



Asymmetric effect of economic policy uncertainty, political stability, energy consumption, and economic growth on CO₂ emissions: evidence from G-7 countries

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Abstract

This study deals with the asymmetric effect of economic policy uncertainty and political stability on carbon dioxide (CO₂) emissions considering also energy consumption and economic growth. In this context, the study investigates G-7 countries, which make up an important part of the world economy. Also, the study uses yearly data between 1997 and 2021 as the most available intersection data for all countries included. Besides, this study applies a novel nonlinear approach as quantile-on-quantile regression (QQR) as the base model, and quantile regression (QR) is used for robustness. The empirical results present that (i) economic policy uncertainty has a decreasing effect on CO₂ emissions in Italy, Japan, and the United States of America (USA), whereas it has a mixed effect in Canada, France, Germany, and the United Kingdom (UK); (ii) political stability also has a mixed effect on CO₂ emissions; (iii) energy consumption has an accelerating effect on CO₂ emissions while the power of effect changes at quantiles; (iv) economic growth has generally an increasing effect on CO₂ emissions, whereas it has a decreasing effect at lower quantiles in Japan, at middle quantiles in France and Germany, and at higher quantiles in Italy; and (v) the QR results support the robustness of QQR findings. Thus, the empirical results highlight that G-7 countries should consider the asymmetric and quantile-based varying effects of the economic policy uncertainty, political stability, and economic growth to reach their carbon neutrality targets.

Keywords Economic policy uncertainty · Political stability · CO₂ · G-7 countries · QQR

JEL Classification C32 · F18 · N50 · O13 · Q56

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Introduction

Greenhouse gas (GHG) emissions have been highly important for societies, economies, and countries due to the negative effects, such as global temperature increase, harsh climatic conditions, and an increase in forest fires, on environmental quality (Volkova et al. 2021; Kılıç Depren et al. 2022). Such effects cause deterioration of environmental quality as well as economic and living conditions. Hence, a reduction in GHG emissions is a crucial thing in combating such adverse progress in air pollution and climate change. Therefore, a variety of studies have been focusing on this issue in recent times.

In the current literature, causes of GHG emissions have been frequently examined. In this context, energy consumption is a highly important factor (Ali et al. 2022; Kartal 2022a). The energy demand of countries increases as economies grow and the population increases (Shahbaz et al. 2018). While renewable energy has a mitigating effect

(Doğan et al. 2022), nonrenewable energy has an increasing effect on GHG emissions (Kartal 2022b). Moreover, economic growth has been used in the examination of GHG emissions (Nurgazina et al. 2022). Hence, energy consumption as well as economic growth have been important factors in terms of GHG emissions.

Apart from the abovementioned well-known factors, some other factors, such as economic policy uncertainty and political stability, can also be considered. These factors may affect GHG emissions by causing delays in long-term economic decisions and postponing environmentally friendly green technologies by making them more expensive (Romano and Fumagalli 2018). Although the current literature about economic policy uncertainty and political stability is limited, it has been growing. For instance, Anser et al. (2021), Syed and Bouri (2021), and Shabir et al. (2022) consider economic policy uncertainty for China, the top ten carbon-emitting countries, the USA, and selected 24 developed and developing countries, respectively. Also, Kartal et al. (2022a, 2022b) and Khan et al. (2022) include political stability for Finland, the UK, and Morocco.

According to data from World Bank (WB), the G-7 countries caused 8.1 billion tons of CO₂ emissions representing 23.6% of total CO₂ emissions based on 2019 year-end figures (WB 2022a). Also, based on British Petroleum (BP) data, G-7 countries emitted a total of 7.8 billion tons of CO₂ representing 22.8% of total CO₂ emissions from energy consumption in 2021 (BP 2022). The progress of G-7 countries' CO₂ emissions over time is presented in Fig. 1.

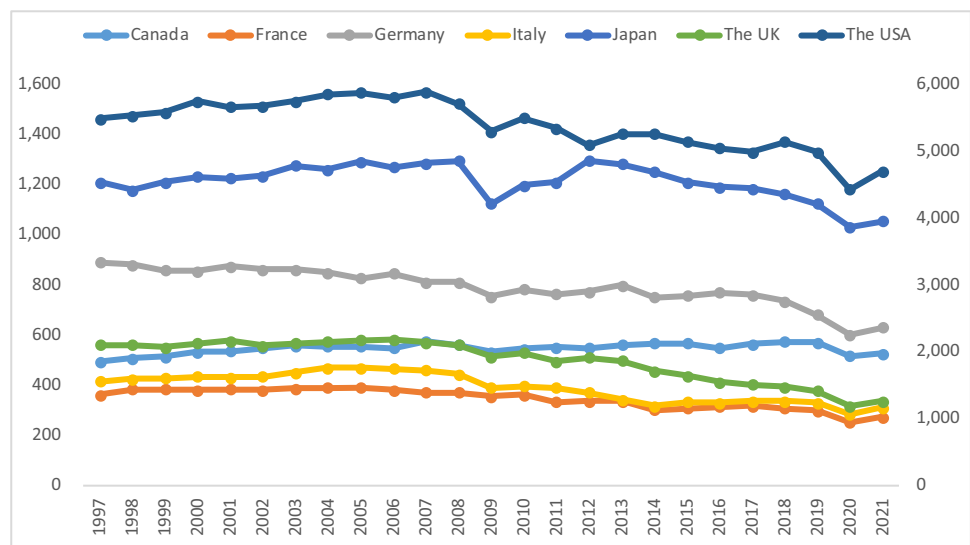
As Fig. 1 shows, the USA has had the highest CO₂ emissions among G-7 countries over time. The USA is followed by Japan, Germany, Canada, the UK, Italy, and France, respectively. Although some G-7 countries have achieved

a decrease in CO₂ emissions in recent years, as a whole, they have been causing an important amount of CO₂ emissions. Furthermore, G-7 countries represent 44.1% of the world economy producing 60.1 trillion United States Dollars (USD) in the gross domestic product (GDP) in 2021 (WB 2022b). Hence, by considering the high amount of CO₂ emissions, economic size, and sensitivity to environmental quality altogether, researching G-7 countries can be evaluated as highly significant in achieving global climate targets through declining CO₂ emissions. That is why such countries have a leading role among all countries.

The current literature includes studies that investigate the effect of different factors on GHG emissions. These studies focus frequently on a single study such as China (Abbasi and Adedoyin 2021), the USA (Syed and Bouri 2021), and Morocco (Khan et al. 2022), whereas some studies handle a group of countries such as top ten carbon-emitting countries (Anser et al. 2021); Brazil, Russia, India, China, and South Africa (BRICS) countries (Dong et al. 2021); Belt and Road Initiative (BRI) countries (Ashraf 2022); and selected developed and developing countries (Shabir et al. 2022). On the other hand, based on the best knowledge, the literature does not include a study that investigates G-7 countries using the most recent data, considering the asymmetric effects of the selected explanatory variables, considering relatively new factors, such as economic policy uncertainty and political stability, as well as using also energy consumption and economic growth on GHG emissions, making a country-based analysis, and applying a novel quantile-on-quantile regression (QQR) approach enabling to investigate the asymmetric effects.

Considering the literature gap and the importance of G-7 countries in terms of CO₂ emissions, energy consumption, and economic size, this study investigates the asymmetric

Fig. 1 Progress of CO₂ emissions in G-7 countries. The unit for CO₂ emissions is million tons



Note: The unit for CO₂ emissions is the million tons

effects of economic policy uncertainty, political stability, energy consumption, and economic growth on CO₂ emissions. In this context, this study focuses on G-7 countries, uses yearly data between 1997 and 2021, and applies a novel QQR as the main model while performing the quantile regression (QR) approach for robustness check. Thus, this study (i) uncovers the asymmetric effects of economic policy uncertainty and political stability on CO₂ emissions at the country level, considering recently growing literature about economic policy uncertainty and political stability. Also, this study does not ignore consumption and economic growth as explanatory variables, (ii) examines the changing effects according to the countries and quantiles, (iii) performs an econometric analysis through a novel QQR approach considering changes in both dependent and independent variables over time, and (iv) validates the robustness of the QQR approach using the QR approach. The empirical results reveal that the effects of economic policy uncertainty, political stability, energy consumption, and economic growth on CO₂ emissions are mainly asymmetric and vary according to countries and quantiles.

This study has some contributions to the literature. Firstly, the study focuses on investigating the asymmetric effect of economic policy uncertainty and political stability on CO₂ emissions in G-7 countries at the country level while not neglecting the effect of energy consumption and economic growth. Secondly, the study applies a novel QQR approach, which is a recently popular approach, to investigate the asymmetric effects of the explanatory variables CO₂ emissions at the country level and various quantiles. It is seen that there are some studies regarding G-7 countries (e.g., Jiang et al. 2022; Peng et al. 2022); however, G-7 countries have not been examined in such a comprehensive approach in a single study by applying a novel QQR approach based on the best knowledge. Third, this study includes the most recent data between 1997 and 2021 that differs this study from the present studies because many present studies have used generally legacy data. Moreover, this study uses the QR approach as a robustness check method for the QQR results. Hence, the consistency of the results is also investigated.

In this approach, part II presents a review of the current literature. Part III introduces data and methodology. Part IV presents empirical results, discussion, and policy implications. Part V concludes.

Literature review

Following the leading studies of Kraft and Kraft (1978) and Grossman and Krueger (1991), many studies have empirically uncovered the effects of energy consumption and economy, which is proxied by various indicators, on

environmental quality. Also, many other hypotheses, such as energy growth, growth, conservation, and renewable energy-led economic growth, are developed based on these pioneering approaches (Apergis and Tang 2013; Kartal et al. 2023).

In later times, the literature has extended so much and a variety of different indicators have been considered by researchers in examining environmental quality. In this context, Gani (2012) is the pioneering study that introduces the political stability effect on environmental quality. Following up this study, many others have included political stability in researching the progress of environmental quality. Moreover, following up on the leading study of Baker et al. (2016) about the economic policy uncertainty index, studies have begun to include this indicator in researching environmental quality development. Based on the developing literature, studies handling environmental quality have been growing because environmental degradation has been negatively affecting societies. Hence, the literature includes various research studies about environmental quality.

The current literature includes various studies about the effect of economic policy uncertainty on CO₂ emissions, such as Adams et al. (2020), Adedoyin and Zakari (2020), Wang et al. (2020), Adedoyin et al. (2021), Amin and Doğan (2021), Anser et al. (2021), and Yu et al. (2021). Adams et al. (2020) focus on resource-rich countries using panel pooled mean group-autoregressive distributed lag (PMG-ARDL) model; Adedoyin and Zakari (2020) investigate the UK, applying the ARDL model; Wang et al. (2020) study the USA, applying the ARDL model; Adedoyin et al. (2021) examine 32 Sub-Saharan African countries using generalized method of moment approach; Amin and Doğan (2021) uncover China through dynamic ARDL simulation model; Anser et al. (2021) examine top ten carbon emitter countries via the PMG-ARDL approach; Atsu and Adams (2021) uncovered BRICS countries through cross-sectionally augmented ARDL (CS-ARDL) and fully modified ordinary least squares; Yu et al. (2021) investigate China, performing fixed effect ordinary least squares (FE-OLS) approach. Such studies conclude that an increase in economic policy uncertainty causes an increasing effect on CO₂ emissions, and there is a causality nexus between economic policy uncertainty and CO₂ emissions. In line with these studies, this study includes economic policy uncertainty as an indicator.

Also, the current literature regarding the effect of political stability on CO₂ emissions has been developing. Although the effect of political stability has not been intensively considered in previous literature, interest in this point has been increasing. Vu and Huang (2020), Zhang and Chiu (2020), Dong et al. (2021), Adebayo et al. (2022), Ashraf (2022), Benlemlih et al. (2022), Hassan et al. (2022), Jiang et al. (2022), Khan et al. (2022), Kartal et al. (2022a, 2022b), Pata et al. (2022), Peng et al. (2022), and Sohail et al. (2022) are some of the examples that consider the political stability as

an indicator in examining CO₂ emissions for Vietnam, 111 countries, 66 countries, BRICS, 75 BRI countries, selected 145 countries, Regional Comprehensive Economic Cooperation economies, G-7, Morocco, Finland, the UK, 4 South Asian countries, G-7, and Pakistan, respectively. Such studies mainly determine that an increase in political stability (i.e., an increase in political risk index) provides a decrease in CO₂ emissions, whereas a few of them, such as Dong et al. (2021), state adverse results. Accordingly, this study includes also political stability as an indicator.

In addition to economic policy uncertainty and political stability, other well-known classical factors should be considered in the examination of CO₂ emissions. In this context, this study includes energy consumption. Unanimously, most of the studies have concluded that energy consumption generally (Abbasi and Adedoyin 2021; Kartal 2022a) and fossil fuel energy consumption specifically (Kartal 2022b) have an increasing effect on CO₂ emissions, whereas renewable energy consumption (Pata 2018; Sharif et al. 2020; Ehigiamusoe and Doğan 2022; Tzeremes et al. 2023) mitigates CO₂ emissions. By considering such studies, this study includes total energy consumption as an indicator.

As the last factor, economic growth is included in this study. Pata (2018), Abbasi et al. (2021), Adedoyin et al. (2021), Kartal et al. (2022a, 2022b), Nurgazina et al. (2022), Pata and Kartal (2022), and Pata et al. (2023) investigate Turkey, the UK, 32 Sub-Saharan African countries, the USA, the UK, China, South Korea, and the USA, respectively. These studies define that economic growth has a generally increasing effect on CO₂ emissions and a decreasing effect on environmental quality. In line with these studies, this study includes also economic growth (proxied by GDP) as an indicator.

Moreover, from the empirical perspective, it can be seen that various econometric techniques, such as ARDL, CS-ARDL, FE-OLS, Granger causality, and PMG-ARDL, are used in the current literature. Some of these econometric approaches (i.e., ARDL) are used more frequently, whereas others are used occasionally.

Overall, there are some studies for G-7 countries, such as Jiang et al. (2022) and Peng et al. (2022). However, any study comprehensively examines G-7 countries by including the most recent available data, considering economic policy uncertainty, political stability, energy consumption, and economic growth in a single study, making a country-based level analysis, focusing on economic policy uncertainty and political stability, and applying a novel QQR approach enabling to examine asymmetric effects of the included variables on CO₂ emissions. This condition presents a gap in the current literature, and the study aims at filling this gap.

Data and methodology

Data

In line with the current literature, the study considers CO₂ emissions as the dependent variable. Besides, economic policy uncertainty, political stability, energy consumption, and economic growth are considered explanatory variables. Moreover, G-7 countries, which consist of Canada (CAN), France (FRA), Germany (DEU), Italy (ITA), Japan (JPN), the UK, and the USA, are included in the scope of the study.

Data for these variables are obtained from four different sources. Data for energy consumption and CO₂ emissions are obtained from BP (2022). Also, data for GDP (proxy of economic growth) is obtained from WB (2022a), while data for policy uncertainty and political stability are obtained from <https://www.policyuncertainty.com> (2022) and Political Risk Services (PRS) Group (2022), respectively. Table 1 presents a summary.

The data used in the study is composed of yearly data between 1997 and 2021 that is an intersection set for all countries so that the same period for all countries can be examined. Hence, the dataset includes 25 observations for each country.

Table 1 A summary of the variables

Variable	Explanation	Unit	Expected effect	Source
CO ₂	Total CO ₂ emissions from energy consumption	Million tons	N/A	BP (2022)
EPU	Economic policy uncertainty index	Bps	–	www.policyuncertainty.com
PS	Political risk index (0 shows a high risk, 100 denotes low risk)	Bps	–	PRS Group (2022)
EC	Total energy consumption	Exajoules	+	BP (2022)
GDP	GDP constant (USD)	Billion USD	+	WB (2022a)

N/A denotes the dependent variable. Bps denotes the basis points

In line with the studies of Sharif et al. (2021), Kartal et al. (2022c, 2022d), and Depren et al. (2023), logarithmic difference series are obtained to study with return series for obtaining comparable empirical findings.

Methodology

Figure 2 shows an eight-step methodology that is applied. Thus, it is aimed to examine the asymmetric effect of economic policy uncertainty, political stability, energy consumption, and economic growth on CO₂ emissions in G-7 countries.

The eight-step methodology starts with data collection from different sources and aggregation of these datasets. After the data aggregation process, descriptive statistics are calculated and preliminary analysis is performed to understand the basic characteristics of the data. This step shows the measure of centrality, variation statistics, and the normality test. In the third step, the stationary analysis, which is crucial to employ the suitable model, is performed. Thus, augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) tests, which are robust and most widely used tests, are performed to determine the stationary level of variables used in the study (Dickey and Fuller 1979; Phillips and Perron 1988). In the fourth phase, the Brock, Dechert, and Scheinkman (BDS) test is run to determine if performing a linear or nonlinear model will allow for the most accurate estimation of this data (Broock et al. 1996). Since the BDS test reveals that variables are nonlinearly distributed, the QQR approach is performed to present the effects of the variables included on CO₂ emissions at different quantiles in the fifth step (Sim and Zhou 2015).

The QQR estimation model is given in Eq. 1.

$$Y_t = Y^\sigma(X_t) + \mu_t^\sigma \tag{1}$$

where Y_t and X_t represent the dependent and independent variables in period t , respectively; σ is the σ th quantile on the distribution of X ; and μ_t^σ represents the quantile error term. Based on the literature, economic policy uncertainty (EPU) and political stability (PS) are anticipated to decrease CO₂ emissions, whereas energy consumption (EC) and GDP are expected to increase CO₂ emissions.

After conducting the QQR approach, in the sixth step, the QR approach is used for the robustness check (Koenker 2005). In the last two steps, discussion, implications, limitations, and future directions are discussed.

More information regarding the methods applied can be collected from the studies of Dickey and Fuller (1979), Phillips and Perron (1988), Broock et al. (1996), Sim and Zhou (2015), and Koenker (2005) for the ADF unit root test, PP unit root test, BDS test, QQR approach, and QR approach, respectively.

Empirical analysis

Descriptive statistics

Table 2 presents the descriptive statistics that are calculated to understand the distribution (i.e., characteristics) of the variables.

According to the coefficient of variation (CV) statistics, which shows the extent of variability concerning the mean of the population, it can be said that the variation of EPU is significantly higher than that of other variables for each country. Once skewness and kurtosis statistics are examined,

Fig. 2 The followed methodology

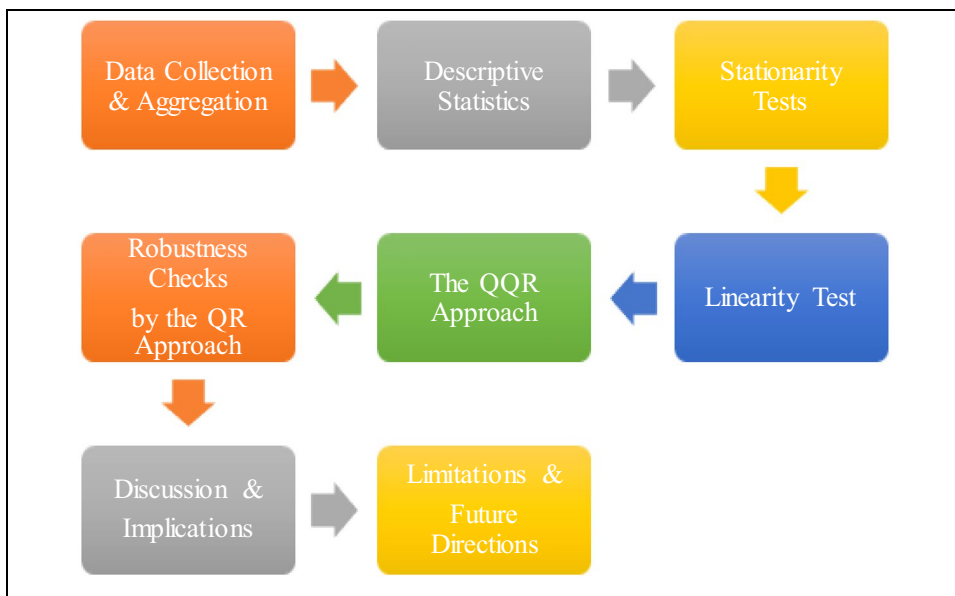


Table 2 Descriptive statistics

Country	Variable	Mean	Minimum	Maximum	SD	CV	Skewness	Kurtosis	SW	SW Prob
CAN	EPU	168.50	53.37	464.24	104.11	61.79	1.07	3.76	0.90	0.02
	PS	86.44	84.63	89.88	1.18	1.37	0.90	4.05	0.94	0.15
	EC	13.75	12.39	14.70	0.67	4.87	-0.36	2.20	0.96	0.35
	GDP	1350.06	634.00	1990.76	449.09	33.26	-0.43	1.69	0.89	0.01
	CO ₂	546.10	493.98	574.99	21.37	3.91	-0.77	2.85	0.94	0.12
FRA	EPU	172.91	37.60	317.12	91.75	53.06	0.07	1.63	0.93	0.07
	PS	76.23	68.29	81.71	3.75	4.92	-0.49	2.20	0.95	0.21
	EC	10.57	8.86	11.42	0.68	6.43	-0.67	2.74	0.93	0.07
	GDP	2316.96	1365.64	2937.47	560.16	24.18	-0.67	1.87	0.84	0.00
	CO ₂	346.10	251.55	389.77	40.17	11.61	-0.69	2.40	0.89	0.01
DEU	EPU	145.81	79.23	322.36	66.40	45.54	1.26	4.03	0.86	0.00
	PS	84.40	81.42	88.08	1.90	2.25	0.29	2.05	0.96	0.43
	EC	13.90	12.36	14.63	0.61	4.39	-0.84	3.12	0.92	0.04
	GDP	3164.41	1945.79	4223.12	723.48	22.86	-0.47	1.80	0.90	0.02
	CO ₂	790.41	600.79	887.99	74.83	9.47	-0.91	3.38	0.91	0.04
ITA	EPU	112.04	60.14	173.08	27.34	24.40	0.21	2.84	0.98	0.85
	PS	77.49	71.29	84.63	3.27	4.22	0.27	2.88	0.97	0.72
	EC	7.12	5.92	7.92	0.57	8.01	-0.28	1.97	0.95	0.19
	GDP	1838.51	1146.68	2408.66	391.66	21.30	-0.64	2.05	0.88	0.01
	CO ₂	391.64	283.80	470.20	57.64	14.72	-0.22	1.68	0.92	0.05
JPN	EPU	110.26	64.86	183.74	27.54	24.98	0.49	3.29	0.95	0.25
	PS	81.89	78.25	87.04	2.57	3.14	0.34	2.06	0.95	0.23
	EC	20.68	17.13	22.55	1.74	8.41	-0.43	1.79	0.87	0.00
	GDP	4938.66	4098.36	6272.36	539.15	10.92	0.97	3.87	0.91	0.03
	CO ₂	1209.92	1029.52	1293.79	70.94	5.86	-0.96	3.45	0.91	0.03
UK	EPU	194.06	47.84	542.77	140.04	72.16	1.05	3.13	0.87	0.00
	PS	83.16	76.42	90.29	4.00	4.81	0.19	2.06	0.95	0.32
	EC	8.83	7.06	9.79	0.82	9.29	-0.58	2.22	0.89	0.01
	GDP	2483.11	1559.57	3186.86	527.43	21.24	-0.63	1.98	0.87	0.00
	CO ₂	499.19	316.91	581.69	82.90	16.61	-0.84	2.36	0.85	0.00
USA	EPU	131.30	67.14	326.32	53.00	40.37	1.90	8.37	0.82	0.00
	PS	82.81	77.42	89.42	2.77	3.35	0.50	3.04	0.96	0.52
	EC	93.68	88.54	97.43	2.27	2.42	-0.25	2.51	0.97	0.63
	GDP	15,070.04	8577.55	22,996.10	4161.66	27.62	0.17	1.98	0.97	0.55
	CO ₂	5382.53	4420.61	5884.22	384.48	7.14	-0.64	2.79	0.94	0.16

The unit for the EPU and PS is basis points (Bps), the unit for the EC is exajoules, the unit for the GDP is billion USD, and the unit for the CO₂ is million tons

SW Shapiro–Wilk, SD standard deviation, CV coefficient of variation

EPU has a right-skewed distribution in all countries, except for FRA. Besides, EPU has a platykurtic distribution in FRA, while in CAN, DEU, and the USA, it has a leptokurtic distribution.

Based on the Shapiro–Wilk (SW) test (Shapiro and Wilk 1965), for EPU, it is revealed that data is not normally distributed in all countries except ITA and JPN. Once the political stability is examined, the range and variation of PS are relatively low in all countries. Also, based on the SW test, for PS in all countries, data is not normally distributed. Also,

skewness and kurtosis statistics support this finding. Similar to PS, the variation of EC is relatively low in all countries, as well. Also, the SW test results show that there is no statistically significant evidence to reject the null hypothesis that assumes EC is normally distributed in CAN, FRA, ITA, and the USA.

The coefficient of variation statistics of GDP in all countries is higher than 20, except for JPN. Besides, in all countries except the USA, the SW test results revealed that GDP is not normally distributed. Once the distribution of CO₂ is examined, it can be

said that the variation of CO₂ is relatively small in all countries. On the other hand, based on the SW test results, there is no significant evidence to reject the null hypothesis that assumes CO₂ is normally distributed in CAN, ITA, and the USA.

Furthermore, Table 3 presents the Pearson correlation coefficients of the variables.

Once the Pearson correlation coefficients are examined, it is seen that there is a negative correlation between EPU and PS in all countries. However, the magnitude of the correlation is relatively higher in FRA, the UK, and CAN. Also, the correlation coefficient between EPU and EC generally has a negative structure in all countries, except CAN. Contrary to the correlation between EPU and PS, there is a positive correlation between EPU and GDP in all

countries. Moreover, the correlation coefficients in CAN, FRA, DEU, and the USA are relatively higher than those in ITA and JPN.

Similar to the results obtained from the relationship between EPU and PS, there is a strong negative correlation between EPU and CO₂ in all countries, except CAN. When the correlation between PS and other factors is examined, it is revealed that the correlation coefficients between EC, GDP, and CO₂ and PS are negative in CAN and the USA while the correlation coefficients between PS and EC and between PS and CO₂ are positive, and the correlation between PS and GDP is negative in the rest of countries.

The correlation between EC and CO₂ is positive, and the correlation between EC and GDP is negative in all

Table 3 Correlation matrix

Country	Variable	EPU	PS	EC	GDP	CO ₂
CAN	EPU	1.00				
	PS	-0.41	1.00			
	EC	0.57	-0.41	1.00		
	GDP	0.66	-0.47	0.86	1.00	
	CO ₂	0.12	-0.08	0.79	0.53	1.00
FRA	EPU	1.00				
	PS	-0.73	1.00			
	EC	-0.81	0.55	1.00		
	GDP	0.76	-0.66	-0.57	1.00	
	CO ₂	-0.83	0.65	0.98	-0.64	1.00
DEU	EPU	1.00				
	PS	-0.37	1.00			
	EC	-0.83	0.35	1.00		
	GDP	0.65	-0.47	-0.78	1.00	
	CO ₂	-0.88	0.40	0.96	-0.83	1.00
ITA	EPU	1.00				
	PS	-0.16	1.00			
	EC	-0.57	0.34	1.00		
	GDP	0.06	-0.48	-0.28	1.00	
	CO ₂	-0.57	0.42	0.99	-0.35	1.00
JPN	EPU	1.00				
	PS	-0.33	1.00			
	EC	-0.26	0.25	1.00		
	GDP	0.17	-0.51	-0.35	1.00	
	CO ₂	-0.39	0.23	0.69	-0.02	1.00
UK	EPU	1.00				
	PS	-0.43	1.00			
	EC	-0.72	0.50	1.00		
	GDP	0.49	-0.74	-0.65	1.00	
	CO ₂	-0.76	0.36	0.97	-0.57	1.00
USA	EPU	1.00				
	PS	-0.10	1.00			
	EC	-0.53	-0.18	1.00		
	GDP	0.60	-0.28	-0.15	1.00	
	CO ₂	-0.77	-0.03	0.64	-0.80	1.00

countries except for CAN. Finally, the correlation between GDP and CO₂ is negative in all countries except for CAN.

Stationarity test

For time series analysis, the existence of unit roots can lead to problems, such as false regressions, which can provide high R-squared values even though the data are uncorrelated. Therefore, it is crucial to check the stationarity for time series before making any estimations to employ the proper detrending techniques. The primary way, in which

the PP unit root and the ADF tests differ from one another, is in how they handle serial correlation and heteroskedasticity in the errors. The PP test specifically disregards any serial correlation in the regression, whereas the ADF test uses a parametric autoregression to simulate the ARMA structure of the errors in the regression. However, both tests generally produce similar results to each other. Table 4 presents the results of the ADF and PP tests that are conducted to check the stationary (or unit root) properties of variables.

Based on Table 4, it is determined that all variables are stationary at the I(1) level in CAN, FRA, DEU, ITA, and the

Table 4 Stationarity test results

Country	Variable	ADF test		PP test		Decision
		I(0)	I(1)	I(0)	I(1)	
CAN	EPU	0.5458	0.0001	0.5458	0.0001	I(1)
	PS	0.2927	0.0022	0.2304	0.0007	I(1)
	EC	0.3257	0.0004	0.3209	0.0003	I(1)
	GDP	0.7902	0.0091	0.7955	0.0107	I(1)
	CO ₂	0.0584	0.0053	0.0367	0.0003	I(1)
FRA	EPU	0.6643	0.0002	0.7311	0.0003	I(1)
	PS	0.4615	0.0067	0.4082	0.0058	I(1)
	EC	0.9909	0.0000	0.9382	0.0000	I(1)
	GDP	0.6559	0.0054	0.6615	0.0060	I(1)
	CO ₂	0.9918	0.0000	0.9737	0.0000	I(1)
DEU	EPU	0.8473	0.0026	0.9425	0.0001	I(1)
	PS	0.0075		0.1293	0.0191	I(1)
	EC	0.6488	0.0000	0.7228	0.0000	I(1)
	GDP	0.8267	0.0020	0.8958	0.0008	I(1)
	CO ₂	0.9425	0.0002	0.9616	0.0002	I(1)
ITA	EPU	0.0645	0.0002	0.0615	0.0002	I(1)
	PS	0.0179		0.0578	0.0012	I(1)
	EC	0.8551	0.0015	0.8551	0.0015	I(1)
	GDP	0.5204	0.0059	0.5187	0.0062	I(1)
	CO ₂	0.9270	0.0043	0.9206	0.0043	I(1)
JPN	EPU	0.0231		0.0265		I(0)
	PS	0.0364		0.0230		I(0)
	EC	0.9920	0.0000	0.9614	0.0000	I(1)
	GDP	0.0779	0.0043	0.2940	0.0043	I(1)
	CO ₂	0.6872	0.0002	0.7036	0.0002	I(1)
UK	EPU	0.3780	0.0008	0.3979	0.0007	I(1)
	PS	0.5069	0.0037	0.5161	0.0040	I(1)
	EC	0.9976	0.0001	0.9952	0.0001	I(1)
	GDP	0.5804	0.1094	0.6018	0.0316	I(1)
	CO ₂	0.9995	0.0002	0.9975	0.0002	I(1)
USA	EPU	0.1131	0.0001	0.1131	0.0001	I(1)
	PS	0.1453	0.0001	0.2078	0.0000	I(1)
	EC	0.0247		0.0255		I(0)
	GDP	0.9955	0.0003	0.9998	0.0003	I(1)
	CO ₂	0.9908	0.0006	0.8970	0.0001	I(1)

The values show *p* values. The maximum length is automatically selected based on SIC criteria in the ADF test and based on Bartlett kernel in the PP test

UK. On the other hand, EPU and PS in JPN and EC in the USA are stationary at the I(0) level, whereas other variables in these countries are stationary at the I(1) level.

Linearity test

Table 5 presents the BDS test results that are applied to check the linearity of variables.

According to Table 5, there is no statistically significant evidence to accept the null hypothesis, which assumes the variable is linearly distributed, in FRA and UK for all variables. On the other hand, in ITA and JPN, it is found that only

EPU is linearly distributed based on the BDS test results. In addition, PS in CAN and EPU and EC in DEU and the USA are linearly distributed.

Evaluation of preliminary test

Through considering the results of the stationarity and linearity test, it is decided to conduct a nonlinear statistical model as the QQR approach because this approach considers linearity characteristics of the variables, whereas it does not have a stationarity pre-requirement. Also, logarithmic difference series are used to study stationarity

Table 5 Linearity test results

Country	Variables	Dimensions				Decision
		2	3	4	5	
CAN	EPU	0.0000	0.0000	0.0223	0.4019	Nonlinear
	PS	0.0103	0.1746	0.6639	0.5744	Linear
	EC	0.0000	0.0000	0.0000	0.0000	Nonlinear
	GDP	0.0000	0.0000	0.0000	0.0000	Nonlinear
	CO ₂	0.0000	0.0000	0.0000	0.0000	Nonlinear
FRA	EPU	0.0000	0.0000	0.0000	0.0000	Nonlinear
	PS	0.0000	0.0000	0.0000	0.0000	Nonlinear
	EC	0.0000	0.0000	0.0000	0.0000	Nonlinear
	GDP	0.0000	0.0000	0.0000	0.0000	Nonlinear
	CO ₂	0.0000	0.0000	0.0000	0.0000	Nonlinear
DEU	EPU	0.0332	0.3598	0.0555	0.5894	Linear
	PS	0.0000	0.0000	0.0001	0.0000	Nonlinear
	EC	0.1957	0.1133	0.0390	0.2574	Linear
	GDP	0.0000	0.0000	0.0000	0.0000	Nonlinear
	CO ₂	0.0000	0.0086	0.0682	0.3223	Nonlinear
ITA	EPU	0.3529	0.0092	0.1686	0.5558	Linear
	PS	0.0000	0.0000	0.0000	0.0000	Nonlinear
	EC	0.0000	0.0000	0.0000	0.0000	Nonlinear
	GDP	0.0000	0.0000	0.0000	0.0000	Nonlinear
	CO ₂	0.0000	0.0000	0.0000	0.0000	Nonlinear
JPN	EPU	0.6655	0.7105	0.3074	0.2068	Linear
	PS	0.0000	0.0000	0.0000	0.0000	Nonlinear
	EC	0.0000	0.0000	0.0000	0.0000	Nonlinear
	GDP	0.0003	0.0000	0.0001	0.0001	Nonlinear
	CO ₂	0.2396	0.1551	0.0042	0.0001	Nonlinear
UK	EPU	0.0000	0.0000	0.0045	0.0316	Nonlinear
	PS	0.0000	0.0000	0.0000	0.0000	Nonlinear
	EC	0.0000	0.0000	0.0000	0.0000	Nonlinear
	GDP	0.0000	0.0000	0.0000	0.0000	Nonlinear
	CO ₂	0.0000	0.0000	0.0000	0.0000	Nonlinear
USA	EPU	0.0012	0.7978	0.1589	0.1124	Linear
	PS	0.0000	0.0000	0.0000	0.0000	Nonlinear
	EC	0.0037	0.5310	0.1046	0.4026	Linear
	GDP	0.0000	0.0000	0.0000	0.0000	Nonlinear
	CO ₂	0.0000	0.0021	0.0053	0.0004	Nonlinear

Values indicate probability values

series, although this is not a pre-requirement for the QQR approach. Moreover, the QR approach is conducted for robustness checks.

QQR results

Figures 3, 4, 5, and 6 present the QQR results to determine the asymmetric effect of EPU, PS, EC, and GDP variables on CO₂ emissions at different quantiles for each G-7 country, respectively. In all QQR figures, the *x*-axis and *y*-axis show the *t*th quantile coefficient of the relevant explanatory variables and the *q*th quantile coefficient of CO₂ emissions.

When the relationship between EPU and CO₂ is examined, it can be said that there is a complex relationship between them. The interaction effects of quantiles for EPU and CO₂ cause this complex relationship. Thus, each quantile of EPU has a different effect on the CO₂ at different quantiles. This is the main cause of many peak and trough values in the 3-dimensional figures. In CAN and FRA, the effect of EPU on CO₂ is relatively higher and positive in the area where the quantiles of EPU are higher than 0.80 and the quantiles of CO₂ are lower than 0.20. Also, in the area where the quantiles of EPU are lower than 0.20 and the quantiles of CO₂ are higher than 0.80, the effect of EPU on CO₂ is relatively at a higher level and positive as well. However, the effect of EPU on CO₂ in the area which is

the outside of the mentioned area above differs by ±0.5 in CAN and FRA.

Contrary to CAN, the effect of EPU on CO₂ is relatively higher and positive in the area where the quantiles of EPU are higher than 0.70 and the quantiles of CO₂ are lower than 0.25 while the effect is relatively higher but negative in the area where the quantiles of EPU are lower than 0.20 and the quantiles of CO₂ are higher than 0.75 in DEU.

In ITA, the coefficients of the effect of EPU on CO₂ are negative in all quantiles. However, once the magnitude of the effect is analyzed, it is seen that the effect of EPU is relatively high in the area at the lower and higher quantiles of EPU.

In JPN, the effect of EPU on CO₂ is significantly strongly negative in the area where the quantiles of CO₂ are between 0.45 and 0.55. In other areas, the effect is strongly positive. The relationship between EPU and CO₂ almost has a similar characteristic, which is the “n-shape” in the UK and the USA. The effect is strongly negative in the area at the lower and the higher quantiles of CO₂. However, in the UK and the USA, this effect is between 0.05 and –0.05 in the area at the middle quantiles of CO₂ and EPU, respectively.

The magnitude of the effect of PS on CO₂ differs from country to country. In CAN, ITA, and JPN, the effect has a similar characteristic. In these countries, the effects of PS on CO₂ in the lowest and highest quantiles of PS are relatively

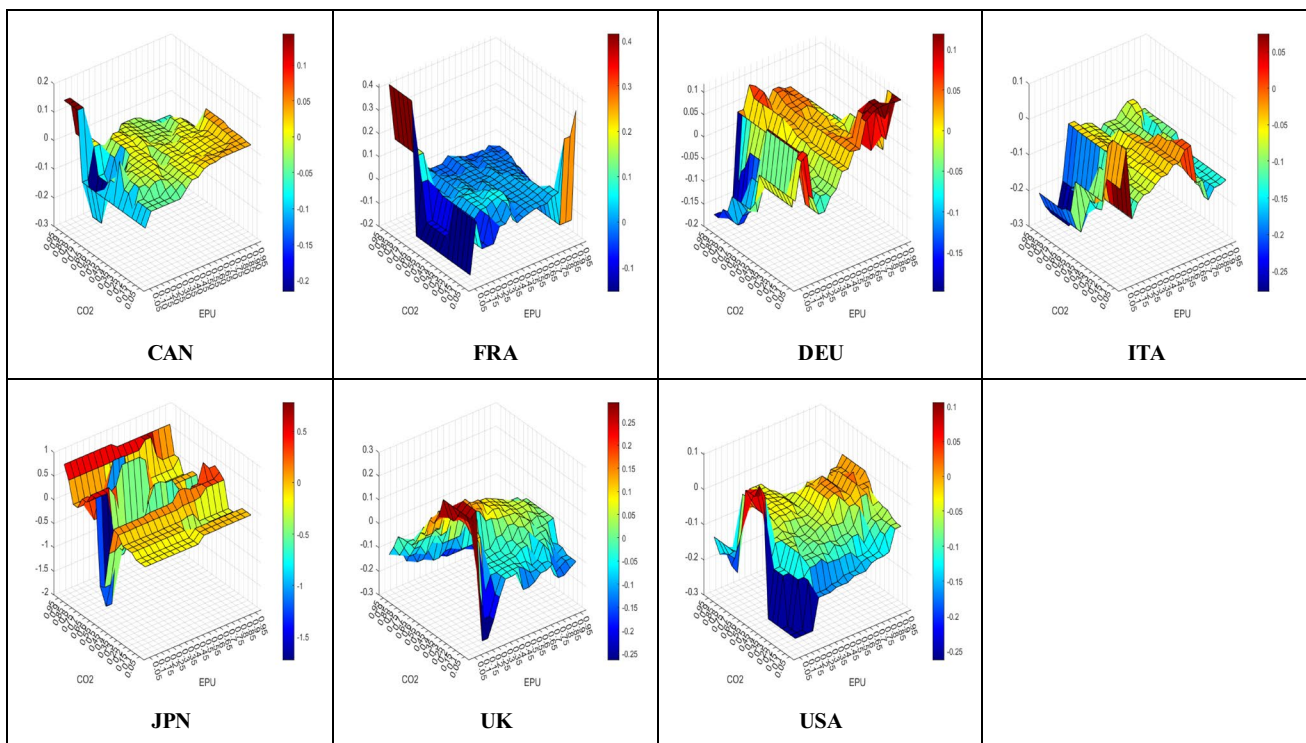


Fig. 3 The QQR results of EPU effect on CO₂ emissions

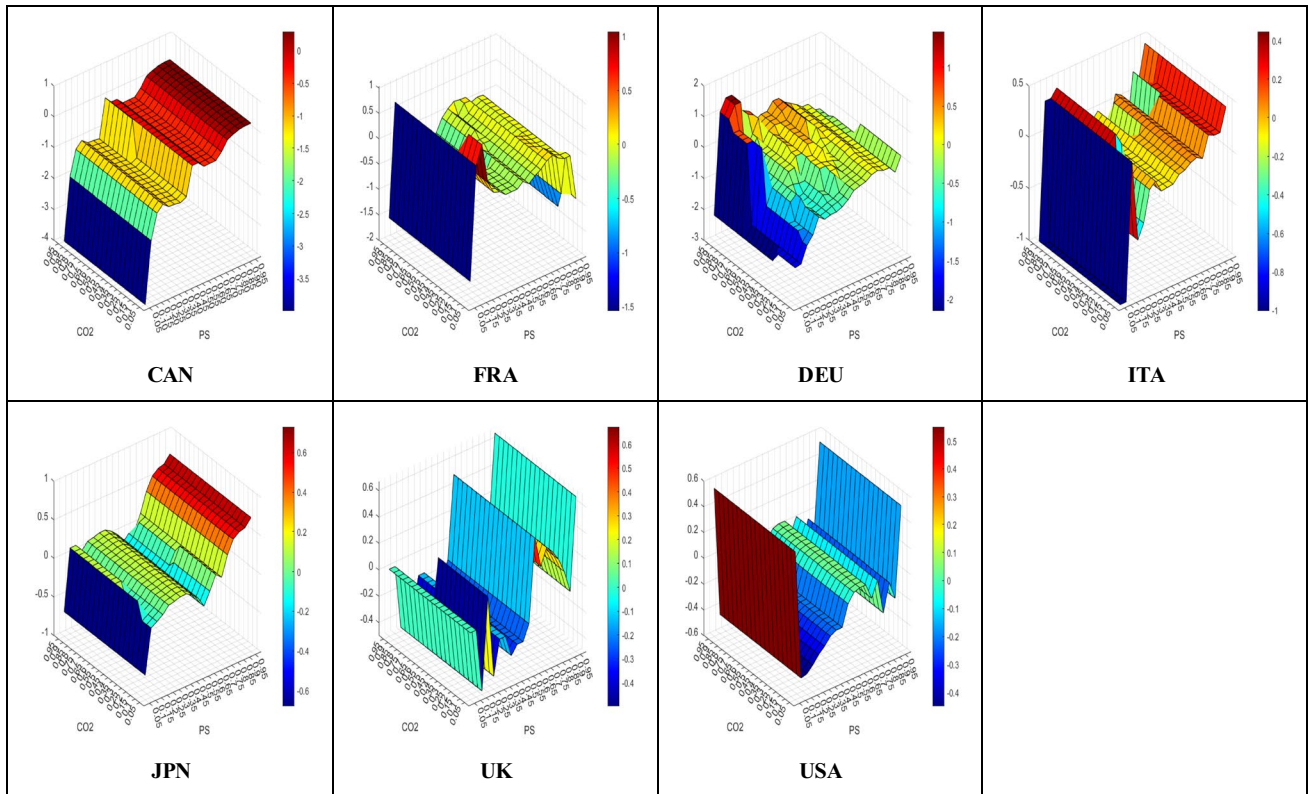


Fig. 4 The QQR results of PS effect on CO₂ emissions

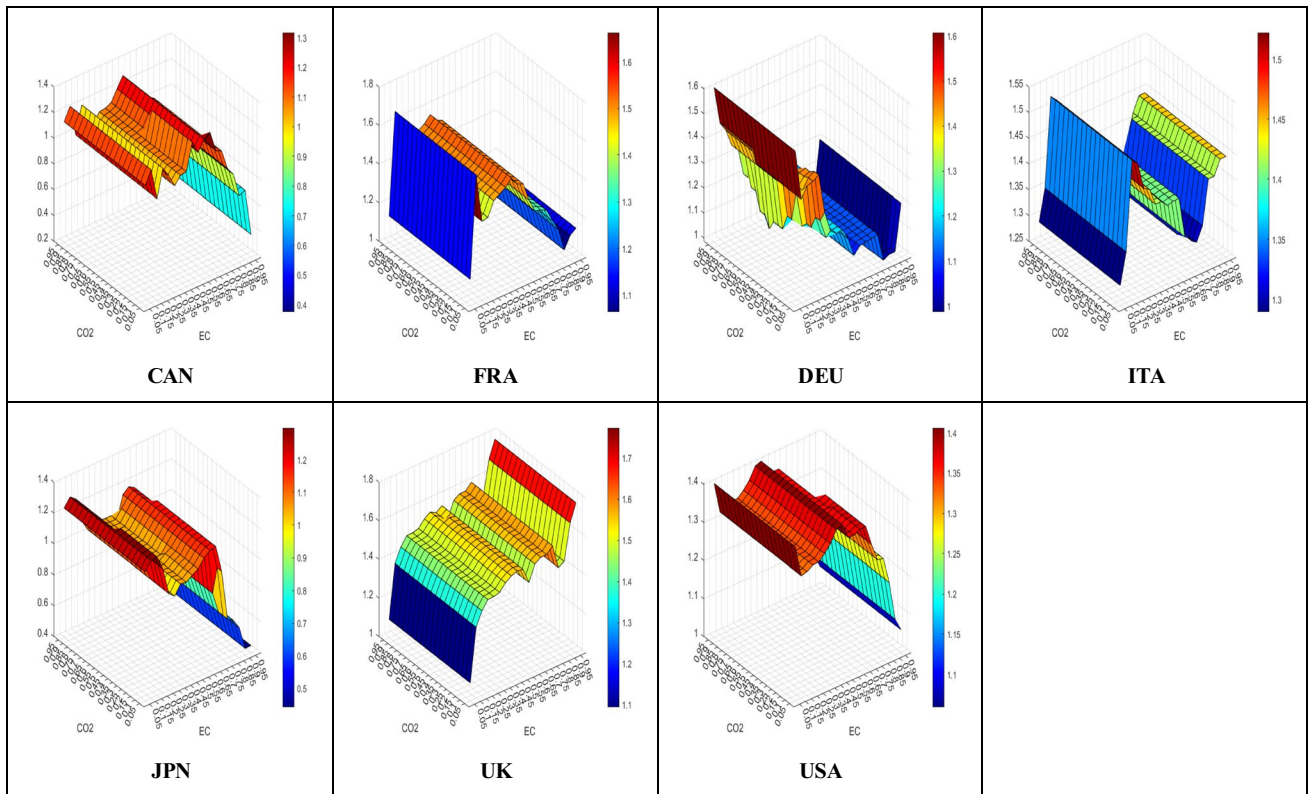


Fig. 5 The QQR results of EC effect on CO₂ emissions

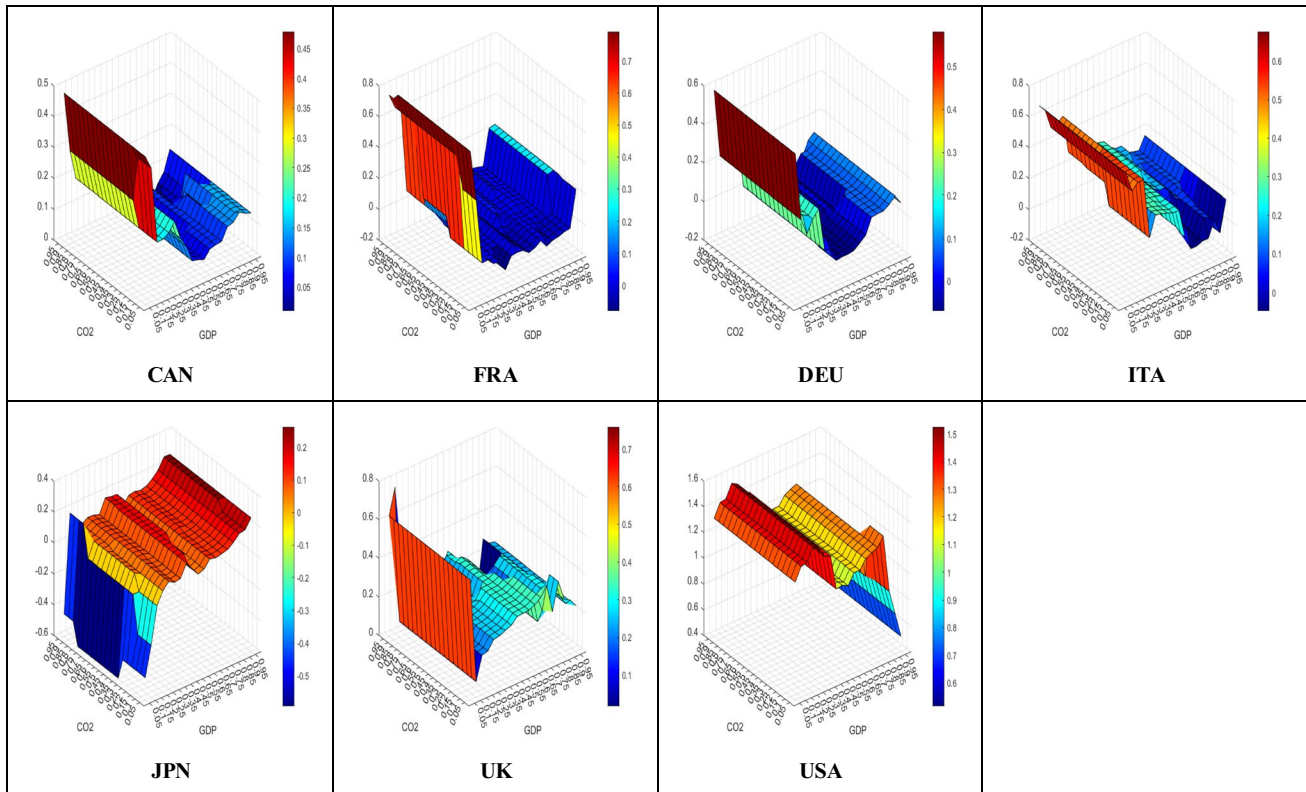


Fig. 6 The QQR results of GDP effect on CO₂ emissions

high. Also, in CAN, PS has a negative effect on CO₂ where the quantiles of PS are lower than 0.75 while PS has a positive effect on CO₂ where the quantiles of PS are higher than 0.75 in JPN. The effect of PS on CO₂ mostly depends on the quantiles of PS. For this reason, the magnitude of the effect corresponding to each quantile of PS does not change concerning the quantiles of CO₂. In FRA, the effect of PS on CO₂ is around ± 0.5 in the area where the quantiles of PS are between 0.25 and 0.90 while it is strong and negative in the area at the lowest and highest quantiles of PS. In the UK, as the quantiles of PS increase, the effect of PS on CO₂ turns from negative to positive, and the magnitude of the effect increases. Similar to FRA, in DEU, the effect of PS on CO₂ is around ± 0.5 in the area where the quantiles of PS are between 0.20 and 0.95. Also, the effect of PS on CO₂ in the area where the quantiles of PS are lower than 0.20 is strongly negative. Unlike the nexus between PS and CO₂ in other countries, the nexus between PS and CO₂ has a “U-shape” characteristic, which means that the effect of PS on CO₂ is strong and positive in the area at the lowest and highest quantiles of PS.

It is ascertained that the effect of EC on CO₂ is strongly positive in all countries, but the magnitude and characteristics of the effect are differentiated by country. In addition, the effect of EC on CO₂ is relatively at a high level with the

lower quantiles of EC while this effect is decreasing from the lower to higher quantiles of EC in CAN, FRA, DEU, JPN, and the USA. The critical thresholds where the effect starts to decrease are 0.6, 0.5, 0.25, 0.65, and 0.8 in CAN, FRA, DEU, JPN, and the USA, respectively. On the other hand, the characteristic of the effect of EC on CO₂ in the UK is different from that in the countries mentioned above. The effect of EC on CO₂ is increasing from the lower to the higher quantiles of EC. In ITA, this effect is relatively at a low level where the quantiles of EC are between 0.55 and 0.75 and lower than 0.20. In other areas, the effect is strong and relatively higher.

Once the nexus between GDP and CO₂ is examined, it is revealed that the coefficients of GDP effect on CO₂ are generally positive in all countries but the magnitude of the effect is differentiated. Besides, the way of effect is determined when the effect of GDP on CO₂ is decreasing from the lower quantiles to the higher quantiles of GDP in CAN, FRA, DEU, ITA, and the USA. But, the trend of decrease differs from country to country. In CAN, FRA, and DEU, there is a sharp decrease at the 0.20 quantile while there is a smooth decrease in ITA and the USA. In FRA and DEU, unlike the other countries, the coefficients of the effect of GDP on CO₂ are around ± 0.1 in the area where the quantiles of GDP are between 0.20 and 0.80.

On the other hand, the effect of GDP on CO₂ is increasing from the lower quantiles to the higher quantiles of GDP in JPN. Similar to JPN, the effect of GDP on CO₂ is increasing if the quantiles of GDP are higher than 0.15 in the UK.

Robustness checks by QR

The coefficients that are provided by the QQR are compared with the QR results for the robustness of the results. This comparison analysis is performed by quantiles of the QQR and QR approaches as presented in the Appendix (see Figs. SA 1–4), and these visualized analyses are summarized in Table 6.

As can be seen in Table 6, the correlation coefficient of slopes for the effects of the PS, EC, and GDP on CO₂ is higher than 97% in CAN, ITA, JPN, the UK, and the USA. Also, these correlations are higher than 88% in FRA and DEU, as well. On the other hand, the correlation coefficient of slopes for the effects of the EPU on CO₂ is relatively lower than that for others. The main reason for this is the

complexity of the relationship between EPU and CO₂, which is mentioned above. It is 79.37%, 56.04%, 95.01%, 82.22%, 33.41%, 63.29%, and 74.20% in CAN, FRA, DEU, ITA, JPN, the UK, and the USA, respectively. These results show that the correlation coefficient of slopes for the effects of the EPU, PS, EC, and GDP on CO₂ are too close to each other in all countries generally at a high level. Besides, the correlation coefficients of EPU and CO₂ are relatively lower than others in all countries. Overall, it can be said that QR results generally confirm the robustness of the QQR results.

Discussion and policy implications

This study examines the asymmetric effects of the selected explanatory variables (i.e., economic policy uncertainty, political stability, energy consumption, and economic growth) on CO₂ emissions in G-7 countries, which are the leading countries. In this context, yearly data for the period between 1990 and 2021 is analyzed by applying a novel QQR approach. Also, the QQR results are compared with the QR approach, which is performed for a robustness check.

By following the abovementioned approach, this study makes a comprehensive analysis to check the study's aims, which are (i) uncovering the asymmetric effects of economic policy uncertainty and political stability on CO₂ emissions at the country level by considering recently growing literature about economic policy uncertainty and political stability, (ii) examining changing effects according to the quantiles and countries, and (iii) performing an econometric analysis through the novel QQR approach by considering changes in both the dependent variable and independent variables over time.

The analysis results prove the aims of the study. In other words, it is determined that the effects of economic policy uncertainty, political stability, energy consumption, and economic growth on CO₂ emissions are mainly asymmetric, and these effects also vary according to quantiles and countries. The empirical results from the novel quantile approaches are mainly consistent with the studies of Amin and Doğan (2021), Anser et al. (2021), and Yu et al. (2021) about the effect of economic policy uncertainty on CO₂ emissions; of Kartal et al. (2022b) and Pata et al. (2022) for the effect of political stability on CO₂ emissions; of Ehigiamusoe and Doğan (2022) for the effect of energy consumption on CO₂ emissions; and of Nurgazina et al. (2022) for the effect of economic growth on CO₂ emissions. Also, the results obtained are consistent with the studies of Jiang et al. (2022) and Peng et al. (2022), who study G-7 countries as well. Hence, the results highlight that policymakers in each G-7 country should consider asymmetric and changing effects on CO₂ emissions at different quantiles and countries.

Table 6 Correlations between the QQR and QR coefficients

Country	Variable	Correlation
CAN	EPU & CO ₂	79.37
	PS & CO ₂	99.56
	EC & CO ₂	99.61
	GDP & CO ₂	98.60
FRA	EPU & CO ₂	56.04
	PS & CO ₂	92.63
	EC & CO ₂	99.99
	GDP & CO ₂	98.96
DEU	EPU & CO ₂	95.01
	PS & CO ₂	88.53
	EC & CO ₂	98.79
	GDP & CO ₂	99.73
ITA	EPU & CO ₂	82.22
	PS & CO ₂	98.18
	EC & CO ₂	99.94
	GDP & CO ₂	98.99
JPN	EPU & CO ₂	33.41
	PS & CO ₂	99.76
	EC & CO ₂	99.96
	GDP & CO ₂	99.08
UK	EPU & CO ₂	63.29
	PS & CO ₂	98.12
	EC & CO ₂	99.99
	GDP & CO ₂	97.19
USA	EPU & CO ₂	74.20
	PS & CO ₂	99.92
	EC & CO ₂	99.45
	GDP & CO ₂	99.72

Based on empirical outcomes, the following policy implications can be recommended. First of all, economic actors, who include also policymakers, should not think of the effects of explanatory variables (i.e., economic policy uncertainty, political stability, energy consumption, economic growth) on CO₂ emission as linear. Instead, this study proves the asymmetric effects of the variables on CO₂ emissions. For this reason, economic actors should consider the asymmetric effects in their policy development and implication processes.

Secondly, by considering the high effect of economic policy uncertainty and political stability, which comes after energy consumption, on CO₂ emissions, policymakers should work on decreasing economic policy uncertainty as well as increasing political stability by applying a set of structural reforms. Hence, they can prevent adverse effects and benefit from decreasing economic policy uncertainty and increasing political stability in terms of their negative effects on environmental quality.

Thirdly, although the relative effects of economic growth are lower than energy consumption, economic policy uncertainty, and political stability, it has still been effective on CO₂ emissions. For this reason, policymakers should continue to transform the structure of economies into a much more environment-friendly structure. This is also related to the transformation of energy structure from fossil-based to renewable-based.

Fourthly, due to the fact that effects are asymmetric and not linear, effects of such variables as economic policy uncertainty, political stability, energy consumption, and economic growth should be continuously monitored and necessary corrective actions in the policy mix should be carried out without any delay.

Lastly, countries and policymakers should handle environmental quality as a macro-prudential concern because it has been influential on a variety of significant issues, such as climate change, global working, economic growth, and energy consumption. Thus, the issue can be handled by high-level management of countries, and application of harmonious policies can be possible. On the other hand, because this study uses yearly data, policymakers of G-7 countries can use much higher-frequency (e.g., quarterly) data and develop much more policies by using such data in turn.

Conclusion

This study examines the asymmetric effects of economic policy uncertainty, political stability, energy consumption, and economic growth on carbon dioxide emissions in G-7 countries, which have an important role in the world economy. With this aim, a novel nonlinear quantile-on-quantile regression approach is applied using the data composed of yearly data from 1997 to 2021. The

empirical results show that economic policy uncertainty has an asymmetric and decreasing effect on carbon dioxide emissions in Italy, Japan, and the USA, while its effect has a mixed characteristic in Canada, France, Germany, and the UK. Also, political stability has a mixed effect on carbon dioxide emissions. Besides, energy consumption has an increasing effect on carbon dioxide emissions but its effect differs from quantile to quantile. Moreover, economic growth has a decreasing effect on carbon dioxide emissions in Japan, France, Germany, and Italy at different quantiles. Furthermore, the robustness of the quantile-on-quantile regression results is validated.

Based on the abovementioned empirical results, this study proposes that economic actors should consider the asymmetric effect of explanatory variables (i.e., economic policy uncertainty, political stability, energy consumption, economic growth) on CO₂ emissions because they are not linear, policymakers should work on decreasing economic policy uncertainty as well as increasing political stability through applying a set of structural reforms to achieve a sustainable environmental quality, the effects of the economic growth should not be ignored, and the effects of the explanatory variables should be monitored over time. Also, it can be possible to state that environmental quality should be considered a macro-prudential concern because environmental quality degradation has been causing various negative effects on humankind.

The contributions of the study to the literature are that (i) the asymmetric effect of economic policy uncertainty and political stability, as well as energy consumption and economic growth on carbon dioxide emissions, is examined for G-7 countries at the country level; (ii) the quantile-on-quantile regression, which is a novel approach for providing results at the quantiles level, is performed to investigate the asymmetric effects of the explanatory variables on carbon dioxide emissions; and (iii) on contrary to the current studies in the literature, in this study, the most recent dataset between 1997 and 2021 is used in the analysis. Thus, policymakers in G-7 countries can take action, considering the asymmetric and changing effects on carbon dioxide emissions at different quantiles for each country.

Naturally, this study has some limitations. Although the study's main focus is to examine the G-7 countries, the effect of the factors included on carbon dioxide emissions in other countries that have high-level carbon dioxide emissions should be also examined. Also, in case of obtaining higher-frequency data, such as monthly, or quarterly, machine learning, deep learning, or mixed models combining time-series econometrics and statistical learning models can be used to analyze this relationship.

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Declarations

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