prices have positive effects on p.c. CO_2. However, in regime 2, a majority of parameters estimated is insignificant for the CO_2 vector. Further, if the significant parameter estimates are analyzed, increases in petrol price innovations and GDP growth innovations have negative effects in regime 2.

The dependent variable of the third vector is dlp_t, the innovations of petrol prices. It should be noted that, at first, one might think that the petrol price is added as a control variable since UK does not have petrol as a natural resource. However, as discussed in Section 1, the petrol companies and refineries of petrol in UK including Shell and BP have major influence on the global economy. Therefore, since UK does not have crude petrol under the land opposed to the USA, UK's economy is highly affected through shocks in crude petrol prices. In regime 1, the majority of the parameter estimates associated with CO_2 and GDP in the petrol price vector are insignificant at 5% significance level. In the expansionary regime (regime 2), however, GDP innovations have positive and significant, CO_2 innovations have negative and significant effects on petrol price innovations.

As pointed out by Bildirici (2013) and Fallahi (2011), the estimation results of the MRS-VAR model could be extended to MRS-VAR based nonlinear Granger causality. In the first vectors (dly_t) of regime 1 and 2, the null hypotheses that $lco2_t$ and lp_t does not cause ly_t are rejected. In addition to the Granger-causality from $lco2_t$, the causality from lp_t to ly_t is also accepted. In regime 2, on the other hand, the null of lp_t does not Granger-cause ly_t cannot be rejected, while the causal link from $lco2_t$ to ly_t is also accepted.

---

[1] *The probability of the switching to an expansionary regime after a recessionary is high, which is estimated as $P(s_t= 2|s_{t-1}=1)=0.4681$. Further, the probability that regime 1 at year t-1 will be followed again with regime 1 at year t (recessionary year followed by another recessionary year) is $P(s_t=1|s_{t-1}=1)=0.5319$ whereas the probability for the opposite, regime 2 followed by regime 2 (expansionary years) is comparatively higher $Prob(s_t=2|s_{t-1}=2)=0.8206$.*

[2] *Accumulated effect of variable x on y is the sum of the parameter estimates which are statistically significant at 5% significance level.*

Table 3

MRSIAH(2)-VAR(8) Model Estimation Results for UK, 1861-2012 Period

	Regime 1			Regime 2		
Variables:	dly_t	$dlco2_t$	dlp_t	dly_t	$dlco2_t$	dlp_t
c	2.19***	-0.19	-1.50	1.30***	2.82***	5.19***
dly_{t-1}	0.65***	0.34**	-0.74*	0.08	0.15*	-0.16
dly_{t-2}	-0.43***	0.01	0.29	-0.06	-0.03	-0.58**
dly_{t-3}	-0.04	0.04	-0.31	0.03	-0.73***	0.02
dly_{t-4}	-0.67***	0.27*	0.49	-0.05	0.11	0.42**
dly_{t-5}	1.01***	-0.28**	-1.30	-0.02	-0.07	-0.08
dly_{t-6}	-0.26**	0.17*	-0.01	-0.04	-0.16*	1.06***
dly_{t-7}	-0.96***	1.60***	1.02	-0.07	0.14*	0.70***
dly_{t-8}	0.25**	0.11	0.19	0.001	0.02	-0.32
$dlco2_{t-1}$	-0.70***	0.69***	0.01	-0.15***	-0.54***	-0.20
$dlco2_{t-2}$	0.28**	0.17	-0.53	0.009	-0.14*	-0.85***
$dlco2_{t-3}$	-0.17*	0.05	0.12	-0.10	-0.08	-0.74***
$dlco2_{t-4}$	-0.24*	-0.71***	0.47	0.07	-0.19***	-0.61***
$dlco2_{t-5}$	-0.21**	-0.45***	1.25*	-0.009	0.05	-1.12***
$dlco2_{t-6}$	-0.09	-0.03	0.54	-0.03	-0.11	-1.18***
$dlco2_{t-7}$	0.42***	-0.55***	0.18	-0.03	-0.16*	-0.85***
$dlco2_{t-8}$	-0.06	-0.30***	-0.16	0.09	-0.04	-0.66***
dlp_{t-1}	-0.02	-0.35***	-0.29*	-0.02	-0.09**	0.34***
dlp_{t-2}	-0.38***	0.42***	0.04	0.04	-0.008	-0.73***
dlp_{t-3}	-0.03	0.13*	-0.17	-0.04	-0.10***	0.19*
dlp_{t-4}	-0.12**	0.29***	-0.21	0.02	0.006	0.03
dlp_{t-5}	0.30***	-0.20***	-0.22	-0.02	0.008	0.09
dlp_{t-6}	-0.21***	-0.24**	0.54***	0.03	0.002	0.11
dlp_{t-7}	0.17***	-0.01	0.05	0.003	-0.002	0.29***
dlp_{t-8}	0.09**	-0.02	0.11	0.02	0.009	0.08
se	0.017	0.047	0.417	0.008	0.005	1.648
LL: 750.9752, Linear system: 790.5755, AIC: -8.2934, linear system: -7.1269, HQ: -6.9631, linear system:-6.4450, LR test of linearity: 320.7995, Chi-Sq(75)=[0.0000]**,Chi-Sq(77)=[0.0000]** DAVIES=[0.0000] **.						
	Prob.	*Duration*		*Trans. Prob.*	*Reg. 1*	*Reg. 2*
Reg. 1	0.2771	2.14		**Reg. 1**	0.5319	0.4681
Reg. 2	0.7229	5.57		**Reg. 2**	0.1794	0.8206

Notes. For the standard deviation terms (se), t-values are not reported. However, testing exclusion of se terms under the null yielded Chi(6)=657.5[0.0000] suggesting acceptance of MRSIAH(2)-VAR(8) model over MRSIA(2)-VAR(8) at 1% significance level.

For regimes 1 and 2, the second vector is the $lco2_t$ vector. The results suggest that, the causal links from ly_t and lp_t to $lco2_t$ cannot be rejected and as a result, both p.c. GDP and petrol prices Granger-cause CO_2 emissions. The third vector in both regimes is the dlp_t. In regime 1, the recessionary regime, $lco2_t$ and ly_t are not Granger causes of lp_t, however, in the expansionary regime, regime 2, the causal links from $lco2_t$ and ly_t to lp_t cannot be rejected. The overall evaluation of the results is that, bidirectional Granger causality cannot be rejected among p.c. GDP and p.c. CO_2 for both of the regimes. Causal links also cannot be rejected from p.c. GDP to petrol prices and from CO_2 emissions to petrol prices in Regime 2.

The results obtained for the USA are shown in Table 4. Similar to the results of UK, the expansionary regime (regime 2) is dominates the recessionary regime (regime 1), as a result, regime 2 is the persistent regime[3].

Similar to the model for UK, the estimated MRSIAH(2)-VAR(5) model for USA consists of three vectors, dly_t, $dlco2_t$ and dlp_t with two regimes. The first vector is for dly_t, in which significant impacts of innovations of petrol prices and CO_2 emissions on economic growth cannot be rejected. In regime 1, at 5% significance level, the overall effect of petrol prices on economic growth is positive though at 10%, the accumulated response sums to -0.03, representing almost zero response of economic growth to petrol price shocks in the recessionary regime. In regime 2, at 1% significance level, the overall effect of petrol prices on GDP growth rates is large and negative and if the 10% significance level is taken, the accumulated response is still negative and is -0.26.

The effects of CO_2 innovations on economic growth are significant in both regimes and are highly asymmetric; negative in regime 2 and positive in regime 1 at 5% significance level. For the purpose of the study, the second vector where $dlco2_t$, innovations of p.c. CO_2 deserves investigation. The overall effect of p.c. GDP innovations on p.c. CO_2 innovations is positive in regime 1 while being negative in regime 2 at 5% significance level. In the recessionary regime, a 1 % increase in the p.c. GDP results in a 0.93% increase in p.c. CO_2 at 1% significance level, however, at 10% significance level, though the effect reduces to 0.34, it is still positive. In the expansionary regime, a 1 % increase in the p.c. GDP leads to a -0.64% decline in p.c. CO_2 at 1% significance level. The overall conclusion suggests that the significant asymmetric impact of economic growth rates on environmental pollution cannot be rejected.

The dependent variable of the third vector is dlp_t, the innovations of petrol prices. It should be noted that USA is among the major petrol producers in the world and the results also confirm the effects of the USA economy on the petrol prices. In regime 1, the overall effect of p.c. GDP innovations of USA on petrol price innovations is negative at 5% significance level suggesting coincidence of economic growth rate inclines during recessions which lead to petrol price declines a negative correlation between economic growth and petrol prices. Contrarily, in the expansionary regimes, a 1% increase in p.c. GDP growth rates result in an accumulated response equal to -0.34% in petrol price innovations, suggesting strong degree of asymmetry between two regimes.

Following Bildirici (2013) and Fallahi (2011), the estimation results of the MRS-VAR model is used to obtain MRS-VAR based nonlinear Granger causality. The 3 vectors in regimes 1 and 2, namely, the ly_t, $lco2_t$ and lp_t could be interpreted for Granger causality. The evaluation suggests that, in the recessionary regime, Granger causality from $lco2_t$ to ly_t and from lp_t to ly_t, cannot be rejected at 5% significance level. Further, ly_t is the Granger cause of $lco2_t$ and

[3] The average durations also confirm the persistency of regime 2 since they are 2.51 years and 4.11 years for regimes 1 and 2, respectively. Note that $P(s_t=2|s_{t-1}=1)$ = 0.3985 and the probability of an expansionary year followed after a recessionary year is not small. Comparatively, the probability of recessionary year followed by another is $P(s_t=1|s_{t-1}=1)$ = 0.6015 and an expansionary year followed by another is much higher: $P(s_t= 2|s_{t-1} = 2)$= 0.7566. The comparison of these also affirms the persistence of each regime while regime 2 is the most persistent. Note that the transition probabilities p_{11}=0.3791 and p_{22}=0.6209 suggest high degree of asymmetry amid the recessionary and expansionary periods of the business cycles in USA.

lp_t. Though the Granger causality from lp_t to $lco2_t$ cannot be accepted for the recessions, the causality in the opposite direction, *i.e.* from $lco2_t$ to lp_t, is accepted at 5% significance level. Accordingly, for the recessionary regimes in the USA, bidirectional causality among p.c. GDP and p.c. CO_2 cannot be rejected while unidirectional causality is accepted among $lco2_t$ to lp_t[4].

Table 4

MRSIAH(2)-VAR(5) Model Estimation Results for USA, 1871-2012 Period

	Regime 1			Regime 2		
Variables	dly_t	$dlco_t$	dlp_t	dly_t	$dlco_t$	dlp_t
c	1.71***	0.64**	1.04	0.93***	1.40***	-1.56**
dly_{t-1}	0.11	0.22	-0.25	-0.55*	0.31*	0.33***
dly_{t-2}	-0.85***	-0.52**	-0.59***	-0.02	0.10	0.32***
dly_{t-3}	-0.21	0.16	0.06	0.77**	-0.64***	-0.33***
dly_{t-4}	0.76***	0.93***	0.001	-0.44	-0.07	0.02
dly_{t-5}	-0.19	-0.59*	-1.04***	0.32	0.07	0.09
$dlco2_{t-1}$	0.05	-0.10	0.38***	0.01	-0.26**	-0.14**
$dlco2_{t-2}$	0.30	0.36**	0.36**	-0.22	-0.07	-0.08
$dlco2_{t-3}$	0.79***	-0.04	-0.01	-0.36*	0.32***	0.12**
$dlco2_{t-4}$	0.18	0.03	0.01	-0.05	-0.08	-0.20***
$dlco2_{t-5}$	-0.04	0.10	-0.10	-0.49**	-0.08	-0.14**
dlp_{t-1}	-0.36	-0.04	0.10	0.31**	-0.24*	-0.17***
dlp_{t-2}	0.24**	-0.15	-0.03***	-0.57***	-0.26	0.05
dlp_{t-3}	-0.27*	0.17	0.35***	-0.07	-0.20***	-0.04
dlp_{t-4}	0.24	0.14	0.07	0.18	-0.06	-0.04
dlp_{t-5}	-0.20	0.09	0.16*	0.25*	0.05	0.04
se	0.028	0.038	0.123	0.048	0.072	1.611
LL: 582.2244, linear system: 510.6084, AIC:-6.9959, linear system:-6.7646, HQ:-6.0339, linear system:-6.2923, LR test of linearity:143.2320.Chi(54) =[0.0000]**.Chi(56)=[0.0000]**.DAVIES=[0.0000]**.						

	Prob.	*Duration*	*Trans.Prob.*	*Reg. 1*	*Reg. 2*
Reg. 1	0.3791	2.51	*Reg. 1*	0.6015	0.3985
Reg. 2	0.6209	4.11	*Reg. 2*	0.2434	0.7566

Notes. For the standard deviation (se) terms, t-values are not reported: by testing exclusion of se terms under the null yielded Chi(6)=470.37[0.0000] suggesting acceptance of MRSIAH(2)-VAR(5) model over MRSIA(2)-VAR(5) at 1% significance level.

Accordingly, the results favor that the causality relations between the analyzed variables are differentiated in the USA and UK. An interesting finding is that, inclusion of the petrol prices to the MRS-VAR models improved the predictive power of the analyzed models for both countries. Additionally, the petrol price shocks not only have statistical impact on GDP p.c. growth rates in both countries, the changes in petrol prices also have significant impact on

[4] *In the expansionary regime, Granger causality from $lco2_t$ to ly_t and from ly_t to $lco2_t$ cannot be rejected at 5% suggesting bidirectional causality among the emission and p.c. GDP. Considering the petrol prices, Granger causality from lp_t to ly_t and from ly_t to lp_t cannot be rejected at 1%, a result in favor of bidirectional causality among the petrol prices and p.c. GDP in the expansions. Additionally, bidirectional Granger causality among lp_t and $lco2_t$ cannot be rejected at 1% in the expansionary periods for USA suggesting lead and lag relations between petrol prices and p.c. CO_2 emissions.*

p.c. CO_2 emissions not to mention the performances of the MRS models improve in terms of regime datings obtained in the models for USA and UK after the inclusion of the petrol prices to the environment-income relationship. The overall results of the paper are in favor of the discussion given in section 1 that aims at the necessity of providing a link between the business cycle literature that suggests that important information could be gathered from the petrol prices in terms of predicting the business cycle and the environmental economics literature that relate national production levels to hazardous environmental pollutions.

5. Discussion and Conclusions

The study aimed at achieving a nonlinear investigation of the relationship between p.c.CO_2 emissions, p.c. income and petrol prices for a historically long span of data for the UK and the USA starting from to the post mid-19th century 1 with the nonlinear MRS-VAR and nonlinear MRS-VAR Granger causality analyses. The novelty of the paper is threefold. i. The per capita GDP and CO2 emissions are subject to nonlinearity during different phases of the business cycle, ii. the nonlinear emissions and income relation is also dependent on the petrol prices, iii. the causal relationship is regime dependent and the nonlinear causality directions deviate from the findings of linear Granger causality analysis, iv. instead of the general approach in the literature that utilize polynomial type regression models which assume single or double turning points in the EKC relation, the relationship is more complex: increased production leading to increased pollution relation is not obtained only before a reaching a certain GDP per capita level; instead, it cannot be rejected most importantly in the expansionary regimes through the phases of the business cycles in the economy.

The historical path of GDP series is subject to disrupt shifts due to factors such as policy shifts, various economic crises and last but not least due to the petrol price shocks in the UK and USA. Petrol is a commodity that has been known to have had significant influence on business cycles. The petrol prices could not only influence the business cycles but it has been an important fossil based and nonrenewable energy source with implications on the environmental degradation.

The nonlinear approach followed in the study based on MRS-VAR and MRS-VAR Granger Causality analyses provide important insights regarding the above-mentioned three-variate environment. Further, the estimated MRS-VAR models led to efficiency in terms of forecasting the recession and crisis cycle dates which coincided closely with the ECRI and NBER recession dates for USA and UK. The dating analysis not only hinted that the MRS-VAR models were capable of predicting the income cycles and regime dependent asymmetric relationships, but the empirical findings also confirmed that the petrol prices and relevant production/income cycles had nonlinear effects on carbon dioxide emissions for the period.

MRS-VAR results for UK showed that, in the recessionary regime, the overall effect of GDP growth innovations on CO_2 innovations were statistically significant and positive. Thus, the GDP growth and petrol price increases both had positive impacts on CO_2 emissions. In the expansionary regime, increases in petrol prices and GDP growth rates had negative effects on emissions. The results for USA showed that the overall effect of GDP growth on CO_2 were positive in regime 1 and negative in regime 2. As expected, as a petrol producer, the USA GDP growth rates had significant and negative effects in regime 1 and positive effects in regime 2 on petrol prices. Further, the petrol price innovations had significant effects on GDP growth rates both in the recessionary and expansionary regimes. The effects of petrol price shocks on CO2 emissions were insignificant for the recessionary regime while being statistically significant during expansions.

Furthermore, the MRS-Granger results for USA suggested that CO_2 emissions and petrol prices were causes of economic growth in both regimes. Considering the impacts of petrol prices and GDP on CO_2 emissions, GDP is measured to be the Granger cause of carbon dioxide emissions in both regimes. For UK, the evidence suggested that petrol prices were Granger causes of GDP p.c. in both regimes. For USA, the GDP and CO_2 emissions were both determined to be Granger-causes of petrol prices. Considering UK, which is not evaluated as a petrol producer at the first sight, given the multi-national petrol companies being originated from UK in addition to their refinery operations in the country, models showed significant interrelations between the petrol prices, the GDP p.c. and the CO_2 emissions. For UK, both the emissions and petrol prices were shown to be Granger-causes of economic growth in regime 1. Most importantly, considering the EKC relationship, both the p.c. GDP of UK and petrol prices were Granger causes of carbon dioxide emissions.

The direction of causality could also be interpreted as playing a role on the determination of the shape of the relationship between the variables analyzed. The findings provided important insights for UK and USA for a large span of data. Accordingly, the acceleration of economic development leads to CO_2 increases, which in turn will show that the inverse U relation fails to hold. The existence of either feedback relation or bidirectional relation would weaken the validity of the inverted U relationship. The results suggested that the parameter estimates and their signs of the respected variables could lead to the result that in both of the countries, the relevant steps in terms of policies were taken against the environmental pollution, however, the bidirectional causality between emissions and GDP growth in UK hinted that UK had been more effective in coping against environmental pollution. For USA, in addition to the bidirectional causality between emissions and GDP, as an important producer and consumer of petrol in the world, USA should consider its petrol policies by taking important steps towards reducing carbon emissions. Both countries are industrialized countries that increased their focus on renewable energy sources starting especially after 1980's. It should be noted that the results are restricted to the emissions and income relationship of the two countries within their borders and, they have had shifted certain level of their industrial production to the developing and emerging economies.

The study has several limitations. First is, the paper focuses on an EKC type relation that requires investigation of countries that underwent the stages of development in the sense of Rostow. EKC type relation dictates the analysis to be conducted for a developed economy, however this should not discourage the researcher to conduct an analysis of emission-income relation for the developing economies. Secondly, the relation requires a large sample covering a historically long period of years. Thirdly, the incorporation of petrol consumption instead of petrol prices could lead to interesting findings however, the availability of data for such a long period is limiting. Lastly, though the nonlinear econometric models are suggested to investigate the environmental impacts of production, similar to the papers evaluated in the literature section, the analysis in this paper is country specific and omits the spillover of pollution from the developed to the developing world. For future studies, the production linkages and shifts in the polluting industries to the developing nations, their effects on the pollutant activities in economies such as China and the incorporation of the pollution-haven hypothesis with the nonlinear analysis of the EKC should deserve special attention.

Though a larger span of data exists, the availability of petrol prices had been restricting. The largest dataset, as of our research, is provided by the British Petrol for the post-1861 period.

To obtain such a long set of yearly historical prices, the BP benefited from three different sources: 1861-1944 period is taken from the USA average yearly prices in current dollars, 1944-1983 period is from the Arabian Light posted at Ras Tanura and the post-1984 period is taken from the current Brent prices obtained from the London stock exchange (BP, 2019). The inclusion of the crude petrol prices in the analysis restricts the dataset to start from 1861 and the last availability of emissions restricts the data to end in 2012 as of the conduct of the analysis in this paper. As a result, the petrol data restricts the dataset to start from 1861 for both UK and USA. Further, our investigation showed that due to rolling estimates for the p.c. CO_2 data for the USA in the pre-1871 period, the sample analyzed is restricted to the 1871-2012 for USA to obtain yearly variability in the time series. These findings are for the 2016 version of the database and do not cover the recent updates. Lastly, as of our research, the availability of the petrol price data could be dated as starting in 1861 which required the estimation of the post 1861 period.

References

Alam, M.J., Begum, I.A., Buysse, J. and Van Huylenbroeck, G., 2012. Energy Consumption, Carbon Emissions and Economic Growth Nexus in Bangladesh: Cointegration and Dynamic Causality Analysis. *Energy Policy*, *45*, pp. 217-225.

Ang, J.B., 2007. CO_2 Emissions, Energy Consumption, and Output in France. *Energy Policy*, *35*(10), pp. 4772–4778.

Arouri, M.E.H., Jawadi, F. and Nguyen, D.K. 2012. Nonlinearities in Carbon Spot-Futures Price Relationships during Phase II of the EU ETS. *Economic Modelling*, 29(3), pp.884–892.

Arouri, M.E.H., Youssef, A.B., M'henni, H. and Rault, C., 2012. Energy Consumption, Economic Growth and CO_2 Emissions in Middle East and North African Countries. *Energy Policy*, 45, pp.342–349.

Aslanidis, N. and Iranzo, S., 2009. Environment and Development: Is there a Kuznets Curve for CO_2 Emissions? *Applied Economics*, 41(6), pp.803–810.

Benz, E. and Trück, S., 2006. CO_2 Emission Allowances Trading in Europe – Specifying a New Class of Assets. *Problems and Perspectives in Management*, 4(3), pp.30–40.

Benz, E. and Trück, S., 2009. Modeling the Price Dynamics of CO_2 Emission Allowances. *Energy Economics*, 31(1), pp.4–15.

Bildirici, M., Alp, E.A. and Bakirtas, T. 2009. The Great Recession and the Effects of Petrol Price Shocks and the U. S. Recession: A Markov-Switching and TAR-VEC Analysis. *Journal of Energy and Development*, 35(1-2), pp.215–277.

Bildirici, M., 2013. Economic Growth and Electricity Consumption: MS-VAR and MS-Granger Causality Analysis. *OPEC Energy Review*, 37(4), pp.447–476.

Bildirici, M. and Ersin, Ö. 2014. Modeling Markov Switching ARMA-GARCH Neural Networks Models and an Application to Forecasting Stock Returns. *The Scientific World Journal*, 2014, pp.1-21.

Bildirici, M. and Ersin, Ö., 2013. Forecasting Petrol Prices: Smooth Transition and Neural Network Augmented GARCH Family Models. *Journal of Petroleum Science and Engineering*, 109, pp.230–240.

Bildirici, M.and Ersin, Ö., 2018a. Economic Growth and CO_2 Emissions: An Investigation with Smooth Transition Autoregressive Distributed Lag Models for the

1800–2014 Period in the USA. *Environmental Science and Pollution Research,* 25(1), pp.200-219.

Bildirici, M., Ersin, Ö., 2018b. Markov-Switching Vector Autoregressive Neural Networks and Sensitivity Analysis of Environment, Economic Growth and Petrol Prices. *Environmental Science and Pollution Research* 25(31), pp.31630-31655.

British Petrol, 2017. Statistical Review of World Energy Data base. [online] Available at: <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/oil/oil-prices.html> [Accessed on 03.07.2017]

Chesney, M. and Taschini, L., 2012. The Endogenous Price Dynamics of Emission Allowances and an Application to CO_2 Option Pricing. *Applied Mathematical Finance*, 19(5), pp. 447–475.

Chevallier, J., 2011. Evaluating the Carbon-Macroeconomy Relationship: Evidence from Threshold Vector Error-Correction and Markov-Switching VAR models. *Economic Modelling*, 28(6), pp.2634–2656.

Clements, M.P. and Krolzig, H.M., 2002. Can Petrol Shocks Explain Asymmetries in the US Business Cycle? *Empirical Economics*, 27(2), pp.185–204.

Cologni, A. and Manera, M., 2008. Petrol Prices, Inflation and Interest rates in a Structural Cointegrated VAR Model for the G-7 Countries. *Energy Economics*, 30(3), pp.856–888.

Elliott, G., Rothenberg, T.J. and Stock, J.H., 1996. Efficient Tests for an Autoregressive Unit Root. *Econometrica,* 64(4), pp.813-836.

Esteve, V. and Tamarit, C., 2012. Threshold Cointegration and Nonlinear Adjustment between CO2 and Income: The Environmental Kuznets Curve in Spain, 1857–2007. *Energy Economics*, 34(6), pp.2148–2156.

Energy Information Association, 2016. EIA Petroleum and other Liquids Statistics Data base. [online]. Available at: < https://www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm> [Accessed on 03.07.2016].

Ersin, Ö., 2016. The Nonlinear Relationship of Environmental Degradation and Income for the 1870-2011 Period in Selected Developed Countries: The Dynamic Panel-STAR Approach. *Procedia Economics and Finance* 38, pp.318-339.

Fallahi, F., 2011. Causal Relationship between Energy Consumption (EC) and GDP: a Markov-Switching (MS) Causality. *Energy*, 36(7), pp.4165–4170.

Fodha, M., Zaghdoud, O., 2010. Economic Growth and Pollutant Emissions in Tunisia: An Empirical Analysis of the Environmental Kuznets Curve. *Energy Policy*, 38(2), pp.1150–1156.

Fosten, J., Morley, B. and Taylor, T., 2012. Dynamic Misspecification in the Environmental Kuznets Curve: Evidence from CO2 and SO2 Emissions in the United Kingdom. *Ecological Economics*, 76, pp.25–33.

Ghosh, S., 2010. Examining Carbon Emissions Economic Growth Nexus for India: A Multivariate Cointegration Approach. *Energy Policy*, 38(6), pp.3008–3014.

Grossman, G.M. and Krueger, A.B., 1991. Environmental Impacts of a North American Free Trade Agreement. *NBER Working papers,* 3914*,* pp.1-57.

Hamilton, J.D., 1990. Analysis of Time Series Subject to Changes in Regime. *Journal of Econometrics*, 45(1–2), pp.39-70.

Hamilton, J.D., 2003. What's an Oil Shock?. *Journal of Econometrics,* 113(2), pp.363-398.

Hamilton, J.D., 2005. Regime-Switching Models. *The New Palgrave Dictionary of Economics*, 2. Available at: <

http://econweb.tamu.edu/keli/Fall2011_679/Readings/Regime_palgrav.pdf > [Accessed on Jan 2016].

Holmes, M. and Wang, P., 2003. Petrol Price Shocks and the Asymmetric Adjustment of UK Output: A Markov-Switching Approach. *International Review of Applied Economics*, 17(2), pp.181–192.

Jalil, A. and Mahmud, S.F., 2009. Environment Kuznets Curve for CO2 Emissions: A Cointegration Analysis for China. *Energy Policy*, 37(12), pp.5167–5172.

Kim, S., Lee, K. and Nam, K., 2010. The Relationship between CO2 Emissions and Economic Growth: The Case of Korea with Nonlinear Evidence. *Energy Policy*, 38(10), pp.5938–5946.

Krolzig, H.M., 1998. Econometric Modelling of Markov-Switching Vector Autoregressions using MSVAR for Ox. *Oxford University Working Papers, [e-journal],* pp. 1-26. Available at: < http://down.cenet.org.cn/ upfile/28/2006491412164.pdf> [Accessed on Jan 2016].

Krolzig, H.M., 2000. Predicting Markov-Switching Vector Autoregressive Processes. *Oxford University Working Papers, [e-journal]*, pp.1-30. Available at: <http://www.nuffield.ox.ac.uk/economics/papers/2000/w31/msvarfor.pdf> [Accessed on Jan 2016].

Krolzig, H.M. and Toro, J., 2005. Classical and Modern Business Cycle Measurement: The European Case. *Spanish Economic Review*, 7(1), pp.1-21.

Maddison Project 2013, Data base. [online] Available at: <https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2013> [01 May 2019].

Menyah, K. and Wolde-Rufael, Y., 2010. Energy Consumption, Pollutant Emissions and Economic Growth In South Africa. *Energy Economics*, 32(6), pp.1374-1382.

Ng, S. and Perron, P., 2001. Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power. *Econometrica*, 69(6), pp.1519-1554.

Pao, H.T. and Tsai, C.M., 2010. CO2 Emissions, Energy Consumption and Economic Growth in BRIC Countries. *Energy Policy*, 38(12), pp.7850-7860.

Park, J. and Hong, T., 2013. Analysis of South Korea's Economic Growth, Carbon Dioxide Emission, and Energy Consumption Using the Markov Switching Model. *Renewable and Sustainable Energy Reviews*, 18, pp.543-551.

Richmond, A.K., Kaufmann, R.K., 2006. Is There a Turning Point in the Relationship Between Income and Energy Use and/or Carbon Emissions?. *Ecological Economics*, 56(2), pp.176-189.

Sanjari, F., Delangizan, S., 2010. Carbon Emissions and Economic Growth: The Iranian Experience. *SSRN Working papers,* 1635233, pp.1-7. Available at: <http://papers.ssrn.com/abstract=1635233> [Accessed on May 2019]

Stanley, T.D., Jarrell, S.B. and Doucouliagos, H., 2012. Could it be better to Discard 90% of the Data? A Statistical Paradox. *The American Statistician*, 64(1), pp.70-77.

Stern, D.I., Common, M.S. and Barbier, E.B., 1996. Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development. *World Development*, 24(7), pp.1151–1160.

Stern, D.I. and Enflo, K. 2013. Causality between Energy and Output in the Long-Run. *Energy Economics*, 39, pp.135-146.

Stern, D.I. and Kander, A. 2013. The Role of Energy in the Industrial Revolution and Modern Economic Growth. *The Energy Journal,* 33(3), pp.125-152.

Stock, J.H. and Watson, M.W., 1988. Variable Trends in Economic Time Series. *Journal of Economic Perspective*, *2*(3), pp.147–174.
Tucker, M., 1995. Carbon Dioxide Emissions and Global GDP. *Ecological Economics*, 15(3), pp.215-223.
Unruh, G.C., Moomaw, W.R., 1998. An Alternative Analysis of Apparent EKC-Type Transitions. *Ecological Economics*, 25(2), pp. 221–229.
Wang, S.S., Zhou, D.Q., Zhou, P. and Wang, Q.W., 2011. CO2 Emissions, Energy Consumption and Economic Growth in China: A Panel Data Analysis. *Energy Policy*, 39(9), pp.4870-4875.
Yu, L., Wang, S. and Lai, K.K., 2008. Forecasting Crude Petrol Price with an Emd-Based Neural Network Ensemble Learning Paradigm. *Energy Economics*, 30(5), pp.2623-2635.
Zhang, X.P. and Cheng, X.M., 2009. Energy Consumption, Carbon Emissions, and Economic Growth in China. *Ecological Economics*, 68(10), pp.2706-2712.

Annex

The brief description of the dataset and the sources are given in Section 4.1. In this section, a discussion of the selection of data is conducted. As noted in the introduction and as discussed in the literature section, the selection of variables selected in the studies could result in differentiated empirical findings even for the same countries and for the same periods. To obtain comparable results with the majority of the literature, the study aimed at utilizing the most commonly used measures of emissions and income variables. A brief explanation of the data utilized is given in the Data section. As of the year 2019, the updated version of the Gapminder database reports various forms of CO_2 datasets including cumulative CO_2 emissions in tons and its per person versions, CO_2 intensity of economic output calculated in kg's and, CO_2 per person - PPP adjusted for 2010 and/or 2011 constant prices. Additionally, CO_2 emissions resulting from different sources of energy exist: from electricity and heat production, from the consumption of various gaseous fuels and from various forms of economic activity including manufacturing industries and emissions resulting from residential use. The dataset could be again measured in kg's, in metric tons and or in kilo tons. In addition, their fuel-oil equivalent forms are also available. Among these, the largest sample could cover the post 1751 period for the cumulative CO_2 emissions (tons per person). In our study, we utilized the old version of the Gapminder data available. It should be noted that compared to the newly updated version, minor variations in the measurement exists. Further, to obtain variability and good distributional aspects of data, a better selection would be to analyze the post 1831 period instead of the post 1751 data since rolling estimations exist for certain periods between 1751-1831. As noted in the introduction section, to achieve comparability with a large amount of studies, the general approach to use the p.c. CO_2 emissions is selected in the current study. The motive is also based on achieving comparability with seminal papers including Grossman & Kruger (1991) and Stern *et al.* (1996) which ignited the investigation of the EKC type relation for a large span of data. One could argue that other nonlinear approaches exist instead of the MRS-VAR approach in the literature such as the TAR and the STAR models. The MRS-VAR approach has further advantages. The TAR and STAR models are also nonlinear in parameters; however, the MRS-VAR approach allows us to provide recession datings and also it could be extended to the nonlinear Granger causality analysis.