Environmental Effects of Fiscal Policy, Oil Production and Renewable Energy in the Presence of the Environmental Kuznets Curve

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ABSTRACT

This thesis primarily aims at analyzing the environmental effects of fiscal policy, oil production and renewable energy consumption in the presence of the environmental Kuznets curve. To this end, this thesis is divided into three different sections. Firstly, the relationship between fiscal policy and CO_2 emissions from different fuel sources is investigated. To ensure robust results, second generation time series econometric procedures which account for multiple structural breaks in the series are employed. The EKC hypothesis is valid in all the four models employed. Results from all four models show that fiscal policy has a positive and insignificant relationship, a negative and significant relationship, a positive and significant relationship and a negative and significant relationship with CO_2 emissions from solid, liquid, gaseous and total sources respectively. Granger causality test with the Toda Yamamoto and Dolado Lutkepohl procedure validates the growth hypothesis for Thailand.

Secondly, the environmental effect of oil production in 15 oil producing countries is investigated while controlling for the environmental Kuznets curve hypothesis. First and second generation panel econometric techniques validate the presence of cointegration in the adopted model. Estimation results imply a positive relationship between oil production and CO_2 emissions which is robust across all mean based panel estimators. The environmental Kuznets curve hypothesis (EKC) is validated in two of the three specified mean based estimators. Quantile regression results show that the EKC hypothesis is significantly valid only at higher emission countries while oil production has a significant positive relationship with CO_2 emissions only at lower emission countries.

Lastly, the relationship between renewable energy consumption, energy prices and CO_2 emissions is investigated for the group of seven (G7) economies. Panel and country specific cointegration tests validate the presence of cointegration for all countries and at the panel level. Estimation results show that renewable energy and energy prices both have negative relationships with CO_2 emissions at the panel level. At country specific levels, energy price abates CO_2 emissions in all the G7 countries. Only in the UK and Italy is there a significant and robust CO2 abatement effect of renewable energy consumption.

Keywords: Fiscal policy, oil production, renewable energy, cointegration, environmental Kuznets curve.

ÖZ

Bu tez öncelikli olarak, çevresel Kuznets eğrisi varlığında maliye politikasının, petrol üretiminin ve yenilenebilir enerji tüketiminin çevresel etkilerini analiz etmeyi amaçlamaktadır. Bu amaçla, bu tez üç farklı bölüme ayrılmıştır. İlk olarak, maliye politikası ile farklı yakıt kaynaklarından kaynaklanan CO2 emisyonları arasındaki ilişki incelenmiştir. Sağlam sonuçlar elde etmek için, serideki çoklu yapısal kırılmaları hesaba katan ikinci nesil zaman serisi ekonometrik prosedürleri kullanılır. EKC hipotezi, kullanılan dört modelde de geçerlidir. Dört modelden elde edilen sonuçlar, maliye politikasının, sırasıyla katı, sıvı, gaz ve toplam kaynaklardan kaynaklanan CO2 emisyonları ile pozitif ve önemsiz bir ilişki, negatif ve önemli bir ilişki, pozitif ve önemli bir ilişki ve negatif ve önemli bir ilişkiye sahip olduğunu göstermektedir. Toda Yamamoto ve Dolado Lutkepohl prosedürü ile yapılan granger nedensellik testi Tayland için büyüme hipotezini doğrulamaktadır.

İkinci olarak, 15 petrol üreticisi ülkedeki petrol üretiminin çevresel etkisi çevresel Kuznets eğrisi hipotezini kontrol ederken incelenmiştir. Birinci ve ikinci nesil panel ekonometrik teknikleri, kabul edilen modelde eşbütünleşme varlığını doğrular. Tahmin sonuçları, tüm ortalama bazlı panel tahminciler arasında dayanıklı olan petrol üretimi ve CO2 emisyonları arasında pozitif bir ilişki olduğunu göstermektedir. Çevresel Kuznets eğrisi hipotezi (EKC) belirtilen üç ortalama tahmin ediciden ikisinde doğrulanmıştır. Kantil regresyon sonuçları EKC hipotezinin sadece yüksek emisyon ülkelerinde önemli derecede geçerli olduğunu gösterirken, petrol üretiminin sadece düşük emisyon ülkelerinde CO2 emisyonları ile önemli bir pozitif ilişkisi olduğunu göstermektedir.

Son olarak, yedi (G7) ekonomisi için yenilenebilir enerji tüketimi, enerji fiyatları ve CO2 emisyonları arasındaki ilişki araştırılmıştır. Panel ve ülkeye özgü eşbütünleşme testleri, tüm ülkeler için ve panel düzeyinde eşbütünleşmenin varlığını doğrulamaktadır. Tahmin sonuçları, yenilenebilir enerji ve enerji fiyatlarının, panel düzeyinde CO2 emisyonları ile negatif ilişkilerinin olduğunu göstermektedir. Ülkeye özgü seviyelerde, enerji fiyatı tüm G7 ülkelerinde CO2 emisyonlarını azaltmaktadır. Sadece İngiltere ve İtalya'da yenilenebilir enerji tüketiminin önemli ve sağlam bir CO2 azaltma etkisi var.

Anahtar Kelimeler: Maliye politikası, petrol üretimi, yenilenebilir enerji, eşbütünleşme, çevresel Kuznets eğrisi.

DEDICATION

To My Family

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
ARDL	Autoregressive distributed lag
ASEAN	Association of Southeast Asian Nations
BRIC	Brazil, Russia, India and China
CD	Cross-sectional Dependence
CO2	Carbon dioxide
DFGLS	Dickey Fuller Generalized Least Squares
DOLS	Dynamic Ordinary Least Squares
ECT	Error Correction Term
EIA	Energy Information Administration
EKC	Environmental Kuznets Curve
EU	European Union
FDI	Foreign Direct Investments
FE-OLS	Fixed Effects Ordinary Least Squares
FMOLS	Fully Modified Ordinary Least Squares
G7	Group of Seven
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPS	Im Pesaran Shin
IRENA	International Renewable Energy Association
KPSS	Kwaitkowski Phillips Schmidt Shin

MENA	Middle East and North Africa region
MMQR	Method of Moments Quantile Regression
NOx	Nitrogen Oxide
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
PHH	Pollutions Haven Hypothesis
PSTR	Panel Smooth Transition
SBIC	Schwarz Bayesian Information Criterion
SDG	Sustainable Development Goals
SO2	Sulfur dioxide
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VAR	Vector Autoregressive
VECM	Vector Error Correction Model
WDI	World Development Indicators

Chapter 1

INTRODUCTION

Prior to the industrial revolution, energy consumption significantly relied on biomass sources while anthropogenic greenhouse gas emissions occurred at baseline levels. Worldwide economic activity significantly relied on subsistence agriculture which required only rudimentary tools. As technological innovation and mechanization improved following the industrial revolution, the scale of agricultural and industrial productivity soared at the expense of the environment. For instance, one of the earliest and most profound events that came about as a result of industrial pollution was observed during a smog episode in 1952 London, England (see Bell *et al*, 2008). The said episode is speculated to have led to the loss of between 4000-12000 lives due to respiratory related health issues. Short-term effects of this magnitude are not observed regularly however it's been projected that if the present tempo of utilizing fossil fuel is sustained to the distant future then the outlook for the climate is not very optimistic. (See Dyson, 2005). Sustainable production practices require that output is generated at very minimal expense to the environment in order to circumvent the potential long-term catastrophic effects on climate and wellbeing. However, due to the capital costs associated with the development of non-fossil alternative energy sources (Eren *et al*, 2019; IRENA, 2015) and the potential revenue loss to governments with a high dependence on fossil fuel exports— the world energy mix is significantly dominated by fossil fuels at the expense of renewables. These developments have led to the adoption of the United Nations Framework on Climate Change in 1992. The treaty sets non-binding targets on greenhouse gas (GHG) reduction for mostly developed countries. It later went into force in 1994. The treaty became an offshoot for the 1997 Kyoto protocol which set legally binding targets for developed economies to reduce their GHG emissions within the periods 2008-2012. The United Nations Climate Change Conference was later set-up in 2010 and an agreement was reached stating that; relative to pre-industrial levels —global warming should not be allowed to exceed a 2.0 °C ceiling. Later on in 2015, the Paris agreement — which further reduced the allowed global warming ceiling from the 2.0 °C level agreed upon in the Kyoto protocol to a new 1.5 °C ceiling was adopted and later went into force in 2016. These international agreements have shown that the threat to the climate is an internationally recognized phenomenon. As such, there is a need to incorporate environmental policies into the overall fiscal policy framework of world economies.

Lopez *et al* (2011) as well as Halkos and Paizanos (2013) have uncovered a pollution mitigation effect for fiscal policy in the fiscal policy pollutant emissions nexus. Other studies however support the reverse scenario (Bernauer and Koubi, 2006; Yuelan *et al*, 2019). This may be because fiscal policies are primarily dependent on government interests which in some countries may not be oriented towards environmental quality. The need to curtail the emissions of GHG's may come up with a lot of difficulties because sustainable environmental policies require sacrifices from countries that are dependent on fossil fuel both as a fuel source and as a revenue source. The fossil fuel market is unarguably the biggest commodity market in the world, crude oil alone had a market demand of about 1.7 trillion US Dollars in 2015(IEA, 2019a,b). Thus, a campaign to limit its use would more likely be met with resistance by market stakeholders. This would have strong implications for long-run environmental sustainability. Gavenas, Rosendahl and Skjerpen (2015) discover that emissions intensity in Norwegian oil fields increased with declining field extraction. This is due to the higher energy requirement of extracting oil from fields in the decline. Their findings also show that a field's share of oil in total oil and gas reserves significantly increased emission intensity. This goes to show that oil production activities can significantly affect environmental degradation in oil producing countries. Ironically though, the resource curse literature has shown that countries that are more dependent on oil revenues tend to have lower income levels relative to countries that do not (Sachs and Warner, 1999) — a situation that arises due to the Dutch Disease (Corden and Neary, 1982). Consequently, oil dependent economies first need to diversify their revenue base. By so doing, they can attain the much-needed capital to switch to cleaner and more sustainable energy sources. Also, economic diversification can lead to less reliance on oil extraction which may significantly improve environmental quality. Furthermore, exploitation of fossil fuels has been shown to follow an environmental Kuznets curve. Esmaeili and Abdollahzadeh (2009) find in their study that oil exploitation is amplified at lower income levels and moderated at higher income levels. This may be because oil producing economies at higher income levels have more diversified economies relative to their low-income counterparts — which results to their reduced dependence in oil production. As such switching over to cleaner energy sources as well as the reduction of production generated CO_2 emissions would require capital costs and capital losses on the scale that only developed countries could manage. This has also largely been corroborated by the large EKC literature that was kick-started by Grossman and Krueger (1991, 1995) which stipulates that environmental degradation is amplified at lower income levels and mitigated at higher income levels. As implied by Copeland and Taylor (1996), the Grossman and Krueger EKC hypothesis wherein CO_2 emissions follows a downward trend after income passes a specific threshold is not market-driven but government induced. As a result, this income induced technique effect can only become a reality if the government is willing to set up stringent environmental policies targeted at curbing pollutant emissions. The motivation of government to set up policies that would abate pollutant emissions depends to a large extent on the opportunity costs of setting up such policies. Narbel (2013) have shown that income significantly influences the adoption of new renewable electricity generation technologies in a cross section of 107 middle and high income economies. This further goes to show that higher income countries may be in a better position to switch from fossil fuel to cleaner energy in a bid to enhance environmental sustainability. This feat can slowly be attained by a fiscal policy that encourages the taxation of fossil fuel energy use and products while making grants and subsidies available for renewable energy investments (Eren *et al*, 2019). However fiscal policy greatly depends on the economic situation of a particular country as it may prove to be emissions abating or emissions increasing depending on the development needs of such a country. The taxation of fossil fuel products as mandated by fiscal policy may have significant impact on its pricing which in turn may reflect on environmental quality. The emissions mitigation effect of energy prices has been documented by Balaguer and Cantavella (2016) as well as Al-mulali and Ozturk (2016) and may be a very efficient way of curbing the intensity of carbon emissions.

What can be immediately perceived from the foregoing developments is that fiscal policy, oil production and renewable energy represent the 3 most critical factors in the quest for sustainable energy sources. All the aforementioned variables are inextricably linked because renewable energy represents a cleaner and more sustainable alternative to fossil fuels while the switch to cleaner energy sources can only be implemented by an effective fiscal policy framework. However, oil production represents the biggest threat to sustainable energy sources because of its very large market and the array of products that can be refined from its crude form. To countries endowed with this natural resource it represents a viable form of government revenue and thus greatly influences the fiscal policy framework of these countries. Thus, the primary objective of this research is the heterogeneous analysis of the environmental impact of fiscal policy, oil production and renewable energy while controlling for the environmental Kuznets curve hypothesis. In order to fulfill the study objectives, the thesis will be divided into 3 different essays underlining 3 different case studies within the environmental Kuznets curve framework which are: The nexus between fiscal policy and CO_2 emissions from different fuel sources in the net oil importing economy of Thailand; the nexus between oil production, CO_2 emissions and the environmental Kuznets curve of 15 oil producing countries; and the nexus between renewable energy consumption, energy prices, trade and CO_2 emissions in G7 countries. These different case studies would help to answer some very germane questions in the energy environment nexus literature of which are:

Firstly; to what extent can the fiscal policy of an emerging economy affect the usage of different fossil fuels? What is the long-run environmental implication of fiscal policy initiatives towards different fossil fuel sources? A few studies have empirically analyzed the nexus between fiscal policy and pollutant emissions (for instance, Bernauer and Koubi, 2006; Katircioglu & Katircioglu, 2018; Yuelan *et al*, 2019).The present study however uses Thailand which is a net energy importing, newly industrialized economy as a case study. Unlike previous studies, the present study unravels Thailand's fiscal policy effect on different fuel sources in light of its gradual adoption of natural gas as the main energy source and what this implies for total CO_2 emissions. The study also controls for the possible effects of multiple structural breaks in the dynamic equilibrium relationship by employing a cointegration test that allows for an unknown number of structural breaks (Maki, 2012). This is done in order to circumvent the potential distorting effects of intercept and regime shifts occasioned by various economic shocks which generate outliers in the data generating process of the variables. Therefore, the instrumentality of fiscal policy in pollution abatement through its heterogeneous effects on heterogeneous fossil fuel sources with varying degrees of carbon content is unraveled by the empirical analysis. The first section of this thesis therefore contributes to the literature by filling this gap.

Secondly, due to the fact that crude oil constitutes about 53% of world energy consumption as at 2016 (IEA, 2019b) and is unarguably the biggest commodity market in the world it would be interesting to analyze the environmental effects of oil production in oil producing countries. The second section of this thesis would then help to throw more light on the heterogeneous effects of oil production on the environment of different oil producing countries at different stages of development. This is done by employing the novel Method of Moments Quantile regression framework of Machado and Silva (2019). This allows for the analysis of the effect of oil production on the conditional distribution of CO_2 emissions. Several key questions are answered from this section which are; what is the nature of the relationship between oil production and CO_2 emissions; is this relationship homogenous or heterogeneous across oil producing countries at different stages of development? What is the nature of the income CO_2 emissions relationship; is this relationship consistent across all quantiles of the conditional distribution? Across the conditional distribution of CO_2 emissions, to what degree is the resource curse visible when comparing the separate effects of oil production and income on CO_2 emissions? Most empirical studies on natural resources generally concentrate on the economic effects of the resource trade *vis-à-vis* the resource curse hypothesis (Corden and Neary, 1982; Matsuyama, 1992; Sachs and Warner, 1999) Other studies that analyze the environmental effects of crude oil (Balaguer and Cantavella, 2016; Al-Mulali, 2011; Saboori *et al*, 2016;) concentrate on demand side effects (price and consumption). This study differs from previous studies in that it analyzes the crude oil – CO_2 emissions relationship across the conditional distribution of CO_2 emissions within the supply domain (production).

Finally, the last section of the study makes an empirical analysis of the dynamic heterogeneous effect of renewable energy consumption and energy prices on CO_2 emissions in a panel of the G7 countries. The study employs panel and country specific time series cointegration and estimation techniques for the empirical analysis. Key questions which are answered by the study are: What is the nature of the long run equilibrium relationship between renewable energy consumption, energy prices and CO_2 emissions in the panel of G7 countries; do these panel relationships hold when each individual member of the G7 is separately analyzed? This study differs from previous ones (for instance Balaguer and Cantavella, 2016; Al-mulali and Ozturk, 2016) in that it separately analyzes the renewable energy CO_2 emissions nexus in each individual member of the G7 while controlling for energy prices, trade and the environmental Kuznets curve.

This thesis will be arranged in the following structure: Chapter 2 will review the literature on the environmental Kuznets curve hypothesis. In chapter 3 the role of fiscal policy in switching to cleaner fossil fuel sources and the implication to environmental quality is empirically analyzed using Thailand as a case study. In chapter 4 the role of oil production in the environmental Kuznets curve of oil producing countries with particular emphasis to distributional heterogeneity is empirically uncovered. Chapter

5 will ascertain the effects of renewable energy and energy prices on the environment of the G7 countries by employing panel and country specific estimation techniques. Chapter 6 will present the summary and concluding remarks.

Chapter 2

LITERATURE REVIEW

The EKC literature is quite broad and continues to expand. The methodology made its first appearance through the seminal paper of Grossman and Krueger (1991) in which the relationship between per capita GDP and a selected set of pollutants notably SO_2, suspended particles and dark matter was analysed. They employed a pooled cross sectional data, and established both an N-shaped and an inverted U shaped relationship between the selected pollutants and per capita GDP in different model specifications. The inverted U shaped relationship is parallel to that portrayed by Kuznets (1955, 1963) who also put forward a hypothesis of an inverted U shape relationship between the level of income and income distribution (income inequality). Thus, the name "Environmental Kuznets Curve" was adopted to identify the non-linear relationship. Suri and Chapman (1998) have also established an inverted U-shaped relationship between per capita GDP and per capita energy consumption while also controlling for the effects of the export and import share of the manufacturing sector. Their research shows that the quadratic GDP term might be a holistic representation of the structural metamorphosis of the economy from the agricultural sector to the pollution inducing industrial sector, to the less pollution inducing service sector. The structural transformation of an economy might also bring with it modifications in the structure of trade flows as service based economies may have a greater import content relative to industrialized economies which may have a greater export content and may have a part to play in the EKC hypothesis (Stern, 1998; Cole,2004). Trade has also been observed to be one of the noteworthy factors to be considered in the EKC literature. The pollution haven hypothesis (PHH) implies a situation where as a result of less stringency in institutional regulations as regards to "cleaner" production practices in developing countries, industries may tend to absorb "dirtier" industries from the developed countries while the developed countries adopt cleaner production practices due to institutional pressures. An attempt to offer the PHH as an explanation for the EKC hypothesis by a few studies came up with very little evidence (Cole, 2004; Kearsley & Riddel, 2010).

The institutional dimension of the EKC paradigm has also been explored by recent studies. Lau et al. (2018) discovered in their study the pollution abatement effect of institutional quality. Specifically, they revealed that the control of corruption and rule of law diminishes the proliferation of environmental toxins in the high-income countries. This result is in line with Mavragani et al. (2016) which revealed a positive correlation between institutional quality and environmental performance index for a panel of 75 countries comprising the G20 and EU economies. On the contrary, Sulemana et al (2017) while validating the EKC hypothesis in both African and developed economies postulated an insignificant effect of institutions on emissions in both sample of countries. They also discovered a positive effect of democracy on emissions in African countries. Similarly, Usman et al. (2019) recently revealed a negative effect of democracy on CO2 emissions within the periods 1971 and 2014 for India. However, the negative effect was only statistically significant in the short-run. These varied results are indicative of the fact that the institutional effect of pollution mitigation (intensification) may be dependent on a country's level of development. Therefore, development stages of different countries need to be taken into consideration when empirical analysis of this nature is being undertaken especially in panel studies.

Development stages of each country would also reflect in their emissions levels; hence, studies incorporating individual heterogeneity as well as distributional heterogeneity across the conditional quantiles of the pollutant's distribution need to be considered in panel studies. One of such studies is Wang (2013) who employed a dataset of 138 countries within the periods 1971 and 2007 and found that the long run elasticity between income and CO_2 emissions declines across the conditional distribution of CO_2 emissions showing a transition from cross-coupling to relative-decoupling and from lower to higher quantiles. Their result also showed that the short-run adjustment coefficient increases speed and gains more stability as the value of the quantiles increases. This might imply that the income-CO_2 relationship attains steady state only at higher quantiles. Employing data for a different set of pollutants (NOx and SO_2) across 48 States in the U.S within the periods 1929 and 1994, Flores et al. (2014) found an N-shaped relationship between Nitrogen Oxide (NOx) and income, which is only significant from the 1st to 5th quantile. Their result also showed a significantly positive income-SO2 relationship albeit with significant evidence for the EKC hypothesis occurring at only the median quantile. The contrast in the two last reviewed studies may be because of the choice of pollutants and geographical locations. Yaduma et al. (2015) applied the fixed effects panel quantile regression on OECD and non-OECD countries across six geographical regions of the world. Their study uncovered coefficient estimates and EKC characteristics that are disparate across regions. Zhu et al. (2016) also employed the fixed effects panel quantile regression to investigate the impact of income, energy consumption, foreign direct investment (FDI), trade and other control variables on CO_2 emissions in 5 ASEAN countries over the periods 1981 till 2011. The results indicated a significantly positive monotonic relationship between GDP and CO_2 emissions that persists from the 5^{th} quantile up until the 70^{th} quantile. The relationship, however becomes U shaped at the 95^{th} quantile. Mishra et al. (2015) went a step further to augment their model with institutional quality proxied by democracy (Polity 2), democratization and bureaucratic quality in a panel of 127 countries for the periods 1960-2003. Although they found a significantly negative relationship between their proxies for institutional quality and pollutant emissions (SO_2 and CO_2), their income- pollutant emissions relationship evinced different curve characteristics at lower and upper quantiles. Their model also lends credence to the pollution haven hypothesis due to a statistically significant positive trade coefficient across all quantiles.

One of the ways through which institutional and development pressures can affect pollutant emissions is through their effect on energy sources. The need to diversify energy sources can be regarded from two perspectives in the literature: first, the need to protect the environment and second, the need to achieve energy security. Studies on energy security began after the first oil shock of 1973. In the aftermath of the 1973 oil crisis, the literature on energy consumption and economic growth made its debut through the seminal work of Kraft and Kraft (1978). This study investigated the empirical notion of energy and economic growth nexus in the United States. Since then, several studies have adapted their framework — by accounting for different macroeconomic variables with the propensity of influencing the energy-growth relationship. These variables include, *inter alia*, renewable energy (Sadorsky, 2009; Almulali *et al*. 2013; Lin and Moubarak, 2014), financial development (Sadorsky, 2010; Islam *et al*. 2013, Rafindadi and Ozturk, 2016; Shahbaz *et al*. 2017d; Destek and

Sarkodie, 2018), investment (Oh and Lee, 2004; Wang *et al* 2019b) and employment (Ozturk and Acaravci, 2010; Bohlmann *et al* 2019).

Studies with the inclusion of environmental indicators began to gain momentum, due to global warming and climate change. The need to account for the environmental effects of energy consumption triggered the augmentation of standard energy consumption economic growth models with environmental degradation proxied by CO_2 emissions (Ang, 2007; Soytas *et al*. 2007; Soytas and Sari, 2009; Apergis and Payne, 2009a; Khan *et al*, 2019, Wang *et al*. 2016; Sarkodie, 2018; Usman *et al*. 2019; Sarkodie and Strezov, 2019). The augmentation also serves a dual purpose of mitigating the effects of omitted variable bias while analyzing the environmental Kuznets Curve (EKC). This analysis flagged off another strand of studies accounting for the effect of urbanization (Kasman and Duman, 2015; Katircioğlu and Katircioğlu, 2018a; Ahmad *et al*. 2019; Wang *et al*. 2018,2019a), trade openness (Shahbaz *et al*. 2013; Ertugrul *et al*. 2016; Shahzad *et al*. 2017; Rafindadi and Ozturk, 2017), Foreign direct investment (Chandran and Tang, 2013; Sarkodie and Strezov, 2019) and globalization (Shahbaz *et al*. 2017a; Haseeb *et al*. 2018; Rafindadi and Usman, 2019; Akadiri *et al*. 2019). These numerous studies have led to the development of several key hypotheses to explain energy-growth-environmental quality interactions. Most notable of the hypotheses are the conservation hypothesis (Kraft and Kraft, 1978; Ozturk *et al*. 2010; Ocal and Aslan, 2013). Conservation hypothesis identifies a unidirectional causality flow from economic growth to CO_2 emissions. The energy-led growth hypothesis (Altinay and Karagol, 2005; Lee, 2005; Yildirim *et al*. 2014) implies a one-way causality flow from energy utilization to economic growth. The feedback hypothesis (Apergis and Payne, 2009a, b; Apergis and Payne, 2011; Belke, *et al*. 2011; Almulali *et al*, 2013) involves a bidirectional causality between energy consumption and economic growth. The neutrality hypothesis (Payne, 2009; Ozturk and Acaravci, 2011; Yalta, 2011) uncovers no-causality between energy utilization and economic development.

Apart from the above reviewed literature, a plethora of other macroeconomic variables are also considered to be causative factors for CO_2 emissions through various transmission mechanisms. Studies that highlight the fiscal factors as regards to CO_2 emissions proliferation and/or mitigation are quite scarce in the literature. There have been a few studies which propose empirical associations between government expenditure and environmental quality (Frederik and Lundström, 2001; Bernauer and Koubi, 2006; Lopez *et al*. 2011; Halkos and Paizanos, 2013; 2016). Lopez *et al*. (2011) isolated four main transmission mechanisms through which the level and structure of fiscal spending may affect pollution levels, *viz:* scale, composition, technique and income effects. The scale effect is the intensification of environmental pressures as a consequence of increasing economic growth. The composition effect implies the development of human-capital intensive occupations as an alternative to physical-capital intensive industries which deteriorates environmental quality. The technique effect involves improved labor efficiency due to more efficient work procedures. The income effect denotes an increased prioritization and demand for environmental quality as a result of higher income levels. Going backward, Frederik and Lundström (2001) empirically discovered that while economic freedom has a total effect of instigating more CO_2 emissions in high and low-income countries, government size, on the other hand, has a mitigating effect in low-income countries. Bernauer and Koubi (2006) suggested that the only scenario where an expansion in government spending could have positive environmental welfare effects is when the expansion is at the instance of the citizenry by way of public goods demand. Their study shows that the size of government puts a negative pressure on the environment by way of increased SO_2 emissions in a panel of 42 countries over a 26 year period. Halkos and Paizanos (2013) employing data for a panel of 77 countries over a 20 year period analyzed the direct and indirect effect of government spending on two specific pollutants, CO_2 and SO_2. Their findings show that government expenditure has a negative direct impact on SO_2 emissions but has an insignificant effect on CO_2 emissions. They further revealed an indirect negative relationship between government expenditure and SO_2 emissions in low-income countries, an effect which becomes positive as income increases. Lopez, Galinato and Islam (2011) employing a dataset spanning 14 years for 38 countries show that the share of public goods in government expenditure and the size of government has negative effects on SO_2 and CO_2 emissions. Adewuyi (2016) employing a dataset spanning 25 years which consists of variables for most world economies empirically ascertain the effect of public and private expenditure on CO_2 emissions. His findings show that government expenditure which is a proxy for public expenditure has a significant negative total effect on CO_2 emissions in the short run and a significant total positive effect in the long run. Zhang (2017) within the study period 2002-2014 show that China's fiscal expenditure has a negative effect on SO_2 and chemical oxygen demand but has a positive effect on soot.

So far, most of the studies reviewed incorporate energy consumption and a few other macroeconomic variables within the Grossman and Krueger (1990, 1991) standard EKC model. Studies which control for oil production effects are quite rare in the literature. Obohon and Ikeme (2006) show through a decomposition analysis that non-oil producing African countries shifted towards less CO_2 intensive energy systems while oil producing African countries shifted toward more CO_2 intensive energy systems. Their findings also show that energy intensity increased in both group of countries within the study interval. Their findings suggest that the production practices of oil producing African countries are less environmentally sustainable relative to the production practices of non-oil producing African countries. Esmaeili and Abdollahzadeh (2009) employing a dataset that spans the period 1990-2000 show in their study that income has a non-monotonic relationship with oil production as it follows an inverted u-shaped relationship analogous to the EKC. Findings from their study also show that increased freedoms and a better income distribution tends to reduce the rate of oil exploitation.

Energy prices and renewable energy can also be said to be influencing factors in pollutions mitigation especially in advanced economies like the G7. The general concept of environmental degradation vis-à-vis CO_2 and energy consumption nexus has also been investigated for advanced economies (Chang, 2015; Nabaee, Shakouri & Tavakoli, 2015; Shahbaz et al., 2017a). For instance, Al-Mulali and Ozturk (2016) examined 27 advanced economies and found that CO_2 is cointegrated with the real Gross Domestic Product (GDP), non-renewable and renewable energy consumptions, trade openness, urbanization, and the energy prices. The study further showed that GDP increases the CO2 emissions and as well that the inverted U-shaped relationship between the GDP and CO2 emissions exists in the examined panel of 27 advanced economies. , Usman et al. (2019b) using two-step SYS-GMM for the 28-EU countries noted that stimulating environmental performance reduces growth in these countries.

Adding to the evidence of the EKC hypothesis illustrated by Al-Mulali and Ozturk (2016), Balaguer and Cantavella (2016) specifically investigated the EKC hypothesis for Spain over the period 1874-2011. The study found that emissions in Spain in 1950 were 24 times more than in 1874 and that the emissions generated in 2011 were 250 times higher than that of CO_2 emissions in 1874. In the wake of the aforementioned observations, the study also observed that the per capita income of Spain may have attained a certain level, thus causing a decline in CO2 emissions since the per-capita income is observed to have experienced a 50% increase in growth rate in 1950 than in 1874. Importantly, Balaguer and Cantavella (2016) found the validity of the EKC hypothesis for Spain when energy prices were incorporated in the estimation model of the Autoregressive Distributed Lag (ARDL) approach. In addition, the per capita income of the country was observed to have peaked for highest CO_2 emissions in 1980 before Spain started experiencing a decline in CO_2 emissions courtesy of its income growth. However, while Balaguer and Cantavella (2016) employed the real oil prices as the energy price variable, Al-Mulali and Ozturk (2016) employed a weighted average of the index of gas prices, liquid fuel and energy heat prices. Sadorsky (2009) empirically determine the drivers of renewable energy consumption in G7 countries. Findings from their study shows that CO_2 emissions and income has a significant positive relationship with renewable energy at the panel level while oil price has an insignificant negative relationship with renewable energy at the panel level. Country level estimations however showed that apart from income which had a positive relationship which was robust across all countries, estimates for oil price and CO_2 emissions were disparate across countries.

Furthermore, the recent study of Yilanci and Ozgur (2019) employed the per-capita ecological footprint (EF) in lieu of the conventional CO_2 as a proxy for environmental degradation to investigate the EKC hypothesis for the G7 countries. They equally analyzed the income-pollution level nexus in the sub-group periods. As such, the findings revealed the validity of the EKC hypothesis for Japan and the USA whereas the evidence of EKC hypothesis is not valid for the other 5 countries. Meanwhile, Shahbaz et al (2017c) found the validity of the EKC hypothesis only for Canada, France, Germany, Italy, UK, and the USA. Shahbaz et al (2017b) further indicated that the feedback effect between the CO_2 and GDP is significant for France and Italy while a neutral effect was uncovered for Japan. Also, CO2 is observed to Granger cause GDP in Canada, Germany, UK, and the USA. Chiang and Wu (2017) investigated the EKC hypothesis in the panel of G7 countries over the period 1991-2008 by considering potential endogeneity biases. With the implementation of the PSTR approach, the study examined the changes in the elasticity of CO2 emissions with country and time to underpin the elasticity of heterogeneous countries and possible structural breaks on CO_2 emissions. As such, the CO2-real income per capita (GDP per capita) nexus in Japan, UK, and the USA favored the environmental quality while such relationship proves otherwise for the rest of the G7 countries. However, an inverted U-shaped relationship between CO_2 emissions and the real income per capita is validated and that the real income per capita is peaked at 20, 488 USD (United States Dollars). Hence, Chiang and Wu (2017) affirms the regime-switching impact of GDP per capita i.e the EKC hypothesis on environmental degradation vis-à-vis CO_2 emissions in the panel of G7 countries.

Moreover, the role of renewable energy consumption in the context of the EKC hypothesis in the panel of G7 countries has been examined in the recent study of Raza and Shah (2018). Their study found that economic growth (GDP) increases CO_2 emissions, thus causing a reduction in environmental quality, especially in the long run. As regards to the consumption of renewable energy, the study found that the development of renewables in the panel of G7 countries is a significant factor for decarbonization policy in the long run. The study also incorporates trade indicators alongside renewable energy consumption and GDP per capita, the investigation supports the validity of the EKC hypothesis for the G7 countries. Cetin (2018), Shahbaz et al (2017c), and Lau et al (2019) are among other studies that have either examined the EKC hypothesis for panel studies or individual countries within the framework of alternative energy source.

Chapter 3

FISCAL POLICY AND CO_2 EMISSIONS FROM DIFFERENT FUEL SOURCES IN THAILAND

3.1 Introduction

Environmental degradation, energy, and economic growth nexus have received scientific attention within recent times. The choice between economic development and environmental sustainability remains a global dilemma. Since the commencement of the industrial revolution in the 18th century, worldwide economic growth has soared at the expense of environmental quality, a direct result of conventional energy sources employed in the production process. Consequently, economic development, energy, and environmental quality symbolize a trilemma of triad complex systems. Energy consumption relies to a significant extent on the extraction and utilization of fossil fuels since the invention of the first steam engine in the United Kingdom — and prior to that, on a much lesser scale. Nonetheless, population growth, economic development, and contemporary technological innovations have increased the demand for energy in the 21st century. This is at a level quite unparalleled before now. As such, the continuous use of fossil fuel in energy technologies have become a worldwide climate emergency (Dyson, 2005; Rafindadi, 2016; Sarkodie and Owusu, 2016; Sarkodie and Strezov, 2018; Alola, 2019). This emergency led to the formation of the UNFCCC[1] — a non-binding international environmental treaty which was adopted in

[1] United Nations Framework Convention on Climate Change

1992. It entered into force in 1994, after being ratified by a sufficient number of countries. The primary objective of the UNFCCC is the stabilization of the intensity of anthropogenic greenhouse gas (GHG) emissions at levels that guarantee environmental sustainability. A follow-up to this framework is the 1997 Kyoto protocol which set targets for developed countries that are legally binding and the 2015 Paris Agreement which further lowered the legally binding targets that came into force in 2016. The IPCC[2] 5th assessment report further reinforces the need to reduce GHG emissions by emphasizing the long-term ecological impact of sustained global warming even in the 1.5°C range[3] (IPCC, 2018). The development raises the concern to synchronize energy and environmental policies into the overall fiscal policy framework — in order to ensure environmental sustainability while achieving energy security.

The main objective of this study is to investigate the dynamic relationship between fiscal policy, energy consumption and CO_2 emissions from heterogeneous fossil fuel sources within the EKC framework in Thailand by incorporating structural breaks over the period of 1972 and 2014. There happens to be very few studies within the scope of the present research. Studies analyzing the effect of fiscal policy by incorporating both government spending and tax revenue on CO_2 emissions is limited — even though the issue of climate change from GHG's can only be resolved with an adequate fiscal response. Studies like Lopez and Palacios (2010), Halkos and Paizanos (2016) augmented their energy and environmental degradation nexus model with fiscal

[2] Intergovernmental Panel on Climate Change
[3] The 2015 Paris agreement further lowered the legally binding targets of the 2010 United Nations Climate conference from 2.0°C to 1.5°C relative to pre-industrial levels. The IPCC report stresses that even at the 1.5°C range, ecological instabilities such as rising sea levels due to the perceived irreversible loss of the notable Ice sheets could occur over centuries.

spending and tax revenues. One potential deficiency of these studies is the neglect of structural breaks in the fiscal policy-pollutant emissions nexus which has the potential of distorting the long-run parameter values (Gregory and Hansen, 1996; Hatemi-j, 2008). Following Katircioglu and Katircioglu (2018b), the present study examines the long-run relationship between energy, income level, and CO_2 emissions while controlling for structural breaks and testing for the EKC hypothesis. While the Katircioglu and Katircioglu (2018b) study is based on the Turkish economy, the present study is oriented towards Thailand. While Halkos and Paizanos (2016) employed a VAR framework to examine the heterogeneous effect of expansionary fiscal policy on consumption and production generated CO_2 emissions,[4] this study makes a novel contribution of determining the effect of fiscal policy on CO_2 emissions from different fuel sources. This empirical route is taken because of the specific idiosyncrasies of the Thai energy sector. This portends significant implications for total CO_2 emissions in view of the gradual shift towards natural gas as the main source of energy.

Therefore, this study gives a fivefold contribution to the literature. First, the study controls for the twin effects of government spending and tax revenues within a standard EKC model. Thus, the effects of fiscal policy on the environment can be empirically established for the newly industrialized net energy importing economy of Thailand. Second, we employ a relatively recent empiric to examine the effect of fiscal policy on CO_2 emissions from the most CO_2 emitting solid sources (coal variants), the intermediate CO_2 emitting liquid sources (gasoline and diesel) and the least CO_2 emitting gaseous fuel sources (natural gas). This is necessary to quantify

[4] Consumption and production generated CO_2 emissions originate from residential and industrial sectors respectively.

heterogeneously, the impact of fiscal policy on different fossil fuel sources and further shed more lights on the fiscal policy-CO_2 emissions nexus in Thailand. Third, the Zivot & Andrews endogenous single break unit root test as well as the Lagrange Multiplier (LM) endogenous double break unit root test are both employed to determine the stationarity properties of the series under study. Fourth, by employing the Maki cointegration, a technique that controls for up to five structural breaks in the model, the possible distorting effects of structural breaks in the cointegration relationship is avoided. Additionally, the dynamic ordinary least squares (DOLS) estimation technique is employed to ascertain the long-run parameters of the fiscal policy-heterogeneous fuel sourced CO_2 emissions nexus while controlling for the structural breaks. Finally, by employing the Toda-Yamamoto Dolado-Lutkepohl Granger causality procedure, the long-run dynamic causal interrelationships between fiscal policy, real GDP and CO_2 emissions nexus is fully determined in Thailand.

3.2 Thailand's Economy, Energy Sector, and Fiscal Policy Dynamics

Our study pays particular attention to Thailand due in part to the distinctive structure of its economy. Also, as the second largest economy in the ASEAN region with a GDP of about 455.3 billion USD as of 2017, Thailand is an export-dependent newly industrialized economy with huge energy demands. Owing to this, a synergy between the government and the private sector is expected in order to develop economic policies in line with environmental sustainability. The Global Carbon Atlas estimated Thailand's contemporary level of GHG emissions at ~337 metric tons of CO_2 equivalent (from the year 2014). Additionally, GHG emissions are estimated to be ~0.85% of global emissions in 2012, a figure that declined to ~0.62% of global emissions in 2015. The share of cumulative emissions over a two-decade timeline (1990-2012) was ~0.75%. The emission profile indicates that 67% of Thailand's total

GHG emissions in 2000 were from the energy sector while it increased to 73% in 2012 (Boden *et al*. 2017). Thailand aims to reduce GHG emissions generated from the energy and transport sectors. However, mitigating the proliferation of GHG requires alternative clean energy sources on a scale that would circumvent energy security challenges. As a net energy importer, this poses an economic danger in relation to the energy policy framework of the government. As of 2014, Thailand imported ~42% (~75000 Kgoe) of its energy use — with fossil fuels accounting for 72% of the total energy import. As the second-largest importer of oil in South East Asia and the second-largest producer of coal in the region, its huge energy requirements propel the importation of additional coal to meet domestic demand. Thailand's huge energy demand poses many environmental sustainability and energy security concerns. The Thai government initiated a fuel shift from oil to natural gas as far back as the 1980s, in order to address these concerns. A move that has seen natural gas dominating the energy mix —accounting for ~72% of electricity generation in 2018. As of 2012, 45% of the primary energy was sourced from natural gas, while oil, coal and hydro accounted for 36%, 16%, and 3%, respectively. Figure 1 shows that the share of energy has changed significantly over the years. Figure 2 shows that natural gas is the cleanest form of fossil fuel —emitting ~30% less CO_2 emissions compared to petroleum and 45% less CO_2 emissions than coal for every equivalent unit of energy produced (UNFCC, 2018).

In a move to attain energy efficiency and environmental sustainability, the Ministry of Energy has formulated the Power Development Plan, Alternative Energy Development plan and Energy efficiency plan. The core aims of achieving the objective by 2036 include the achievement of a 20% share of renewable energy-based power generation, a 30% share of renewable energy in the total final energy consumption and a reduction in energy intensity by 30% (IRENA, 2017; BP, 2018). As a developing country, it lacks high technical capacity, effective coordination, and logistics required to support optimal energy efficiency reforms. The government has instituted policies to mitigate these challenges like readily accessible investment grants, tax incentives, feed-in tariffs and venture capital for promoting renewable energy expansion.

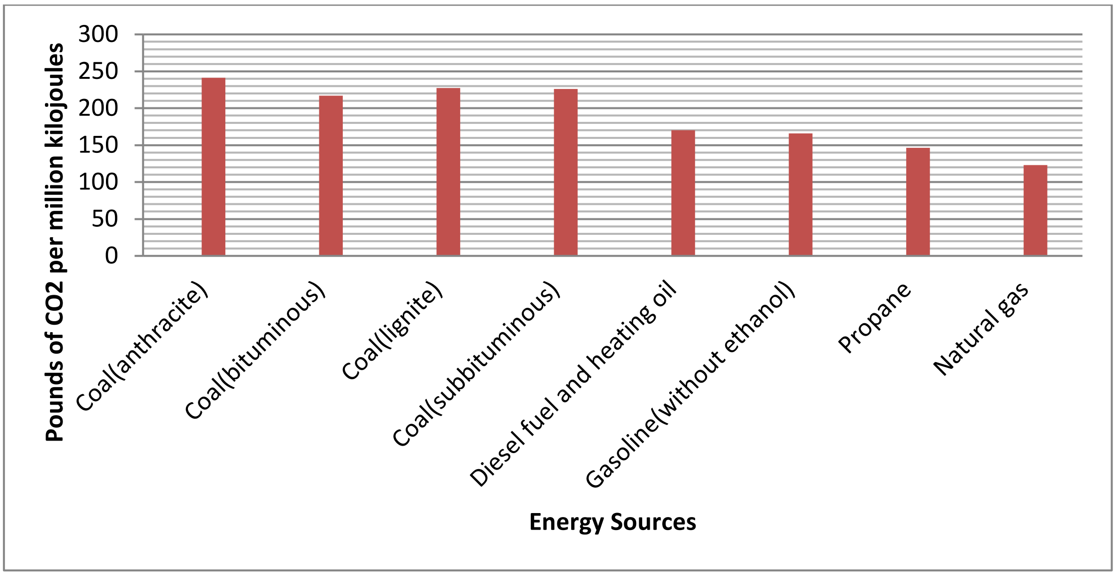

Figure 1: Pounds of CO2 emitted per million kilojoules of energy for various fuels
Source: U.S. Energy Information Administration.

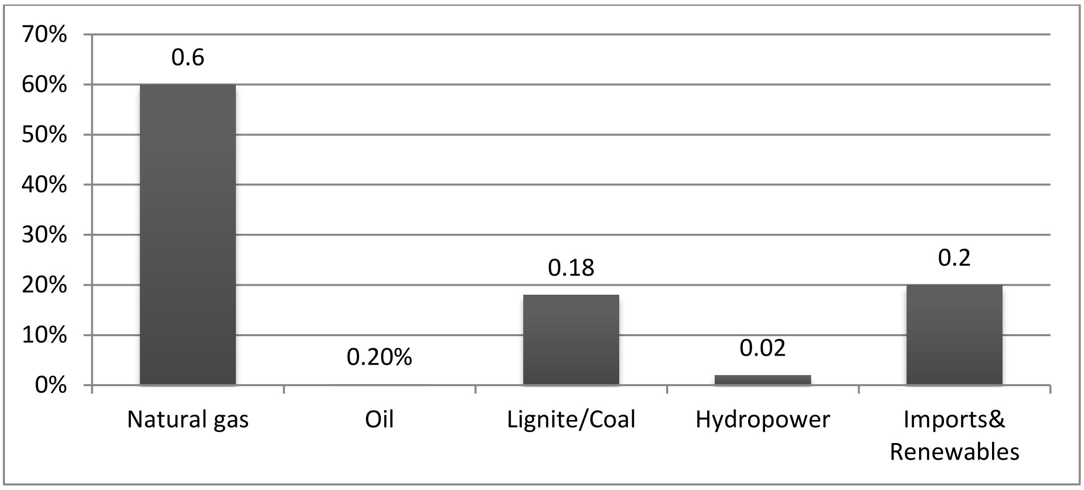

Figure 2: Energy mix of Thailand as of 2017.
Source: Energy Policy and Planning Office (2017), Thailand.

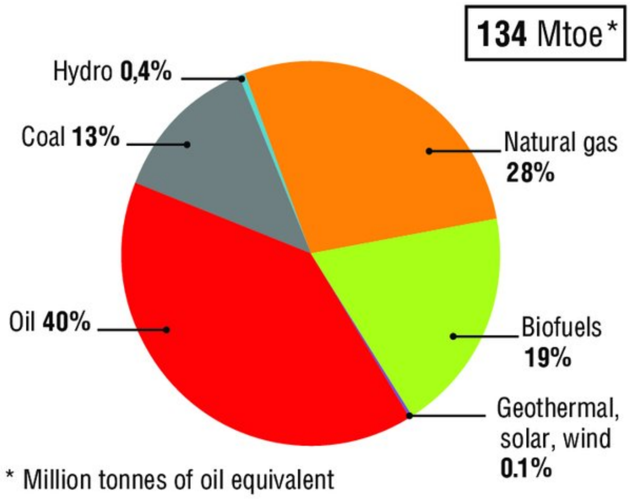

Figure 3: Energy mix of Thailand as of 2013
Source: U.S Energy Information Administration (EIA)

3.3 Theoretical Propositions and Framework

3.3.1 Theoretical Propositions

There are two basic broad classes of theories which relates the size of government to the provision of public goods, these are:

I. Citizen over state theories

II. State over citizen theories

Citizen over state theories assume the size of government to be endogenous to citizens' demand for public goods as such government acts as a corrector of widespread externalities such as the provision of education and health care. This group of theories assumes that public goods provision which increases government size is demand driven. For instance, Olson (2009) postulates the theory of government as a provider of favor to special interest groups. Such pressure groups by applying political pressure can influence government policy decisions towards policies that are beneficial to them as a group and sometimes at the expense of society.

The actions of these groups can lead to a reduction in the size of government by way of reduced taxes or could have an opposite effect of increasing the size of government by way of increased fiscal spending. If these pressure groups are oriented towards pro-environment policies then public goods provision will be oriented towards the reduction of environmental pollutants and environmental taxes may be instituted against polluting industries while government grants may be awarded to research and investments in clean energy. State over citizen theories on the other hand sees the size of the government as supply driven. There are two main versions of these theories which are the Leviathan theory and the bureaucracy theory.

The bureaucracy theory postulates that government has a high tendency of attempting to maximize the discretionary budget of their agencies even though the cost of the public services which the budget has been earmarked for may fall below the budget (Niskanen, 2017). The Leviathan theory on the other hand postulates that the provision of public and private goods by elected officials are sometimes incentivized by the potential of accruing financial gains to the elected officials and also the possibility of getting re-elected which all play a part in increasing the size of government (Tullock, 1959).

3.3.2 Theoretical Framework

This chapter adopts the conceptual framework of Hua et al. (2018) wherein the control of air pollution is described as a dynamic optimization problem. A Social planner's social utility function is maximized by the allocation of final output across consumption, investment and tax-revenue funded fiscal spending on public goods assuming a finite time period.

$$U(C,P) = lnC - \Phi \frac{P^{1+\gamma}}{1+\gamma} \tag{1}$$

The utility function is assumed to be additively separable in the utility of consumption C and the disutility of pollution *P*. Ln *C* denotes a standard logarithmic utility function while $\frac{P^{1+\gamma}}{1+\gamma}$ denotes a power utility function with a non-negative γ value. Both functions satisfy Inada conditions. $\Phi > 0$ represents the coefficient of social tolerance towards pollution. Assuming fixed labor supply:

$$P(t) = Q(t)/F(t) = SK^{\alpha}(t)/F(t) \tag{2}$$

From equation (2) *Q* denotes output which is produced by a neoclassical Cobb-Douglas production process with physical capital, *K,* as the only variable input. *F* denotes fiscal spending which is fully funded by tax revenues assuming a balanced budget within a neutral fiscal policy framework. 1< α < 0 and *S* denotes the technology adopted such as fuel switching which ensures a cleaner production process. From the foregoing, the current valued objective function can be depicted as

$$\max_{C,I\ \geq 0} \int_0^T e^{-rt} \left[lnc - \Phi \frac{(SK^{\alpha}/F)^{1+\gamma}}{1+\gamma} \right] dt \tag{3}$$

Subject to the following constraints:

$$F(t) = Q(t) - I(t) - C(t) \tag{4}$$

$$K'(t) = I(t) - \eta K(t) \tag{5}$$

$$K(0) = K_0,\ K(T) = K_T; F(0) = F_0, F(T) = F_T \tag{6}$$

From equation (4) the final product *Q* is decomposed into consumption *C*, investment *I*, and tax revenue funded fiscal expenditure *F*. *C* and *I* act as exogenous control variables while *F* is a state variable which depends on *C* and *I.* The movement of capital *K* which depreciates at a constant rate η >0 as a function of *I* is described in equation (5) which is the equation of motion.

The problem follows a current valued Hamiltonian given as:

$$H(C,I,K,F,t) = e^{-rt}U(C,P) + \lambda_1(SK^{\alpha} - I - F - C) + \lambda_2(I - \eta K) \tag{7}$$

In order to exclude endpoint solutions, it is assumed that H is strictly concave and differentiable in C and I. λ_1 and λ_2 depict costate variables which are associated with constraint (4) and (5). The optimality conditions follow the Pontryagin maximum principle which is written as:

$$\partial H/\partial I = -\lambda_1 + \lambda_2 = 0 \quad (8)$$

$$\partial H/\partial C = C^{-1}e^{-rt} - \lambda_1 = 0 \quad (9)$$

$$\partial H/\partial K = e^{-rt}\alpha\phi S^{\gamma+1}K^{\alpha(\gamma+1)-1}F^{-1-\gamma} + \alpha\lambda_1 SK^{\alpha-1} - \eta\lambda_2 = -\lambda_2' \quad (10)$$

$$\partial H/\partial F = e^{-rt}\phi S^{\gamma+1}K^{\alpha(\gamma+1)}F^{-\gamma-2} = -\lambda_1' \quad (11)$$

Equation (8) and (9) denote first order extremum conditions for the two control variables. The Euler conditions associated with the two state variables are depicted in (10) and (11). A steady state study can be performed without analytically solving the model in order to conduct comparative static analysis that yields hypotheses on the fiscal spending- pollution relationship. Setting K, C and F as positive constants $\bar{K}, \bar{C}$ and $\bar{F}$, a unique stationary state exists for the system:

$$\frac{[S-\bar{K}^{1-\alpha}(\eta+r)/\alpha]^{\gamma+2}}{\bar{K}^{1-\alpha}} = \phi\bar{F}S^{\gamma+1}[(\eta+r)/(\alpha-\eta)] \quad (12)$$

$$\bar{F} = S\bar{K}^{\alpha} - \bar{K}(\eta+r)/\alpha \quad (13)$$

From equations (12) and (13) two empirically testable hypotheses related to the present study can be derived. From Equation (12) it can be seen that physical capital $\bar{K}$ decreases with tax revenue funded fiscal spending on public goods which could create a cleaner environment if funds are re-allocated from dirtier industries to cleaner industries which is consistent with the composition effect. Equation (13) shows that the technology adopted is increasing in tax-revenue funded fiscal spending and this would lead to better environmental quality if cleaner technologies are adopted which is consistent with the technique effect.

3.4 Data, Model and Methodology

3.4.1 Data and Model

Annual data from the period 1972 to 2014 for Thailand were sourced from the World Bank World Development Indicators database. The data employed include per capita GDP measured at constant 2010 US Dollars — used as a proxy income level, Energy use (kg of oil equivalent per capita) and CO_2 emissions in metric tonnes per capita. Following Katircioglou and Katircioglou (2018b), fiscal spending (per capita general government final consumption expenditure at constant 2010 USD) and taxation (per capita tax revenues at constant 2010 USD) were both log-transformed and used in the construction of the fiscal policy index (FPI). Also, following Wang et al (2016), Shabaz et al (2017), Khan et al (2019) amongst others, all the other variables are transformed to their natural logarithms — to simplify coefficient interpretations and to mitigate the potential incidence of heteroscedasticity. Thus, the coefficients of the log-transformed variables are interpreted as elasticities. Log transformed real per capita GDP is squared and incorporated in the model to test the EKC hypothesis. In order to control for population effects, all the quantitative variables were measured in per capita values. Fiscal policy, energy use, real income, quadratic real income, and CO_2 emissions were assumed to follow a linear relationship of the form:

$$lCO_{2\,t} = \beta_0 + \beta_1 lrgdp_t + \beta_2 lrgdp_t^2 + \beta_3 lec_t + \beta_4 fpi_t + u_t \qquad (14)$$

From equation (14) lCO_{2t} can either be the natural logarithm (l) of per capita CO_2 emissions from solid (lCO_2spk), liquid (lCO_2lpk), gaseous (lCO_2gpk) or aggregate (lCO_2pk) sources. All these are measured in metric tons per capita. For the exogenous variables, $lrgdp_t$ and its quadratic term denote per capita GDP at constant 2010 USD prices. The quadratic term of the GDP variable is controlled for — in order to ascertain the shape of the environmental Kuznets curve. lec_t indicates the per capita energy use measured in kg of oil equivalent per capita. Fiscal policy index (constructed through a principal component analysis of government expenditure and tax revenue) is indicated as *FPI*. β_1 to β_4 are the unknown estimated coefficients of the aforementioned exogenous variables while β_0 denotes a constant term, u_t is the error term which is assumed to be a stationary white noise process. If all the variables in Equation (14) follow an I(1) process then u_t would have to be stationary for the long-run relationship to be non-spurious.

3.4.2 Developing a Fiscal Policy Index

Although Fiscal spending and Tax-revenues move in opposite directions when the fiscal policy framework revolves from contractionary to expansionary regimes it is still noteworthy to know that fiscal discipline entails that these two variables commove together across the business cycle. This is due to the fact that fiscal expenditures are financed by tax-revenues and a balanced fiscal budget presupposes the notion that fiscal expenditures are fully tax-revenues funded and thus are equal to each other. At the two opposite points of this state lies deficit financed and surplus fiscal regimes which alternate across the business cycle depending on whether the economy is booming or is in recession. Contractionary fiscal policies which involve lowering fiscal spending and increasing tax-rates are usually employed in booming economies to curtail the incidence of inflation while expansionary fiscal policies which involves the reduction of taxes and increment of fiscal spending are employed to stimulate growth in recessionary economies.

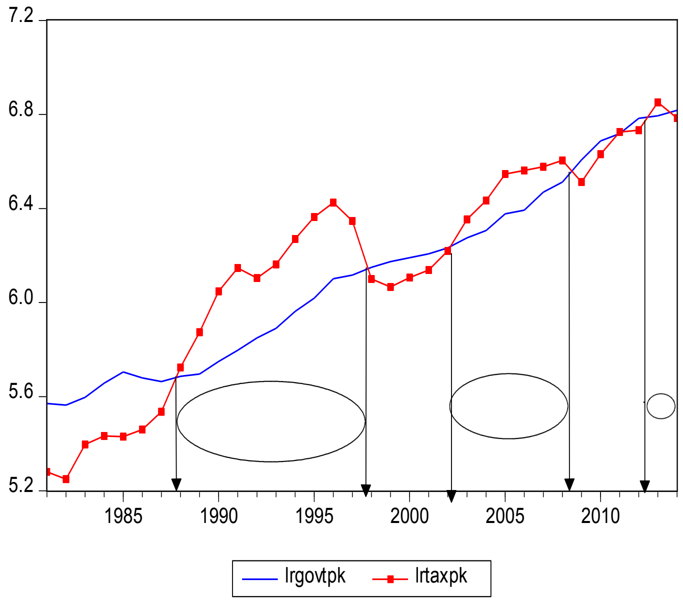

Figure 4: Thailand Fiscal variables. Per capita government expenditure (lrgovtpk) and per capita tax revenues (lrtaxpk) are commoving across time. The ellipses indicate contractionary fiscal policy regimes. The beginnings of expansionary regimes correspond to major recessionary periods such as the 1997/1998 Asian financial crisis and the 2007/2008 Global financial crisis.

Constructing a composite fiscal policy index enables the capturing of the direction of maximum variation between tax revenues and fiscal expenditures in order to more holistically analyze the CO_2 emissions effect of fiscal policy in Thailand. This is because fiscal spending can enhance environmental performance through the provision of grants for the development of cleaner energy technologies and investments while taxation can also be used to enhance environmental quality by way of pollution taxation. If for instance only fiscal spending enhances environmental quality by way of awarding grants for cleaner energy technologies and the government simultaneously reduces environmental taxes on polluting industries by way of subsidies, then the overall fiscal policy framework may prove to be insignificant in abating pollution. However, if environmental taxes are adequately imposed also, then the overall fiscal policy framework may be significant enough to mitigate pollution. Developing a fiscal policy index follows the study of Katircioglu and Katircioglu (2018b) which also constructs a fiscal policy index to analyze the impact of fiscal policy on the CO_2 emissions of Turkey. In this analysis, the ιth component is employed in the analysis if:

$$\lambda_\iota = \frac{1}{L}\sum_\iota^L \lambda_\iota = \frac{1}{L} I \quad (15)$$

Where L denotes the rank of the matrix **X** which represents the set of data to be analyzed which is comprised of I observations and described by J variables. For correlation PCAs this implies that eigenvalues greater than one and factor loadings greater than 0.5 entails that the factor or indicator is significant and can thus be employed in the empirical analysis (see Kaiser, 1961; Abdi and Williams, 2010). Results from Table 1 shows that, of the 2 components extracted from the dataset, only one component is suitable enough to be employed in the empirical analysis as the proportion of variance explained by it is about 95.5% with factor loadings of 0.7 for both fiscal spending and tax-revenues with an eigenvalue of 1.9.

Table 1: Principal component analysis of Thailand fiscal spending and tax revenues

Principal Component	Eigenvalues	Cumulative Eigenvalues	Percentage of Variance Extracted	Cumulative Percentage of Variance Extracted
1	1.9099	1.9099	0.9550	0.9550
2	0.0900	2.0000	0.0450	1.0000
Ordinary correlations	Lrgovtpk	Lrtaxpk	Principal Component 1	Principal Component 2
Lrgovtpk	1.0000	0.9099	0.7071	-0.7071
Lrtaxpk	0.9099	1.0000	0.7071	0.7071

3.4.3 Unit Root Test with Structural Breaks

In order to ascertain the stationarity properties of the data series, we employ the Zivot & Andrews unit root test with one unknown structural break and Lee & Strazicich minimum Lagrange multiplier unit root test with two structural breaks. Time series data are prone to the distorting effects of structural breaks in the series, which is occasioned by economic shocks. There have been quite a number of global as well as regional political and economic events which can potentially induce strong macro-economic shocks in the Thai economy. Some of the events which are related to the Thai economy include *inter alia*; the 1997-1998 Asian financial crises and the 2008-2009 Global financial crises. These events can potentially induce strong external shocks which can introduce outliers or structural breaks in the data generating process of the Thai macro-economic variables. These structural breaks can lead to a spurious (non)rejection of the unit root null. As such, the Zivot and Andrews (2002) test which endogenously determines a single structural break and the Lee and Strazicich (2003) test which endogenously ascertains the location of two structural breaks while testing for the null of a unit root are much more robust unit root testing procedures compared to conventional variants which do not incorporate structural breaks.

3.4.4 Cointegration with Multiple Structural Breaks

If the stationarity assumption of u_t from equation (14) holds then, a stable long-run relationship exists amongst the variables and thus, equation (14) is a cointegrated model. In order to determine the existence of a stable long-run relationship, the Maki (2012) cointegration test that allows for up to five structural breaks in the series is employed. Several other cointegration tests (Johansen and Juselius, 1990; Phillips and Ouliaris, 1990; Gregory and Hansen, 1996; Hatemi-j, 2008) all either do not allow for structural breaks or allow for only up to one or two structural breaks in the series.

However, structural breaks in economic time series may occur in very unpredictable patterns and frequency. As such, in order to establish robust cointegration relationships amongst the variables the four models of the Maki (2012) cointegration test is considered. The models are specified as follows:

Model 0: Level shifts

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \beta' \boldsymbol{A}_t + u_t \tag{16}$$

Model 1: level shifts with trend

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \gamma t + \sum_{i=1}^{k} \gamma_i t D_{i,t} + \beta' \mathbf{A}_t + \sum_{i=1}^{k} \beta'_i \mathbf{A}_t D_{i,t} + u_t \tag{17}$$

Model 2: Regime shifts

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \beta' \mathbf{A}_t + \sum_{i=1}^{k} \beta'_i \mathbf{A}_t D_{i,t} + u_t \tag{18}$$

Model 3: Regime shifts with a trend

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \gamma t + \beta' \mathbf{A}_t + \sum_{i=1}^{k} \beta'_i \mathbf{A}_t D_{i,t} + u_t \tag{19}$$

From equations (16) to (19), $t = 1,2,\ldots,T$. y_t and $\mathbf{A}_t = (A_{1t,\ldots,}A_{mt})'$ indicate observable variables which follow an I(1) process while u_t indicates the equilibrium error, y_t is a scalar, and $\mathbf{A}_t = (A_{1t,\ldots,}A_{mt})$ is an (m×1) vector. If $t > T_{Bi}$ (i=1, ⋯, k) then $D_{i,t}$ will take a value of 1 and 0 if otherwise. Also, the maximum number of breaks is denoted by k while T_{Bi} signifies the time of the break's occurrence.

3.4.5 Long-run Parameter Estimation

Equation (14) being a static model assumes that the effects of the exogenous variables on the endogenous variable are contemporaneous and, in most scenarios, this is usually not the case. The effect of fiscal policies may not be felt at the particular period they were instituted. This may be due to habit persistence in industrial practices (Halkos and Paizanos, 2017) and delays stemming from bureaucratic red-tapism, which has the potential of increasing the time lags between policy announcements and the impacts from their actual execution. In order to control for delayed convergence to the steady-state, we employ the DOLS technique and specify the model as:

$$lCO_{2\,t} = \beta_0 + \beta_1 lrgdp_t + \beta_2 lrgdp_t^2 + \beta_3 lec_t + \beta_4 FPI + \sum_{k=-p}^{p} \theta_1 \Delta lrgdp_{t-k} + \sum_{k=-q}^{q} \theta_2 \Delta lrgdp_{t-k}^2 + \sum_{k=-r}^{r} \theta_3 \Delta lec_{t-k} + \sum_{k=-s}^{s} \theta_4 \Delta FPI_{t-k} + \eta' \boldsymbol{D}_i + u_t \quad (20)$$

From equation (20) Δ is the difference operator, coefficients β_1, β_2, β_3 and β_4 indicates respectively the long-run effect of a change in *lrgdp*, $lrgdp^2$, *lec* and *FPI* on $lCO_{2\,t}$. Also, *p, q, r* and *s* denote lead lengths while *–p, -q, -r* and *–s* denote lag lengths which are determined by the Akaike information criterion (AIC) and serve the purpose of making the error term independent of all past innovations emanating from the endogenous variables. Additionally, η indicates the effect of the five structural breaks obtained from the Maki cointegration tests. The structural breaks are denoted by the vector $\boldsymbol{D}_i = (D_1, \ldots, D_5)$.

3.4.6 TY-DL Granger Causality Procedure

This study employs the Toda-Yamamoto (1995) and Dolado-Lutkepohl (TY-DL) (1996) methodology, which is applicable irrespective of the integrating and cointegrating order of the variables in the system. The method involves determining the significance of the parameters of a VAR(*p*) model by employing a Modified Wald statistic. The procedure is applied by artificially augmenting the correct VAR order, *p* with *d* extra lags (d_{max}). The asymptotic χ^2 distribution of the Wald statistic is guaranteed by the estimation of a *VAR* (p+d_{max}), where d_{max} is the maximal order of integration in the VAR system. A lag length of 2 is employed, using the AIC. In testing for Granger causality, the remaining d_{max} autoregressive parameters are ignored as their use is limited to overcoming the problem of non-standard asymptotic properties associated with standard Wald tests for integrated variables. The application of the Granger causality procedure will be limited to only the aggregate per-capita CO_2

equation in order to unveil the direction of causality amongst the study variables. As such, structural break dates from the Maki cointegration tests pertaining to the aggregate per-capita CO_2 equation will be exogenously augmented to the model as dummy variables in order to circumvent the distorting effects of structural breaks in the series. A dynamic VAR(p) within the framework of Toda-Yamamoto is specified as:

$$\begin{bmatrix} lCO_{2\,t} \\ lrgdpk_t \\ lrgdpk_t^2 \\ lec_t \\ FPI_t \end{bmatrix} = \begin{bmatrix} \beta \\ \tau \\ \varpi \\ \alpha \\ \nu \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} \theta_{11i}\theta_{12i}\theta_{13i}\theta_{14i}\theta_{15i} \\ \theta_{21i}\theta_{22i}\theta_{23i}\theta_{24i}\theta_{25i} \\ \theta_{31i}\theta_{32i}\theta_{33i}\theta_{34i}\theta_{35i} \\ \theta_{41i}\theta_{42i}\theta_{43i}\theta_{44i}\theta_{45i} \\ \theta_{51i}\theta_{52i}\theta_{53i}\theta_{54i}\theta_{55i} \end{bmatrix} \times \begin{bmatrix} lCO_{2\,t-i} \\ lrgdpk_{t-i} \\ lrgdpk_{t-i}^2 \\ lec_{t-i} \\ FPI_{t-i} \end{bmatrix}$$

$$+ \sum_{j=p+1}^{d_{max}} \begin{bmatrix} \varphi_{11j}\varphi_{12j}\varphi_{13j}\varphi_{14j}\varphi_{15j} \\ \varphi_{21j}\varphi_{22j}\varphi_{23j}\varphi_{24j}\varphi_{25j} \\ \varphi_{31j}\varphi_{32j}\varphi_{33j}\varphi_{34j}\varphi_{35j} \\ \varphi_{41j}\varphi_{42j}\varphi_{43j}\varphi_{44j}\varphi_{45j} \\ \varphi_{51j}\varphi_{52j}\varphi_{53j}\varphi_{54j}\varphi_{55j} \end{bmatrix} \times \begin{bmatrix} lCO_{2\,t-j} \\ lrgdpk_{t-j} \\ lrgdpk_{t-j}^2 \\ lec_{t-j} \\ FPI_{t-j} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ u_{4t} \\ u_{5t} \end{bmatrix} \quad (21)$$

From equation (21), Granger causality from FPI_t to lCO_{2t} implies that $\Theta_{15i} \neq 0\forall_i$; likewise, Granger causality from lCO_{2t} to FPI_t implies that $\Theta_{51i} \neq 0\forall_{i.}$

3.5 Results and Discussions

3.5.1 Results

The section outlines the empirical results and discussion of the estimated models. The descriptive statistics shown in Table 2 indicates that the quadratic term (lrgdpk^2) is more volatile compared to the remaining variables — followed by CO_2 emissions from solid fuel sources (lCO_2spk). All the variables are negatively skewed except for energy consumption, which is positively skewed. A cursory look at the time plots in Figure 5 shows that the variables do not exhibit mean reversion in their evolution and thus the potential for data non-stationarity becomes quite high. Also, various intercept shifts which may constitute structural breaks can be observed in the time series. Table 3 shows the Zivot & Andrews and Lee & Strazicich structural break unit root tests.

Evidence from Table 3 reveals that all the variables are non-stationary at level ($p<0.05$), but turns stationary at first difference. Thus, all the variables are integrated of order one [I(1)]. After fulfilling the requirement of the order of integration, the study proceeds to empirically test for cointegration using multiple structural break cointegration test by Maki (2012).

Table 2: Descriptive statistics

	FPI	lCO$_2$gpk	lCO$_2$lpk	lCO$_2$spk	lCO$_2$pk	leng	lrgdpk	lrgdpk^2
Mean	-8.88E-16	-7.941950	11.05539	-8.617924	0.573363	6.728479	7.849035	61.91283
Median	0.260968	-7.690053	11.24783	-8.070447	0.761194	6.776903	8.033254	64.53316
Maximum	2.187064	-6.664907	11.92630	-6.933470	1.530797	7.596712	8.628932	74.45847
Minimum	-2.681329	-11.35690	9.890375	-11.45231	-0.581545	5.907714	6.866538	47.14934
Std. Dev.	1.416228	1.116830	0.668738	1.492349	0.730964	0.565879	0.559241	8.697718
Skewness	-0.305118	-1.024310	-0.287373	-0.640010	-0.220108	0.000672	-0.273645	-0.209738
Kurtosis	2.047505	3.787460	1.493650	1.961576	1.445314	1.470435	1.674038	1.645633

Source: Authors' computations.

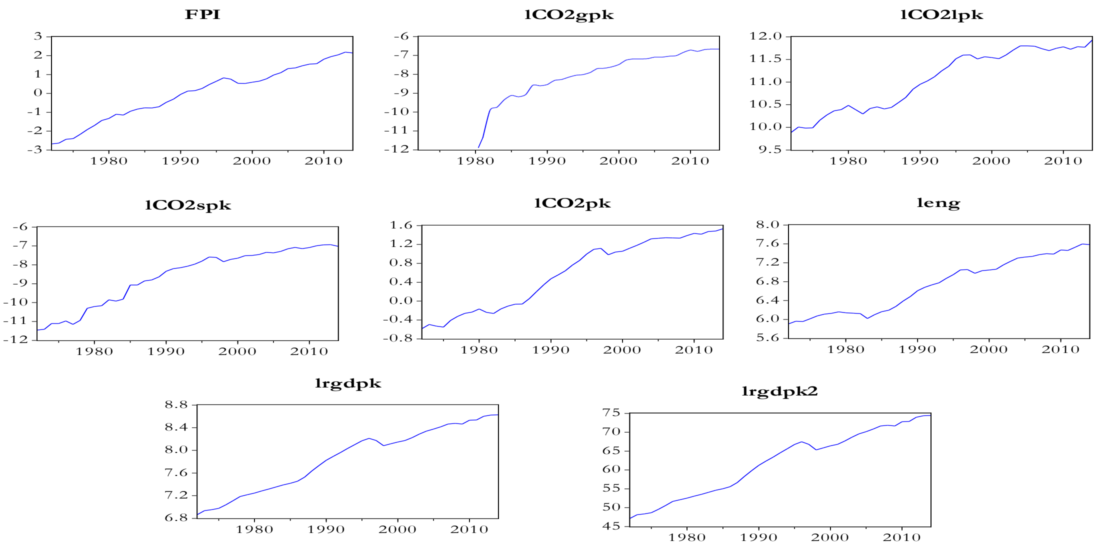

Figure 5: Time plot of variables

Table 3: Unit root tests with structural breaks

Variables at levels	Lee and Strazicich (2003)		Zivot and Andrew (2002)	
	T-statistics	Break Years	T-statistics	Break Year
lCO_2pk	-2.6675	1983, 1998	-3.4483	1988
lCO_2spk	-2.1983	1976, 1984	-2.6104	1985
lCO_2lpk	-2.7482	1998, 2010	-3.4223	1989
lCO_2gpk	-0.0668	1977, 1980	-4.0036	1983
lrgdpk	-3.0524	1998, 2010	-3.6008	1988
leng	-2.1096	1984,1998	-3.6563	1994
FPI	-2.9005	1974,1996	-4.5836^{*}	1998
At first difference				
ΔlCO_2pk	-5.7222^{***}	1985, 1995	-5.7117^{***}	1997
ΔlCO_2spk	-6.1500^{***}	1974, 1986	-8.2485^{***}	1979
ΔlCO_2lpk	-5.1238^{***}	1977, 1996	-5.1148^{**}	1997
ΔlCO_2gpk	-58.129^{***}	1988, 2007	-7.7690^{***}	1983
Δlrgdpk	-4.8333^{***}	1984, 1996	-4.9812^{**}	1996
Δleng	-4.0617^{**}	1996, 2009	-6.2828^{***}	1996
ΔFPI	-4.9133^{***}	1992, 2000	-5.4664^{***}	2002

Note: '***', '**'and '*' denotes the rejection of the null hypothesis of a unit root at the 1%, 5% and 10% significance levels respectively.
Source: Authors' computations

The results from the Maki cointegration test in Table 4 incorporates up to five structural breaks —the empirical evidence confirms the presence of cointegration in all equations. For the first equation with lCO_2spk as the dependent variable, it can be observed that the second model of Maki provides significant evidence for cointegration — implying the presence of regime shifts in the cointegration relationship. For the second equation with lCO_2lpk as the dependent variable, model 1 and model 3 of Maki provide valid evidence for cointegration. For the third equation of lCO_2gpk, models 0, 2 and 3 of Maki provide significant evidence for cointegration. The aggregated carbon emissions denoted by lCO_2pk in models 0, 1 and 2 of Maki empirically support the existence of cointegration.

Table 4: Maki (2012) Cointegration test with 5 structural breaks

Model specifications	Test statistics [5% Critical values]	Break points
(1) lCO_2spk=f (lrgdpk, lrgdpk2, FPI,leng)		
Model 0	-4.800481 [-6.306]	1977,1982,1984,1994,2004
Model 1	-5.884090 [-6.494]	1977,1982,1984,1995,1998
Model 2	-13.53773 [8.869] ***	1982,1987,1993,1998,2007
Model 3	-6.689667 [-9.482]	1978,1989,1992,1998,2005
(2) lCO_2lpk=f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	-6.0023359 [-6.306]	1984,1988,1997,2000,2009
Model 1	-6.4993405 [-6.494]**	1975,1989,1999,2004,2006
Model 2	-8.1600012 [-8.869]	1977,1988,1995,2003,2008
Model 3	-31.10311 [9.482]***	1977,1983,1991,1999,2008
(3) lCO_2gpk=f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	-9.096776 [-6.306] ***	1983,1986,1992,2004,2008
Model 1	-5.943001 [-6.494]	1985,1992,1995,2003,2010
Model 2	-15.84944 [-8.869] ***	1985,1991,1996,2001,2008
Model 3	-10.63653 [-9.482] ***	1987,1990,1995,1999,2004
(4) lCO_2pk=f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	-6.6082485 [-6.306]**	1975,1978,1984,1993,2004
Model 1	-7.870113 [-6.494]***	1974,1993,1997,1999,2005
Model 2	-9.705195 [-8.869]***	1989,1986,2004,2000,2008
Model 3	-8.4571419 [-9.482]	1980,1988,1994,2002,2008

Note: '***', '**'and '*' denotes statistical significance at the 1%, 5% and 10% significance levels respectively.

In order to unveil the long-run parameter estimates, the study augmented the DOLS estimation of each equation with dummies to represent the structural breaks obtained from the Maki cointegration test. Structural breaks obtained from the most significant models of the Maki cointegration test of each equation were used following Balcilar *et al*. (2019). The findings from the DOLS estimation in Table 5 with lCO_2spk as dependent variable show that fiscal policy has no significant relationship with CO_2 emissions from solid fuel sources. Energy consumption is also observed to have no significant relationship with per-capita CO_2 emissions from solid fuel sources while the EKC hypothesis is validated for per-capita CO_2 emissions from solid fuel sources. The insignificance of the relationship between energy consumption and CO_2 emissions from solid fuel sources stems from the under-utilization of coal energy sources compared to natural gas and other less CO_2 emitting energy sources such as solar, hydro, wind, nuclear, biofuels, solid biomass, etc. More so, two significant structural break years, 1987 and 1998 are uncovered for the equation with lCO2spk. The 1987 date corresponds to the growth in exports and increased direct and indirect investments following relatively stable inflation. The break in 1998 is traceable to the 1997-1998 Asian financial crises, — which saw a reduction in aggregate demand for South-east Asia. In the second equation with lCO_2lpk as the dependent variable, the DOLS estimates show that a 1% increase in fiscal policy reduces in per-capita CO_2 emissions from liquid fuel sources by 0.21%. This implies that fiscal policy is geared towards initiatives which impede the utilization of liquid fuel sources such as petrol and diesel. A 1% increment in energy consumption triggers a 1.23% increase in per-capita CO_2 emissions from liquid fuel sources — implying that a large portion of the Thai economy are dependent on liquid fuel sources. Notwithstanding that the fiscal policy initiatives aid in curtailing its consumption. The EKC hypothesis is validated for per-capita CO_2 emissions from liquid fuel sources. Three significant structural breaks namely 1991, 2001 and 2008 are uncovered for the lCO_2lpk equation. The 1991 period closely coincides with the 1990 Iraqi invasion of Kuwait and the onset of the Gulf war— which led to an interruption of Kuwaiti oil exports till 1994 and a resultant increase in crude oil prices within the same period. The 2001 break period coincides with the 9/11 attacks and the US invasion of Iraq which led to a significant hike in crude oil prices due to concerns about middle east stability. The 2008 break date indicates the period of the global financial crisis and a period of reduced global demand, which also saw a significant drop in oil consumption. A 1% increase in fiscal policy increases per-capita CO_2 emissions from gaseous fuel sources by 6.5%.

Meaning that fiscal policy in Thailand is effectively geared towards a gradual replacement of more price volatile and relatively more CO_2 emitting liquid fuel sources (Crude oil derivatives) with the relatively less CO_2 emitting gaseous fuel sources (natural gas). A 1% increase in energy consumption corresponds to 6.6% increase in CO_2 emissions from gaseous fuel sources. This implies that natural gas is the main source of energy for the Thai economy— corroborating the visual inspection in Figure 2 which divulges the energy mix in Thailand. The EKC hypothesis is also validated for per capita CO_2 emissions from gaseous fuel sources. The net effect of fiscal policy on aggregate emissions per capita shows a negative relationship —as an increment of fiscal policy by 1% causes ~0.2% reduction in aggregate CO_2 emissions per capita. Energy consumption has a weakly significant relationship with aggregate per-capita CO_2 emissions. This result may be indicative of the fiscal policy initiatives geared towards the reduction of CO_2 emissions in Thailand.

Furthermore, when CO_2 emissions are aggregated (lCO_2pk), the results indicate that a 1% increase in energy consumption leads to ~0.48% increase in CO_2 emissions. Two significant structural breaks are uncovered in the lCO_2pk relationship. The first one with a date period of 2004 shows a positive intercept shift, which falls within the period of crude oil production stagnation — a period that coincides with an increased Asian demand for crude oil and the decline of Saudi Arabian spare capacity. The second one with a break period of 2008 and a negative intercept shift indicates the period of the 2008 global financial crisis. Comparing our results with the previous studies, we discover that the negative relationship between fiscal policy and CO_2 emissions in Thailand is consistent with Katircioglou and Katircioglou (2018b) — a negative effect between fiscal policy and aggregate CO_2 emissions was found for Turkey. However, inconsistent with Yuelan *et al*. (2019) in which a positive effect between fiscal policy and CO_2 emissions was uncovered for China. The DOLS estimations reveal the key transmission mechanism through which fiscal policy in Thailand mitigates CO_2 emissions in the long-run. This is achieved through fostering policies, which encourage the utilization of low CO_2 emitting energy sources like natural gas — leading to a net reduction in aggregate CO_2 emissions while discouraging the utilization of high CO_2 emitting sources like petroleum products.

Table 5: Dynamic OLS estimates

Exogenous Variables	Endogenous Variables			
	lCO_2spk	lCO_2lpk	lCO_2gpk	lCO_2pk
lrgdpk	14.5039***	11.3354***	88.7694**	4.7124***
	[2.724]	[1.037]	[37.47]	[1.013]
$lrgdpk^2$	-0.8168***	-0.6989***	-6.8563**	-0.2118***
	[0.254]	[0.082]	[2.709]	[0.087]
leng	0.1405	1.2380***	6.6276**	0.4808*
	[0.318]	[0.238]	[2.556]	[0.059]
FPI	0.2032	-0.2103***	6.5183**	-0.2324**
	[0.930]	[0.064]	[2.229]	[0.267]
Intercept	-72.7298***	-42.9418***	-32.084**	-26.517***
	[10.827]	[4.462]	[13.329]	[4.253]
D1	0.1444	0.0425	-0.0487	0.0136
	[0.205]	[0.035]	[0.561]	[0.031]
D2	0.2515*	-0.0838**	-0.2859	0.0075
	[0.125]	[0.033]	[0.252]	[0.022]
D3	-0.0734	0.0148	-0.4615*	0.0555*
	[0.115]	[0.023]	[0.203]	[0.031]
D4	-0.3433***	-0.0972**	-0.1047	-0.0313
	[0.114]	[0.028]	[0.203]	[0.030]
D5	0.0630	-0.0960**	-0.5114	-0.0625***
	[0.070]	[0.023]	[0.349]	[0.013]
Adj. R^2	0.988	0.996	0.958	0.997
Jarque Bera	0.299	0.606	0.662	0.524

Note: '***', '**'and '*' denotes statistical significance at the 1%, 5% and 10% significance levels respectively. Heteroscedasticity and Autocorrelation robust standard errors in squared brackets.

In Table 6, results from the Toda-Yamamoto Dolado-Lutkepol Granger causality procedure shows bi-directional causality from fiscal policy to per capita CO_2 emissions implying a feedback mechanism between the environmental impacts of CO_2 emissions and the fiscal policy environmental initiatives. Unidirectional causality from fiscal policy to per capita real GDP is consistent with Katircioglou and Katircioglou (2018b), as well as, unidirectional causality from fiscal policy to per capita energy consumption. Furthermore, we find a unidirectional causality from per capita energy consumption to per capita real GDP — validating the growth hypothesis — implying that energy conservation policies may have far-reaching negative economic consequences for Thailand.

Table 6: Toda Yamamoto dynamic causality analysis.

Dependent variables	Causal variables				
	lCO_2pk	lrgdpk	$lrgdpk^2$	leng	FPI
lCO_2pk	___	2.3793	2.9606	5.8121	15.1815^{***}
lrgdpk	3.1329	___	4.9029	17.7561^{***}	14.4175^{***}
$lrgdpk^2$	3.1781	6.0446	___	17.8737^{***}	14.1830^{***}
leng	4.8098	7.325198	7.6484	___	11.1239^{**}
FPI	8.5622^{*}	2.3328	1.8465	9.5691	___

Note: '***', '**'and '*' denotes statistical significance at the 1%, 5% and 10% significance levels respectively. Source: Authors' computations

3.5.2 Discussions

The positive effect of energy consumption on CO_2 emissions is consistent with numerous studies in the literature. In disaggregating CO_2 emissions into different fossil fuel sources, we are able to simultaneously analyze fiscal policy initiatives towards different fossil fuel sources and what these effects may have on net CO_2 emissions. Decoupling initiatives in developing economies emphasize either the increase in GDP growth rate occurring at a faster rate than the growth rate of energy consumption (Wang *et al* 2019b) or the increase in GDP growth rate occurring at a faster rate than CO_2 emissions (Wang *et al* 2018). In the event the two aforementioned scenarios are not mutually exclusive, decoupling initiatives may obstruct economic growth due to energy conservation. Fossil fuel switching presents a better alternative to energy conservation for countries whose economic growth path is tied to energy consumption. This is because fossil fuel switching involves the switching over to fuel sources with less CO_2 emissions per equivalent energy produced. As such, energy consumption and economic growth does not have to be sacrificed for environmental quality. The present study validates the energy led growth hypothesis for Thailand, thus making it a viable candidate for fossil fuel switching. The energy-led growth hypothesis is inconsistent with Saboori and Sulaiman (2013), which uncovers a feedback hypothesis between energy consumption and economic growth for Thailand. However, consistent with the findings of Lean and Smyth (2013) in which unidirectional causality from electricity consumption to economic growth was uncovered for the ASEAN-5 economies including Thailand. The results further surmise that fiscal policy can also be an important factor in the decoupling initiatives of developing economies

3.6 Conclusion

In view of the dominance of natural gas in the Thai economic and energy structure, this study empirically assessed the valid pathways through which fiscal policy abates the proliferation of CO_2 emissions in Thailand. We investigated the dynamic linkage between fiscal policy, energy consumption and CO_2 emissions from heterogeneous fossil fuel sources within the EKC framework from 1972 to 2014. We employed estimation techniques that are robust to the distorting effects of multiple structural breaks and uncover heterogeneous fiscal policy effects on CO_2 emissions from different fossil fuel sources. While fiscal policy had a positive effect on low CO_2 emitting gaseous fuel sources (natural gas), a negative effect on high CO_2 emitting liquid fuel sources (crude oil derivatives), and a positively insignificant effect on CO_2

emitting solid fuel sources (coal derivatives) were deduced from the empirical results. The results validated the existence of the EKC hypothesis in all equations — meaning that while economic development facilitates environmental pollution, increasing levels of income has a pollution-mitigation effect. The Toda-Yamamoto & Dolado-Lutkepohl Granger causality framework reveals a unidirectional causal flow from fiscal policy to CO_2 emissions and from fiscal policy to energy consumption, implying that fiscal policy initiatives towards energy consumption have long-run implications for environmental quality. The empirical analysis further supports the energy-led growth hypothesis for the Thai economy, meaning that harnessing cleaner and efficient energy sources (i.e. fossil fuel switching) should be encouraged, rather than energy conservation. Investment in renewable energy technologies should be encouraged by government and other stakeholders in a way that does not obstruct the country's energy supply and consumption, due to the imposition of inordinate carbon taxes on conventional energy sources. But to complement less CO_2 emitting fossil fuel sources with clean and renewable energy sources till capacity is built-up in the renewable energy sector. To this end, fiscal policy initiatives should be channeled towards the gradual taxation of non-renewable energy use and the fostering of incentives for investment in renewable energy through tax exemptions and special government grants. Because of the massive infrastructural needs of the renewable energy sector, there is a need to develop a long-term infrastructural development plan funded from carbon tax receipts from fossil fuel energy utilization. The net negative effect of fiscal policy on aggregate CO_2 emissions and the gradual replacement of crude oil derivatives with natural gas as the primary energy source should not be a final solution to CO_2 abatement in Thailand but should rather be an intermediate one. Efforts should be made towards a gradual phasing out of fossil fuel energy sources and the attainment of net-zero emissions. This also should form the basis for future research direction.

Chapter 4

OIL PRODUCTION AND THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS IN OIL PRODUCING COUNTRIES

4.1 Introduction

One of the major issues of concern to governments and policymakers in the 21st century is centred on environmental degradation associated with climate change. This issue arises due to the overdependence on fossil fuels (oil, gas, and coal) as the main source of energy to power economic growth (Bhattacharya et al. 2016; Rafindadi, 2016; Sarkodie, 2018; Sarkodie and Strezov, 2018; Ranfidandi and Usman, 2019). The Intergovernmental Panel on Climate Change (IPCC) (2013) documents that about 76.6% of the emissions of carbon dioxide (CO_2) in the world can be traced to the various efforts to accelerate the pace of economic growth and raise the standard of living particularly in developing countries. According to Enerdata (2019), world electricity production grew by 2.8% in 2017 and 1.9% in 2018 with a greater part of that growth coming from oil producing countries where energy sources are predominantly fossil fuel based. Similarly, out of the 49 Gt emissions of CO_2 equivalent in 2010, the contribution of electricity and heat production amounts to about 25%. This is closely followed by agricultural, forestry and land use with 24% while industrialization, transportation, other energy, and buildings are 21%, 14%, 9.6% and 6.4% (See IPCC, 2016). In addition, Katircioglu (2017) demonstrates that crude oil accounts for about 35% of world demand for energy and fossil fuels as a whole account for over 80% of the world demand for energy in 2004.

Furthermore, several researchers have examined the effect of economic growth on environmental degradation. Most studies provide a positive relationship between economic growth and environmental degradation (See Shahbaz et al. 2013; 2017d; Sarkodie and Strezov, 2018; Bekun et al. 2019; Usman et al. 2019; Rafindadi and Usman, 2019). These results are theoretically underpinned by the pioneering work of Grossman and Krueger (1991), which categorically states that as a country progresses in the path of development, environmental degradation would initially increase as income per capita increases, but reduces subsequently as income per capita increases. This process leads to what is known as the Environmental Kuznets Curve hypothesis in the environmental economics literature. This hypothesis has been validated by several empirical studies over the years under three major channels, namely; the scale effect, the composition effect, and the technique effect. Regarding the scale effect, increasing the consumption of energy stimulates economic growth and hence increases environmental emissions (Cole, 2006; Dedeoğlu and Kaya, 2013; Zaman & Moemen, 2017; Stern and Van Dijk, 2018; Sarkodie, 2018). Conversely, the composition effect, which is typically the case for industrial economies, arises where a decrease in energy consumption stimulates economic activities due to a decline in the share of the carbon-intensive goods in the production of goods and services (Stern, 2004; Farhani & Ozturk, 2015). Finally, the technique effect which arises when a decrease in energy consumption, particularly fossil fuels, decreases CO_2 emissions due to the transmission of advanced technologies and technical know-how, which helps to power economic growth (Antweiler et al. 2001; Dollar and Kraay, 2004; Lorente and Alvarez-Herranz, 2016; Nassani et al. 2017).

Moreover, in addition to the debates on the interactions between economic growth and environmental quality, several studies have examined whether international trade can contribute to environmental deterioration (Cole and Elliott 2003, Cole 2004; Nasir and Rehman 2011; Farhani et al. 2014; Ozturk and Acaravci 2016; Ozatac et al. 2017). Theoretically, international trade is expected to stimulate economic growth because it helps to re-allocate capital for investments from the capital abundant countries to labour abundant countries. As economic growth increases due to trade, the greenhouse gas (GHG) emissions resulting from the increase in energy consumption continues to threaten the quality of life and the environment (Cole and Elliott, 2003; Twerefou et al. 2019).

Recently, there is a growing evidence that democratic regime exerts pressure on environmental degradation (Farzin and Bond, 2006; Usman et al. 2019). This strand of literature is built on a well-known theory of modernization accredited to Lipset (1959). This theory submits that a positive correlation exists between income and democracy. To this extent, democracy is expected to affect the level of environmental degradation through its effect on income. However, the direction to which democracy exerts pressure on CO_2 emissions can be either positive or negative. Some studies report that democracy improves environmental quality through adequate and effective implementation of government policies. Their argument is that as a country's level of democracy increases, peoples' freedom to express their preferences through protests tends to increase. This liberty in a democratic setting forces the government to pursue environmentally friendly policies (Farzin and Bond, 2006; Payne, 1995; Torras &

Boyce, 1998; Barrett & Graddy, 2000; and Shahbaz, et al. 2013; Usman et al. 2019). On the other hand, some studies report that environmental quality is threatened in a democratic setting. This is because as income increases with the level of democracy, $C0_2$ emissions also tend to rise (see Heilbronner, 1994; Midlarsky, 1998; Scruggs, 1998; Roberts and Parks, 2007; Lv, 2017).

Even though the empirical research on the EKC has significantly increased over the years, the debates on the role of oil production, trade, and democracy in determining the position of the EKC for oil producing countries remains unclear. Those studies that have attempted to address this issue, such as Farzin and Bond (2006), Lv, (2017), Usman et al. (2019) failed to consider the case of oil producing countries particularly in the developing countries where the challenge of high emissions of the GHGs remain a threat to lives and property due to less stringent environmental law and order. Furthermore, the idiosyncrasies of oil producing countries require that a separate empirical study on the income-pollutions nexus be undertaken for these countries. Going by the Dutch disease and resource curse literature, oil-producing countries may be subject to a different set of economic realities in contrast to their non-oil producing counterparts. The resource curse literature is inundated with empirical evidence suggestive of a growth mitigating effect of resource dependence (Corden and Neary, 1982; Sachs and Warner, 1999). One often mentioned transmission mechanism is the downscaling of the industrial sector due to resource trade induced capital inflows, which undercuts the competition of other tradable commodities (Corden and Neary, 1982; Corden, 1984; Singer, 1950; Matsuyama, 1992). The present study would help to ascertain whether the growth mitigating effect of natural resources would have a similar effect on the emissions profile of oil producing countries. Also, our choice of oil producing economies stems from the fact that point sourced resources tend to have stronger negative growth effects than diffuse ones (Isham et al. 2005; Mehlum et al. 2006). Our sample cuts across both developed and developing oil producing economies with an inclusion of institutional control variables like democracy in order to give more robust inferences because sound institutions have been seen to diminish the growth mitigating effect of resource dependence (Leite and Weidmann, 1999) or even reverse it (Boschini et al, 2003).

The primary objective of the present study is to uncover the long run effects of oil production on environmental degradation in oil producing countries while controlling for the degree of democracy, electricity production, and trade. The 15 oil producing countries captured include: Algeria, Argentina, Brazil, Canada, China, Indonesia, Iran, Kuwait, Mexico, Nigeria, Norway, Saudi Arabia, United Kingdom, United States and Venezuela. The period of the study spans from 1980 to 2010.[5] Therefore, because the selected countries are at different levels of economic development, our study investigates the validity of the income-induced CO_2 emissions nexus in the presence of oil production and other control variables across different quantiles of the conditional distribution of CO2 emissions through the Method of Moments Quantile Regression of Machado and Silva (2019). This approach incorporates fixed effects, which provides empirical insights into the distributional heterogeneity of this relationship. The method allows for heterogeneous income-emissions relationships at different conditional quantiles distribution of the emissions, which might not be captured by the application of conventional mean regressions. Consequently, a comprehensive examination of the EKC hypothesis in oil producing countries is explored. To the best of our knowledge, this paper is the first to introduce distributional

[5] The period chosen is apparently influenced by the data availability.

heterogeneity in investigating the income-induced CO_2 emissions in oil producing countries by accounting for oil production, electricity production democracy, and international trade. An assessment of the EKC hypothesis at different quantiles of the conditional distribution of emissions is necessary due to several reasons. Firstly, unlike the estimates of the conditional mean which are prone to the distorting effects of outliers, the estimates of the conditional quantiles are more robust to outliers emanating from the dependent variable (Koenker 2004, 2005). Secondly, the conditional mean estimation fails to portray the full distributional impact of income on emissions. Quantile regression on the other hand has a more intuitive appeal especially in panel regressions as it stratifies the distributional effect of the independent variables on the dependent variable into different quantile ranges. Thus, it becomes easier to classify the heterogeneous effects of heterogeneous cross-sectional groups. Consequently, conditional quantile estimations provide information, which is not accessible with conditional mean estimations.

4.2 Theoretical Framework

Going from the core model of Corden and Neary (1982) and Corden (1984) the Dutch disease entails a situation whereby there are three sectors which are the booming sector (B), the lagging sector (L), and the non-tradable sector (N). B and L are tradable sectors with exogenously given world prices assuming a small open economy. In all three sectors only labor has inter-sectoral mobility and both labor and capital are internationally immobile. Assuming for the purposes of this thesis that both B and L are the dirty sectors and N is the clean sector (services). A boom in B would have the effect of increasing pollution in B and reducing pollution in L due to the spending effect and the resource movement effect. The spending effect comes about if the extra income from B is spent on N (services) by either factor owners directly or by government through tax accruals. As a result, prices of N rise in relation to prices in B and L and labor moves away from L to N.

The resource movement effect occurs when there is an increase in the marginal product of B due to the boom. This brings about both direct-deindustrialization and Indirect deindustrialization. Direct deindustrialization occurs as a result of the reduction of output in L (dirty sector) due to the movement of labor from L to B. Due to the spending effect induced excess demand for N, labor moves from L to N further reducing output in L bringing about indirect-deindustrialisation. The combined effect of direct and indirect de-industrialization would reduce pollution in L and increase pollution in B.

4.2.1 Model Building

This chapter of the thesis adopts the Stochastic Impacts by Regression on Population, Output and Technology (STIRPAT) which was developed by Dietz and Rosa (1994) and York et al. (2003). The model isolates three key drivers of pollution which are population, output and technology. The STIRPAT identity was developed out of a need to overcome the weaknesses of the earlier developed IPAT (Commoner, 1990; Ehrlich and Holdren, 1972; Ehrlich and Ehrlich, 1990; Raskin, 1995) and ImPACT (Waggoner and Ausubel, 2002) identities which do not allow for nonlinear and disproportional effects from the environmental impacts and their drivers. The STIRPAT model follows the following specification:

$$I_i = aP_i^b A_i^c T_i^d e_i \tag{22}$$

Where a is the constant which scales the model, the exponents *a, b, c* and *d* are parameters to be estimated while e is the error term. Log transformation of Equation

(22) gives the additive regression model and allows for estimation and hypothesis testing:

$$logI = a + b(logP) + c(logA) + d(logT) + e \quad (23)$$

From Equation (23), I denotes environmental impact, P denotes population, A denotes Affluence while T denotes technology. Dividing through by population the following specification is obtained:

$$\log(I/P) = a + b[log(A/P)] + c[\log\ (T/P)] + e \quad (24)$$

CO_2 emissions per capita will be used to proxy impact per capita *(I/P)* while GDP per capita will be used to proxy affluence per capita *(A/P)*. York et al (2003) suggests that T encompasses anything in the model that affects impact per unit of production while Dietz and Rosa (1994) also suggest that T not only captures technology in the narrow sense but can be decomposed to capture everything else not captured in the model such as culture and institutional arrangements. This chapter of the thesis shall employ oil production, electricity production, democracy and trade volume to capture T. Trade can enhance technological transfer which can either be clean or dirty and can thus significantly affect impact per output while democracy can affect operational procedures which can also affect impact per output. Oil production and electricity production depending on extraction and production procedures employed can also significantly affect impact per output

4.3 Data and Methodology

To achieve the objective of this study, annual data is obtained from the World Bank's World Development Indicators' databank (WDI), the Polity IV database, and the US Energy Information Administration (EIA) for the period 1980 to 2010, and constructed a panel for the countries used. The data, measurement unit, transformation, and their different sources are tabulated and shown in Table 7.

Table 7: Data, Units, Transformations and Sources.

Data	Measurement Unit	Transformation	Source
GDP per capita	Constant 2010 USD	Natural logarithm Transformation	World Development Indicators (WDI), 2013
CO_2	Metric tons per capita	Natural logarithm Transformation	World Development Indicators (WDI), 2013
Democracy	Polity2 Index measured from -10 (most autocratic) to +10 (most democratic).	Transformed to values ranging from 0 – 20 to remove negative numbers. Higher value indicates more democratic regime and vice versa.	Polity IV dataset http://www.systemicpeace.org/polity/polity4.htm.
Electricity Production	Kilowatt hour per capita	Natural logarithm Transformation	World Development Indicators (WDI), 2013
Oil production	1000 barrels per day	Multiplied by 365 to obtain average annual rates and divided by the population to obtain per capita values. The data is transformed to the natural logarithm.	U.S Energy Information Administration (EIA) 2018
Trade	Percentage of GDP	Multiplied by real GDP and divided by 100 to obtain real aggregate values. The values are divided by population to obtain per capita values. The data is transformed to the natural logarithm	World Development Indicators (WDI), 2013

4.3.1 Summary Statistics

Generally, From Table 8, the dataset appears to be fairly symmetric. It can be observed from Table 8 that the variables exhibit positive and negative skewness. Particularly, the CO_2 emission, democracy and real GDP are negatively skewed while oil production, electricity production, and trade are positively skewed. Democracy has the lightest tails due to its very low kurtosis and is the most volatile by virtue of its high standard deviation with the implication of higher dispersion of data points.

Table 8: Summary Statistics

Variables	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
CO2 emissions	-5.30	1.07	-8.0	-3.4	-0.39	2.46
Democracy	21.85	7.76	10	30	-0.29	1.33
Real GDP	9.20	1.26	5.85	11.42	-0.29	2.27
Oil production	-9.99	1.61	-13.1	-6.6	0.20	2.54
Electricity production	7.83	1.53	3.92	10.3	0.33	2.40
Trade	8.36	1.54	3.76	11.12	0.20	2.50

Note: The values are from already transformed variables.

4.3.2 Panel Estimation Techniques

For comparative purposes, we employ the Fully Modified Ordinary Least Squares (FMOLS), the Dynamic Ordinary Least Squares (DOLS) and the Fixed Effects Ordinary least squares OLS (FE-OLS). The FE-OLS technique is augmented with Driscoll and Kraay standard errors, which are robust to general forms of cross-sectional dependence and autocorrelation up to a certain lag. The central reasons for concern in estimating dynamic cointegrated panels as highlighted by Pedroni (2004) are heterogeneity issues with differences in means between cross-sections and differences in cross-sectional adjustment to the cointegrating equilibrium. Pedroni's

FMOLS model includes individual-specific intercepts and allows for heterogeneous serial correlation properties of the error processes across individual members of the panel, and thus, deals with these issues accordingly. The DOLS estimator was extended to panel data settings by Kao and Chiang (2001) — based on the results of Monte Carlo simulations, the DOLS estimator was found to be unbiased compared to both OLS and the FMOLS estimators in finite samples. The DOLS estimator also controls for endogeneity through the augmentation of lead and lagged differences to suppress the endogenous feedback.

Due to the limitations of previous estimation methods, a panel quantile regression technique was employed to examine the distributional and heterogeneous effect across quantiles (Sarkodie and Strezov, 2019). The panel quantile regression method was introduced by the seminal paper of Koenker & Basett (1978). Generally, the quantile regressions are utilized to estimate the conditional median or a variety of different quantiles of the response variables subject to certain values of the exogenous variables unlike regular regressions of the least squares' variant —which yield estimates of the conditional mean of the endogenous variable subject to certain values of the exogenous variables. Quantile regressions are more robust to incidences of outliers in the estimation. Aside that it is the most pertinent in cases where the relationship between the conditional means of two variables is weak or non-existent (Binder & Coad, 2011).

However, in this present study, we employed the Machado and Silva (2019) Method of Moments Quantile Regression (MMQR) with fixed effects. A quantile regression whilst being robust to outliers does not consider possible unobserved heterogeneity across individuals within a panel. The MMQR method makes it possible to identify the conditional heterogeneous covariance effects of the determinants of CO_2 emissions by allowing the individual effects to affect the entire distribution rather than just shifting means as in the case of Koenker (2004), Canay (2011) amongst others. The MMQR estimation technique is particularly relevant in scenarios where the panel data model is embedded with individual effects and when the model possesses endogenous explanatory variables. The MMQR approach is also quite intuitive because it yields non-crossing estimates of the regression quantiles. The estimation of the conditional quantiles $Q_Y(\tau|X)$ for a model of the location-scale variant takes the following form:

$$Y_{it} = \alpha_i + X'_{it}\beta + (\delta_i + Z'_{it}\gamma)U_{it} \tag{25}$$

Where the probability, $\mathrm{P}\{\delta_i + Z'_{it}\gamma > 0\} = 1$. $(\alpha, \beta', \delta, \gamma')'$ are parameters to be estimated. $(\alpha_i, \delta_i), i = 1, \ldots, n,$ designates the individual i fixed effects and Z is a k-vector of identified components of X which are differentiable transformations with element l given by:

$$Z_l = Z_l(X), \quad l = 1, \ldots, k \tag{26}$$

X_{it} is independently and identically distributed for any fixed i and is independent across time (t). U_{it} *is* independently and identically distributed across individuals (i) and through time (t) and are orthogonal to X_{it} and normalized to satisfy the moment conditions in Machado and Silva (2019) which amongst other things do not imply strict exogeneity. Equation (25) implies the following;

$$Q_Y(\tau|X_{it}) = \big(\alpha_i + \delta_i q(\tau)\big) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \tag{27}$$

From equation (27), X'_{it} is a vector of independent variables which in the present study are the natural logarithm of GDP per capita (LGDP), the natural logarithm of squared GDP (LGDP^2), democracy (DEMOC), the natural logarithm of oil production per capita (LOILPD), the natural logarithm of electricity production per capita (LELEPD) and the natural logarithm of trade per capita (LTRD). $Q_Y(\tau|X_{it})$ indicates the quantile distribution of the dependent variable Y_{it} (natural logarithm of CO_2

emissions per capita) which is conditional on the location of independent variable X_{it}. $\alpha_i(\tau) \equiv \alpha_i + \delta_i q(\tau)$ is the scalar coefficient which is indicative of the quantile-τ fixed effect for individual i. The individual effect does not denote an intercept shift unlike the usual least squares fixed effects. They are time invariant parameters whose heterogeneous impacts are allowed to differ across the quantiles of the conditional distribution of the endogenous variable *Y*. $q(\tau)$ denotes the τ-th sample quantile which is estimated by solving the following optimization problem;

$$min_q \sum_i \sum_t \rho_\tau \left(\hat{R}_{it} - \left(\hat{\delta}_i + Z'_{it}\hat{\gamma}\right)q\right) \tag{28}$$

where $\rho_\tau(\mathrm{A}) = (\tau - 1)\mathrm{AI}\{\mathrm{A} \leq 0\} + \tau\mathrm{AI}\{\mathrm{A} > 0\}$ denotes the check function.

4.4 Empirical results

4.4.1 Cross-sectional Dependence and Unit Root Test Results

Before estimating the unknown parameters, some standard preliminary tests are undertaken in order to ascertain the time series properties of the variables. We first check the existence of cross-sectional dependence (CD) within the panel. Cross-sectional dependence can distort the true parameter values of coefficient estimates. Cross-sectional dependence which may arise as a result of unobserved common factors can greatly diminish panel data efficiency gains if ignored (Phillips & Sul, 2003). It is, therefore, important to consider this issue in order to produce robust coefficient estimates. We employ the Pesaran (2004) CD test in order to assess cross-sectional dependence within the panel. From Table 9, apart from oil production, all the other quantitative variables exhibit significant cross-sectional dependence across countries. Thus, our unit root and cointegration tests, as well as panel estimation techniques, must incorporate methodologies that are robust to the effects of cross-sectional dependence in order to mitigate the potential size distortions.

In order to objectively assess the integrating properties of the investigated variables, we employ the Im, Pesaran and Shin (2003) (IPS), Breitung (2000) and the Breitung and Das (2006) panel non-stationarity tests. The Breitung (2000) and the Breitung and Das (2006) panel unit root tests assume a common autoregressive parameter for all individuals in the panel while the Im-Pesaran-Shin (IPS) (2003) test relaxes this assumption, and instead allows each individual to have its own autoregressive parameter. The Breitung (2000) panel unit root test has been shown to outperform other similar unit root tests in terms of power for moderately sized panel datasets such as the one employed for the present study. The Breitung and Das (2005) panel unit root test is a variant of the test that controls for cross-sectional dependence. We employ these three tests to ascertain the extent to which cross-sectional dependence affects the panel unit root tests. It can be observed from Table 8 that all the variables are non-stationary at levels but stationary at first differences in all unit root test specifications. This implies that all the variables used in the estimation are integrated of order one, I (1).

Table 9: Cross-Sectional Dependence and Panel Unit Root Test Results

Variable	LCO_2	Loilpd	Democ	Ltrd	Lelepd	Lgdp
Panel A: Cross-sectional dependence test						
Pesaran (2004)	9.40^{***}	1.23	-	33.3^{***}	47.9^{***}	30^{***}
Panel B : Unit root tests						
Levels						
IPS (2003)	0.410	-1.046	-1.442	2.477	-0.264	1.108
Breitung (2000)	1.790	3.350	0.610	6.550	9.100	2.701
Breitung &Das (2006)	-1.1301	-0.380	-0.080	2.601	5.440	1.200
First difference						
IPS (2003)	-18.24^{***}	-12.13^{***}	-5.719^{***}	-10.53^{***}	-16.03^{***}	-15.52^{***}
Breitung (2000)	-6.028^{***}	-3.873^{***}	-7.450^{***}	-5.710^{***}	-5.970^{***}	-8.810^{***}
Breitung & Das (2006)	-4.205^{***}	-3.700^{***}	-10.30^{***}	-3.430^{***}	-7.120^{***}	-1.920^{**}

Note: "*"," **" and" ***" indicates statistical significance at the 10%,5% and 1% levels respectively.

4.4.2 Panel Cointegration Test Results

In order to ascertain the existence of a non-spurious long-run relationship between the variables, we employ the Pedroni (2004) panel cointegration test and the Bootstrapped panel cointegration test of Westerlund (2007). Pedroni (2004) proposes a comprehensive framework for panel cointegration testing under the spirit of the Engle and Granger 2-step methodology. Pedroni's approach filters out short-run parameters and individual-specific deterministic trends in the first step of the procedure, thus controlling for heterogeneity. Based on estimated residuals, Pedroni derives seven different test statistics, which can either be those assuming a common process, commonly denoted as "pooled" or "within-dimension" tests, and those assuming individual processes denoted as "grouped" or "between-dimension" tests. Under the

Westerlund (2007) technique, four new tests with the null hypothesis of no cointegration are proposed. The test relaxes the imposition of common factor restrictions on tests based on residual dynamics because these dynamics are structural in nature rather than residual. Structural dynamics are necessary because the failure of common factor restrictions can significantly reduce the power of residual-based cointegration tests (Kremers et al. 1992). With the removal of this restriction, long and short-run adjustment processes need not be identical. Employing the bootstrap approach of Westerlund (2007), we can mitigate the distortionary effects of cross-sectional dependence and thus produce robust critical values. The results from Table 10 shows that both the Pedroni (2004) test and the Westerlund (2007) bootstrapped cointegration test provides robust support for cointegration.

Table 10: Panel Cointegration Tests

Panel A: Pedroni (2004) residual based cointegration test				
Statistic	Panel PP	Panel ADF	Group PP	Group ADF
Values	-2.262**	-2.683***	-6.466***	-5.988***
Weighted values	-2.041**	-5.223***		
Panel B: Westerlund (2007) Bootstrapped error correction based cointegration test				
Statistic	Pτ	Pα	Gτ	Gα
Values	-9.419	-4.500	-2.400	-5.076
P-values	0.160	0.992	0.540	1.000
P-values (Robust)	0.022**	0.215	0.042**	0.205

Note: *** and ** indicate significance of the cointegration test at the 1% and 5%levels.

4.4.3 Panel Estimation Results

The results from FMOLS, DOLS and FE-OLS estimation procedures are presented in Table 11. From Table 11, we observe that the coefficient estimates obtained from all three specifications are on the average, quite close to each other even though they all vary in terms of statistical significance. Electricity production and trade are the most robust across all three specifications in terms of statistical significance and coefficient size. A percentage increase in electricity production positively impacts CO_2 emissions by ~0.32% in the case of the FE-OLS estimator and ~0.41% in the case of the DOLS estimator. Trade, on the other hand, exerts a significantly negative impact on the level of CO_2 emissions. Put differently, a percentage increase in trade mitigates emissions by ~ 0.33% in the case of the DOLS estimator. This validates the pollution halo hypothesis for the panel of oil-producing countries. This result echoes the major conclusion of Nasir and Rehman (2011) but contradicts Ozatac et al. (2017) who found a positive and inelastic impact of trade on CO_2 emissions in Turkey. More so, democracy is seen to have a positive effect, which is only significant in the FMOLS estimation specification. This finding contradicts Usman et al. (2019a) but aligns with the theory of modernization. There is a weak statistically significant support for the EKC hypothesis in the FMOLS specification and a strong statistically significant support in the FE-OLS estimation specification, but no statistically significant evidence is found in the DOLS specification even though the curve is visible. Oil production as expected exhibits a positive statistically significant relationship with CO_2 emissions, but its coefficient seems disparate across specifications — ranging between 0.083% and 0.273% increase in CO_2 emissions for a percentage increase in oil production for the FE-OLS and DOLS estimators, respectively.

Table 11: Panel Estimation Results

Variables	FMOLS	DOLS	FE-OLS (D-K S.E)
Lgdp	1.236***	0.737	0.925***
$Lgdp^2$	-0.031*	-0.018	-0.024**
Democ	0.005***	0.003	0.005
Loilpd	0.189***	0.273***	0.083***
Lelepd	0.382***	0.413***	0.324***
Ltrd	-0.316***	-0.330***	-0.218***

Note: "***"," **"and "*" indicates significance of the cointegration test at the 1% level.

From Table 12, the panel quantile regression estimates show that the effect of oil production on CO_2 emissions is strongly statistically significant ($p < 0.05$) from the 3rd to median quantiles and weakly statistically significant ($p < 0.1 > 0.05$) at the 1st, 2nd and 6th quantiles. At higher quantiles (i.e. 7th, 8th, and 9th quantiles) the effect of oil production is insignificant. This result validates the effectiveness of environmental policies pertaining to oil production at higher polluting countries. The effect of income captured by GDP on CO_2 emissions is significant across all quantiles with the EKC hypothesis being validated from 4th to 9th quantiles and being strongly validated from the median to 9th quantile. The results show that the EKC hypothesis is only valid in countries with median to above median CO_2 emissions. This implies that at countries below the median, development is prioritized above environmental quality. Also, countries below the median being at lesser developmental stages by virtue of their emissions level may find it more challenging to switch fuels from renewable to non-renewable sources due to the investment cost implication. Oil production has no significant effect on CO_2 emissions in countries with the highest emissions level. This may stem from the different extraction practices obtainable in developed and developing oil producing economies. These results portend serious implications for policy — it therefore, concurs with Shahbaz et al. (2017b) and Sarkodie and Strezov (2018) who validated the EKC hypothesis for China, which emits very high levels of GHGs and carbon dioxide. Our finding is also congenial to the recent empirical study by Usman et al. (2019a) who confirmed the EKC hypothesis in India, another top emitter of CO_2. The results are also consistent with Rafindadi and Usman (2019) who established the presence of EKC hypothesis for the largest emitter of GHGs and CO_2 in Africa. The results based on democracy, however, showed that its effect on CO_2 emissions is positive in all the quantiles but only weakly statistically significant in the average CO_2 emissions countries (i.e. 3rd, 4th, and 5th quantiles). Interestingly though, this corresponds to quantiles were oil production has a strong statistically significant relationship with CO_2 emissions. This finding could be attributed to the positive correlation between democracy and income, a cornerstone of the theory of modernization. Therefore, it is partly not consistent with Farzin and Bond (2006) and Usman et al. (2019a) who posited that the freedom of the people in democracy pushes the government and its managers to pursue environmentally-friendly policies. This is because environmentally friendly policies are prioritized in countries with the highest emission levels. Apart from environmental concerns the pursuit of environmental policies in higher emissions countries is also due in part to the fact that these countries have the income to pursue these policies due to their production scale. As expected, the impact electricity production on CO_2 emissions is positive. Specifically, while the impact of electricity production is highly significant in all the quantiles, it is evident that the impact of oil production is only significant in the lower and average quantiles, suggesting that these countries are obviously advancing towards reducing oil producing-induced emissions. Finally, our quantile results revealed a negative and significant relationship between trade and CO_2 emissions. This finding agrees with Nasir and Rehman (2011) and disagrees with Cole (2004) as well as Ozatac et al. (2017) who argued that trade gives room for the penetration of unclean industries in countries with less stringent environmental laws, causing a pollution haven hypothesis. This may be true for non-oil producing emerging economies but may not hold for their oil producing counterparts due to the deindustrialization inducing resource curse hypothesis which may undercut the competitiveness of other pollution inducing export-oriented industries. The results based on the location and scale parameters succinctly show that while democracy may not significantly affect the average CO_2 emissions, it, however, has a higher negative dispersion across quantiles. Putting it differently, democracy has an increased variance across quantiles as can be seen from Figure 6. The EKC hypothesis is not only observed from the locational dimension but also from the dimension of scale as the scale of the effect of both LGDP and $LGDP^2$ are significantly dispersed across quantiles as can also be observed from Figure 6. This further validates the use of the MMQR procedure.

Table 12: Panel Quantile Estimation Results

Variables	Method of Moments Quantile regression with fixed effects										
	Location	Scale	Quantiles								
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Lgdp	0.925*	0.209***	0.612*	0.687***	0.768***	0.853***	0.929***	0.999***	1.080***	1.145***	1.209***
$Lgdp^2$	-0.023	-0.015***	-0.001	-0.007	-0.012	-0.019*	-0.024***	-0.029***	-0.035***	-0.039***	-0.044***
Democ	0.005	-0.002*	0.008	0.008	0.007*	0.006*	0.005*	0.004	0.004	0.002	0.002
Loilpd	0.083	-0.029	0.127*	0.117*	0.105***	0.093***	0.083**	0.073*	0.061	0.052	0.044
Lelepd	0.324***	-0.025	0.361***	0.352***	0.343***	0.332***	0.323***	0.315***	0.305***	0.297***	0.289***
Ltrd	-0.218***	0.027	-0.258***	-0.249***	0.238***	-0.227***	-0.216***	-0.208***	-0.918***	-0.190***	-0.181***

Notes: *,* and *** indicate significance at the 10%, 5% and 1% levels respectively.

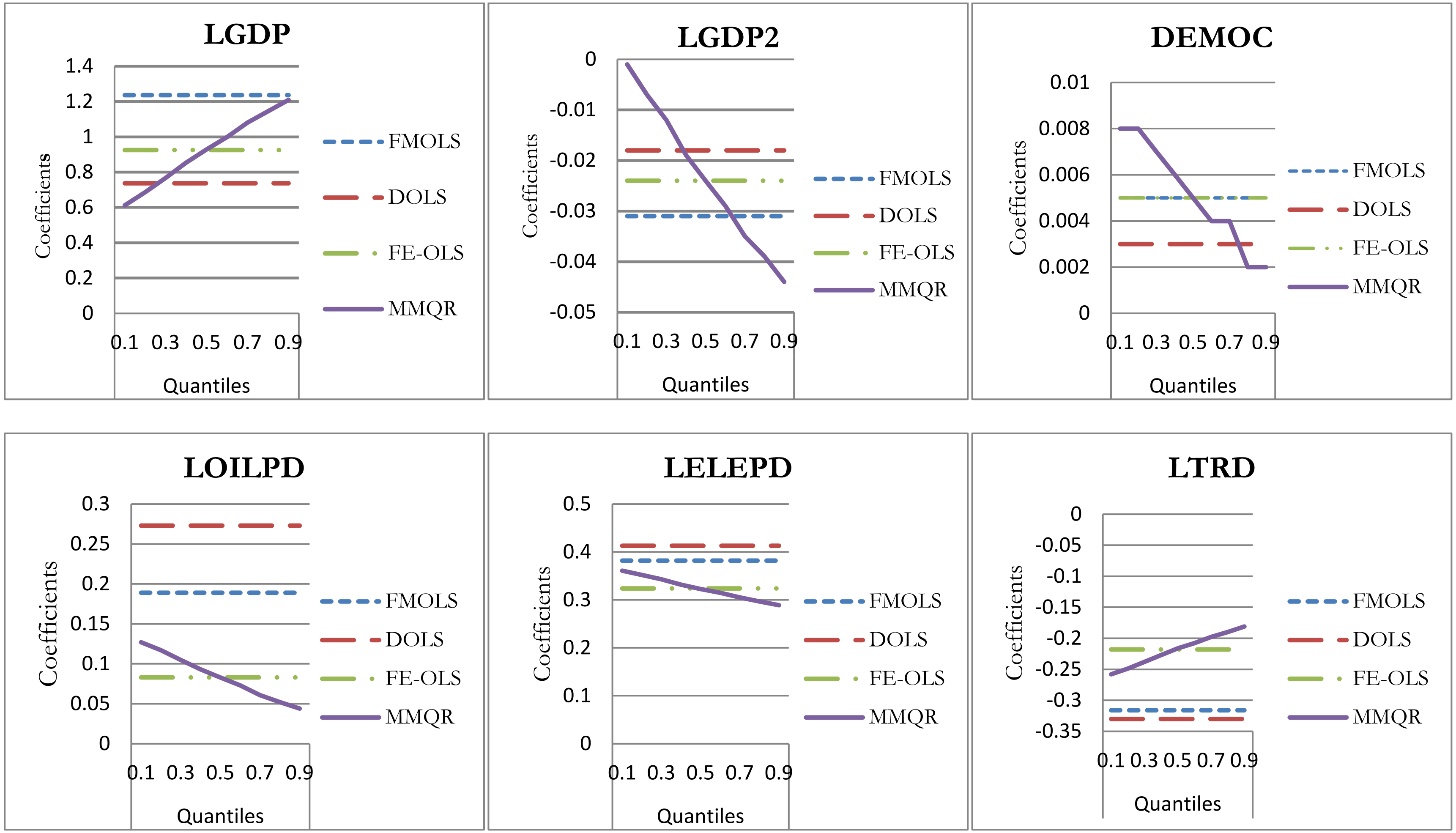

Figure 6: Graphical representation of coefficient estimates across quantiles, obtained from all 4 estimators

4.5 Conclusion and Policy Implications

As a contribution to the energy and environment-related literature on environmental pollution in the light of oil production and economic development, this study investigates the empirical relationship between oil production, electricity production, trade, democracy, GDP and CO_2 emissions whilst accounting for the EKC hypothesis. We employ panel unit roots, panel cointegration and panel estimation techniques with data spanning over 30 years in 15 oil-producing countries. The quantitative variables (except democracy) are all measured in per-capita terms to control for population. Panel unit root and panel cointegration techniques show that the variables all follow an I(1) process with the existence of a non-spurious long-run relationship between these variables. Traditional panel cointegration estimation techniques show disparities in coefficient significance even though the sizes obtained from the different specifications are not too far apart. We employ the MMQR technique of Machado and Silva (2019) which allows for the analysis of the different impacts of the exogenous variables across different quantiles of the conditional distribution of CO_2 emissions in order to get a clearer and more robust assessment of the empirical relationship.

The coefficient estimates of FMOLS, DOLS, and FE-OLS validates the EKC and Pollution Halo hypotheses for oil-producing countries. Our findings from the MMQR indicates that oil production is positively significant from the 1st to 6th quantiles while democracy is positively significant from the 3rd to median quantiles which implies that the positive relationship between oil production and CO_2 emissions are only felt at the lower quantiles of the conditional distribution of CO_2 emissions. This may probably imply that oil production has a positive effect in oil-producing countries at their early and transitional development stages while democracy only statistically increased CO_2 emissions in quantiles close to the median. It is also noteworthy to point out that more developed oil producing economies with higher emissions are more economically diversified than their developing counterparts who are much more dependent on oil extraction. This implies that they may probably have oil taking up a relatively lesser share of their emissions profile. What can be observed in Figure 1 is that the MMQR estimates of oil production (LOILPD) and income (LGDP) follow different dynamics. The estimate of oil production has its highest coefficient at the lowest quantile while that of income has the highest coefficient at the highest quantile. While the coefficient of oil production is reducing from the lowest to highest quantile that of income is increasing from the lowest to the highest quantile. This implies that CO2 emissions are at their lowest levels at quantiles where oil production effects on emissions are highest and economic growth (income) effects on emissions are lowest. While at quantiles where CO_2 emissions are highest, the reverse scenario occurs. This entails that more overall production occurs at countries that are least dependent on oil production. Dependence in this case does not necessarily imply abundance. This gives yet another evidence for the de-industrialization induced resource curse. However, income coefficients at the highest emissions countries should be interpreted cautiously as they represent threshold values implying that lower emissions countries have not yet attained the threshold production levels where environmental degradation would instigate public concerns towards the creation of pollution abatement policies. The implication from this is that lower emissions countries need to diversify their economy in order to attain the much needed capital to pursue sustainable development policies. Also, economic diversification could seriously dampen the dependence on the pollution inducing process of crude oil extraction. The insignificance of the positive impact of democracy in the higher quantiles could be traceable to the recent government environmental policies towards circumventing the continuous proliferation of the GHGs and CO_2 emissions. Environmental quality has relatively more importance to citizens of countries with higher emissions compared to their lesser emissions counterparts. Thus, democratic regimes which conform to the peoples' will would deploy more policies towards emissions abatement in order to gain the goodwill of the electorate. The fact that pollution abatement policies may be detrimental to growth, democratic regimes in the higher emission countries may also be open to a lot of compromises— thus the insignificance of democracy at higher emissions quantiles. At quantiles close to the median where democracy has a positively significant impact on carbon emissions —environmental quality may not be too much of a concern to citizens of these countries because the effects of environmental degradation may not be immediately visible. Thus, economic growth which may be reliant on emissions dependent production activities may be given more priority by the electorate and the elected. At lower emission countries, the effect of democracy may not be felt due to the preponderance of oil extraction activities and a higher presence of the resource curse. The positive and insignificant effect of democracy in the higher quantiles is indicative of improvement in the democratization process of the oil-producing countries. The experience of India as documented by Usman et al. (2019a), Romania documented by Shahbaz et al. (2013) and emerging countries documented by Lv (2017) is an assurance that improving the level of democracy would reduce emissions. This could be seen from the reduction of democracy coefficient estimates from the lowest to the highest quantiles. Therefore, we suggest the need to improve the degree of democratization in the oil-producing countries, especially in oil-producing countries with high atmospheric emissions.

Electricity production is positive and significant across all quantiles while trade has a negative relationship with CO_2 emissions across quantiles. This result validates the pollution halo hypothesis in the existing literature. Within the context of oil-producing countries, the findings may imply different causes for different quantiles. At lower quantiles a possible cause would be the effect of de-industrialization — a condition that occurs when oil production crowds out all the other emissions dependent tradable sectors of the economy. This condition consequently makes them more import dependent thus a significant amount of their trade will be composed of imports and oil exports. At higher quantiles, the movement of labour-intensive export-oriented industries from higher wage economies to lower wage economies in order to increase profits may tilt the trade dynamics towards imports and significantly cut down emissions levels in these countries. Also, at higher emission countries the effect of the pollution halo hypothesis may apply directly due to the stringency of environmental laws on emissions dependent export-oriented industries. This may bring about a situation whereby onshore industries are forced to cut down on their emissions production. Due to the cost implication of employing improved energy efficiency technologies and fuel switching — in a bid to appropriate more profit a lot of firms may reallocate their firms to overseas location with less stringent environmental policies. Electricity production affects all the productive sectors of the economy and thus expected to be positively related with carbon emissions. From Figure 1, however, it can be observed that the effect of electricity production on carbon emissions is highest at the lowest quantile and lowest at the highest quantile. This does not necessarily imply a reduction of productivity from the lowest to the highest quantile but an increase in energy efficiency from the lowest to the highest quantile as less CO_2 emissions is produced per unit of energy produced due to more efficient energy systems. It may also imply the effect of switching from non-renewable to renewable electricity production sources at higher emissions countries that can afford the investment cost implications. The fact that electricity production is still significantly positively related to CO_2 emissions may imply that electricity production in these countries is from both renewable and non-renewable sources. The implication of this result is that to reduce the level of CO_2 emissions in the oil-producing countries, more effort should be put in place to reduce electricity production from fossil fuel energy sources. In other words, electricity production from clean and renewable sources like hydropower, wind, solar and nuclear power, etc. should be encouraged. Better still, where the countries have no sufficient resources to embrace renewable electricity generation, such countries should embrace moderate environmental tax policies. These policies entail the moderate taxation of emissions dependent industries. The revenue accrued from such taxes should be re-invested in long-term infrastructural development of renewable energy sources.

Chapter 5

HETEREGENOUS EFFECTS OF RENEWABLE ENERGY CONSUMPTION AND ENERGY PRICES ON THE CO2 EMISSIONS OF G7 COUNTRIES

5.1 Introduction

The viewpoints of policymakers on global energy-environment dynamics could be well-posited on two main paradigm shifts. The first perception is based on the argument that energy diversifications (portfolios) of the downstream sector is capable of curbing the incessant oil price fluctuations. From another perspective, these conjectures by most environmentalists have consistently been hinged on the need for a global drive toward a cleaner, sustainable environment and economy. Hence, tilting towards the environmental context and especially the conventional Environmental Kuznets Curve (EKC) hypothesis, the role of global energy prices dynamics amidst the increasing use of low carbon energy sources and energy technologies is worth further scientific examination. The dynamic effects of global energy prices are observed to cut across various energy products which includes the heavy fuel oil for industry, light fuel oil for households, automotive diesel oil, unleaded premium, natural gas for industry, natural gas for households, steam coal for industry, electricity for industry, and electricity for households (International Energy Agency, IEA, 2019). For instance, as noted by the IEA; the average price of gasoline in 2018 increased by 14% from the previous year (International Energy Agency, IEA 2019b). The IEA further observed that the European consumers paid the highest gasoline price, thus suggesting a reflection of the continent's high taxes on fuels as a measure to achieving the low carbon energy targets and Sustainable Development Goals (SDGs) target.

The use of renewable energy and clean energy technologies is one of the prominent mechanisms through which the long-standing link between fuel pollution *vis-à-vis* carbon emissions (CO_2) and economic growth can be broken. This is because energy utilization is unarguably linked with economic growth. Because energy is sourced predominantly from CO_2 emitting fossil fuels, it is thus suggestive that energy consumption is responsible for determining environmental quality (Rafindadi, 2016; Rafindadi and Ozturk, 2017; Rafindadi & Usman, 2019; Usman, Iorember & Olanipekun, 2019a).

Consequently, in achieving global environmental sustainability, the United Nations Framework Convention on Climate Change (UNFCC)[6], and a growing number of states among other stakeholders have consistently urged for more commitment to the comprehensive 2015 Paris Agreement[7]. For instance, the share of renewables in total energy consumption will reportedly increase in five-year periods to attain 12.4% growth by 2023 (International Energy Agency, IEA (2019c). With about 30% of power demand being met by 2023 through renewables. 70% of global growth in electricity generation is to come from renewable energy through solar Photovoltaic (PV), wind, hydropower and bioenergy. Renewable energy from the electricity sector is projected

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[6] The United Nations Framework Convention on Climate Change (UNFCC) is the section of the United Nations organization that is saddled with mitigating global climate change. Further information on UNFCCC is available at https://unfccc.int/.

[7] The Paris Agreement is the United Nations Framework Convention on Climate Change of 2015. More details relating to the Paris Agreement of 2015 are available at: https://unfccc.int/process/conferences/pastconferences/ paris-climate-change-conference-november-2015/ Paris-agreement.

to be the fastest growing by 2023 (International Energy Agency, IEA (2019c). However, the current global outlook suggests that energy generation from renewables is less sufficient at meeting the global demands prominently from heating, cooling, and transportation (REN21, 2019). It then implies that the heavy reliance on fossil fuels which are mostly subsidized in many countries is persistent due to the high cost of renewable energy generation and the prevalence of fossil fuel-based energy technologies.

Considering the role of the world leading economies such as the G-7 countries (Canada, France, Germany, Italy, United Kingdom (UK), United States (USA), and Japan) in influencing energy price dynamics and global environment perspectives (especially through policy directions), the current study underpins this role within the EKC framework. While studies have considered the role of renewable energy consumption in mitigating environmental degradation (Alola, Alola & Saint Akadiri, 2019; Alola, Bekun & Sarkodie, 2019; Alola et al., 2019; Bekun Alola & Sarkodie, 2019; Saint Akadiri et al., 2019) as well as examining the link between energy prices and environmental degradation (Al-Mulali & Ozturk, 2016; Balaguer & Cantavella, 2016; Yilanci & Ozgur, 2019), the distinction of the current study can be observed from a few perspectives. The novelty of the current study is hinged on the basis that the nexus of energy prices in the concept of the EKC hypothesis is considered for the first time for the panel of G7 countries. In addition, this study equally contributes to the extant literature by jointly investigating the role of energy prices and the renewables within the EKC framework for the G7 countries. More importantly, the current study considered the aforementioned nexus in both the panel framework and for each specific member country of the G7 countries in order to unravel panel as well as country specific price and renewables effect. This is due in part to the fact that government and stakeholder attitudes towards renewable energy consumption may vary across each individual member of the G7. As such there is the potential to have different price and renewables effect across the different individual members of the G7.

5.2 Theoretical Framework

This chapter of the thesis adopts the IPAT identity. This is a well employed framework for analyzing the driving forces of environmental change. In the IPAT framework the impact on the environment is specified to be the multiplicative product of three principal driving forces which are: population, affluence and technology. However, IPAT is an accounting framework and thus cannot identify disproportional and non-monotonic effects. In order to make allowance for empirical hypothesis testing the IPAT model is re-formulated within a stochastic specification of the following form:

$$logI = a + b(logP) + c(logA) + d(logT) + e \tag{29}$$

From Equation (23), I denotes environmental impact, P denotes population, A denotes Affluence while T denotes technology. Dividing through by population the following specification is obtained:

$$\log(I/P) = a + b[log(A/P)] + c[\log\ (T/P)] + e \tag{30}$$

In this chapter of the thesis CO_2 emissions per capita will proxy for environmental impact (I) while per capita GDP will proxy for affluence (A). The technology parameter shall be controlled for by accounting for renewable energy consumption, energy price and trade. All these variables can affect impact per output via various mechanisms. Renewable energy consumption can reduce impact per output directly if its use is employed on a large scale relative to fossil fuel energy sources. Higher energy prices can induce a substitution effect from energy intensive technologies to more energy efficient technologies and thus could affect impact per output. Trade on the other hand can go either direction. It can increase the transfer of cleaner technologies which could essentially reduce impact per output or it can induce the transfer of dirtier technologies which can in effect increase impact per output.

5.3 Methodology and Data

5.3.1 Methodology

In line with the purpose of this research, the conventional EKC model of Grossman and Krueger (1991,1995) is augmented with renewable energy, energy prices and trade, and is specified as;

$$LCO2PK_{it} = \beta_0 + \beta_1 LRGDPK_{it} + \beta_2 LRGDPK2_{it} + \beta_3 LRENPK_{it} + \beta_4 LCPIE_{it} + \beta_5 LTRADPK_{it} + u_{it} \quad (31)$$

From equation (31) *LCO2PK*, *LRGDPK*, *LRGDPK2, LRENPK, LCPIE* and *LTRADPK* denotes respectively, the real per-capita GDP, the square of real per capita GDP, per capita renewable energy consumption, energy prices and per capita trade volume of country *i* at time *t*, *u* denotes the stochastic white noise error term. β_1, β_2, β_3, β_4 and β_5 indicate the slope coefficients of the aforementioned variables while β_0 is a time invariant country specific effect. With the exception of energy prices, all quantitative variables are measured in per-capita terms in order to control for population effects. All variables including energy prices are log transformed in order to reduce the incidence of heteroscedasticity consequently, slope coefficients are interpreted as elasticities.

We employ heterogeneous panel estimation methods of the mean group (group mean) variants because of the unbalanced nature of the dataset employed. Unlike conventional pooled panel estimation procedures, panel mean group estimation techniques employ full heterogeneity with the implication of both long-run and short-run heterogeneity. In mean group estimations, N time series equations are estimated for each individual country in the panel. The estimated coefficients are then averaged to represent the overall panel estimate. The estimation sequence of mean group techniques makes them ideal for unbalanced panel data of the type applied in the present study. We employ both the group mean FMOLS of Pedroni (2001a, 2001b), the group mean DOLS of Kao and Chiang (2001) and Pedroni(2001b) as well as the mean group estimator of Peseran and Smith (1995). While the FMOLS procedure eliminates serial correlation and endogeneity in OLS estimations through a semi-parametric correction, the DOLS procedure conversely applies a parametric correction to OLS estimators to eliminate endogeneity and serial correlation. Kao and Chiang (2001) also argue that the DOLS model exhibits the least bias in small samples when compared to the FMOLS and the OLS procedures. An advantage of group mean estimators over the other pooled panel estimators is that their formulation is based on the "between dimension" of the panel rather than the "within dimension" of pooled estimators as such the t-static implies a more flexible alternative hypothesis (Pedroni, 2001a). Pesaran & Smith (1995) further argue within the perspective of OLS regressions, that when the true slope coefficients are heterogeneous, group mean estimators provide consistent sample mean point estimates of the heterogeneous cointegrating vectors, a feat which cannot be replicated by traditional pooled estimators. All 3 estimation procedures would be employed to ascertain whether or not the model parameters are robust to different estimation techniques.

The panel vector error correction model (VECM) is a suitable Granger causality testing approach to apply when the variables follow an I(I) process and long-run cointegration has been validated among the series. In the present study, the panel VECM would be employed to test both the long-run and short-run Granger causality relationship. The VECM Granger causality method for the present study is specified as follows:

$$\Delta\begin{bmatrix} LCO2PK_{it} \\ LCPIE_{it} \\ LRENPK_{it} \\ LRGDPK_{it} \\ LRGDPK2_{it} \\ LTRADPK_{it} \end{bmatrix} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \\ \beta_6 \end{bmatrix} + \sum_{k=1}^{p} \Delta \begin{bmatrix} \theta_{11ik}\theta_{12ik}\theta_{13ik}\theta_{14ik}\theta_{15ik}\theta_{16ik} \\ \theta_{21ik}\theta_{22ik}\theta_{23ik}\theta_{24ik}\theta_{25ik}\theta_{26ik} \\ \theta_{31ik}\theta_{32ik}\theta_{33ik}\theta_{34ik}\theta_{35ik}\theta_{36ik} \\ \theta_{41ik}\theta_{42ik}\theta_{43ik}\theta_{44ik}\theta_{45ik}\theta_{46ik} \\ \theta_{51ik}\theta_{52ik}\theta_{53ik}\theta_{54ik}\theta_{55ik}\theta_{56ik} \\ \theta_{61ik}\theta_{62ik}\theta_{63ik}\theta_{64ik}\theta_{65ik}\theta_{66ik} \end{bmatrix}$$

$$\times \begin{vmatrix} LCO2PK_{it-k} \\ LCPIE_{it-k} \\ LRENPK_{it-k} \\ LRGDPK_{it-k} \\ LRGDPK2_{it-k} \\ LTRADPK_{it-k} \end{vmatrix} + \begin{bmatrix} \lambda_{1i} \\ \lambda_{2i} \\ \lambda_{3i} \\ \lambda_{4i} \\ \lambda_{5i} \\ \lambda_{6i} \end{bmatrix} ECT_{it-1} + \begin{bmatrix} u_{1it} \\ u_{2it} \\ u_{3it} \\ u_{4it} \\ u_{5it} \\ u_{6it} \end{bmatrix} \tag{32}$$

where, ECT_{t-1} denotes the lagged residual which is from the long-run relationship, Δ denotes the difference operator and u_{xit} denotes the stochastic error term at time t in the x^{th} equation of the i^{th} country, which are independently and identically distributed. Furthermore, the significance of the estimated coefficient of the ECT_{t-1} in any equation indicates the validation of long-run causality from the independent variables to the dependent variable of the specific equation. For instance, $\lambda_{1i} \neq 0$ implies that long-run causality flows from the independent variables to *LCO2PK*. Short-run causality is depicted by the joint statistical significance of the lagged differences of the explanatory variables. For instance, $\sum_{k=1}^{p} \Delta\theta_{12ik} \neq 0$ implies that *LCPIE* has short run predictive content for *LCO2PK*.

5.3.2 Data

We use an unbalanced panel dataset sampled at different time periods for the United Kingdom (1970-2014) and Germany (1990-2014) due to data limitations in these countries. Data for the other 5 countries in the panel are sampled from 1960-2014. CO2 emissions are measured in metric tons per-capita, per-capita real GDP is measured in constant 2010 USD, renewable energy consumption is measured in kg of oil equivalent per-capita, per capita trade volume is measured in constant 2010 USD, all 3 aforementioned variables are obtained from the World Bank world development indicators (https://databank.worldbank.org). The energy price index follows the United Nations classification of individual consumption by purpose which was adopted in the compilation of the Harmonized Index of Consumer Prices (HICP) of the EU, the Euro area as well as OECD countries. The index includes the COICOP 04.5 classification (Electricity, gas and other fuels) which incorporates the weighted index of the price of electricity, gas, natural gas and town gas, liquefied hydrocarbons, domestic heating and lighting oils, solid fuels and heat energy. It also includes the COICOP 07.2.2 classification which covers fuels (diesel and petrol) and lubricants for personal transport equipment. The energy price index was obtained from OECD Statistics (http://www.oecd.org/sdd). A cursory look at the summary statistics shows that while log transformed real per-capita GDP (LRGDPK) has the lowest standard deviation and thus is the least volatile of all the variables, its squared counterpart (LRGDPK2) however is the most volatile with the highest standard deviation. This implies that EKC inflection points would most likely be disparate across countries. Per-capita renewable energy consumption follows suit with the 2nd most volatile variable in the dataset signifying potential differences in the attitude of stakeholders towards the production and utilization of renewable energy in their respective economies. Furthermore, from figure 7 it can be clearly seen that per capita CO2 emissions for all countries is initially upward sloping from the beginning of the 1960's. It however becomes downward sloping during the mid-part of the 2000's, a period which coincides with the coming into force of the Kyoto protocol in February of 2005. Glancing through the time-series plot of the energy price variable, what may seem to be an energy price level convergence across the G7 countries can be observed. A major reason for this may be because of the regional economic integration of the EU which was aided with the introduction of the Euro as a single currency for EU member countries. Also, in line with the law of one price, Euro area price convergence with other advanced economies such as the US has been validated in various studies (Sosvilla-Rivero & Gil-Pareja, 2004; Goldberg& Verboven, 2005; Rogers, 2007). The implication of this observation is that energy price effects across G7 countries may not be too far apart.

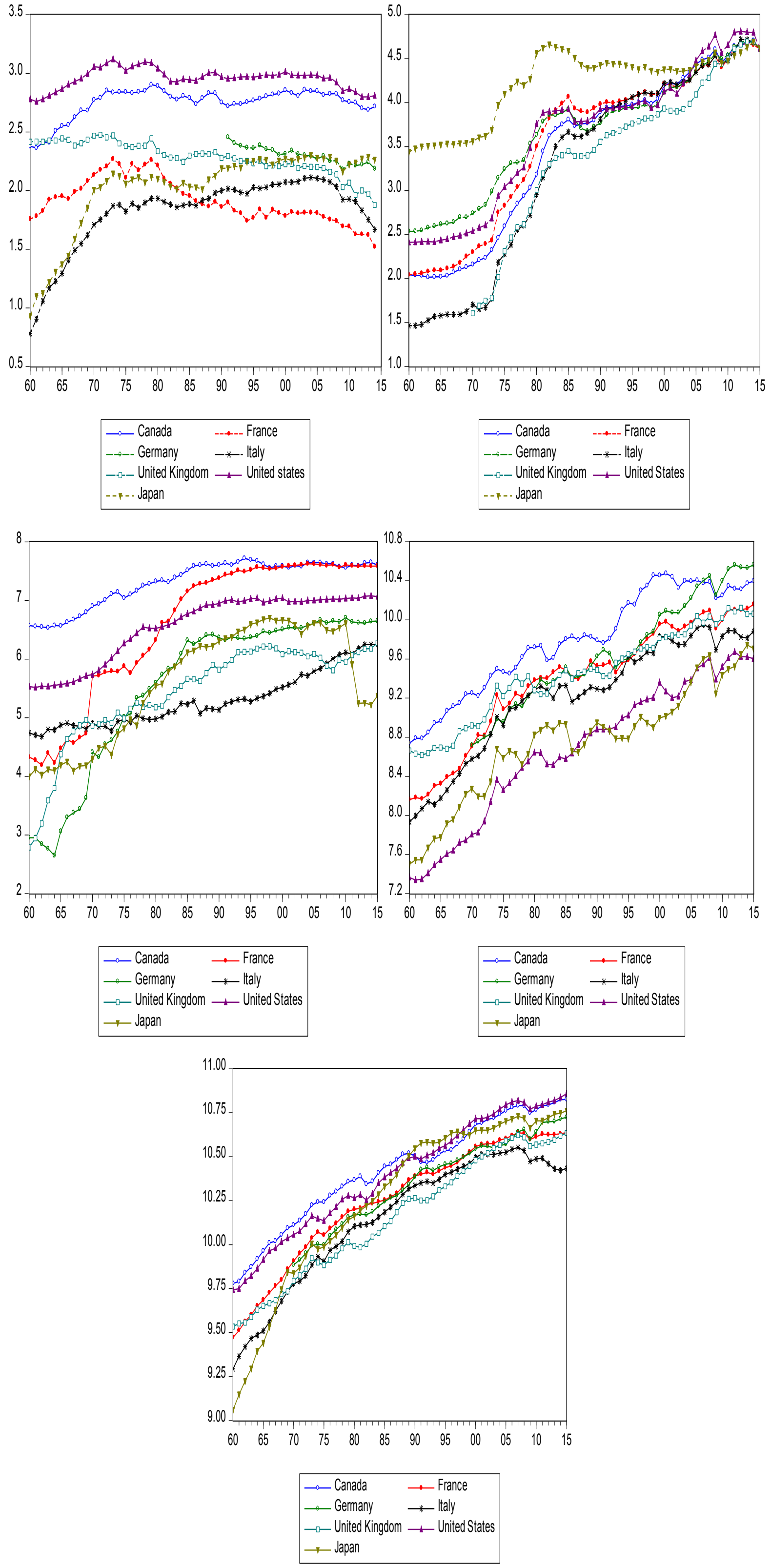

Figure 7: Grouped time plot of variables

Table 13: G7 Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
LCO2PK	354	2.286567	.4639481	.7786112	3.113986
LCPIE	382	3.612786	.8852169	1.460868	4.79814
LRECNPK	392	6.046653	1.13742	2.646366	7.715763
LRGDPK	382	10.28365	.3676815	9.060408	10.85772
LRGDPK2	382	105.8882	7.466323	82.09099	117.89

5.4 Results and Discussions

Prior to estimating the model coefficients we employ several pretesting procedures to ascertain the time series properties of the variables as well as the status of cointegration. To this end, we employ country specific and panel unit root techniques as well as country specific cointegration and panel cointegration techniques. Detailed results are outlined in subsequent sections.

5.4.1 Unit Root and Stationarity Test Results

We employ the Dickey-Fuller generalized least squares (Elliot et al, 1996) as well as the Kwaitkowski-Phillips-Schmidt-Shin (Kwaitkowski et al, 1992) stationarity test in order to ascertain the country specific time series properties of the variables. A rejection of the null hypothesis of the DFGLS unit root test implies variable stationarity, however a rejection of the null hypothesis of the KPSS stationarity test implies that the variable is non-stationary. Results of the unit root and stationarity tests are outlined in Table 14. From Table 14, the KPSS stationarity test rejects the null hypothesis of stationarity for all variables at levels in all 6 countries at all conventional significance levels. This is also corroborated by the DFGLS unit root test in which the null of a unit root cannot be rejected for all variables at levels in all 6 countries at the 1% significance levels. After first differencing the variables, the KPSS stationarity test cannot reject the null of stationarity at either the 1% or 5% significance levels for all variables in all countries. The DFGLS unit root test also rejects the null of a unit root at either the 1% or 5% or 10% significance level for all variables in all countries. Going by the results obtained by the stationarity and unit root test, it is safe to infer that all the variables are integrated of the 1st order or I(1) as such employing conventional panel estimation techniques may yield spurious results if the variables are not cointegrated. Against this backdrop, it is now appropriate to undertake panel and country specific cointegration tests.

5.4.2 Cointegration Test Results

In order to ascertain the existence of a non-spurious long run relationship between the variables we employ the Fisher and Johansen panel and country specific cointegration test procedure. In this procedure, the p-values of the Johansen maximum likelihood cointegration test statistics (Johansen and Juselius, 1990) are aggregated via the Fisher test (see Maddala and Kim; 1998, p. 137). The test statistic can be computed as $-2\sum_{i=1}^{N} logp_i \sim\chi_{2N}^2$ where p_i indicates the p-value of the Johansen test statistic for the *ith* country. The test assumes heterogeneity of coefficients across countries. From Table 14, the hypothesis of at most 3 cointegrating relationship could not be rejected at both the 5% and 1% level of significance for the whole panel. Moving on to country specific statistics in Table 16 it can be seen that the null hypothesis of no cointegration for each country was rejected at the 5% significance level for both Japan and the United Kingdom and was rejected at the 1% significance level for the rest of the countries under the maximum eigen value statistic. Also, the hypothesis of at most 1 cointegrating relationships cannot be rejected for the United States and Japan at the 1% and 5% significance levels respectively under the maximum eigen value statistic. However, the hypothesis of at most 2 cointegrating relationship cannot be rejected for the rest of the countries under the maximum eigen value statistic. Having identified panel and country specific cointegration we now move on to estimating the panel and country specific long-run coefficients.

Table 14: Stationarity and Unit root tests

Countries	Panel A: Variables at Levels									
	LCO2PK		LCPIE		LRENPK		LRGDPK		LTRADPK	
	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS
Canada	0.423[a]	-1.129	0.476[a]	-1.223	0.687[a]	-0.764	0.459[a]	-1.207	0.364[a]	-1.768
France	0.374[a]	-0.901	0.559[a]	-1.081	0.669[a]	-0.786	0.607[a]	-0.409	0.515[a]	-1.347
Germany	1.66[a]	-2.709	0.357[a]	-2.098	0.681[a]	-0.690	0.484[a]	-1.639	0.291[a]	-3.124[c]
Italy	0.504[a]	0.127	0.543[a]	-1.068	0.596[a]	-0.758	0.643[a]	-0.048	0.495[a]	-1.000
UK	0.285[a]	-0.951	0.387[a]	-1.624	0.478[a]	-1.133	0.326[a]	-2.057	0.280[a]	-2.484
US	0.367[a]	-1.537	0.335[a]	-1.754	0.683[a]	-0.827	0.435[a]	-1.502	0.486[a]	-1.684
Japan	0.441[a]	-0.979	0.532[a]	-1.374	0.560[a]	-0.808	0.628[a]	-0.584	0.322[a]	-2.263
Countries	**Panel B: Variables at First Difference**									
	D.LCO2PK		D.LCPIE		D.LRENPK		D.LRGDPK		D.LTRADPK	
	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS
Canada	0.398[c]	-4.811[a]	0.149	-3.184[a]	0.430[c]	-3.981[a]	0.418[c]	-4.784[a]	0.263	-5.152[a]
France	0.415[c]	-4.270[a]	0.180	-3.355[b]	0.408[c]	-4.006[a]	0.431[c]	-4.812[a]	0.309	-5.501[a]
Germany	0.414[c]	-3.365[b]	0.101	-3.594[b]	0.414[c]	-4.063[a]	0.417[c]	-6.233[a]	0.126	-5.841[a]
Italy	0.634[c]	-2.879[b]	0.203	-3.502[b]	0.461[c]	-5.414[a]	0.464[c]	-5.837[a]	0.431[c]	-6.337[a]
UK	0.431[c]	-4.616[a]	0.324	-2.964[c]	0.402[c]	-3.729[b]	0.244	-4.645[a]	0.117	-5.259[a]
US	0.343[c]	-4.732[a]	0.104	-3.735[b]	0.347	-2.853	0.418[c]	-4.829[a]	0.330	-5.108[a]
Japan	0.432[c]	-2.627	0.168	-4.074[a]	0.418[c]	-4.956[a]	0.426[c]	-4.538[a]	0.217	-5.112[a]

Note: "a"," b"and "c" denotes statistical significance at the 1%, 5% and 10% levels respectively

Table 15: Johansen and Fisher unrestricted cointegration rank test

Panel (H_0: No cointegration)	Fisher Stat.		Fisher Stat.	
Hypothesized No. of CE(s)	trace test	Prob.	max-eigen	Prob.
None	195.0***	0.0000	101.5***	0.0000
At most 1	107.0***	0.0000	56.98***	0.0000
At most 2	58.64***	0.0000	29.34***	0.0094
At most 3	38.70***	0.0004	21.35*	0.0929
At most 4	29.84***	0.0080	22.35*	0.0717
At most 5	29.25***	0.0097	29.25***	0.0097

Notes:'***'and'*' denotes statistical significance at the 1% and 10% levels respectively

5.4.3 Estimation Results

Results of the mean group, the group mean FMOLS as well as the group mean DOLS estimators are outlined in Table 17. It can be seen that the EKC hypothesis has been validated in all panel estimation specifications. Energy price has a negative relationship with CO2 emissions a result that is robust to all 3 panel estimators. In the mean group OLS specification a 10% increment in energy prices reduces CO2 emissions by about 2.3%, in the FMOLS specification same increment also brings about a 2.3% reduction in CO2 emissions, however in the Group mean-DOLS specification this becomes a 1.7% reduction in CO2 emissions which is not too far from the estimates from other specifications. This result is consistent with Balaguar & Cantavella (2016) as well as Al-mulali & Ozturk (2016).

Table 16: Johansen and Fisher Country Specific Statistics (H_0 : No cointegration)

Country	Trace	Prob.	Max-Eigen	Prob.
Canada	183.6009***	0.0000	83.8097***	0.0000
France	155.4070***	0.0000	62.9737***	0.0000
Germany	144.9472***	0.0000	48.3776***	0.0047
Italy	143.9627***	0.0000	46.1954***	0.0091
UK	133.2015***	0.0000	42.9367**	0.0232
US	124.6195***	0.0001	52.6724***	0.0012
Japan	126.8427***	0.0001	45.0071**	0.0129
Hypothesis of at most 1 cointegrating relationship				
Canada	99.7911***	0.0000	42.1215***	0.0042
France	92.4334***	0.0003	37.6373**	0.0169
Germany	96.5696***	0.0001	42.1582***	0.0041
Italy	97.7673***	0.0001	43.0538***	0.0031
UK	90.2648***	0.0005	37.2873**	0.0188
US	71.9471**	0.0335	26.7706	0.2758
Japan	81.8356***	0.0041	31.5820*	0.0917
Hypothesis of at most 2 cointegrating relationships				
Canada	57.6696***	0.0046	23.1424	0.1675
France	54.7960***	0.0097	20.3003	0.3207
Germany	54.4114**	0.0107	25.3668*	0.0936
Italy	54.7135***	0.0099	26.0167*	0.0782
UK	52.9775**	0.0153	26.3967*	0.0703
US	45.1765*	0.0874	23.8327	0.1407
Japan	50.2536**	0.0292	24.7966	0.1092

Notes:'***'and'*' denotes statistical significance at the 1% and 10% levels respectively

Moving on to the coefficients for renewable energy we see that the estimates for the mean group OLS as well as the group mean FMOLS specifications are quite close but quite different from that which is obtained from the group mean DOLS specification.

A 10% increment in renewable energy consumption brings about a 0.8% reduction in the mean group OLS specification and a 0.9% reduction in the group mean FMOLS specification. The group mean DOLS however supports a 2.6% reduction in CO2 emissions for a 10% increment in renewable energy consumption which is also consistent with Al-mulali and Ozturk (2016) in which a significantly negative relationship between renewable electricity consumption and CO2 emissions was uncovered. Going further, a 10% increment in international trade volumes brings about a 2% increment in CO2 emissions for the mean group OLS specification, a 2% reduction for the group mean FMOLS and a 1.9% reduction in the group mean FMOLS specification. This result is inconsistent with Al-mulali and Ozturk (2016) in which a negative relationship between trade openness and CO2 emissions is discovered for 27 advanced economies. Country specific estimations show that the EKC hypothesis is supported in all countries, for all specifications and that energy prices have a significant negative effect on CO2 emissions. The EKC turning points and the magnitude of the energy price effects are however disparate across countries. Also, the effects of renewable energy consumption and trade volume are also disparate across countries. Subsequent sections discuss country specific results in detail.

Table 17: Panel and country specific estimation results

Panel			
Variables	Mean-Group OLS	Group-Mean FMOLS	Group-Mean DOLS
LCPIE	-0.225758***	-0.234366***	-0.169350***
LRENPK	-0.084570***	-0.093201***	-0.264111***
LRGDPK	16.46624***	8.156401***	26.98987***
LRGDPK2	-0.785871***	-0.397318***	-1.289601***
LTRADPK	0.199876*	0.205477***	0.193246***
	OLS	FMOLS	DOLS
Canada			
LCPIE	-0.165598***	-0.165073***	-0.18810 ***
LRENPK	-0.003313	-0.001461	0.145211
LRGDPK	17.05942 ***	17.27092 ***	15.79845 ***
LRGDPK2	-0.790878***	-0.805969***	-0.728383***
LTRADPK	0.053669	0.100522 *	0.066165
France			
LCPIE	-0.2614522***	-0.306934***	-0.310585***
LRENPK	-0.0283194	-0.000760	0.034400
LRGDPK	22.949730 ***	21.07187 ***	19.75640 ***
LRGDPK2	-1.1651271 ***	-1.072235***	-0.994348***
LTRADPK	0.6500363 ***	0.654864 ***	0.546640 ***
Germany			
LCPIE	-0.242736***	-0.243457***	0.183390
LRENPK	-0.215821	-0.211918	-1.71519 ***
LRGDPK	-44.30459*	-48.65094 **	94.84620 **
LRGDPK2	2.046318 *	2.249479 **	-4.601248 **
LTRADPK	0.371235	0.380486 ***	0.830798 ***
Italy			
LCPIE	-0.2722195***	-0.284322***	-0.273339***
LRENPK	-0.1249403***	-0.146004***	-0.121201**
LRGDPK	10.068650***	9.773414***	7.023427***
LRGDPK2	-0.4246356***	-0.408180***	-0.271091***
LTRADPK	0.0622173	0.070995	-0.006995
UK			
LCPIE	-0.1983623***	-0.212368***	-0.175060***
LRENPK	-0.1403334***	-0.203227***	-0.148706*
LRGDPK	23.738801***	32.47268***	28.75883***
LRGDPK2	-1.1350860***	-1.557730***	-1.375380***
LTRADPK	-0.113512	-0.065921	-0.168786

Notes:'***','**', and'*' denotes statistical significance at the 1% , 5% and 10% levels respectively

Table 17 (continued)

Variables	OLS	FMOLS	DOLS
US			
LCPIE	-0.222528***	-0.216244***	-0.194485***
LRENPK	-0.082263*	-0.068526	-0.015279
LRGDPK	14.28918***	14.88632***	13.63381***
LRGDPK2	-0.691411***	-0.713346***	-0.641208***
LTRADPK	0.312883***	0.223587**	0.058092
Japan			
LCPIE	-0.211497***	-0.212166***	-0.227266***
LRENPK	-0.013192	-0.020514	-0.028008
LRGDPK	11.25163***	10.27055***	9.111988***
LRGDPK2	-0.526431***	-0.473241***	-0.415546***
LTRADPK	0.141856**	0.073805	0.026806

Notes:'***','**',and'*' denotes statistical significance at the 1% , 5% and 10% levels respectively

Estimation results for Canada

For Canada, a 10% increment in energy prices brings about a 1.656 % reduction in CO2 emissions in both OLS and FMOLS specifications as well as a 1.88% reduction in the DOLS specification. This is consistent with He & Richard (2010) in which a negative relationship between oil and CO2 emissions was uncovered for Canada though with a lot lesser magnitude of 0.279 % reduction for a 10% increment in emissions. Renewable energy consumption on the other hand has an insignificant effect on CO2 emissions which is also consistent with Bilgili et al (2016) in which an insignificant relationship between renewables and CO2 emissions was uncovered for Canada via a DOLS estimation. This may have arisen due to Canada's renewed dependence on fossil fuels which necessitated its dropping out of the Kyoto protocol. Trade volume effect is insignificant for both the OLS and DOLS model but is statistically significant in the FMOLS model at the 10% significance level. A 10% increment in trade increases emissions by 1% as evinced by the FMOLS model.

Estimation results for France

In France a different scenario is observed as energy prices seem to have a relatively larger effect on CO2 emissions compared to what was obtained previously in Canada, a 10% increment in energy prices brings about a 2.6%, a 3.0% and a 3.1% reduction in CO2 emissions for the OLS, FMOLS and DOLS specifications respectively. Renewable energy effect on CO2 emissions in France has no statistical evidence for all 3 specifications a result which is also consistent with Bilgili et al (2016). Trade volume has a statistically significant positive relationship on CO2 emissions as evinced from all specifications. A 10% increment in trade brings about a 6.5% reduction in CO2 emissions for both OLS and FMOLS specifications and a 5.4% reduction in the DOLS specification.

Estimation results for Germany

For Germany, renewable energy consumption is seen to be negatively related with CO2 emissions in all 3 specifications but only significant in the DOLS specification. A 10% increment in renewable energy consumption brings about a 17% reduction in CO2 emissions as evinced from the DOLS specification. Energy prices is seen to have a significantly negative and near identical relationship in both FMOLS and DOLS specifications as a 10% increment of renewable energy consumption reduces CO2 emissions by about 2.4% in both specifications. Trade volume is seen to have a significantly positive impact on CO2 emissions in both the FMOLS and DOLS specifications as a 10% increment in trade brings about a 3.8% and an 8.3% increment in CO2 emissions for both the FMOLS and DOLS models respectively. Quite peculiarly however, the EKC hypothesis was validated in only the DOLS specification which is unlike what has been observed in other countries wherein the EKC hypothesis was validated in all specifications. There is nevertheless a need to interpret these results cautiously because of the shorter time series (1991-2014) employed for the German estimation which may have brought about the coefficients' sensitivity to the different estimation techniques.

Estimation results for Italy

In the Italian model, energy price is seen to have a significantly negative relationship with CO_2 emissions in all 3 specifications. A 10% increment in energy price brings about a 2.7% reduction in CO_2 emissions for both the OLS and DOLS specification and a 2.8% reduction in CO_2 emissions for the FMOLS specification. Renewable energy consumption is seen to have a significantly negative relationship with CO_2 emissions in all 3 specifications. A 10% increment in renewable energy consumption brings about a 1.25%, a 1.46% and a 1.21% reduction in CO_2 emissions in the OLS, FMOLS and DOLS specifications respectively, a result that is inconsistent with Bilgili et al (2016) in which an insignificant relationship was uncovered between renewable energy consumption and CO_2 emissions. It is however consistent with Bento & Moutinho (2016) wherein a significantly negative relationship was uncovered between renewable electricity consumption and CO_2 emissions in Italy. Trade volume however has no significant relationship with CO_2 emissions in all specifications a result which is inconsistent with Bento & Moutinho in which a significantly positive relationship between international trade and CO_2 emissions was uncovered.

Estimation results for the United Kingdom

Results for the United Kingdom are a bit similiar with what was previously obtained in Italy as energy price and renewable energy consumption both significantly reduce CO_2 emissions. A 10% increment in energy prices brings about a 1.98%, a 2.12% and a 1.75% reduction in CO_2 emissions for the OLS, FMOLS and DOLS specifications respectively. Also, a 10% increment in renewable energy consumption brings about a 1.4%, a 2.0% and a 1.5% reduction in CO2 emissions for the OLS, FMOLS and DOLS specifications respectively. Trade volume on the other hand has no significant relationship with CO2 emissions.

Estimation results for the United States

Going by its status as the world's biggest economy, the energy needs of the US would be quite enormous which may bring about difficulties in sustaining lower CO2 emissions. It can however be seen from the estimated coefficients that increasing energy prices is more effective in reducing CO2 emissions than increasing renewable energy consumption. A 10% increment in energy prices in the US brought about a 2.22%, a 2.16% and a 1.94% reduction in CO2 emissions in the OLS, FMOLS and DOLS specifications respectively. The effect of renewable energy consumption is significant only for the OLS specification at the 10% level. A 10% percent increment in renewable energy consumption brings about a 0.8% reduction in CO2 emissions as evinced from the OLS specification. Trade volume shows a significantly positive relationship with CO2 emissions for both the OLS and FMOLS specifications as a 10% increment in trade volume brings about a 3.12% reduction and a 2.2% reduction in CO2 emissions in both the OLS and FMOLS specifications respectively.

Estimation results for Japan

Finally, estimation results for Japan also show that energy prices is more effective in reducing CO2 emissions as the coefficient of energy price is negative and significant in all 3 specifications compared to that which was obtained for renewable energy consumption which is positive but however insignificant for all 3 specifications employed. A 10% increment in energy price brings about a 2.11%, a 2.12% and a

2.27% reduction in CO2 emissions for the OLS, FMOLS and DOLS specifications respectively. Trade is seen to have a significantly positive relationship with CO2 emissions only in the OLS specification as a 10% increment in trade volume brings about a 1.4% significant reduction in CO2 emissions.

5.4.4 Panel Granger Causality Test Results.

Results for the panel granger causality tests are outlined in Table 18. Starting from the long run segment it can be seen that long-run causality is validated for all the variables with LRGDP and its quadratic counterpart having the fastest adjustment speed. About 99% deviation of GDP from its equilibrium values are corrected every year. As expected, energy prices have the slowest adjustment speed as only a 20% deviation from its equilibrium values is corrected every year, this may probably be due to nominal price rigidities. Renewable energy consumption also has a modest adjustment speed compared to other adjustment speeds in the model as a 24% deviation from its equilibrium path is adjusted every year. This implies that renewable energy consumption and energy prices are the most exogenous variables in the model. The adjustment parameter for trade volume and CO2 emissions are quite sizable at 62.2% and 57.2% respectively. Moving on to short-run causality results, we observe short-run causality flowing from energy prices, GDP, quadratic GDP and trade towards CO2 emissions. Renewable energy consumption however has no short-run predictive content for CO2 emissions. We can also see that, trade volume, renewable energy consumption and GDP has short-run predictive content for energy prices. However, CO2 emissions have no short-run predictive content for energy prices implying that energy prices are affected by economic shocks rather than shocks to the environment. In summary, a unidirectional causality is observed to flow from energy prices to CO2 emissions, from GDP and quadratic GDP to CO2 emissions and from trade volume to

CO_2 emissions. A unidirectional causality is also observed for GDP and quadratic GDP to energy prices and from renewable energy to energy prices with the implication that renewable energy consumption has an indirect impact on CO_2 emissions through its direct effect on energy prices.

Table 18: Panel Granger causality analysis. (vector error-correction framework)

Endogenous variables	Exogenous variables						
	Short- run						Long -run
	ΔLCO2PK	ΔLCPIE	ΔLRGDPK	ΔLRGDPK2	ΔLRENPK	ΔLTRADPK	ECT_{t-1}
ΔLCO2PK	__	8.80^{**}	6.48^{**}	7.30^{**}	4.40	5.13^{*}	-0.6^{**}
ΔLCPIE	4.46	__	5.01^{*}	4.86^{*}	6.16^{**}	13.33^{***}	-0.2^{**}
ΔLRGDP	1.35	1.82	__	0.14	0.34	12.67^{***}	-1.0^{***}
ΔLRGDP2	1.33	1.23	0.39	__	0.52	13.22^{***}	-1.0^{***}
ΔLRENPK	1.80	0.68	5.41^{*}	5.65^{*}	__	0.8348	-0.3^{***}
ΔLTRADPK	3.25	32.44^{***}	44.74^{***}	46.63^{***}	4.35	__	-0.6^{***}

Notes: ECT represents the coefficient of the error-correction term. Significance at the 1%, 5% and 10% levels are denoted by "***", "**" and "*" respectively. Numbers in the short-run cells indicate the χ^2 statistics for the Wald tests of the null H_0: $\sum_{k=1}^{p} \theta_{jik} = 0$. Numbers in the long-run cells indicate the estimated adjustment parameter λ_j under homogeneity assumption $\lambda = \lambda_i$. 2 lags were employed for the estimation based on the AIC and SBIC criterion.

Bidirectional causality is observed between energy prices and trade volume with the implication that energy price convergence across the G7 countries is as a result of trade instigated economic integration within the region. Bidirectional causality is also uncovered between trade volume and GDP which shows a strong interdependence between trade and output in the G7 economies. GDP and its quadratic counterpart have a unidirectional causal flow towards renewable energy consumption implying that economic growth exacts pressure on renewable energy consumption due to the environmental consequences of growth instigated high energy needs. This consequently brings about the need to seek out alternative cleaner energy sources.

5.5 Conclusion and Policy Implications

We employ fully heterogeneous panel and country specific estimation techniques in order to unravel the long-run equilibrium as well as causal relationship amongst energy prices, renewable energy consumption, CO2 emissions, trade volume as well as the Environmental Kuznets curve hypothesis in G7 countries. From what is observed in the results, energy price seems to have a stronger impact in the reduction of CO2 emissions than renewable energy consumption. Even though the pollution abatement effect of renewable energy consumption is observed for the whole panel, individual estimations show that the effect of renewable energy consumption is quite disparate across the G7 countries. This may be due to the different attitudes of country specific stakeholders in harnessing and distributing renewable energy fuels in their various countries. For instance, due to the high energy requirements and renewed fossil fuel dependence as a result of oil sands and shale oil boom in Canada and the US respectively, phasing out non-renewable energy sources may not be in the best economic interests of the 2 mentioned countries. Also, Canada backed out of the Kyoto protocol and the United States is yet to ratify the Paris agreement. Out of the 5 countries which has ratified the protocol in the G7 only in Italy, United Kingdom and Germany does renewable energy consumption seem to have any type of pollution abatement effects. According to IRENA (2018) and EIA (2018) renewable electricity generation as a percentage of total electricity generation stood at 37% for Italy and 28% for the United Kingdom as of 2016. Of all the G7countries, Canada has the highest share at 65% but its oil extraction activities may have largely offset any gains it may have garnered from renewable energy. Germany's share stands at 29%. However, the short span of data employed for Germany may have brought about its renewable energy coefficient being significant only in the DOLS specification. The shares for France, Japan and the United States stand at 17.5%, 15% and 14.7% respectively. This may be why estimates for these countries have no strong statistical evidence across all specification.

The pollution abatement effect of energy prices however seems to be robust across all countries regardless of estimation techniques. The findings from the panel granger causality tests show that while renewable energy Granger causes energy prices, energy prices in turn has a Granger causal effect on CO_2 emissions which would imply that a synergy between harnessing renewable energy sources and the imposition of fossil fuel taxes in order to forestall climate change and further environmental degradation exists in the G7 countries. This synergy can also be enhanced by formulating a tax program wherein the tax on fossil fuels would be directly proportional to the availability of renewable energy fuel sources, as renewable energy sources begin to rise steadily so also will the authorities increase the taxes on fossil fuel sources till it gets to the level where renewable energy sources become more economically viable than their non-renewable counterparts. An application of this synergy in all countries would greatly reduce the pressure on the environment and would significantly improve worldwide environmental sustainability in the short and long run. This also provides a clear pathway towards the attainment of the United Nations sustainable development goals.

Chapter 6

CONCLUSION

In view of the importance of sustainable industrial practices as regards to economic development this thesis attempts to unravel the heterogeneous effects of specific macroeconomic variables on the CO_2 emissions of selected countries at different development stages. Fiscal policy, oil production and renewable energy are all significant variables in the quest for environmentally sustainable production practices as such it becomes important to empirically quantify their heterogeneous effects on the environmental quality of the selected countries. The thesis employs 3 different case studies in 3 different chapters in order to unravel the dynamic effects of the selected macroeconomic variables on the environmental quality of the selected countries.

In chapter 3 the thesis empirically determines the role of fiscal policy in affecting the level of CO_2 emissions from different fuel sources and what this implies for environmental quality in the long-run. The newly industrialized net energy importing economy of Thailand is chosen as a case study because of its long-term gradual shift towards the less CO_2 emitting natural gas as an energy source. Four different models analyzing the effect of the fiscal policy index on CO_2 emissions from solid, liquid and gaseous sources as well as total CO_2 emissions within the EKC framework are adopted for the empirical analysis. The thesis also adopts the Maki (2012) cointegration test which controls for multiple structural breaks in order to determine the long-run equilibrium relationship amongst the variables in the four models. Findings from the empirical analysis show that the presence of cointegration amidst the impact of significant structural breaks is validated for all four models. The DOLS technique is employed to estimate the long-run coefficients for all four models. Findings show that fiscal policy has an insignificant positive effect on CO_2 emissions from solid fuel sources, a significant negative effect on CO_2 emissions from liquid fuel sources, a significant positive effect on CO_2 emissions from gaseous fuel sources and a significant negative effect on total CO_2 emissions. The EKC hypothesis is validated in all 4 models. Also, the dummy variables obtained from the Maki cointegration test shows that the dummy variables are not just mere statistical artefacts but correspond with both global and regional real-life economic events. These events created shocks which generated outliers in the data generating process of some of Thailand's macroeconomic variables. Also employing the Granger causality test within the spirit of Toda-Yamamoto and Dolado-Lutkepohl validates the presence of bi-directional causality or a feed-back mechanism between fiscal policy and environmental quality. Thus, environmental shocks can also spur government's fiscal policy initiatives towards the environment. Also, unidirectional causality flowing from fiscal policy to GDP as well as from fiscal policy to energy consumption shows that the fiscal policy initiatives of the Thai authorities are economic as well as energy oriented. The energy led growth hypothesis is validated for the Thai economy due to a unidirectional causal flow from energy consumption to GDP. Also, the findings show that Thailand's economic growth path exerts significant pressure on its environment due to a unidirectional causal flow from GDP(GDP^2) to CO_2 emissions. Energy consumption has no direct impact on CO_2 emissions but affects the environment indirectly through its impact on GDP. The findings portend serious implications for the government and development stakeholders in Thailand due to the fact that fiscal policy initiatives towards different fuel sources in Thailand has long-run implications for environmental sustainability. The switch to natural gas should not be viewed as a permanent solution to pollution abatement but an intermediate one. Efforts should be put into the total phasing out of fossil fuel sources in order to make way for renewable energy sources with net zero emissions. As such government and other stakeholders should channel more attention into the long-term development of renewable energy systems in order to traverse the path to sustainable development.

In chapter 4 the environmental effect of oil production within the framework of the environmental Kuznets curve is analyzed for a panel of 15 oil producing countries. Because the countries under study are at different development stages, the novel method of moments quantile regression of Machado and Silva (2019) is employed to control for distributional heterogeneity. As well as controlling for the environmental Kuznets curve hypothesis, the effects of electricity production, trade and democracy are also controlled for in order to mitigate the bias that may emanate from omitting relevant variables. The FMOLS, DOLS and the fixed effects OLS with common correlated effects robust Driscoll and Kraay standard errors are also employed for comparative purposes and to also ascertain if the estimates are sensitive to different measurement specifications. Prior to estimating the long run parameters, the model is subjected to two different types of cointegration test within the framework of Pedroni (2004) and Westerlund (2007). The cointegration tests both identify a stable long-run relationship for the model. The long-run estimation results show that the long-run coefficients obtained from all models are not too far apart. Also, the EKC hypothesis is validated for all 3 models but only attains statistical significance in the FMOLS and FE-OLS models. Oil production has a statistically significant positive relationship with CO_2 emissions in all 3 models. Electricity production also significantly affects CO_2

emissions in the positive direction. Trade volume which is measured as the sum of total import and export normalized on total population has a significantly negative relationship with CO_2 emissions. The effect of Democracy is positive but only significant in the FMOLS specification. The coefficient estimates from the method of moments quantile regression technique shows that the EKC hypothesis is valid at countries below the median quantile. Putting it differently, income has a monotonic relationship with CO_2 emissions from the 1st to 4th quantiles and a non-monotonic relationship with CO_2 emissions from the 5th to 9th quantiles. Oil production has a strong statistically significant positive relationship with CO_2 emissions at the 3rd 4th and 5th quantiles but a weaker statistically significant positive relationship at the 1st, 2nd and 6th quantiles. This goes to show that countries above the median quantiles are much more resilient at pursuing environmentally sustainable production practices. Notwithstanding, the results also show that the coefficient of income is highest at higher emission quantiles. Also, the coefficient values of higher emission countries represent threshold values which have not yet been attained by their lower emissions counterparts. Furthermore, because the coefficient of oil production is highest at the lowest emissions quantiles and is decreasing from the lowest quantile to the highest quantile, it can be inferred that oil production is highest at countries with the lowest overall emissions profile. This lends further evidence to the deindustrialization inducing resource curse hypothesis. The impact of democracy is positive and weakly significant at the 3rd, 4th and 5th quantiles. Trade has a negative and significant relationship with carbon emissions at all quantiles. This implies the presence of deindustrialization at lower quantiles and the presence of the pollution halo hypothesis at higher quantiles. The effect of electricity production is positive across all quantiles which shows that non-renewable electricity production is far more utilized than renewable electricity production in the selected oil producing countries. This goes to show that lower emissions countries are in dire need of diversification policies in order to pull them out of the vicious cycle of the resource curse to pursue the sustainable economic growth path.

Finally, in chapter 5, this thesis makes an empirical assessment of the degree to which renewable energy consumption and energy prices abates carbon emissions in the 7 advanced economies of the G7. In the empirical analysis, full heterogeneity is controlled for through the mean group OLS, the group mean FMOLS and the group mean DOLS models at the panel level. The empirical analysis also includes country specific estimation techniques namely; OLS, FMOLS and DOLS techniques. Prior to estimating the long-run coefficients the Johansen and Fisher cointegration technique is employed to ascertain if there exists a stable long-run relationship amongst the variables. After validating cointegration at both panel and country specific levels the long run estimates show that the EKC hypothesis is valid for the G7 countries. This estimation result is robust across all specification at the panel level. At the country specific level however, the validity of the EKC hypothesis is not robust across all specifications for only Germany, probably because of its shorter time series data. The estimation results also show that renewable energy consumption is pollution abating at the panel level due to a significant negative relationship between renewable energy consumption and CO_2 emissions. This effect is robust across all panel specifications. However, looking at the country level estimations it can be seen that the pollution abatement effects of renewable energy consumption is significant and robust only in Italy and the United Kingdom. This may be due to the different attitudes of government and energy sector stakeholders in the G7 countries as regards to renewable energy. However, statistical evidence for renewable energy consumption is uncovered for

Germany only in the DOLS specification while weak statistical evidence is uncovered for the United States only in the OLS specification. Energy prices on the other hand has a statistically significant negative relationship with CO_2 emissions at both panel and country specific levels. This result is robust to all specifications at the panel level. It is also robust to all the specifications in the country level estimations for all countries except Germany which shows a positive but insignificant relationship between energy prices and carbon emissions for only the DOLS specification. Results for the OLS and FMOLS specifications however uncover negative and statistically significant relationships between energy prices and CO_2 emissions for Germany. Trade is however seen to have a positive relationship with CO2 emissions at the panel level with significance attained at both the OLS and FMOLS specifications. At the country level only in the United Kingdom does a negative relationship exist between trade and CO_2 emissions across all specifications. Coefficients for trade is however insignificant across all specifications for the UK. The findings show that even though renewable energy consumption is assuming an upward trend across the G7 countries, a significant amount of investment still needs to be put in place in order to reap significant environmental dividends. Short-run causality tests show that of all the variables only renewable energy consumption has no short-run predictive content for CO_2 emissions. It however has short-run predictive content for energy prices which in turn has short-run predictive content for CO_2 emissions. Trade is also seen to have short-run predictive content for energy prices with a feedback effect. The results show that a synergy between renewable energy consumption and trade can be employed to abate carbon emissions in advanced economies. The taxation of fossil fuels may be more efficient for curbing fossil fuel use than the development of renewable energy technologies. However, subsidizing renewable energy investments with tax receipts from fossil fuels may be a more efficient path to take on the quest for sustainable development.

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