Environmental quality and the role of economic policy uncertainty, economic complexity, renewable energy, energy intensity: the case of G7 countries

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Abstract

This study explores the environmental impacts of economic policy uncertainty, economic complexity, renewable energy, and energy intensity for G7 countries. To this end, the study employs Fully Modified Ordinary Least Squares and fixed effect model with Driscoll and Kraay (1998) robust standard errors for a panel dataset from 1997 to 2015. The findings demonstrate a long-term relationship between interested variables and carbon dioxide emissions and ecological footprint. Specifically, high energy intensity propels environmental pollution while economic policy uncertainty and renewable energy prove effective in controlling environmental degradation. The environmental Kuznet curve of economic complexity and environmental quality holds for G7 countries. Moreover, economic policy uncertainty strongly moderates the environmental effect of renewable energy, economic complexity, and energy intensity. While economic policy uncertainty amplifies the beneficial environmental effects of renewable energy and economic complexity, it magnifies the harmful effect of energy intensity on environmental quality. These empirical outcomes allow us to draw useful implications for policymakers to mitigate the environmental degradation.

1. Introduction

Environmental degradation has been becoming the most challenging threat for the world prosperity and sustainability. Increasing human demand for natural resources puts high pressures on the ecosystem, leading to severe environmental problems. They include but are not limited to climate change, soil degradation, water contamination, air pollution, biodiversity loss, and global warming. The governments have made great efforts to decarbonize energy systems and to support the recovery of ecosystem, such as enforcing strict environmental regulation, adopting high environmental tax, providing financial subsidies and favorable prices for both renewable energy production and consumption, sponsoring for researching energy-efficient technologies, implementing environment raising awareness programs for citizens, and so on. On the international scale cooperation among governments, several measures have been initiated and implemented to protect worsening environmental quality, including The Montreal Protocol on phasing out substances that deplete the ozone layer in 1989, The Kyoto Protocol on reducing greenhouse gas emissions in 1998, and The Paris Agreement on keeping the rise in global average temperature in 2016. Despite all these efforts, environmental quality has still aggravated significantly. According to United Nation (2019), greenhouse gas emissions have risen at a rate of 1.5 per cent per year in the last decade. A record high of 55.3 GtCO2e was reached in 2018, of which fossil carbon emissions contribute most. The Global Footprint Network (2019) reports that the world average ecological footprint was 2.75 global hectares per person in 2016 while the world average bio capacity was only 1.63 global hectares per person. It means that humanity exceeds the planet’s ability to provide biological resources by 69%.

Since the global financial and Eurozone debt crisis, the governments, economists, and researchers have paid much attention to economic policy uncertainty (hereafter EPU). As a reflection of institutional factor, EPU exerts significant impacts on business environment of economic activities. A great number of research has proved the adverse impacts of EPU on real economy (Gu et al., 2021; Li et al., 2020), firm investments (Liu et al., 2020; Suh and Yang, 2021; Zhou et al., 2021), innovation activities (Guan et al., 2021; He et al., 2020), financial markets (Danisman et al., 2020; Nguyen et al., 2020; Phan et al., 2021), and energy market (Xiao and Wang, 2021; Zhang and Yan, 2020). Based on the close link between economic activities and environmental quality, several authors propose the potential outcomes of EPU on environmental quality (Jiang et al., 2019; Yu et al., 2021). According to Jiang et al. (2019), EPU may affect carbon dioxide emissions through three channels. First, high EPU diverts the attention of the government on environmental issues. Consequently, the implementation of environmental regulation is negatively affected. Second, the economic performance of enterprises deteriorates under uncertain economic condition, reducing both natural resources exploitation and energy consumption. However, if the firms decide to choose cheaper and more polluted energy in response to uncertain economic environment, higher pollution is expected. Third, firms may reduce their commitments to control carbon emissions if the government is expected to relax the environmental regulation under high EPU condition. Yu et al. (2021) speculate that the EPU can influence firm emissions through three channels, including innovation, share of fossil fuels, and energy intensity. However, the relationship between EPU and environmental quality has been empirically investigated by a limited number of research on international level (Adedoyin et al., 2021; Anser et al., 2021; Pirgaip and Dincergok, 2020), national level (Adedoyin and Zakari, 2020; Danish et al., 2020; Yu et al., 2021), and sectoral level (Jiang et al., 2019).

Another terminology has been recently received much attention from policymakers and scholars is economic complexity (hereafter ECI). Becker and Murphy (1992) define “complexity” as the number of different inputs required for production of one unit of the good. Appling this definition on a country scale, the complexity level of a country could be defined as the diversity of knowledge and the efficient combination of knowledge to make use of it (Hausmann and Hidalgo et al. 2014). In other words, ECI is a non-monetary and non-income based proxy for economic development of a country. Several authors mention the link between ECI and environmental quality. In the first stage of the development, less sophisticated countries focus on the limited production of primary goods, which are less polluted intensive. More developed countries with higher level of knowledge exploit more resources and produce more goods, which result in excessive environmental degradation. However, after a certain level of knowledge accumulated, the structural shift from energy-intensive to technology-intensive industries and prevalence of cleaner production technologies can reduce environmental externalities (Can and Gozgor, 2017; Chu, 2021; Yilanci and Pata, 2020).

Although there have been several studies on environmental effect of ECI and EPU in Group of 7 (hereafter G7) countries or in each G7 country member (Adedoyin and Zakari, 2020; Pirgaip and Dincergok, 2020; Pata, 2021), to our best knowledge, there has not been any research that takes into consideration the effect of both factors as well as the moderating effects of EPU. This on-hand paper relates the three strands of literature, EPU, ECI, and environmental quality. G7 economies are chosen as research sample because of several reasons. First, not only G7 economies contribute significantly to global production and consumption, it also produces 24.4% of world carbon dioxide emissions (Fig. 1). Although this proportion has declined gradually since 2000, United States still ranks second, Japan ranks 5th, and Germany ranks 6th among top ten countries that emit the most carbon dioxide. Second, G7 countries are ranked in the top of sophisticated economies. Except Canada ranked 39th, other economies are in top 20. Especially, Japan and Germany are placed in 1st and 4th, respectively. Therefore, we start by examining the effect of economic policy uncertainty, economic complexity, renewable energy, and energy intensity on carbon dioxide emissions and ecological footprint.

Figure 1 shows that the recent decline in G7's carbon dioxide emissions occurs with the increasing trend of renewable energy consumption, which account for 40% of world renewable energy consumption. The similar relationship between renewable energy consumption and carbon dioxide emissions per capita is illustrated in Fig. 2. Figure 2 also indicates that the high level of EPU in G7 countries since the global financial crisis occurs concurrently with the declining trends of carbon dioxide emissions and ECI, as well as the higher popularity of renewable energy consumption. These patterns raise the second question of whether EPU affects the environmental effect of renewable energy consumption and economic complexity. This objective is further reinforced by above-mentioned literature on the effects of EPU on many economic and environmental indicators. Thus, the present paper tests whether EPU magnifies or dampens the environmental effect of its influencing factors.

To achieve these objectives, we employ a panel dataset over the period from 1997 to 2015. The co-integration tests are used to identify the existence of long-run relationship among interested variables. Once the co-integration relationship is determined, the Fully Modified Ordinary Least Squares (hereafter FMOLS) and fixed effect model with Driscoll and Kraay (1998) robust standard errors are employed to estimate the environmental effect of each variable on carbon dioxide emissions and ecological footprint. To explore the moderating effect of EPU, the interactions between EPU and three mentioned variables are introduced into regression models. We calculate the marginal effect of ECI, renewable energy, and energy intensity on two environmental quality indicators conditional on the evolution of EPU.

We obtain the following results, which are stable through extensive robustness checks. First, higher EPU reduces environmental degradation in G7 countries. Second, ECI increases environmental externalities at its initial stage of evolution. After reaching a certain high level, ECI decreases the level of carbon dioxide emissions and ecological footprint. Third, while renewable energy consumption significantly suppresses environmental pollution, energy intensity propels high levels of environmental degradation. Forth, EPU strongly moderates the environmental effect of renewable energy, ECI, and energy intensity. On the one hand, EPU amplifies the beneficial environmental effects of renewable energy and ECI. On the other hand, it also magnifies the harmful effect of energy intensity on environmental quality. These empirical outcomes allow us to draw useful implications for policymakers.

The rest of this paper is structured as follows. Section 2 provides a review of the relevant literature. Section 3 describes the data set as well as methodology. Section 4 reports and discusses estimation results. In Sect. 5, we draw conclusions and suggest policy implications.

2. Brief Literature Review

This section provides a brief review of the literature on the role of renewable energy, energy intensity, EPU, and ECI on environmental quality. In the literature review of environmental quality, energy has been closely linked to both carbon dioxide emissions and ecological footprint. Among energy factors, renewable energy consumption and energy intensity are often identified as the key ones. Given the growth of the world population and unavoidable higher energy demand, the continuous use and high dependency on fossil fuel sources lead to significant degradation of environmental quality. In contrast, renewable energy sources are cleaner, inexhaustible, and environmental friendly, and less affected by geopolitical risks (Adedoyin et al., 2021; Pata, 2020). Most research find that renewable energy consumption reduces carbon dioxide emissions and plays an important role in achieving sustainable development goals (Adams and Acheampon, 2019; Khan et al., 2020; Vural, 2020; Swain and Karimu, 2020; Wang et al., 2020). On the role of energy intensity, lowering the energy intensity or increasing the energy efficiency is considered a major solution to reducing carbon dioxide emissions (Neagu, 2019; Talaei et al., 2018; Worrell et al., 2001).

Empirical studies on the relationship between EPU and environmental quality have emerged recently in the literature. These studies rely on the reliable and comprehensive measure of EPU index released by Baker et al. (2016). While some studies focus on a single country context, other research examine a boarder context. In the former group, the studied country is one of the top carbon emitter countries, such as China, the United Kingdom, and the United States. Jiang et al. (2019) conclude that EPU is relevant for explaining the behavior of total and sectoral carbon dioxide emissions (industrial, residential, transportation, and electric sectors) in the United States. Specifically, EPU Granger causes carbon dioxide emissions growth in the lower quantiles of emissions growth distribution. It is also noteworthy that EPU has no impact on the carbon emissions growth for the commercial sector. Sohail et al. (2021) indicate that effects of the United States’ monetary policy uncertainty on renewable and non-renewable energy consumption are asymmetric in direction and magnitude. Danish et al. (2020) find that not only does EPU adversely affect environmental quality in the United States it also strengthens the detrimental effect of energy intensity on carbon dioxide emissions. Yu et al. (2021) explore the impact of EPU on the Chinese firms’ carbon dioxide emissions as well as identify the channels through which EPU can affect firm emission intensity. The results show that China’s provincial EPU imposes a positive impact on firm’s carbon dioxide emissions. This unwilling effect works through the share of fossil fuels and energy intensity in the short-run but not through firm innovation channel. In the United Kingdom, EPU reduces the growth of carbon dioxide emissions in the short-term but yields a harmful effect in the long-term (Adedoyin and Zakari, 2020). With regard to the latter group, Anser et al. (2021) explore the impact of world uncertainty index on carbon dioxide emissions in top ten carbon emitter countries. According to the empirical results, an increase in world uncertainty index mitigates carbon dioxide emissions in the short-run but escalates emissions in the long-run. Pirgaip and Dincergok (2020) provide evidences for a unidirectional causality running from EPU to energy consumption in Japan, to carbon dixoide emissions in the United States and Germany, and to both energy consumption and carbon dioxide emissions in Canada. Adedoyin et al. (2021) pay attention to environmental issues in Sub-Saharan Africa region. They find that the disruption of economic activities due to uncertainty in economic policy causes significant increase in carbon dioxide emissions. Similarly, Adams et al. (2020) conclude a significant association between EPU and carbon dioxide emissions in the long-run.

Since the publication of ECI developed by Hidalgo and Hausmann (2009), there have been a great number of research exploring its environmental impact. The empirical results are inconsistent in both single country and group country contexts. Pata (2020) examine the impact of ECI on both carbon dioxide emissions and ecological footprint in the United States. The main finding indicates that the inverted U-shaped Environmental Kuznet Curve relationship between ECI and environmental pollution holds for the United States. Shahzad et al. (2021) conclude that fossil fuel energy and ECI contribute to enhance the environmental externalities in the United States. Similarly, Yilanci and Pata (2020) find that ECI increases ecological footprint in China. In contrast, it is observed that higher ECI suppresses the level of carbon dioxide emissions in the long-run in France (Can and Gozgor, 2017). In a boarder context, several researchers investigate the environmental effect of ECI for leading complex countries (Neagu, 2020; Wang et al., 2021), OECD countries (Dogan et al., 2020), and European Union countries (Neagu, 2019). For complex countries, Neagu (2020) and Wang et al. (2021) find that an increase in ECI leads to environmental degradation. For OECD countries, Dogan et al. (2020) conclude that ECI proves effective in mitigating the environmental degradation. Neagu (2019) find that the Environmental Kuznet Curve hypothesis is valid for both whole sample of 25 European Union countries and six country members (Belgium, France, Italy, Finland, Sweden, and the United Kingdom). Other authors, such as Boleti et al. (2021), Chu (2021), Dogan et al. (2019), and Romero and Gramkow (2021) extend to a larger sample. Boleti et al. (2021) find that higher level of ECI leads to better overall environmental performance (which is constituted from three aspects, namely health impacts, air quality, and water and sanitation) but induces air polluted in a sample of 88 developed and developing countries. Dogan et al. (2019) find that impact of ECI on carbon dioxide emissions varies according to the economic development of a country. Specifically, ECI increases environmental degradation in low- and middle-income countries but controls it in case of high-income countries. Romero and Gramkow (2021) find a negative relationship between ECI and greenhouse gas emissions for a sample of 67 countries. Chu (2021) reports an inverted U-shaped relationship between ECI and carbon dioxide emissions for a sample of 118 countries. In addition, while ECI is found to benefit environmental quality in high-income countries, it leads to significant degradation in air pollution in middle-income countries.

These studies provide meaningful theoretical and empirical results for the determinants of environmental quality. However, there exists still some gaps. First, a limited number of studies have already examined the environmental Kuznet curve of ECI and environmental impact of EPU for a group of highly sophisticated economies like G7. Second, the moderating impacts of EPU on the environmental impact of renewable energy (only Adedoyin et al., 2021), energy intensity, and economic complexity have been largely ignored. For these reason, it is expected that this study will contribute to the environmental literature by providing a more comprehensive and detailed analysis.

3. Data And Methodology

3.1. Data

This study complies panel data for G7 countries from 1997 to 2015. The two proxies for environmental quality, carbon dioxide emission (kg per 2010 US$ of GDP) and ecological footprint (global hectares per capita), act as the dependent variables. While carbon dioxide emissions does not include water and soil pollution, ecological footprint introduced by Rees (1992) is considered as a boarder indicator for environment quality, covering cropland, forest, build-up land, carbon dioxide emissions, and water pollution. While the data on the former is taken from World Bank' World Development Indicators database, the latter is sourced from the Global Footprint Network. For robustness test, we also use ecological footprint of consumption and biological capacity deficit to proxy for environmental externalities.

The three main independent variables include renewable energy consumption, EPU, and ECI. We utilize the index of EPU developed by Baker et al. (2016) for United States and eleven other major economies. Baker et al. (2016) count the frequency of articles that contain trio terms about the economy, policy, and uncertainty in leading newspapers. The raw counts then are scaled by the total number of articles in the same newspaper, standardized to unit standard deviation, and averaged across all newspapers. The data on EPU are collected from Economic Policy Uncertainty website. For robustness, we use world uncertainty index as a substitution for economic policy uncertainty. Developed by Ahir et al. (2018), this index is constructed based on the frequency counts of the words “uncertainty” (and its variants) in the Economist Intelligence Unit’s country reports. The coverage of world uncertainty index is boarder than economic policy uncertainty index because the former takes into consideration both major political and economic developments in each country.

The ECI is a concept developed to reflect the stock of productive knowledge accumulated in a population. Because knowledge is a crucial input of the production process as well as a country produces and exports products that it has relative competitive advantages, economic sophistication could be measured through the international trade practices. Based on that idea, Hidalgo and Hausmann (2009) build ECI index, which represents the diversity and ubiquity of products a country exports. While the former represents the spectrum of products that a country can make competitively, the latter measures the pervasiveness of such products. We also use the improved ECI index, which considers the difficulty level of exporting products for sensitivity check. The data on these two indices can be extracted from MIT Media Lab’s Observatory of Economic Complexity index.

This study chooses the proportion of renewable energy consumption in total final energy consumption to proxy for the renewable energy. Moreover, the renewable electricity output as of total electricity output is selected for robustness test. Other explanatory variables include real GDP per capita (constant 2010 US$) and energy intensity (kg of oil equivalent per capita). The data on these two variables are drawn out from the World Bank’ World Development Indicators database. The abbreviation, measurement, and source of the data are provided in Table 1.

Table 1
Variable description

Variable	Abbreviation	Measurement	Source
Carbon dioxide emissions	CO_2	kg per 2010 US$ of GDP	World Development Indicators
Ecological footprint	EFP	global hectares per capita	Global Footprint Network
GDP per capita	GDPpc	constant 2010 US$	World Development Indicators
Energy intensity	ENE	kg of oil equivalent per capita	World Development Indicators
Renewable energy consumption	REN	% of total final energy consumption	World Development Indicators
Economic policy uncertainty	EPU	index	https://www.policyuncertainty.com/index.html
Economic complexity	ECI	index	Atlas Media database

Table 2 contains descriptive statistics of all variables in full sample and for each G7 country. The average carbon dioxide emissions of the sample is -1.420 (equivalent to 0.257 kg per 2010 US$ of GDP). The mean of energy intensity is 8.412 (equivalent to 4,832 ton of oil equivalent per capita). The average proportion of renewable energy consumption is around 1.926 (equivalent to 9%). Table 2 Panel B shows that the United States and Canada, in turn, takes the first and second place in carbon dioxide emissions, ecological footprint, EPU, and energy intensity. In contrast, France and Italy are two countries that emit less carbon dioxide (and also two lowest energy intensity) than other G7 members. Canada has the highest proportion of its energy consumption, which come from renewable sources, followed by France and Italy. Japan and United Kingdom depend more on non-renewable energy. While Japan is the most sophisticated economy, followed by Germany, Canada is the least complex one.

The correlation matrix is given in Appendix 1. It is apparent that there are significant relationships between energy intensity, ECI, EPU, and environmental quality. EPU is positively correlated with renewable energy while negatively correlated with ECI.

Table 2. Descriptive statistics

Panel A. Full sample

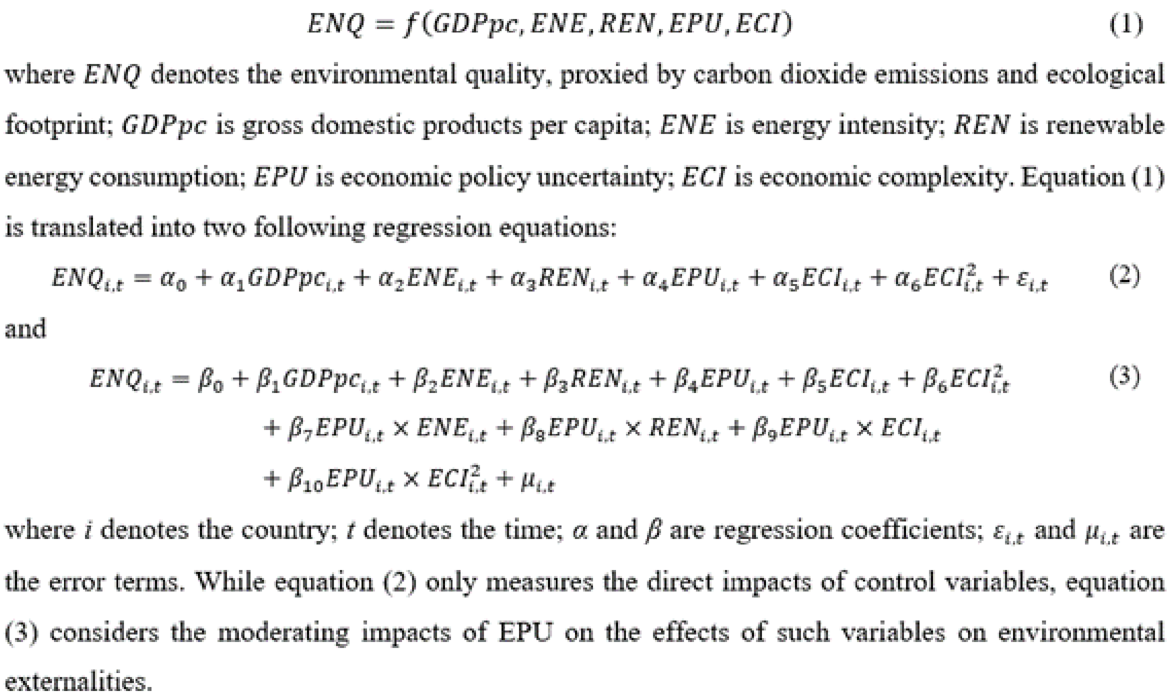
Variable	Obs	Mean	Std. Dev.	Min	Max
CO_2	131	-1.420	0.351	-2.205	-0.724
EFP	133	1.679	0.480	0.953	2.651
GDPpc	133	10.626	0.111	10.389	10.862
ENE	133	8.412	0.368	7.789	9.043
REN	133	1.926	0.799	-0.159	3.122
EPU	133	4.675	0.501	3.232	5.883
ECI	133	1.645	0.507	0.411	2.612

Panel B. Country group (mean)

Countries	CO_2	EFP	GDPpc	ENE	REN	EPU	ECI
Canada	-0.988	2.547	10.694	8.992	3.087	4.637	0.773
France	-1.940	1.490	10.589	8.306	2.332	4.729	1.482
Germany	-1.429	1.592	10.603	8.299	1.920	4.686	2.078
Italy	-1.596	1.185	10.490	7.977	2.133	4.610	1.373
Japan	-1.533	1.351	10.689	8.256	1.445	4.665	2.396
United Kingdom	-1.545	1.353	10.558	8.132	0.722	4.680	1.737
United States	-0.943	2.231	10.762	8.921	1.846	4.718	1.677

3.2. Model specification and estimation method

For empirical analysis, the authors follow the specification model developed by (Adams et al., 2020; Adedoyin et al., 2021; Chu, 2021) where they consider GDP per capita, energy intensity, renewable energy, EPU, and ECI as key determinants of environmental quality. The econometrical model is expressed as follows:



$$ENQ = f(GDPpc, ENE, REN, EPU, ECI) \quad (1)$$

where ENQ denotes the environmental quality, proxied by carbon dioxide emissions and ecological footprint; $GDPpc$ is gross domestic products per capita; ENE is energy intensity; REN is renewable energy consumption; EPU is economic policy uncertainty; ECI is economic complexity. Equation (1) is translated into two following regression equations:

$$ENQ_{i,t} = \alpha_0 + \alpha_1 GDPpc_{i,t} + \alpha_2 ENE_{i,t} + \alpha_3 REN_{i,t} + \alpha_4 EPU_{i,t} + \alpha_5 ECI_{i,t} + \alpha_6 ECI_{i,t}^2 + \varepsilon_{i,t} \quad (2)$$

and

$$\begin{aligned} ENQ_{i,t} = {} & \beta_0 + \beta_1 GDPpc_{i,t} + \beta_2 ENE_{i,t} + \beta_3 REN_{i,t} + \beta_4 EPU_{i,t} + \beta_5 ECI_{i,t} + \beta_6 ECI_{i,t}^2 \\ & + \beta_7 EPU_{i,t} \times ENE_{i,t} + \beta_8 EPU_{i,t} \times REN_{i,t} + \beta_9 EPU_{i,t} \times ECI_{i,t} \\ & + \beta_{10} EPU_{i,t} \times ECI_{i,t}^2 + \mu_{i,t} \end{aligned} \quad (3)$$

where i denotes the country; t denotes the time; α and β are regression coefficients; $\varepsilon_{i,t}$ and $\mu_{i,t}$ are the error terms. While equation (2) only measures the direct impacts of control variables, equation (3) considers the moderating impacts of EPU on the effects of such variables on environmental externalities.

The sequence of the econometric methods is as follows: checking the cross-sectional dependence among variables; checking the variables' stationarity; testing co-integration relationship between variables; testing the presence heteroskedasticity and serial correlation; and if the existence of co-integration is confirmed, performing the FMOLS and fixed effect model.

To check the cross-sectional dependence among variables, the on-hand paper applies the method shown in Pesaran (2004). The null hypothesis advocates for the absence of cross-sectional dependence while the alternative hypothesis supports the presence of cross-sectional dependence.

If the test indicates the presence of cross-sectional dependence, we proceed with testing the stationarity of variables. In method proposed by Pesaran (2007), to eliminate the cross-dependence, the standard Dickey Fuller regressions are augmented with the cross section averages of lagged levels and first-differences of the individual series. The null hypothesis of all panels contain unit roots is tested against the alternative hypothesis of a fraction of the series is stationary. We also employ Levin-Lin-Chu (2002) and Im-Pesaran-Shin (2003) tests with the null hypothesis that all panels contain a unit root.

To determine whether there exists a long-run co-integration between variables, the methods proposed by Westerlund (2005) and Pedroni (1999, 2004) are applied. Westerlund (2005) designs the null hypothesis of no co-integration against the alternative hypothesis that the panel is co-integration as a whole or the fraction of co-integrated individuals is positive. In Pedroni (1999, 2004)'s tests, the null hypothesis assumes that there is no co-integration in a heterogeneous panel with one or more nonstationary regressors. The alternative hypothesis claims that there is a long-run co-integration among variables.

The paper also tests the presence of heteroskedasticity and auto-correlation in two regression equations by using Wald statistics. The two null hypotheses are homoskedasiticty and no serial correlation in the residuals. After confirming the co-integration association among variables, we further examine the long-run relationship by employing FMOLS and fixed effect model with Driscoll and Kraay (1998) robust standard errors. The FMOLS is chosen because it relies on a non-parametric to deal with serial auto-correlation and endogeneity problems. The latter approach, fixed effect model with Driscoll and Kraay (1998) robust standard errors is able to account for heteroskedasticity, cross-sectional dependency, and auto-correlation. To test whether the fixed effect and random effect is appropriate, the Hausman test is conducted.

4. Empirical Results And Discussion

4.1. Main results and discussion

The outcomes of cross-sectional dependence test are reported in Appendix 2. All three tests, Pesaran, Friedman, and Frees, indicate the null hypothesis of cross-sectional independence are rejected at conventional levels for both carbon dioxide emissions and ecological footprint equations. This finding is further supported by the co-movement of variables between countries in Fig. 2. This leads us continue checking the stationarity proprieties of variables, taking into consideration the presence of cross-sectional dependence. Appendix 3 illustrates the results of Pesaran (2007), Levin-Lin-Chu (2002), and Im-Pesaran-Shin (2003) tests for all variables and their first differences. The empirical estimates indicate that economic policy uncertainty is stationary at level in case of Levin-Lin-Chu (2002) and Im-Pesaran-Shin (2003)'s tests, somewhat stationary at first difference in case of Pesaran (2007)'s test. All other variables have a unit root at level but become stationary at first difference. Appendix 4 shows the empirical values of Westerlund (2005)'s and Pedroni (1999, 2004)'s co-integration tests. In Panel A, most Westerlund (2005)'s tests are statistically significant at conventional levels for both carbon dioxide emissions and ecological footprint equations, confirming the occurrence of co-integration among variables. In Panel B, four out of seven statistics have the corresponding value of probability under conventional significance levels, rejecting the null hypothesis of no co-integration. Overall, two tests indicate a valid co-integration relationship between variables for both equations. Appendix 5 and 6 respectively illustrate that the null hypotheses of no heteroskedasticity and no serial correlation are rejected. The Hausman test results presented in Appendix 7 support for the use of fixed effect over random effect model.

Given the identified co-integration relationship between variables, we examine the long-run relationship by using the FMOLS and fixed effect with Driscoll-Kraay standard errors. Table 3 report the estimation results for Eqs. (2) and (3) when carbon dioxide emissions and ecological footprint are proxies for environmental degradation. We start by discussing the results of the Eq. (2) first, then considering the moderating effect of EPU in Eq. (3). Column (1), (3), (5), and (7) indicate that all interested variables are influencing determinants of carbon dioxide emissions and ecological footprint. First, the negative and statistically significant of estimated GDP per capita coefficients indicate that effect of higher income on environmental quality is favorable in G7 countries.

In contrast, the estimated coefficient of energy intensity is positive and statistically significant. It means that higher energy usage causes environmental degradation. This result is similar to the findings of (Danish et al., 2020; Neagu, 2019). Energy intensity and environmental degradation have a strongly positive relationship. Activities of both businesses and households rely largely on the consumption of energy, which often consumes large sources of fossil fuels and non-renewable sources. By emitting enormous pollutants into the environment and reducing the bio-capacity below its sustainable level, high energy usage causes serious concern for human being. Thus, shifting energy technologies from less efficient to more efficient ones is necessary to protect environment while still supports economic growth.

Third, it is obvious that the harmful effects of fossil fuels usage and dependence are multi-faceted, including economy-, health- and environment-threatening. However, the adverse impact on environment could be controlled with renewable energy, as the estimated coefficient of renewable energy consumption is negatively significant. Adedoyin (2021), Chu (2021), Dogan et al. (2020), Puta (2020), and Wang et al. (2021) find the significant role of renewable energy in pollution mitigation in different countries or country groups. Thus, transforming both energy sources and technologies from non-renewable to renewable ones could be a good solution to mitigate the pressure on environment.

Forth, the estimated coefficients of ECI and its squared are positive and negatively significant at conventional levels, respectively. In the early stage of development, higher economic sophistication damages environmental quality. Countries in this stage mostly conduct extensive activities in the primary sector with less sophisticated products that barely contribute to environmental degradation. However, the harmful environmental effects start increasing when a country moves gradually into industrialization stage with higher energy intensive industries (such as textile, refining, and basic chemical industries). When a country knowledge evolves to a certain high level, it is able to create and adopt environmental friendly energy sources as well as cleaner production technologies. At this point, the transition from energy intensive to technology intensive industries happens, mitigating the environmental externalities. Our finding on the inverted U-shaped relationship between ECI and environmental quality is similar to the conclusion of Chu (2021), Neagu (2019), and Pata (2020) but different from the outcome of Neagu (2020) and Wang et al. (2021).

With regard to EPU, the estimated coefficient is negative and statistically significant, implying that higher uncertainties reduce carbon dioxide emissions and ecological footprint. For countries in our samples, the economic contraction caused by high EPU overwhelms the neglected implementation of environmental regulation, reduced commitments on environmental protection of enterprises, as well as the higher use of cheaper but more polluted energy sources. While this outcome confirms the significantly environmental impact of EPU, it is different from empirical literature that indicate a positive long-run relationship between two variables (Adams et al., 2020; Adedoyin et al., 2021; Anser et al., 2021; Danish et al., 2020; Sohail et al., 2021; Yu et al., 2021).

Table 3
Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Model 1: Carbon dioxide emissions				Model 2: Ecological footprint			
	Fully modified OLS		Fixed effect with Driscoll – Kraay standard errors		Fully modified OLS		Fixed effect with Driscoll – Kraay standard errors	
GDPpc	-1.031***	-1.021***	-0.885***	-0.719***	-0.320***	-0.257***	-0.089	-0.082
	(0.006)	(0.005)	(0.080)	(0.116)	(0.012)	(0.014)	(0.080)	(0.086)
ENE	1.230***	-0.376***	0.860***	0.646***	1.148***	-3.466***	0.880***	0.911***
	(0.008)	(0.111)	(0.101)	(0.082)	(0.016)	(0.546)	(0.104)	(0.114)
REN	-0.049***	0.091**	-0.056***	0.106**	-0.024***	0.013	-0.020	0.109***
	(0.003)	(0.044)	(0.011)	(0.045)	(0.006)	(0.117)	(0.016)	(0.036)
EPU	-0.001*	-2.728***	-0.014***	-0.263**	-0.016***	-7.284***	-0.016***	0.266*
	(0.001)	(0.209)	(0.004)	(0.114)	(0.001)	(0.733)	(0.005)	(0.137)
ECI	0.504***	1.265***	0.382***	0.540***	1.177***	7.227***	0.356***	1.176***
	(0.022)	(0.054)	(0.092)	(0.072)	(0.044)	(1.840)	(0.080)	(0.297)
ECIsq	-0.159***	-0.211***	-0.102***	-0.103***	-0.379***	-1.701***	-0.116***	-0.366***
	(0.007)	(0.007)	(0.026)	(0.016)	(0.013)	(0.498)	(0.024)	(0.094)
EPU x ENE		0.334***		0.040**		0.979***		-0.011
		(0.023)		(0.015)		(0.116)		(0.014)
EPU x REN		-0.029***		-0.034***		-0.017		-0.030***
		(0.009)		(0.010)		(0.025)		(0.008)
EPU x ECI		-0.130***		-0.051***		-1.384***		-0.173***
		(0.012)		(0.011)		(0.411)		(0.051)
EPU x ECIsq		0.007***		0.032***		0.308***		0.052***

Note: This table reports the estimation results of model (2) and (3). The dependent variable is carbon dioxide emissions and ecological footprint. The independent variables include energy intensity (ENE), renewable energy consumption (REN), economic policy uncertainty (EPU), and economic complexity (ECI). ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		(0.000)		(0.007)		(0.111)		(0.015)
Constant	-1.116***	11.745***	0.593	0.084	-5.346***	28.733***	-4.901***	-6.108***
	(0.087)	(0.992)	(1.074)	(1.814)	(0.174)	(3.475)	(0.866)	(1.036)
R-squared	0.998	0.999	0.940	0.964	0.981	0.983	0.807	0.828

Note: This table reports the estimation results of model (2) and (3). The dependent variable is carbon dioxide emissions and ecological footprint. The independent variables include energy intensity (ENE), renewable energy consumption (REN), economic policy uncertainty (EPU), and economic complexity (ECI). ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

We further explore the moderating effect of EPU on the relationship between energy intensity, renewable energy, ECI, and environmental quality. The estimated results are presented in column (2), (4), (6), and (8). For carbon dioxide emissions and under FMOLS, we find that the sign of estimated coefficient of energy intensity changes from positive to negative while the the sign of estimated coefficients of renewable energy consumption changes from negative to positive. However, the signs of estimated coefficients of ECI and its square remain unchanged. It is also noteworthy that the signs of estimated coefficients of three interaction variables are in opposite direction with those of main effects. Similar results are found in the case of ecological footprint.

By including the interaction terms in the regression model, it is not appropriate to interpret the results by simply combining the effect of each variable with the effect of interaction variable (Brambor et al., 2006). The environmental effects of energy intensity, renewable energy, and ECI are now conditional on the level of EPU. To examine deeper into these results, we illustrate the marginal effects of three mentioned variables (at their means) on the evolution of EPU in Fig. 3. Figure 3 Panel A shows that the marginal effects of energy intensity on both carbon dioxide emissions and ecological footprint are positive and statistically significant when EPU of all G7 countries is within the current range for the studied period. High EPU amplifies the unwilling environmental effect of energy intensity. The reason behind this phenomenon could be in the case of high uncertainties, companies and households tend to use more intensive energy sources and adopt less efficient energy technologies.

The marginal effect of renewable energy consumption is shown in Fig. 3 Panel B. Although its effects on carbon dioxide emissions and ecological footprint are in the same direction, the magnitude is larger in the case of the latter. On the one hand, renewable energy consumption increases air pollution at extreme low level of EPU. On the other hand, renewable energy consumption deteriorates ecological footprint from low to medium level of EPU. However, these harmful effects are statistically insignificant (within the current range of G7 countries' EPU level). In contrast, high level of EPU magnifies the beneficial effect of renewable energy on environmental quality. Uncertain environment encourages firms deploy conventional cheap energy sources to compensate for the low turnover. In the long-run, this production adjustment eventually leads to higher net income, allowing firms to invest in technologies that use renewable energy sources (Majeed and Luni, 2019). Moreover, the supply and price of non-renewable energy sources, such as fossil fuel, are highly sensitive to the business cycle and political conditions. Under such uncertainties, risk adverse firms have a tendency to shift their dependence in non-renewable to renewable energy sources, which are less volatile. The governments also want to solve the national energy insecurity by reducing country's dependency on imported energy sources as well as erratic supply and fluctuated price of non-renewable energies.

In Fig. 3 Panel C, we find similar effect of ECI on environmental quality conditional on the level of EPU. EPU affects the environmental effects of economic complexity through several channels. First, the contraction of production and consumption activities due to economic shocks mitigate the emitted pollution. The second channel is the shift from non-renewable and traditional to renewable and cleaner energy sources over the long term. However, given the inverted U-shaped relationship between two variables, we further illustrate the environmental effect of ECI under its different levels in Fig. 4. As shown Table 3, the relationship between ECI and environmental quality follows an inverted U-shape. At its low level, an increase in ECI damages environmental quality and higher EPU magnifies this unwilling effect. However, at its high level, an upgrade in economic sophistication lessens environmental losses and higher EPU amplifies this beneficial effect.

4.2. Robustness test

This section conducts several tests to check the robustness of the baseline results. First, we use different proxies for interested variables. For dependent variable, environmental quality is proxied by ecological footprint of consumption and biological capacity deficit. The regression results presented in Table 4 Panel A indicate that the environmental effects of energy usage, renewable energy, and ECI on two environmental indicators are similar to those in Table 3. For explanatory variables, we replace renewable energy consumption, ECI index, and EPU by renewable electricity output (as of total electricity output), improved ECI index, and world uncertainty index, respectively. The Eq. (3) are then re-estimated for both dependent variables, carbon dioxide emissions and ecological footprint. From the regression outputs in Table 4 Panel B, it is still observed that the effect of energy intensity, renewable energy, and ECI on environment are conditional on the level of EPU.

Second, we calculate the threshold levels of ECI over which its impacts on different environmental indicators (carbon dioxide emissions, ecological footprint of production, ecological footprint of consumption, and biological capacity deficit) change from harmful to beneficial ones. Then, spline regressions are employed to permit for different slopes associated with ECI when they reach such threshold levels. Specifically, we allow the dummy variables, which equal one if ECI is higher than threshold level and zero otherwise, to interact with ECI and EPU variables. The results (not reported here to save space but available upon request) yield similar results to our main conclusion.

Table 4. Robustness

Panel A

	(1)	(2)	(3)	(4)
	Ecological footprint		Biological deficit	
GDPpc	-0.104***	-0.057***	1.075***	1.148***
	(0.012)	(0.014)	(0.062)	(0.056)
ENE	1.212***	-0.896	2.526***	9.765***
	(0.016)	(0.548)	(0.084)	(2.149)
REN	-0.079***	0.346***	-0.319***	4.806***
	(0.006)	(0.118)	(0.030)	(0.462)
EPU	-0.036***	-2.587***	-0.038***	24.087***
	(0.001)	(0.736)	(0.005)	(2.888)
ECI	1.314***	6.846***	2.718***	45.599***
	(0.042)	(1.846)	(0.226)	(7.246)
ECIsq	-0.415***	-1.667***	-0.866***	-12.295***
	(0.013)	(0.500)	(0.069)	(1.962)
EPU x ENE		0.451***		-1.479***
		(0.116)		(0.457)
EPU x REN		-0.096***		-1.090***
		(0.025)		(0.098)
EPU x ECI		-1.273***		-9.727***
		(0.412)		(1.618)
EPU x ECIsq		0.294***		2.609***
		(0.112)		(0.439)
Constant	-8.159***	3.664	-32.879***	-147.260***
	(0.169)	(3.487)	(0.899)	(13.684)
R-squared	0.987	0.987	0.922	0.942

Note: This table reports the robustness of estimation results. In column (1) and (2), ecological footprint is ecological footprint of consumption. In column (3) and (4), biological deficit is measured by the ratio of ecological footprint divided by ecological capacity. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel B

	(1)	(2)	(3)	(4)	(5)	(6)
	Model 1: Carbon dioxide emissions			Model 2: Ecological footprint		
GDPpc	-1.111***	-1.051***	-1.066***	-0.338***	-0.079***	-0.198***
	(0.004)	(0.004)	(0.006)	(0.019)	(0.010)	(0.009)
ENE	-0.015	-0.006	-0.803***	4.174***	0.212	-2.581***
	(0.229)	(0.059)	(0.148)	(0.445)	(0.136)	(0.271)
REN	-0.777***	-0.022***	-0.532***	1.508***	0.189***	-0.940***
	(0.055)	(0.005)	(0.059)	(0.177)	(0.011)	(0.097)
EPU	-3.475***	1.913***	-4.047***	5.975***	-0.115	-2.408***
	(0.370)	(0.096)	(0.296)	(0.888)	(0.220)	(0.506)
ECI	-4.700***	6.602***	0.130**	1.432***	9.082***	40.226***
	(0.676)	(0.261)	(0.061)	(0.182)	(0.601)	(4.552)
ECIsq	1.321***	-1.844***	-0.037*	-0.452***	-2.571***	-16.000***
	(0.188)	(0.072)	(0.019)	(0.058)	(0.166)	(1.768)
EPU x ENE	0.242***	-0.415***	0.394***	-0.613***	-0.277***	0.769***
	(0.048)	(0.019)	(0.029)	(0.088)	(0.044)	(0.057)
EPU x REN	0.151***	0.007***	0.099***	-0.311***	0.097***	0.185***
	(0.011)	(0.002)	(0.012)	(0.035)	(0.003)	(0.020)
EPU x ECI	1.113***	1.988***	0.464***	0.310*	2.696***	-7.637***
	(0.150)	(0.087)	(0.058)	(0.175)	(0.200)	(0.984)
EPU x ECIsq	-0.315***	-0.548***	-0.180***	-0.124*	-0.749***	3.027***
	(0.042)	(0.024)	(0.023)	(0.069)	(0.055)	(0.382)
Constant	17.074***	4.632***	18.822***	-35.876***	-7.121***	3.972*
	(1.812)	(0.274)	(1.476)	(4.426)	(0.631)	(2.352)
R-squared	0.999	0.999	0.999	0.974	0.988	0.968

Note: This table reports the robustness of estimation results. In column (1) and (4), renewable energy is renewable electricity output as of total electricity output. In column (2) and (5), economic policy uncertainty is world uncertainty index. In column (3) and (6), economic complexity is improved economic complexity index. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

5. Conclusion And Policy Implications

This study explores the environmental impacts of energy intensity, renewable energy, ECI, and EPU for G7 countries over the period covering 1997 to 2015. Because the co-integration tests confirm a long-run relationship between variables, we apply FMOLS and fixed effect with Driscoll-Kraay standard errors estimation. Findings show that energy intensity propels high levels of environmental degradation while renewable energy consumption and EPU lead to reduction in carbon dioxide emissions and ecological footprint. Moreover, there exists a threshold, above which the effect of ECI on environmental quality changes from harmful to beneficial. We also find that EPU has moderating effects on the relationships between interested variables and environmental indicators. Specifically, it magnifies the unwilling environmental effect of energy intensity but extends the beneficial effects of renewable energy and ECI.

The obtained findings provide an opportunity to suggest some valuable policy recommendations for the governments in G7 countries. First, the government should implement policies that increase energy efficiency by sponsoring for researching, developing (for companies), and adopting (for both companies and households) energy-saving technologies. Although G7 countries are classified in high-income group, the shift from high to low energy intensive facilities still requires huge costs, which burdens the budget of economic agents. Thus, a fair cost-sharing scheme between the government and economic agents should be taken into consideration of policymakers.

Second, renewables can be used as an effective tool to lessen both carbon dioxide emissions and ecological footprint. Although the proportions of renewable energy in both production and consumption have been increased in recent years, the G7 countries have a long history of large dependency on non-renewable energy sources. As a result, the governments should provide additional tax exemptions and implement favorable feed-in tariff structure to increase incentives for renewable energy producing companies. With regard to consumers, environmental awareness-raising programs (for households) and stricter requirements for a fixed proportion of renewable energy consumption (for manufacturers) should be adopted.

Third, the inverted U-shaped relationship between ECI and environmental quality suggests the G7 governments to support knowledge creation and diffusion. In other words, economies that are more sophisticated possess the potential to stimulate the creation and application of environmentally friendly technologies. Tax exemptions or financial supports should be given to companies that spend substantial money on researching, developing, and adopting advanced production technologies. Moreover, the government should continue implementing strict environmental regulations and make arrangements to protect the environment during the process of knowledge development. By encouraging the application of more efficient and cleaner production techniques and energy sources, the aims of better environmental quality could be achieved.

Forth, not only does EPU directly reduces carbon dioxide emissions and ecological footprint, it also influences the environmental impacts of energy intensity, renewable energy, and ECI. Although this finding looks like a double-edged sword for economic prosperity and environmental sustainability, the policy implication toward sustainable development goals is straightforward. The government should focus on controlling uncertainties around economic policies and at the same time, encouraging the adoption of renewable energy sources, energy efficient technologies, as well as creation and transfer of knowledge.

Future research on the impact of energy intensity, renewable energy, ECI, and EPU on environmental quality can be implemented in a specific country (to avoid the heterogeneous cross-sectional characteristics), larger country groups (to make more general conclusions), or in longer time span. This can also be extended by including other environmental quality indicators such as sulfur dioxide, nitrogen oxide, greenhouse gas emissions, or water and soil pollution, for example.

Declarations

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Consent for publication: Not applicable

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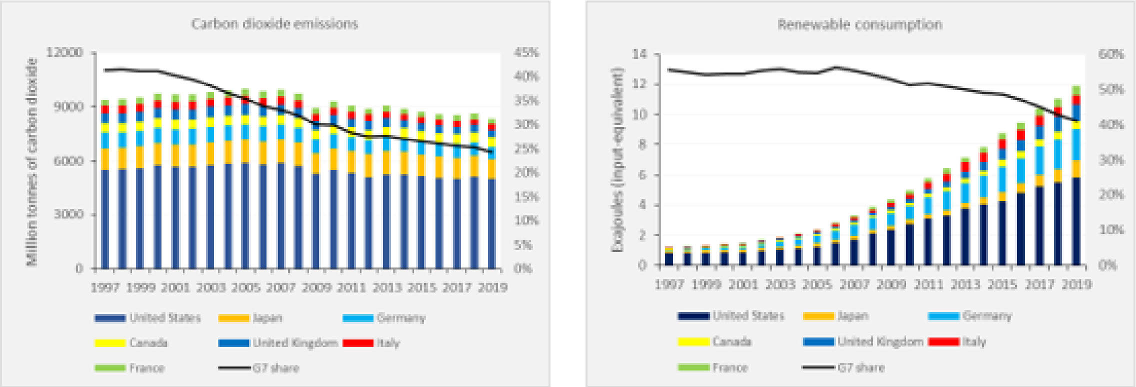
Figures



Carbon dioxide emissions

Renewable consumption

Figure 1

Carbon dioxide emissions and renewable energy consumption in G7 countries and G7’s share of the world. Note: The carbon emissions reflect only those through consumption of oil, gas and coal for combustion related activities, renewable consumption is based on gross generation and not accounting for cross-border electricity supply. G7’s share of the world in the right axis. Sources: the 2020 BP Statistical Review of World Energy.

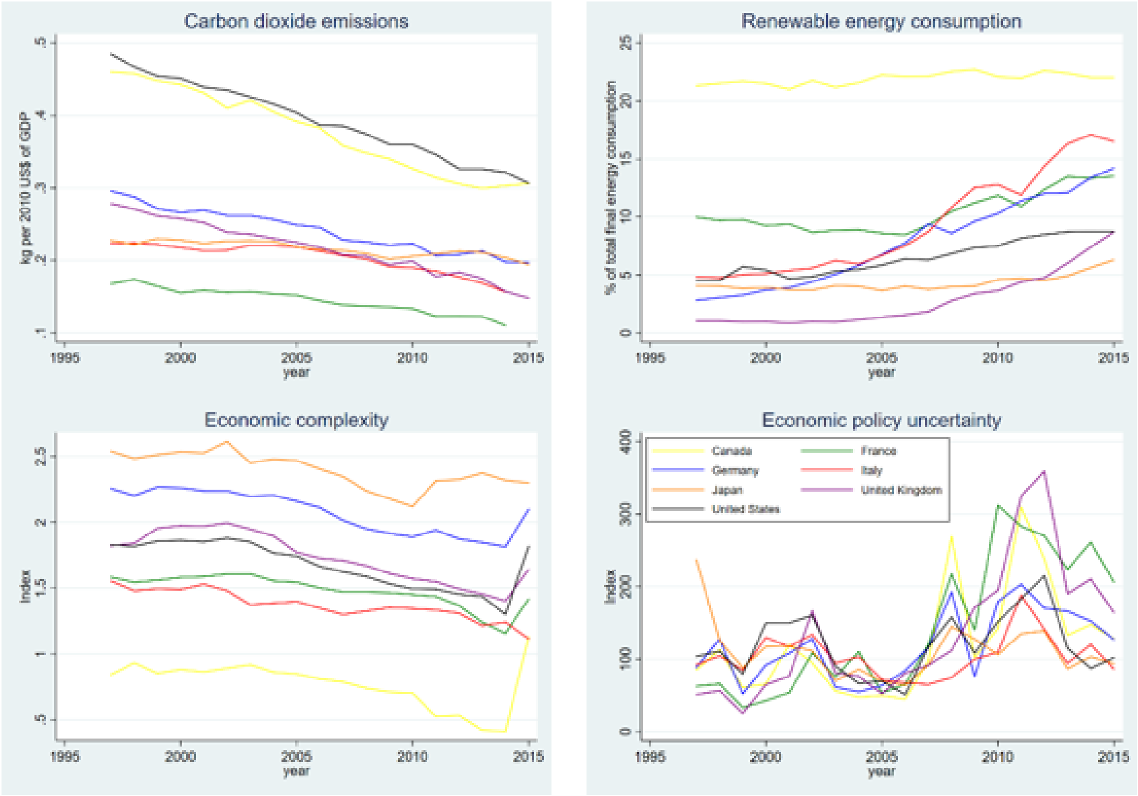


Figure 2

Carbon dioxide emissions, renewable energy consumption, economic complexity, and economic policy uncertainty in G7 countries. Note: Carbon dioxide emissions (kg per 2010 US$ of GDP), renewable energy consumption (% of total final energy consumption), economic complexity (index), economic policy uncertainty (index). Sources: World Development Indicators database, Atlas Media database, and https://www.policyuncertainty.com/index.html.

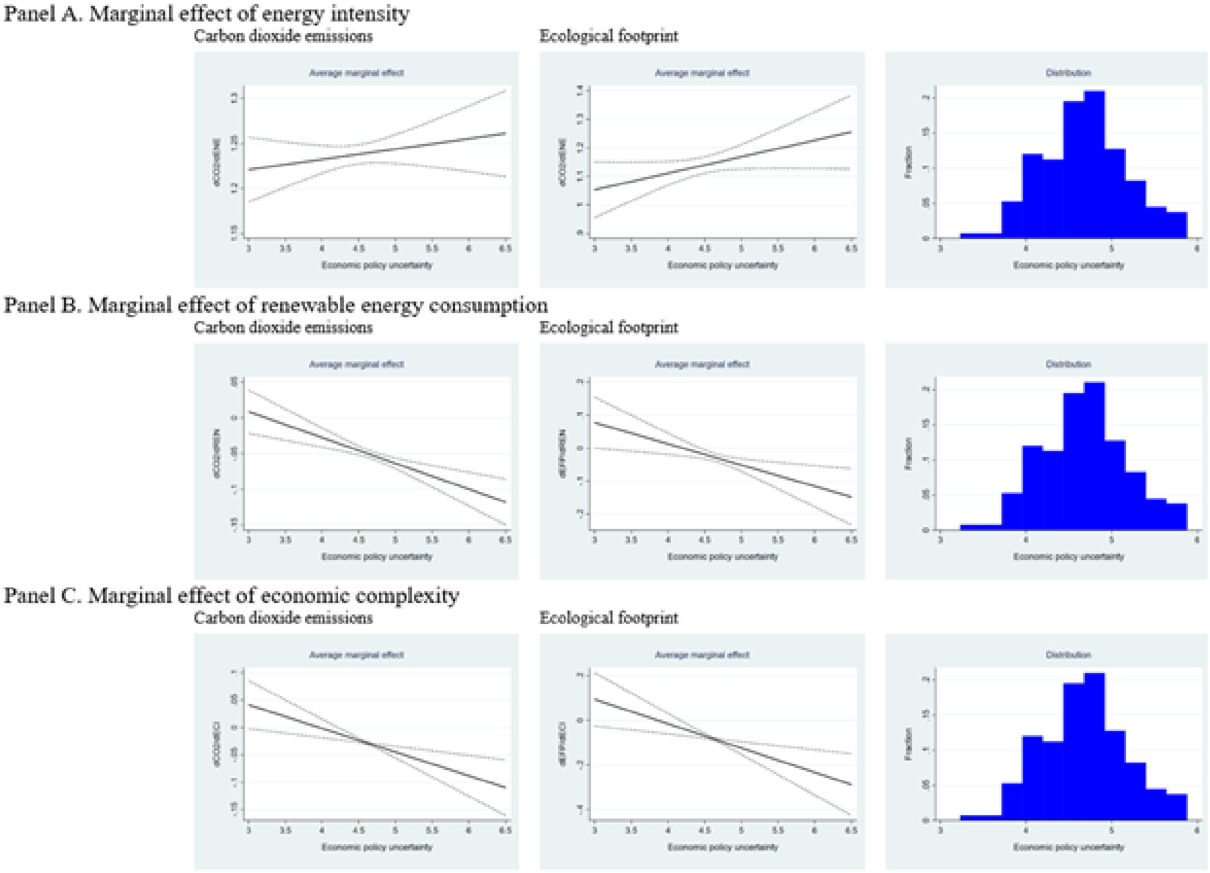


Figure 3

Marginal effect of energy intensity, renewable energy consumption, and economic complexity on environmental quality conditional on the economic policy uncertainty. Note: This figure represents the impact of energy intensity, renewable energy consumption, and economic complexity (at their means) on environmental quality based on estimation results of Table 3 column (2) and (6). The solid black line plots the marginal effect of interested variable on environmental quality conditional on economic policy uncertainty. The dotted lines are 90% confidence intervals.

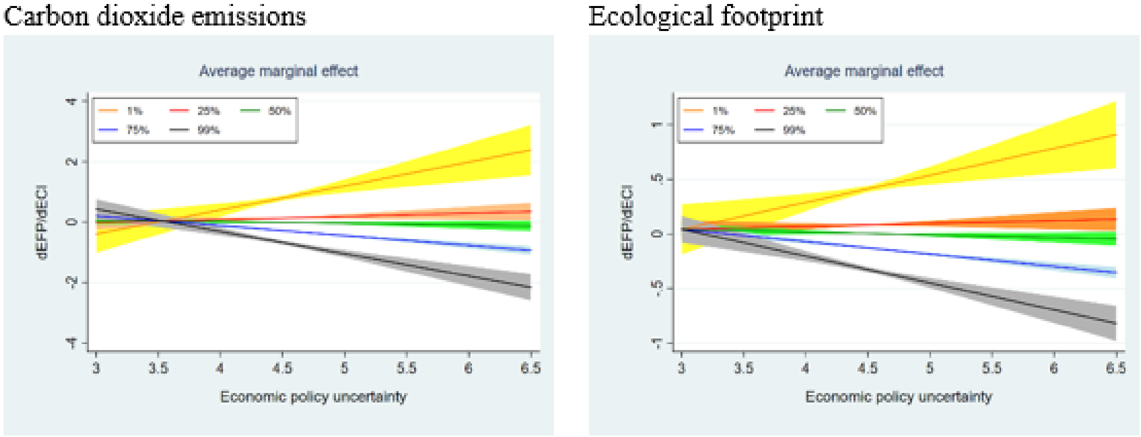


Figure 4

Different marginal effect of economic complexity on environmental quality conditional on the economic policy uncertainty level. Note: This figure represents the impact of economic complexity (at its 1%, 25%, 50%, 75%, 99% percentile) on environmental quality conditional on economic policy uncertainty based on estimation results of Table 3 column (2) and (6). The solid line plots the marginal effect of economic complexity on environmental quality conditional on economic policy uncertainty level. The colored areas are 90% confidence intervals.

Supplementary Files

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- Appendix.docx