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Expansion of financial system and production-based carbon emissions: evidence from high-income countries

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ABSTRACT

The recent environmental and energy economics is more influential towards sustainability of the environment. Unlike the existing literature covering extensively consumption-based carbon emissions factors, this research tends to identify the factors influencing production-based carbon emissions in the G7 economies from 1989 to 2020. The study utilised various panel econometric approaches to find the presence of cross-section dependence, stationarity of variables, and the validation of long-run cointegration association between the variables. This study uses a non-parametric long-run estimator (method of moment quantile regression) to explore the association between these variables at four ($Q^{0.25}$, $Q^{0.50}$, $Q^{0.75}$, $Q^{0.90}$) quantiles. The estimated results revealed that economic growth is a significant positive factor of production-based carbon emissions, whereas the influence of imports is positive but insignificant across the quantiles. On the other hand, this study found the negative and significant influence of exports and financial expansion on the production-based carbon emissions and helps to achieve environmental sustainability in the region. The non-parametric (bootstrap quantile regression) and parametric (robust regression) robustness tests also validate the earlier estimator's empirical findings. Based on the results obtained, this study recommends increased investment in environmentally friendly energy resources, technologies, and energy efficiency, increased exports, and strengthening financial institutions.

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1. Introduction

The economic activities in the country are the drivers of environmental changes leading to severe climate concerns (Carey et al., 2016; Zhao et al., 2022). The dominant cause of global warming and climate change is carbon dioxide (CO_2) and greenhouse gas emissions. Even in the year 2020, the system of United Nations Organizations produced almost two million tons of CO_2 equivalent and other Greenhouse Gas emission (GHG) gaseous emissions alone (UNO and Sustainability, 2022). However, in

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every economy, carbon emissions have gotten a certain amount of attention, but so far, minimum effort is being made to abate those emissions, which makes the world difficult to achieve sustainable development goals (Hafeez et al., 2022; Zhao et al., 2022). Attributable to this, the research on this area for environmental sustainability is extensive. Several economies, including the United Nations, came to the forefront to combat this challenge globally. In addition, UNO has adopted Climate Actions Plans and transitioned towards renewable energy and green technology (Rizvi et al., 2020, 2022). Besides, countries, especially world leaders, should work on carbon neutrality targets. In the prevailing literature, scholars have scrutinised the nexus between carbon emissions and its determinants for education, policy framework, and mitigation of emissions (Hasanov et al., 2018). Among those factors, economic growth strongly correlates with CO_2 emissions since the increase in economic production activities increases emissions (Chen et al., 2020a; Wu et al., 2022). Likewise, financial development and international trade are a few factors that have a momentous impact on carbon emissions (Adams & Opoku, 2020; Jiang & Ma, 2019).

The research query is whether financial development, economic growth, and international trade contribute to production-based emissions in developed nations. Therefore, the study aims to have the following objectives. The study's primary objective is to evaluate the influence of financial expansion on production-based carbon emissions in a Group of Seven (G7) nations. The secondary objective is to assess the role of control variables on territorial emissions in developed (G7) economies. To accomplish these two objectives, the authors employed variables such as financial expansion, PCO_2 emissions (territorial or production-based carbon emissions) from the Global Carbon Atlas, gross domestic product (GDP) (economic growth), EX exports as a percentage of GDP, and IM imports as a percentage of GDP from the World Bank, and original cointegration and quantile regressions econometric approaches are applied.

The study is significant in estimating the role of financial expansion on production-based emissions in G7 economies. Financial development is imperative for economic stability as it increases economic growth. But somehow, it impacts the environmental quality by increasing production-based emissions (Abbasi et al., 2022). Thus, the research is significant in evaluating the stimulus of financial development on territorial emissions. Moreover, the developed G7 economies are advanced nations that substantially contribute to those rousing harmful emissions. Nearly 40% of the global GDP is covered, whereas G7 countries emit 25% of the global emissions. Among these economies, the USA is the largest emitter, while others are included in emitting CO_2 emissions. Thus, they have a huge responsibility to lower these detrimental emissions for the planet's sustainability but have net zero long-term pledges (Karbassi, 2021). The heavy industry emits GHG and production emissions, and carbon neutrality cannot be achieved without limiting industry emissions. Nonetheless, G7 countries are powerful nations that have a significant role in reducing emissions level globally because it is the leading cause of escalating global warming. G7 needs to come forward in limiting heavy industry emissions (production-based emissions) to secure a pathway towards zero emissions by 2050. Therefore, the current study signifies the importance of G7 countries in abating emissions. The findings can be crucial for manoeuvring the environmental and trade/production policies for sustainability. This is because the reliable statistic which is related to emission for formulating climate change responses, thereby contributing to providing reliable information for environmental and economic stability.

The study contributes to the literature in the following ways. First, the study contributes to the literature examining the determinants of production-based or territorial emissions in the case of G7 economies. To the best of the authors' knowledge, former studies (Abbasi et al., 2022; Adams & Opoku, 2020; Hafeez et al., 2022; Liu et al., 2020) have ignored the G7 economies for scrutinising the determinant of territorial emissions. Hence, the present study contributes to the empirical literature in assessing the factors that impact production-based emissions. Second, the present study analyses the influence of financial expansion on territorial emissions, as the existing literature is scarce on this nexus because researchers have seldom focussed. However, Abbasi et al. (2022) recently examined the linkage between financial development and territorial emissions in Pakistan. Therefore, assessing the wide relationship range of empirical indications is obligatory for comparative analysis between different studies in diverse countries for the precision of the association for future policy making. Besides, the current study intends to contribute to this empirically. Third, the study utilises a long data period available from 1989 to 2020 for the first time for the scrutiny of territorial emissions determinants, which is imperative pragmatically, and no prior study has considered using quantile regressions for non-normal linear associations.

The rest of the manuscript is ordered as follows. The upcoming Section 2 elaborates on the empirical evidence from the prevailing literature for a better understanding of the variables and their associations. The data, model, and methodology are presented in Section 3. Section 4 documents the estimated results and their economic discussion. At the same time, the conclusion and policy implications are mentioned in Section 5 of the study.

2. Literature review

This segment documents the relevant empirical shreds in the existing literature for the variables under consideration. The first sub-section defines the production-based emissions, while the other sub-segment demonstrates the association between explanatory variables and production-based emissions.

2.1. Production-based emissions

The greenhouse gas emissions produced during production activities are referred to as production-based emissions consisting of six harmful gasses targeted in the Kyoto Protocol such as CH4, N20, CFK, HFK, SF6, CO_2, and its equivalents (Ritchie et al., 2020). During goods manufacturing, certain emissions are released due to exporting of goods. The companies engaged in production activities are included in discharging production-based emissions (CBS, 2022). Moreover, these emissions are within territorial boundaries or due to fuel emissions are called production-based or territorial emissions (OECD, 2016).

2.2. Role of GDP, imports, exports, and financial development on PCO_2 emissions

The existing literature has extensively examined the determinants of CO_2 emissions. However, the paper examines the relationship between production-based emissions and other explanatory variables under consideration. Among the determinants of production-based CO_2 emissions, economic growth is one of the imperative determinants of increasing production-based emissions. Weimin and Zubair Chishti (2021) and Mir and Storm (2016) examined the Kuznets hypothesis in 40 economies and observed that economic growth (GDP) significantly impacts production-based emissions. The increase in income (GDP) increases production-based emissions in the country, leading to environmental deterioration (Mirza et al., 2020, 2022). In China, Luo et al. (2017) inspected that agricultural production activities substantially contribute to increasing production-based emissions. Agricultural production activities intensify economic growth, which significantly escalates the production of CO_2 emissions. In another study in China, Hafeez et al. (2022) employed autoregressive distributive lag (ARDL) and nonlinear autoregressive distributed lag (NARDL) econometric approaches for the relationship between GDP and production-based emissions. The empirical findings of ARDL demonstrated that GDP has no significant impact on production-based emissions. Likewise, the NARDL also depicted that a positive and a negative shock has no substantial impact on reducing production-based emissions. In another innovative research, Cohen et al. (2019) also investigated Chinese data for decoupling emissions and economic growth. The results depicted a significant association, though the elasticity of production-based emissions was greater than consumption-based emissions. The increasing production activities in the economy aggravate the production-based CO_2 emissions (Dorfleitner & Grebler, 2022; Ferrat et al., 2021;; Kaiser & Welters, 2019). However, lower economic growth due to lesser economic production decreases the amount of production-based emissions in the economy (Karstensen et al., 2018). In the case of 29 high-income economies, Knight and Schor (2014) inspected the positive association between production-based emissions and economic growth. The increase in GDP significantly increases territorial emissions in the country (Gao et al., 2021; Hmaittane et al., 2019). Similarly, economic globalisation has a crucial role in intensifying production-based emissions in Argentina. However, consumption-based emissions are more highly correlated to economic growth than production-based emissions (Fan et al., 2016). Due to the declining growth rate of production-based emissions since 2010 and diverse trade structures in 2012, there was a declining trend in production-based CO_2 emissions (Shao et al., 2016). PCO_2 emissions and economic growth are positively associated (Liu et al., 2020).

The import sector of the economy has a substantial impact on production emissions. Weimin and Zubair Chishti (2021) examined the role of import taxes which caused a positive and significant effect on the rise of PCO_2 emissions with unidirectional causality from imports to PCO_2 emissions. In the case of 110 countries of the world, Franzen and Mader (2018) examined that the increasing number of imports in the economy leads to increasing production-based emissions. Exports also have significant causal associations with territorial emissions. Bosupeng (2016) and Adams and Opoku (2020) observed that exports tend to increase production-based emissions, while imports increased consumption-based emissions in the economy. However, the trade sector substantially affects carbon emissions. Correspondingly, the export sector has a positive and momentous nexus with production-based emissions in South America. While for the linkage between imports and production emissions, no substantial impact has been discovered in South America (Mahmood, 2022a). Similarly, in some studies, imports and exports both have no significant impact on the production emissions of the economy, while offsetting influence on CCO_2 emissions was observed in Africa (Tenaw & Hawitibo, 2021). The empirical results from common correlated effect estimation (CCE-MG) and Augmented Mean Group (AMG) analysis from 1990 to 2017 depicted insignificant associations. In another novel study, Hasanov et al. (2018) scrutinised the relationship between imports, exports, and carbon emissions in oil-exporting economies. The empirical findings demonstrated that imports and exports have a insignificant association with production-based emissions. Nonetheless, Mahmood (2022b) inspected the nexus between imports and emissions, export and emissions in GCC economies. The empirical findings from the spatial Durbin model depict the positive and significant influence of exports and imports on territorial-based emissions.

The financial expansion has also had a momentous influence on carbon emissions. The role of financial development on product-based emissions is limited. However, the succeeding set of studies elaborates on the relationship between the said. In the case of Turkey, Gokmenoglu et al. (2015) investigated the relationship between financial development and carbon emissions due to industrial production activities. The study presented the long-run and causal association between financial expansion and carbon emissions. The increasing financial expansion has positively contributed to increasing harmful emissions. Ahmad et al. (2018) scrutinised the positive nexus between financial development and carbon emissions, validating their symmetrical relationship. Abbasi et al. (2022) investigated the linkage between financial expansion and carbon emissions in Pakistan. The empirical findings of dynamic autoregressive distributive lag and frequency domain causality demonstrated that financial expansion positively stimulates production-based emissions and consumption-based emissions in both long- and short-run periods. Khan et al. (2022) found a significant relationship between financial expansion and carbon emissions. From a global point of view, financial expansion has a substantial effect on upsurging production-based emissions in the economy (Jiang & Ma, 2019). In dissimilarity, financial expansion negatively impacts carbon emissions in EU economies and Pakistan (Park et al., 2018; Usman et al., 2022).

2.3. Research gap

After critically analysing the available literature, the current is noteworthy in examining the nexus between financial expansion and production-based emissions. Second, international trade has gained much attention for carbon emissions due to production and consumption activities. Thus, the study significantly scrutinises the determinants of territorial emissions in developed economies as prior researchers ignored to assess that in G7 economies (Abbasi et al., 2022; Adams & Opoku, 2020; Hafeez et al., 2022; Liu et al., 2020). The study exploits economic growth and international trade (imports and exports separately) as control factors, while production-based CO_2 emissions and financial expansion are dependent and independent factors, respectively.

3. Data and methods

3.1. Variables and model development

Following the given literature and the study's objectives, this research explores the influencing factors of production-based carbon (PCO_2) emissions. In this context, the current study uses the GDP (constant US$2015 prices) to proxy economic growth, while financial expansion (FEX) is captured via domestic credit to the private sector by banks (% of GDP) and trade. In the latter variable, this study uses the imports (IM: % of GDP) and exports (EX: % of GDP) to deal with the trading variable more comprehensively and its distinctive influence on the PCO_2. Data for the variable PCO_2 is extracted from Global Carbon Atlas (2021),[1] whereas data for GDP, IM, EX, and FEX is obtained from the World Bank (2021).[2] This study focuses on the most developed nations, i.e., the G7, which includes the United Kingdom, Canada, Japan, France, the United States, Germany, and Italy.

Following the empirical modelling of Jamel and Maktouf (2017) and Sy et al. (2016), this study developed the model given below:

$$PCO_{2,it} = \beta_0 + \alpha_1 GDP_{it} + \alpha_2 EX_{it} + \alpha_3 IM_{it} + \alpha_4 FEX_{it} + \varepsilon_{it} \quad (1)$$

From the above model, it is observed that PCO_2 is the function of GDP, EX, IM, and FEX, where β_0 is the intercept of the model, while $\alpha_1, \alpha_2, \alpha_3,$ and α_4 are the slopes for the mentioned regressors, respectively. Besides, ε reports the error term of the model, while i indicate the G7 as a cross-section and t demonstrates the time period, which is from 1989 to 2020.

3.2. Estimation technique

This study explores summary analysis for examined variables to describe the dataset comprehensively. Specifically, descriptive analytics encompasses the mean, median, and range stats, with the latter including the lowest and greatest data observation. This study also looks into the variable's standard deviation, which further illustrates the destabilisation of time variables by showing the data's deviation from the mean. In addition, two normalcy measures are used to evaluate the data's distributional features. Specifically, Skewness and Kurtosis are used to determine if the distribution of a variable meets the normalising criterion. Both Kurtosis and Skewness offer factual results on the spread of the variable. Even so, this article concentrates more precisely on the issue of normality. Therefore, the present study employed the Jarque and Bera (1987) normality test, which evaluates skewness and excess Kurtosis and maintains their value at zero, thereby creating the normality claim. Jarque-Bera's mathematical formula for normality statistics is expressed below:

$$JB = \frac{N}{6}\left(S^2 + \frac{(K-3)^{\ 2}}{4}\right) \tag{2}$$

In today's globalised world, various factors may enhance a nation's dependency on other economies of the globe. Therefore, a shift in a single variable in one region may have implications for another economy or region. Nevertheless, disregarding cross-sectional dependence in the panel data may result in perplexing and erroneous conclusions (Wei et al., 2022). In this sense, the current study uses three estimators to detect the cross-sectional dependence in the panel of the G7 economies. Specifically, this study uses the Breusch-Pagan LM test proposed by Breusch and Pagan (1980), Pesaran scaled Lagrange Multiplier (LM) proposed by Pesaran (2004), and the Pesaran Cross Sectional Dependence (CD) test proposed by Pesaran (2015). All of these tests assume the cross-sectional independence of the panel.

This research employed a unit root estimator to examine the stationarity of the data. Despite the prevalence of the panel data issue, such as the cross-sectional dependence, a suitable unit root estimation approach is employed to overcome such issue. This study employed the cross-sectional Im, Pesaran and Shin (IPS) (i.e., CIPS) estimator developed by Pesaran (2007) because it is more reliable and efficient compared to other unit root approximations such as the ADF, Levin, Lin, and the Chu, etc., in terms of adapting for the panel data challenge and delivering more accurate findings. Pesaran (2006) first suggested a factor model for cross-sectional dependency analysis of unexplainable cross-sectional means. Pesaran (2007) employs a similar method to include the mean and first differentiating cross-section lags in the ADF linear model. This approach gives cross-sectional dependence regardless of the panel's imbalance ($T > N$ or $N > T$). Using the following equation, one might calculate the CIPS estimates:

$$\text{CIPS} = N^{-1} \sum_{i=1}^{N} CADF_i \tag{3}$$

From the perspective of the aforementioned method, the CIPS test presupposes the presence of a unit root in the panel's time series.

Considering that all variables are expected to be stationary, it is essential to include static data in an analysis of panel data. This allows for determining the long-term equilibrium relationship between the studied components. As a consequence, the diagnostic test reveals cross-section dependency. Therefore, this research employs an adequate empirical method that accounts for the aforementioned obstacle. Specifically for cointegration test we used the Westerlund (2007) cointegration test. This test implies that the error correction parameter has zero value, which is the null hypothesis. Specifically, this assessment is beneficial because it considers both the group mean statistics as well as panel statistics, which are given below:

$$G_\tau = \frac{1}{N} \sum\nolimits_{i=1}^{N} \frac{\hat{\alpha}_i}{S.E\hat{\alpha}_i} \tag{4}$$

$$G_a = \frac{1}{N} \sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \tag{5}$$

Eqs. (4) and (5) provide the group mean statistics.

$$P_\tau = \frac{\hat{\alpha}}{S.E(\hat{\alpha})} \tag{6}$$

$$P_a = T.\hat{\alpha} \tag{7}$$

while Eqs. (6) and (7) indicate the panel statistics.

Since the investigated variables displayed stationarity, one of the conditions for determining long-run elasticities and the characteristics of long-run cointegration may be calculated. Consequently, the present research considers the asymmetrical data distribution, mandating using a unique method of moment quantile regression (MMQR) technique. Koenker and Bassett (1978) presented the quantile regression method to assess the mean dependency and conditional variance to minimise non-linearity issues. Machado and Silva (2019) developed the MMQR strategy for assessing the dispersion of quantile estimates based on this methodology (Sarkodie & Strezov, 2019). The simple equation for the conditional location-scale variance $Q_y(\tau|R)$ is as follows:

$$Y_{it} = \alpha_i + \beta R_{it} + \left(\gamma_i + \rho \acute{Z}_{it}\right)\mu_{it} \tag{8}$$

In the above equation, the likelihood formulation $p\left(\gamma_i + \rho \acute{Z}_{it} > 0\right)$ is equal to 1; α, β, γ, and ρ represent the values that this study chooses to forecast. The subscript i denotes the fixed effect described by the parameters α_i and γ_i which would be confined to the values $i = 1, 2, \ldots, n$. Thus, the typical element of R, denoted by Z, is the k-vector, while the vector denotes the variability '$\imath$'.

$$Z_{\mathbb{l}} = Z_\imath(R), \ \imath = 1, 2, \ldots, k \tag{9}$$

Here, R_{it} is spread identically and independently for the total fixed I and time (t), which in itself is orthogonal to i as well as t (Machado & Silva, 2019). Consequently, the outside features and reserves are both stable. Based on the above reasoning, the research model [Eq. (1)] may be reformulated as follows:

$$Q_y(\tau|R_{it}) = (\alpha_i + \gamma_i q(\tau)) + \beta R_{it} + \rho \acute{Z}_{it} q(\tau) \tag{10}$$

In the new research framework, the set of explanatory variables, which comprises GDP, EX, IM, and FEX, have been captured by R_{it}. All the study variables are converted into natural logarithms, rendering them unitless, and the estimated outcome is expressed as a percentage. Also, R_{it} represents the quantile distribution of the regressors, as shown by Y_{it} and is supposed to be PCO_2 in this case, which also depends on the quantile location. In contrast, the expression $-\alpha_i(\tau) \ \equiv \alpha_i + \gamma_i q(\tau)$ indicates the scalar element that generates the fixed impact of quantiles on I; nevertheless, these quantiles have no impact on the intercept. Numerous outputs are susceptible to

Table 1. Descriptive statistics and normality.

	PCO_2	GDP	EX	IM	FEX
Mean	2.916191	12.46904	1.345698	1.346913	1.957207
Median	2.758443	12.39739	1.401533	1.400853	1.974928
Maximum	3.787781	13.29941	1.674871	1.614194	2.280906
Minimum	2.441905	11.97023	0.945295	0.841109	1.647048
Std. Dev.	0.379638	0.328149	0.199131	0.182187	0.153899
Skewness	1.278095	1.083392	−0.557244	−0.858087	−0.042268
Kurtosis	3.483662	3.554113	2.280874	2.937598	2.452710
Jarque-Bera	63.16831	46.68527	16.41943	27.52536	2.862276
Probability	0.000000	0.000000	0.000272	0.000001	0.239037
Observations	224	224	224	224	224

Source: Authors calculation.

change due to the factors' structural independence. Lastly, $q(\tau)$ provides the τth quantile sample, which are $Q^{0.25}$, $Q^{0.50}$, $Q^{0.75}$, and $Q^{0.90}$. Therefore, the quantile equation used in this study is as follows:

$$\min_q \sum_i \sum_t \theta_\tau \left(R_{it} - \left(\gamma_i + \rho \acute{Z}_{it}\right) q \right) \tag{11}$$

where $\theta_\tau(A) = (\tau - 1)\ AI\{A \leq 0\} + TAI\{A > 0\}$ denotes the procedure for testing.

Nevertheless, the MMQR method delivers precise predictions at a particular scale and location, displaying the results of each quantile. However, the present work tends to evaluate the model's stability. This research used bootstrap quantile regression (BSQR), which is also a non-parametric panel data estimator. The BSQR is a substitutional approach for studying confidence intervals and significance tests. The benefit of this estimator is that it resamples the data to provide statistical results while avoiding the asymptotically normal sample distribution limitation (Efron & Tibshirani, 1994). The BSQR employs algorithmic pressures to assess the actual sampling distribution of the evaluation model, which offers favourable estimating strategies and reveals empirical outcomes (Efron & Tibshirani, 1994). In addition to the robustness of the model, this research also employed the parametric approach, which is a robust regression. Unlike the MMQR and BSR, this estimator provides the average influence of each explanatory variable on PCO_2.

4. Results and discussion

4.1. Results

This part of the manuscript presents the estimated results and their discussion for each variable under consideration. In the first phase, this study calculated the descriptive statistics, which provides the summarised representation of the variables. The calculated descriptive and the normality statistics are provided in Table 1. From the results estimation of the mean, median, and range specifications, the study noted that all of these stated specifications are positive, validating the progressiveness of these variables. This indicates that along with economic growth, trading (both imports and exports), and financial expansion, production-based CO_2 emissions also increase. Besides, the range value exhibits a significant variability, which leads this study to evaluate the standard deviation for each variable. The estimation outcomes regarding the latter specification

Table 2. Cross-section dependence.

Residual cross-section dependence test		
Test	Statists	Probability
Breusch-Pagan LM	330.5393***	0.0000
Pesaran scaled LM	47.76296***	0.0000
Pesaran CD	17.42855***	0.0000

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**), and 10% (*).
Source: Authors calculation.

validate the presence of volatility in all variables, which is highest in the PCO_2, followed by GDP, IM, FEX, and EX. After the validation of fluctuations in each variable, this study tends to examine the normality of the study variables. In this regard, this study uses the Skewness and Kurtosis specification. These specifications asserted that the statistical values differ from their critical values, which leads to the conclusion that all the variables are non-normally distributed. Since the issue of non-normality leads to an estimation-biased problem. Therefore, this study also employed the JB test of normality, which considers both the skewness and excess Kurtosis and considers their critical value as zero to propose the normal distribution of the data. The examined results found that PCO_2, GDP, EX, and IM probability values are significant at a 1% level. Therefore, the proposition of the JB test could be rejected, and it is concluded that these variables follow asymmetric distribution, which leads to adopting an appropriate estimator to deal with the asymmetrical data distribution.

After the attainment of descriptive and normality estimates, this study tends to analyse the panel data issues in the dataset of the G7 economies – provided in Table 2. In this context, the current study uses three tests, i.e., the Breusch and Pagan LM test (Breusch & Pagan, 1980), Pesaran scaled LM (Pesaran, 2004), and the Pesaran CD test (Pesaran, 2015), and the empirical results for these tests are provided in Table 2. The estimated results asserted that the statistical values for the stated three cross-section dependencies are significant at a 1% level. This rejects the null hypothesis of no cross-section dependence. Instead, all the tests validate the presence of cross-sectional dependence in the G7 panel for the variables.

After the cross-section dependence test, the present research examines the unit root of variables under consideration. Since the issue of cross-section dependence is found valid in the panel's variables, it is essential to utilise the second-generation unit root testing approach proposed by Pesaran (2007). The results of the said approach are reported in Table 3. The results examined revealed that only PCO_2 is stationary at I(0), whereas GDP, EX, IM, and FEX hold unit roots. Since it is essential that all the variables must be stationary for the determination of the long-run coefficients, therefore, this study employed a similar test in I(1) data. At the first difference, all the non-stationary variables became stationary, which is sufficient to explore the long-run association between the variables.

Table 4 presents the Westerlund's (2007) cointegration estimates. The empirical results asserted that the group mean (Gt and Ga) stats and the panel (Pt and Pa) stats are statistically significant at 1%. The significant estimates lead to the conclusion that the error correction term is non-zero, which further rejects the Westerlund's (2007)

Table 3. Stationarity testing.

	(Pesaran, 2007) CIPS		
Variable	I(0)	I(1)	Integration
PCO_2	−3.016**	–	I(0)
GDP	−2.353	−3.563***	I(1)
EX	−1.640	−3.548***	I(1)
IM	−2.326	−4.504***	I(1)
FEX	−1.176	−3.602***	I(1)

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**), and 10% (*).
Source: Authors calculation.

Table 4. Cointegration test.

(Westerlund, 2007)		
Statistic	Value	Z-value
G_t	−6.990***	−12.892
G_a	−20.551***	−3.970
P_t	−18.009***	−10.839
P_a	−21.293***	−5.493

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**), and 10% (*).
Source: Authors calculation.

proposition. Therefore, this research concludes that the long-run cointegration association exists between the variables.

After the validity of the cointegration between the variables, this study analyses the long-run coefficient by applying the MMQR approach due to asymmetrical data distribution. The results obtained via the MMQR technique are reported in Table 5. From the estimation of the results, the study noted that economic growth (GDP) is the only significant factor of PCO_2 among the selected variables. Where a 1% increase leads to enhancing the PCO_2 levels by 0.910–0.653% at a 1% significance level. Also, the study found that IM was positively but insignificantly associated with PCO_2 emissions in the medium and upper quantiles. On the other hand, the results demonstrate that EX and FEX adversely affected the PCO_2 emissions in the G7 economies. More specifically, an increase of 1% in both these variables substantially reduces the level of PCO_2 emissions by 0.715–0.838 and 0.257–0.384%, respectively. These estimates are significant at 10%, 5%, and 1% levels for EX ($Q^{0.75}$ and $Q^{0.90}$) and FEX ($Q^{0.50}$, $Q^{0.75}$, and $Q^{0.90}$). Further significance of these results could be captured from the significant estimates of the location.

In addition to the MMQR estimates, this study employed another non-parametric approach for the robustness of the model. The estimated results of the BSQR results are given in Table 6. The robustness of the study is also tested in four quantiles, where economic growth is found to positively and significantly affect the PCO_2 level. Besides, the influence of IM on the PCO_2 emissions is also positive yet insignificant at all the quantiles. On the contrary, EX and FEX are significant environmental sustainability factors that substantially reduce the PCO_2 emissions level throughout several quantiles (i.e., $Q^{0.25}$, $Q^{0.75}$, and $Q^{0.90}$). Apart from the tabular representation of the coefficients, this study also provides the coefficients estimates graphically (see Figure 1).

Table 5. MMQR estimates.

			Quantiles			
Variable	Location	Scale	$Q^{0.25}$	$Q^{0.50}$	$Q^{0.75}$	$Q^{0.90}$
GDP	0.824***	−0.104	0.910***	0.822***	0.713***	0.653***
	[0.103]	[0.086]	[0.153]	[0.101]	[0.383]	[0.111]
EX	−0.484	−0.216	−0.308	−0.489	−0.715**	−0.838*
	[0.439]	[0.367]	[0.666]	[0.433]	[0.356]	[0.468]
IM	0.100	0.358	−0.190	0.108	0.481	0.685
	[0.386]	[0.323]	[0.581]	[0.381]	[0.312]	[0.416]
FEX	−0.255*	−0.078	−0.191	−0.257**	−0.339***	−0.384***
	[0.131]	[0.110]	[0.197]	[0.130]	[0.106]	[0.140]
Constant	−6.349***	1.391	−7.481***	−−6.318***	−4.870***	−4.078**
	[1.546]	[1.292]	[2.307]	[1.519]	[1.245]	[1.663]

Note: The dependent variable is PCO_2. Asterisks indicate a statistical significance level of 1% (***), 5% (**), and 10% (*).
Source: Authors calculation.

Table 6. Robustness – bootstrap quantile regression.

	Quantiles			
Variable	$Q^{0.25}$	$Q^{0.50}$	$Q^{0.75}$	$Q^{0.90}$
GDP	0.926***	1.020***	0.696***	0.600***
EX	−0.617**	−0.341	−0.619***	−0.430***
IM	0.032	0.048	0.310	0.041
FEX	−0.159**	−0.087	−0.401**	−0.620***
Constant	−7.641***	−9.273***	−4.431***	−2.666***

Note: The dependent variable is PCO_2. Asterisks indicate a statistical significance level of 1% (***), 5% (**), and 10% (*).
Source: Authors calculation.

Once the statistical values of the variables' coefficients were in a robustness test, this research also tested the model's robustness by employing a parametric approach, i.e., robust regression. The empirics are provided in Table 7. From the estimation of the results, this study found that the influence of economic growth is positive and significant, whereas exports and financial expansion significantly and adversely affect the PCO_2 emissions. However, imports are found to have a positive association yet are insignificant. These estimates validate the earlier empirical estimates of both the non-parametric approaches, i.e., MMQR and BSQR.

4.2. Discussion

There is a growing consensus that when the economy expands, industrial activities expand, resulting in greater PCO_2 emissions. PCO_2 emissions have had incredibly huge impacts on the environment, influencing the ecosystem and human health (Chen et al., 2022a; Wei et al., 2022). With rising productivity and consumption, environmental costs are expected to grow. The ecological effect of economic expansion encompasses the increasing use of non-renewable energy resources, increasing pollution levels, climate change, and the probable loss of natural ecosystems. Increased levels of economic activity are often accompanied by increased energy utilisation and the use of natural resources such as coal, natural gas, oil, etc. As fossil fuels continue to make up 80% of the global energy mix, the relationship between energy consumption and pollution emissions and, therefore, climate forcing remains

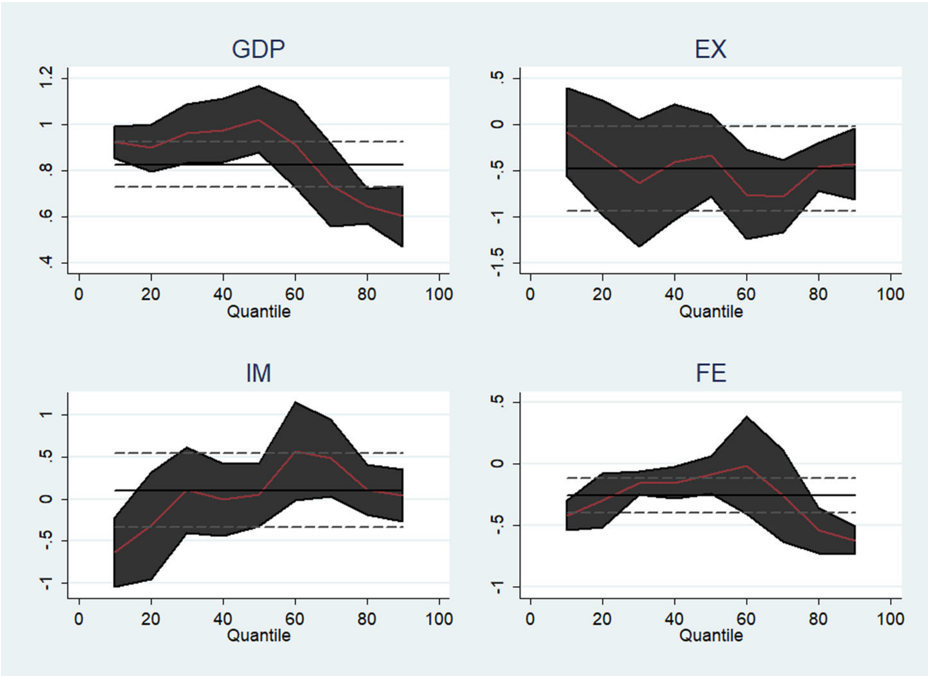

Figure 1. Graphical depiction of bootstrap quantile regression coefficients.
Source: Authors Own Visualization.

Table 7. Parametric robust analysis.

Robust regression			
Variable	Coefficient	Standard error	z-stat.
GDP	0.848333***	0.051507	16.47019
EX	−0.511852**	0.242843	−2.107745
IM	0.141307	0.233275	0.605752
FEX	−0.227902***	0.075095	−3.034873
C	−6.717745***	0.754875	−8.899143

Source: Authors calculation.

strong. From the empirical perspective, the empirical results are consistent with the existing studies of Hafeez et al. (2022), Luo et al. (2017), Mir and Storm (2016) and Weimin and Zubair Chishti (2021), which provide evidence regarding the positive association between economic growth and production-based carbon emissions. In the form of increased pollution or natural resource depletion, trade development may have a direct and evident influence on the environment. Trading is an important driver of economic development and higher living conditions in both developed and developing nations. However, there is still an indication that a rise in international trade, especially imports, may contribute to a rise in global pollution emissions due to greater consumption – a phenomenon known as the 'scale effect'. Furthermore, increasing imports tends to raise the global scale of production, which is expected to increase the overall volume of pollution and environmental harm. Additionally, trade necessitates energy consumption for transport, leading to air pollution and other consequences. Nonetheless, the impact of imports on PCO_2 emissions is positive yet insignificant, which is also proved (Chen et al., 2020b; Franzen & Mader, 2018; Weimin & Zubair Chishti, 2021). At the same time, the findings are consistent with the recent study by Mahmood (2022b), which also provides an insignificant influence on imports on PCO_2 emissions. On the other hand, exports of the G7 economies reduce the PCO_2 emissions. Specifically, exports increase the transfer of energy intensive products and services. This leads to the transfer of pollution to other regions of the world. The estimated results also support the stance on the negative impact of exports on PCO_2 emissions (Bosupeng, 2016; Mahmood, 2022a). Apart from the influence of economic growth and trade, this study also explores the impact of financial expansion on the PCO_2 of developed economies. Nonetheless, the development of the financial system tends to provide finances in the shape of loans, cash, bonds, etc., which could lead to enhanced economic activities in the region. However, in contemporary times, the financial system also stimulates environmentally friendly technologies and energy resources. In this respect, green finances, a factor of financial development, helps to encourage the production and consumption of environmentally friendly energy resources, improve energy efficiency, and reduce traditional fossil fuel consumption by financing renewables. Therefore, financial expansion could play a substantial role in environmental sustainability. This study's empirical estimates are found to adversely affect the PCO_2 emissions, which are in line with the empirical studies of Park et al. (2018) and Usman et al. (2022) in developed economies. Therefore, appropriate policies could be developed and implemented to achieve carbon neutrality and environmental sustainability.

5. Conclusion and policy implications

5.1. Conclusion

The recent environmental and energy economics trend is regarding the increased environmental problems and exploring remedial measures for increased carbon emissions. Most recent studies are paying more attention to consumption-based carbon emissions in such trending literature while ignoring production-based emissions. In this context, the current study tends to explore the association between production-based carbon emissions and its factors, such as economic growth, imports, exports, and financial expansion in the case of the developed economies (G7). Using the second-generation panel data estimating approaches, this study found that cross-sectional dependence exists in the variables of G7 countries. Also, the long-run cointegration is found valid between the study variables. Due to the lack of normal distribution between the variables, this study uses the non-parametric MMQR technique to obtain empirical estimates at a particular scale and location. The examined results asserted that economic growth is a significant factor in PCO_2, whereas imports also positively but insignificantly affect the PCO_2 in the study region. The economic growth and imports are generally linked to the consumption of energy and carbon-intensive goods and services, which further leads to the increased emissions level in the region. On the other hand, exports and financial expansion significantly reduce the production-based emissions level across quantiles. Since the exports are linked to the transfer of energy and carbon-intensive services and goods to other regions, financial expansion strengthens the production and adoption of environmentally friendly energy resources and energy efficiency. As a result, the consumption of traditional fossil fuel reduces, and the economy moves towards low carbon emissions.

5.2. Policy implications

Based on the estimated outcomes, this study suggested policies that could help the G7 and other developed economies to reduce pollution to attain carbon neutrality and environmental stability. First, since the economic growth is adversely affecting environmental quality, policies regarding economic growth shall be revised that could divert the increased level of aggregate income towards the production and improvement in environmentally friendly energy resources such as investment in renewable energy, energy efficiency, and environmentally friendly technologies, among others. This will not only reduce the level of emissions but also contributes to economic growth by expanding the employment level and industrial sector. Second, the exports shall be promoted in a sense that could target the increased exports of energy-intensive and pollution-intensive commodities to other regions. The higher level of such types of exports not only reduces the level of pollution but also encourages economic growth. Lastly, the financial institutions must be strengthened and improved by encouraging investment and financial support for environmentally friendly technologies, innovations, and energy resources. Besides, authorities must intervene in the industrial set-up by providing subsidies to those industrial sectors targeting environmental sustainability, while imposing higher taxes on those industries using energy and pollution-intensive products and equipment. Moreover, the research and development investment in these developed economies shall be increased to generate technologically advanced equipment, which assists in reducing the natural resources demand and its extensive consumption.

Notes

1. Visit http://cms2018a.globalcarbonatlas.org/en/content/welcome-carbon-atlas
2. Visit https://databank.worldbank.org/source/world-development-indicators#

Disclosure statement

No potential conflict of interest was reported by the authors.

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