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Fiscal policy and CO_2 emissions from heterogeneous fuel sources in Thailand: Evidence from multiple structural breaks cointegration test

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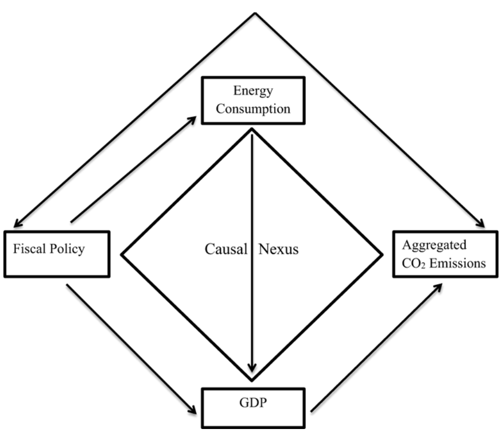
HIGHLIGHTS

- Nexus between fiscal policy, energy, and emissions from heterogeneous fossil fuel is examined.
- Fiscal policy initiatives toward energy have long-run implications for environmental quality.
- The results confirmed the energy-led growth hypothesis for the Thai economy.
- Unidirectional causality from fiscal policy to CO2 emissions and energy consumption.
- The environmental Kuznets curve hypothesis is valid in Thailand.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the dynamic linkage between fiscal policy, energy and CO_2 emissions from heterogeneous fossil fuel sources in the context of the environmental Kuznets curve (EKC) framework for Thailand. With annual data from 1972 to 2014 while incorporating structural breaks, the study employed a Maki cointegration test and the dynamic ordinary least squares estimation approach. The results found that a 1% increase in fiscal policy brought about a 6.5% ($p < 0.05$) increase in the low CO_2 emitting gaseous fuel sources (natural gas), a 0.2% ($p < 0.01$) reduction in the intermediate CO_2 emitting liquid fuel sources (crude oil derivatives), and an insignificant increase 0.2% ($p > 0.05$) in the high CO_2 emitting solid fuel sources (coal derivatives). While a 1% increase in fiscal policy abates aggregated CO_2 emissions by 0.2% ($p < 0.05$), the existence of the EKC hypothesis was validated in all models. The causality test revealed a bi-directional causal relationship between fiscal policy and CO_2 emissions and unidirectional flow from fiscal policy to energy consumption. This confirms that fiscal policy initiatives towards energy consumption have long-run implications for environmental quality. Our findings support the energy-led growth hypothesis for the Thai economy. The implication of the finding is that increasing the share of clean and renewable energy sources should be encouraged—rather than energy conservation

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policies, which obstruct energy supply and utilization. This highlights a more efficient way of harnessing energy sources through the instrumentality of fiscal policy.

1. Introduction

Environmental degradation, energy, and economic growth nexus have received scientific attention within the past decades. The choice between economic development and environmental sustainability remains a global dilemma. Since the inception of the industrial revolution in the 18th century, global economic growth has soared at the expense of environmental quality, a direct consequence of conventional energy sources employed in the production process. Thus, economic development, energy, and environmental quality represent an ensemble of triad complex systems—trilemma. 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. However, population growth, economic development, and contemporary technological innovations have increased the demand for energy in the 21st century. This is at a level quite unprecedented before now, making the continuous use of fossil fuel and its energy technologies 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 adopted in 1992 and entered into force in 1994, after being ratified by a sufficient number of countries. The main objective of the UNFCCC is the stabilization of the concentrations of anthropogenic greenhouse gas (GHG) emissions at levels that ensure environmental sustainability. Sequel to this framework is the 1997 Kyoto protocol, which set targets for developing 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 underpins the need to reduce GHG emissions—by highlighting 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 need to diversify energy sources can be viewed 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; Al-Mulali et al., 2013; Lin and Moubarak, 2014), financial development (Sadorsky, 2010; Islam et al. 2013, Rafindadi and Ozturk, 2016; Shahbaz et al., 2017a, 2017b; Destek and Sarkodie, 2019), 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 environmental effects triggered the augmentation of 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). The EKC hypothesis was first analyzed in a seminal work by Grossman and Krueger (1991, 1995) —which dwelt on the environmental impacts of income level—wherein, they employed pooled cross-sectional data. They found both N-shaped and an inverted U-shaped relationship between income level and a selected set of environmental pollutants. This analysis paved way for a second 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; Rafindadi and Ozturk, 2017), Foreign direct investment (Chandran and Tang, 2013; Sarkodie and Strezov, 2019) and globalization (Shahbaz et al., 2017a, 2017b; 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; Yıldırım 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; Al-Mulali et al., 2013) involves a bidirectional causality between energy consumption, while the neutrality hypothesis (Payne, 2009; Ozturk and Acaravci, 2011; Yalta, 2011) uncovers no-causality between energy utilization and economic development.

Apart from the above-mentioned literature, the plethora of macroeconomic variables are labeled as causative factors for CO_2 emissions through various transmission mechanisms. Studies that emphasize on the fiscal role as regards to CO_2 emissions proliferation and/or mitigation are quite scarce in the literature. There have been few studies that suggest an empirical link between government expenditure and environmental quality (Frederik and Lundstrom, 2001; Bernauer and Koubi, 2006; Lopez et al., 2011; Halkos and Paizanos, 2013; 2016). Lopez et al. (2011) isolated four key 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 amplification of environmental pressures as a result of increasing economic growth. The composition effect implies the development of human-capital intensive activities instead of physical-capital intensive industries that degrade environmental quality. The technique effect entails improved labor efficiency due to more efficient work routines. The income effect denotes an increased prioritiza-

[1] United Nations Framework Convention on Climate Change.

[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.

tion and demand for environmental quality as a result of higher income levels. Going backward, Frederik and Lundstrom (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. Halkos and Paizanos (2013) analyzed the direct and indirect effect of government spending on two specific pollutants: CO_2 and SO_2 and uncovered 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. Drawing from the conclusions of the aforementioned studies and the summary of the fiscal policy-environmental degradation nexus literature as presented in Table 1, it is evident that fiscal policy effects are heterogeneous across different types of pollutants and geographical locations. This highlights the need for more empirical research in this scope.

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. Very few and sporadic research exist in the scope of the study, however, the effect of fiscal policy by incorporating both government spending and tax revenue on CO_2 emissions is limited—even though the problem of climate change from GHG can only be resolved with an adequate fiscal response. Studies like Halkos and Paizanos (2016), Katircioglu and Katircioglu (2018b) incorporated fiscal spending and tax revenues in a model of energy-environmental degradation nexus. 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 study examines the long-run relationship between energy, income level, and CO_2 emissions while controlling for structural breaks and testing the EKC hypothesis. While this study (Katircioglu and Katircioglu, 2018b) is based on the Turkish economy, our study is however oriented towards Thailand. While Halkos and Paizanos (2016) utilized a VAR framework to assess the heterogeneous effect of expansionary fiscal policy on consumption and production generated CO_2 emissions,[4] this study first time isolates the effect of fiscal policy on CO_2 emissions from different fuel sources—considering the specific idiosyncrasies of the Thailand energy sector. This has implications for total CO_2 emissions in view of the gradual shift towards natural gas as the main source of energy.

Therefore, this study contributes to the literature in five-fold. First, by controlling for the twin effect of government spending and tax revenues within a standard EKC model. The effects of fiscal policy on the environment can be empirically established for the newly industrialized net energy importing economy of Thailand. Second, we use a novel 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 essential to quantify 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 assess the stationarity properties of the series under study. Fourth, by employing the Maki cointegration, a multiple structural break technique, the potentially distorting effects of structural breaks in the cointegration relationship is circumvented. Additionally, the dynamic ordinary least squares (DOLS) technique is employed to determine the long-run parameters of the fiscal policy-heterogeneous fuel sourced CO_2 emissions nexus while controlling for the structural breaks. Lastly, 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 isolated in Thailand.

The subsequent sections of the study are structured as follows; Section 2 elaborates on how Thailand's economy, energy sector, and fiscal policy intersect through a series of stylized facts. Section 3 outlines the data, the empirical model and methodology employed in the estimation. Section 4 outlines the empirical results while Section 5 concludes the study by briefly summarizing empirical results with policy implications.

2. Thailand's economy, energy sector, and fiscal policy nexus: Some stylized facts

Our study pays particular attention to Thailand because of the unique structure of its economy. 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 enormous 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 much environmental sustainability and energy security concerns. The Thai government initiated a 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. Fig. 1 shows that the share of energy has changed significantly over the years. Fig. 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 (UNFCCC,2018).

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

Table 1
Summary of the fiscal policy CO_2 nexus literature.

Authors (study year)	Study location(s) and (period)	Fiscal variable(s) [pollutant variable(s)]	Methods	Findings
Frederik and Lundstrom (2001)	77 countries (1977–1996)	Govt. size [CO_2 per Capita]	Fixed effects, Random effects regression	(−) Direct effects (+) Total effects for low income countries
Bernauer and Koubi (2006)	42 countries (1971–1996)	Govt size [SO_2]	OLS	(+) effects
Lopez et al. (2011)	38 countries for air pollution, 47 countries for water pollution (1986–1999)	Share of public goods in govt expenditure, Govt size [SO_2, lead, BOD]	OLS, Fixed site effects	(−) effects for all pollutants by all fiscal measures
Halkos and Paizanos (2013)	77 countries (1980–2000)	Govt size [SO_2, CO_2]	Fixed effects, Dynamic fixed effects	(−) Direct effects for SO_2, Insignificant direct effect on CO_2. Nonlinear indirect effect on SO_2. (−) Indirect effects for CO_2
Halkos and Paizanos (2016)	USA (1973–2013)	Total government expenditure, total tax revenue [Residence and Industry generated CO_2 emissions]	Bayesian VAR with cointegrated variables	(−) effect for consumption and production generated CO_2 emissions by expansionary fiscal spending. (+) effects by tax cuts for consumption generated CO_2 emissions
Adewuyi (2016)	World economies (1990–2015)	Total government expenditure [CO_2 emissions]	Common correlated effects Mean group, pooled mean group and dynamic fixed effects.	(−) total effects in the short-run. (+) total effects in the long-run. EKC valid in PMG and DFE estimations.
Katircioglu and Katircioglu (2018b)	Turkey (1960–2013)	Government expenditure, Tax and Fiscal Policy Index [CO_2 emissions]	ARDL, conditional Granger causality, FEVD, IRF	(−) effects of all fiscal variables. EKC valid in 3 out of 4 specifications.
Yuelan et al. (2019)	China (1980–2016)	Government expenditure, Government revenue [CO_2 emissions]	ARDL, innovation accounting techniques.	(+) effects of all fiscal variables.
Zhang et al. (2017)	China (2002–2014)	Government expenditure, [Sulfur dioxide (SO_2), soot, chemical oxygen demand COD]	First difference GMM, orthogonal deviation GMM	Decreasing (−) effects for SO_2 and COD. Increasing (+) effects for soot.

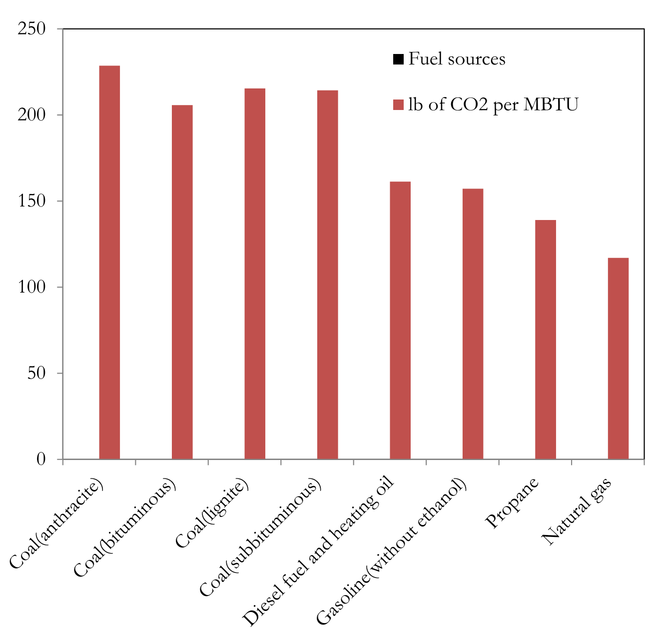

Fig. 1. Energy-related CO_2 emitted from the various fuels. Source: U.S. Energy Information Administration.

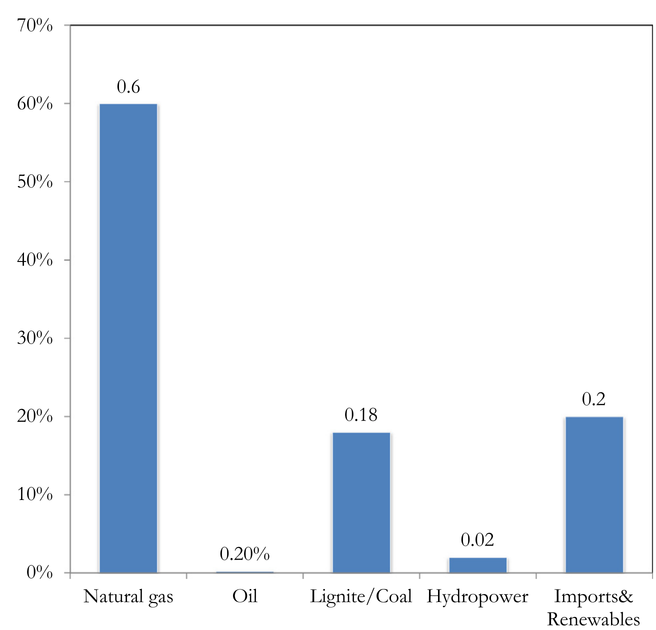

Fig. 2. Energy mix of Thailand. Source: Energy Policy and Planning Office (2017), Thailand.

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.

3. Materials and methods

3.1. Data and model

An annual data from 1972 to 2014 for Thailand were obtained 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 Katircioglu and Katircioglu (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), Shahbaz et al. (2017a, 2017b), 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:

$$lCO_{2t} = \beta_0 + \beta_1 lrgdp_t + \beta_2 lrgdp_t^2 + \beta_3 lec_t + \beta_4 fpi_t + u_t \quad (1)$$

From Eq. (1) 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 Eq. (1) follow an I(1) process then u_t would have to be stationary for the long-run relationship to be non-spurious.

3.2. 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 (none)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.

3.3. Cointegration with multiple structural breaks

If the stationarity assumption of u_t from Eq. (1) holds, then, a stable long-run relationship exists amongst the variables and thus, Eq. (1) 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

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \beta' \mathbf{A}_t + u_t (2)$$

Model 1: level shifts with trend

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \gamma t + \sum_{i=1}^{k} \gamma_i t D_{i,t} + \beta \mathbf{A}_t + \sum_{i=1}^{k} \beta'_i \mathbf{A}_t D_{i,t} + u_t \quad (3)$$

Model 2: Regime shifts

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \beta' \mathbf{A}_t + \sum_{i=1}^{k} \beta'_i \mathbf{A}_t D_{i,t} + u_t \quad (4)$$

Model 3: Regime shifts with a trend

$$y_t = \psi + \sum_{i=1}^{k} \psi_i D_{i,t} + \gamma t + \beta' \mathbf{A}_t + \sum_{i=1}^{k} \beta'_i \mathbf{A}_t D_{i,t} + u_t \quad (5)$$

From Eqs. (2)–(5), t = 1,2,…,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 $(m \times 1)$ vector. If $t > T_{Bi}$ ($i = 1, \cdots, k$) 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. Long-run parameter estimation

Eq. (1) 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:

$$\begin{aligned} lCO_{2t} = {} & \beta_0 + \beta_1 lrgdp_t + \beta_2 lrgdp_t^2 + \beta_3 lec_t + \beta_4 FPI \\ & + \sum\nolimits_{k=-p}^{p} \theta_1 \Delta lrgdp_{t-k} + \sum\nolimits_{k=-q}^{q} \theta_2 \Delta lrgdp_{t-k}^2 \\ & + \sum\nolimits_{k=-r}^{r} \theta_3 \Delta lec_{t-k} + \sum\nolimits_{k=-s}^{s} \theta_4 \Delta FPI_{t-k} + \eta' \mathbf{D}_i + u_t \end{aligned} \quad (6)$$

From Eq. (6) 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_{2t}. Also, *p*, *q*, *r* and *s* denotes 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 $\boldsymbol{D}_i = (D_1,\ldots,D_5)$.

3.5. Toda-Yamamoto and Dolado-Lutkepohl (TY-DL) Granger causality analysis

This study employs the Toda and Yamamoto (1995) and Dolado and Lütkepohl (1996) (TY-DL) 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:

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

$$+ \sum_{j=p+1}^{d_{max}} \begin{bmatrix} \varphi_{11j} & \varphi_{12j} & \varphi_{13j} & \varphi_{14j} & \varphi_{15j} \\ \varphi_{21j} & \varphi_{22j} & \varphi_{23j} & \varphi_{24j} & \varphi_{25j} \\ \varphi_{31j} & \varphi_{32j} & \varphi_{33j} & \varphi_{34j} & \varphi_{35j} \\ \varphi_{41j} & \varphi_{42j} & \varphi_{43j} & \varphi_{44j} & \varphi_{45j} \\ \varphi_{51j} & \varphi_{52j} & \varphi_{53j} & \varphi_{54j} & \varphi_{55j} \end{bmatrix} \times \begin{bmatrix} lCO_{2t-j} \\ lrgdpk_{t-j} \\ lrgdpk_{t-j}^2 \\ lec_{t-j} \\ FPI_{t-j} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{1t} \\ u_{1t} \\ u_{1t} \\ u_{1t} \end{bmatrix} \quad (7)$$

From Eq. (7), 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 $\Theta_{51i} \neq 0\forall_i$.

4. Results and discussion

4.1. 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 Fig. 3 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).

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.

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 Southeast 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 is dependent on liquid fuel sources. Notwithstanding, 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 attack 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 emit-

Table 2
Descriptive statistics.

	FISCPI	lCO_2gpk	lCO_2lpk	lCO_2spk	lCO_2pk	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.

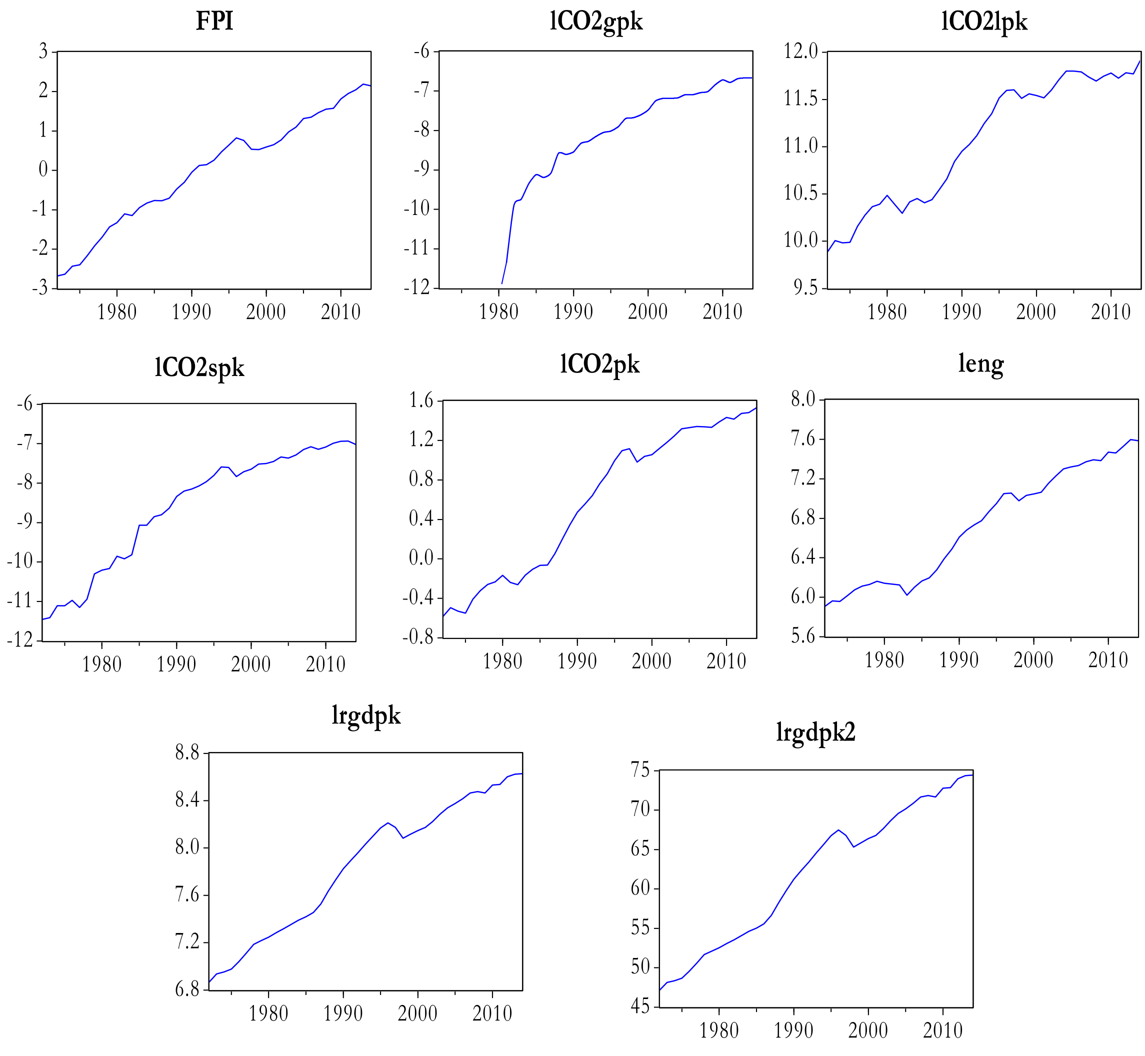

Fig. 3. Time plot of variables.

ting 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 a 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 Fig. 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.

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 previ-

Table 3
Unit root tests with structural breaks.

Variables at levels	Lee and Strazicich (2003)		Zivot and Andrews (2002)	
	T-statistics	Break Years	T-statistics	Break Year
lCO_2pk	−2.67	1983, 1998	−3.45	1988
lCO_2spk	−2.20	1976, 1984	−2.61	1985
lCO_2lpk	−2.75	1998, 2010	−3.42	1989
lCO_2gpk	−0.07	1977, 1980	−4.00	1983
lrgdpk	−3.05	1998, 2010	−3.60	1988
leng	−2.11	1984, 1998	−3.66	1994
FPI	−2.90	1974, 1996	−4.58*	1998
At first difference				
ΔlCO_2pk	−5.72***	1985, 1995	−5.71***	1997
ΔlCO_2spk	−6.15***	1974, 1986	−8.25***	1979
ΔlCO_2lpk	−5.12***	1977, 1996	−5.11**	1997
ΔlCO_2gpk	−58.1***	1988, 2007	−7.77***	1983
Δlrgdpk	−4.83***	1984, 1996	−4.98**	1996
Δleng	−4.06**	1996, 2009	−6.28***	1996
ΔFPI	−4.91***	1992, 2000	−5.47***	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.

Table 4
Maki Cointegration test with 5 structural breaks.

Model specifications	Test statistics [5% Critical values]	Breakpoints
(1) lCO_2spk = f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	−4.800 [−6.306]	1977,1982,1984,1994,2004
Model 1	−5.884 [−6.494]	1977,1982,1984,1995,1998
Model 2	−13.54 [−8.869]***	1982,1987,1993,1998,2007
Model 3	−6.690 [−9.482]	1978,1989,1992,1998,2005
(2) lCO_2lpk = f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	−6.002 [−6.306]	1984,1988,1997,2000,2009
Model 1	−6.499 [−6.494]**	1975,1989,1999,2004,2006
Model 2	−8.160 [−8.869]	1977,1988,1995,2003,2008
Model 3	−31.10 [−9.482]***	1977,1983,1991,1999,2008
(3) lCO_2gpk = f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	−9.097 [−6.306]***	1983,1986,1992,2004,2008
Model 1	−5.943 [−6.494]	1985,1992,1995,2003,2010
Model 2	−15.85 [−8.869]***	1985,1991,1996,2001,2008
Model 3	−10.64 [−9.482]***	1987,1990,1995,1999,2004
(4) lCO_2pk = f(lrgdpk,lrgdpk2,FPI,leng)		
Model 0	−6.608 [−6.306]**	1975,1978,1984,1993,2004
Model 1	−7.870 [−6.494]***	1974,1993,1997,1999,2005
Model 2	−9.705 [−8.869]***	1989,1986,2004,2000,2008
Model 3	−8.457 [−9.482]	1980,1988,1994,2002,2008

Note: $T_{Bi} \leq 5$.

ous studies, we discover that the negative relationship between fiscal policy and CO_2 emissions in Thailand is consistent with Katircioglu and Katircioglu (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.

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 Katircioglu and Katircioglu (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.

4.2. Discussion of findings

The results found a positive effect of energy consumption on CO_2 emissions, which is consistent with numerous studies in the literature (See Yuelan et al., 2019). 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, which is consistent with Wang et al. (2019b) or the increase in GDP growth rate occurring at a faster rate than CO_2 emissions, which is congenial with 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. Therefore, fossil fuel switching seems to present a better alternative to energy conservation for countries whose economic growth path is tied to energy consumption. This reason is that fuel switching involves the switching over to fuel sources with less CO_2 emissions per equivalent energy produced.

Furthermore, the finding of the energy-led growth hypothesis is indicative that Thailand is a viable candidate for fossil fuel switching which is critical to reducing greenhouse gas emissions related to energy systems. This result is inconsistent with Saboori and Sulaiman (2013), which uncovers a feedback hypothesis between energy consumption and economic growth for Thailand. However, this finding is consistent with Lean and Smyth (2010) 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 essential instrument in the decoupling initiatives and as such minimize the sacrifice of environmental quality as a result of stimulating economic growth by consuming more of energy with low emissions such as gaseous fuel sources (natural gas) and reducing consumption of intermediate CO_2 emitting liquid fuel sources (crude oil derivatives), and the high CO_2 emitting solid fuel sources (coal derivatives).

Table 5
Dynamic OLS estimates.

Exogenous Variables	Endogenous Variables			
	lCO_2spk	lCO_2lpk	lCO_2gpk	lCO_2pk
lrgdpk	14.50***	11.34***	88.77**	4.71***
	[2.72]	[1.04]	[37.5]	[1.01]
$lrgdpk^2$	−0.82***	−0.70***	−6.86**	−0.21***
	[0.25]	[0.08]	[2.71]	[0.09]
leng	0.14	1.24***	6.63**	0.48*
	[0.32]	[0.24]	[2.56]	[0.06]
FPI	0.20	−0.21***	6.52**	−0.23**
	[0.93]	[0.06]	[2.23]	[0.27]
Intercept	−72.7***	−42.9***	−32.08**	−26.5***
	[10.8]	[4.46]	[13.33]	[4.25]
D1	0.14	0.04	−0.05	0.01
	[0.21]	[0.04]	[0.56]	[0.03]
D2	0.25*	−0.08**	−0.29	0.008
	[0.13]	[0.03]	[0.25]	[0.02]
D3	−0.07	0.01	−0.46*	0.06*
	[0.12]	[0.02]	[0.20]	[0.03]
D4	−0.34***	−0.10**	−0.10	−0.03
	[0.11]	[0.03]	[0.20]	[0.03]
D5	0.06	−0.10**	−0.51	−0.06***
	[0.07]	[0.02]	[0.35]	[0.01]
Adj. R^2	0.99	0.10	0.96	0.10
Jarque Bera	0.30	0.61	0.66	0.52

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

Table 6
The Toda Yamamoto dynamic causality analysis.

Dependent variables	Causal variables				
	lCO_2pk	lrgdpk	$lrgdpk^2$	leng	FPI
lCO_2pk	–	2.379	2.961	5.812	15.18***
lrgdpk	3.133	–	4.903	17.76***	14.42***
$lrgdpk^2$	3.178	6.045	–	17.87***	14.18***
leng	4.810	7.325	7.648	–	11.12**
FPI	8.562*	2.333	1.847	9.569	–

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

5. Conclusion

Fossil fuel switching is critical to reducing greenhouse gas emissions related to energy systems. However, assessing the role of heterogeneous fossil fuel sources on environmental pollution while controlling for fiscal policy remains a grey area. Motivated by the limited studies in the scope, 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.

Declaration of Competing Interest

The authors declare no conflict of interest.

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