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How do technological innovation and fiscal decentralization affect the environment? A story of the fourth industrial revolution and sustainable growth

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Abstract

Deteriorating environmental quality poses a serious threat to life on earth. Similar to other countries, China has been attempting to reduce its reliance on non-renewable energy sources by adopting new energy-efficient technologies that help create a more sustainable industrial structure. Various studies have been conducted to determine the leading causes of environmental degradation. However, unlike international trade, economic activities, and eco-innovation, the political structure of a country is often ignored by scholars because of its indirect impact—which is difficult to evaluate—on emission reduction. In this study, we examine the impact of technological innovation and fiscal decentralization on carbon dioxide (CO2) emissions in the presence of gross domestic product (GDP) and globalization in the case of China for the period 2005Q1 to 2018Q4. By using time series econometric techniques, we find that technological innovation, fiscal decentralization, GDP, and globalization are influential factors in explaining CO2 emissions in China. In terms of policy implications, we suggest that to deal with deteriorating environmental quality, China needs to formulate policies to mitigate emission levels by promoting an energy-efficient system. Moreover, to smoothen the process, it is imperative to clarify the responsibilities at different levels of government to successfully achieve the targets of low CO2 emissions and energy-saving functions of fiscal expenditures.

Keywords:

CO2 emissions, Fiscal decentralization,Globalization,Technological innovation,China

1. Introduction

Environmental degradation is one of the most pressing problems worldwide. Given its strong association with human lives and biodi-versity, the issue has received enormous attention. The primary concern of the future of humanity is to achieve green growth (Hao et al., 2021), for which, countries around the globe are striving to reduce greenhouse gas emissions (Su et al., 2021; Umar et al., 2020a; Wang et al., 2020). However, the continuous increase in economic activities is considered as one of the persistent causes of environmental degradation. The world output is increasing at an annual rate of 3–4%, which has resulted in increased demand for fossil fuels. The excessive use of fossil fuels has raised the earth's temperature by 1.9°C, which has serious implications for human lives and biodiversity (Change, 2020; Umar et al., 2020b). To cope with deteriorating environmental quality, several global fra-meworks have been established, such as the Kyoto Protocol in 1997 and the Paris agreement in 2016, which aims to formulate policies to mitigate emission levels. To achieve the milestone set by these accords, countries are transforming their industrial structure by promoting en-ergy-efcient systems. Some countries such as Denmark, Norway, and Sweden have partially succeeded in achieving these milestones. How-ever, a majority of the countries worldwide have failed to implement policies to facilitate adapting to climate change. Consequently, carbon dioxide (CO_2) emissions grew by 1.6% in 2017 and 2.7% in 2018, reaching another record high. This high growth in COemissions has led researchers to determine the infuential factors of COemissions.

China, with a population of 1.393 billion and a gross domestic product (GDP) of $ 13.61 trillion, emitted 9.8 billion metric tons of CO_2 in 2018, making it the largest CO_2 emitter in the world. Despite the famous Paris agreement, the CO_2emissions in China are growing at an alarming rate (3% in 2018). However, the CO_2emissions in China are expected to decrease in future because of the country's less reliance on coal in re-cent years. Moreover, China is transforming from a non-renewable energy based industrial structure to that based on renewable energies.

It is widely recognized that international trade and economic ac-tivities result in growing demands for energy, and hence, are the leading causes of environmental degradation (Alola et al., 2019; Hasanov et al., 2018; Ulucak and Khan, 2020). To mitigate the negative consequences of international trade and economic activities on en-vironmental quality, countries are adopting new energy-efcient tech-nologies, which help create a more sustainable industrial structure (Li et al., 2020; Su et al., 2020; K. Zhang et al., 2017). The introduction of environment-friendly technologies such as grid modernization, carbon storage system, and electricity usage through renewable re-sources have widespread implications for the environment (Ulucak and Khan, 2020). If other countries of the world successfully implement these technologies, CO2 emissions may tremendously reduce in these countries. However, without institutional arrangements and suitable government's fscal expenditure schemes, the low CO2 emissions target is difcult to achieve. Fiscal decentralization (FD) is a tool to improve public service delivery aimed at developing theories on how to allocate and organize revenue and expenditure between central and local gov-ernments (Ji et al., 2020; Please, 2020). By authorizing the lower unit of the state, countries can successfully implement policies related to improving environmental quality. Hence, there is a strong association between FD and COemissions. To successfully achieve the low CO2 emissions target and energy-saving functions of fscal expenditures, it is imperative to clarify the responsibilities at diferent levels of govern-ment (Cheng, 2019). By contrast, Millimet (2003), Batterbury and Fernando (2006), Sigman (2014), and Fell and Kafne (2014) argue that FD deteriorates environmental quality. The greater is the possibi-lity of environmental degradation due to free-riding issues between jurisdictions, the greater is the budget authorization granted to lower state-level units (Cheng, 2019). Therefore, the essence of the relation-ship between FD and CO2 pollution is unclear and needs further analysis.

Deteriorating environmental quality poses a serious threat to life on earth. With a growing population, international trade, and economic activities, the environment faces increasing strain. Similar to other countries, China is trying to lessen its reliance on non-renewable energy sources by adopting new energy-efcient technologies, which help create a more sustainable industrial structure. The high growth in CO2 emissions has attracted the attention of scholars to ascertain the in-fuential factors of CO2 emissions.

Various studies have been conducted to fnd out the leading causes of environmental degradation. However, unlike international trade, economic activities, and eco-innovation, the political structure of a country is often ignored by researchers due to its indirect impact—which is difcult to evaluate—on emission reduction. In this study, we examine the impact of FD on CO2 emissions in the presence of GDP, economic globalization (GL), and technological in-novation (TI) in the case of China. Understanding the nexus between FD and CO2 emissions is important when formulating policies to achieve sustainable development. This study flls the gap in the existing lit-erature by examining the role of FD and TI on CO2 emissions in the case of China. To the best of our knowledge, it seems that a research gap exists for the case of China. The present study ofers new insights into the role of TI, GL, and GDP as key determinants of CO2 emissions.Moreover, this study empirically contributes to the literature by em-ploying advanced time series estimation methods to scrutinize the im-pact of FD on environmental quality. The fndings of this study can help in designing policies related to FD and the environment in China. The remainder of this study is organized as follows: Section 2 reviews the literature, and Section 3 describes the theoretical model and empirical methodology. Section 4 presents a discussion of the results, while Section 5 concludes the study.

2. Literature review

The extant literature intensely discusses the factors infuencing CO2 emissions (Bhattacharya et al., 2016; Hasanov et al., 2018; Liddle, 2018; Shahbaz et al., 2020; Ulucak and Khan, 2020; K. Zhang et al., 2017; Y.-J. Zhang et al., 2017). Output, globalization, population, fnancial development, energy consumption, deforestation, human capital, carbon pricing, and environmental innovation are considered as crucial factors afecting CO2 emissions. The infuential work of Grossman and Krueger (1995) provides an introduction to study the relationship between income and environment. Subse-quently, researchers introduced energy consumption, deforestation, and international trade to examine the factors responsible for CO2 emissions. Recently, studies on the environment include eco-innovation as a factor of environmental quality by arguing that energy-efcient technologies help create a more sustainable industrial structure, and hence, reduce CO2 emissions. Apergis and Ozturk (2015), Ulucak and Khan (2020), Wang et al. (2020), K. Zhang et al. (2017), and Y.- J. Zhang et al. (2017) analyzed the role of eco-innovation in afecting the environmental quality in G7 countries and found that by adopting eco-friendly technologies, G7 countries can achieve environmental sustainability. Wang et al. (2020) analyzed the role of export diversi-fcation and environmental innovation on environmental quality in G7 countries. The authors proposed that to weaken the negative impact of export diversifcation on the environment, G7 countries must improve their eco-innovation through high expenditures on research and de-velopment. Researchers have recently introduced a new set of factors responsible for environmental quality. For instance, Apergis et al. (2018) examined the role of renewable energy con-sumption and health expenditures in afecting environmental quality in sub-Saharan African countries. The authors found that by relying on renewable energy consumption in the production of goods, African countries can improve their environment. Balsalobre- Lorente et al. (2019) introduced innovation and governance as im-portant factors for environmental quality by arguing that both factors improve environmental quality. Researchers such as David and Venkatachalam (2018) and Shahbaz et al. (2020) introduced pub-lic–private partnership investments in energy as an important factor for environmental quality.

On the role of FD on environmental degradation, a bulk of studies is conducted to investigate the efect of FD on environmental quality (Batterbury and Fernando, 2006; Cheng, 2019; Fell and Kafne, 2014; Konisky, 2007; Millimet, 2003; Sigman, 2014; K. Zhang et al., 2017; Y.-J. Zhang et al., 2017). In this context, the literature can be divided into two major groups of studies. The frst group, which includes Cheng (2019), Fredriksson and Millimet (2002), Konisky (2007), and Levinson (2003), support the positive impact of FD on environmental quality. Konisky (2007) argued that a high degree of FD is a pre-requisite for improving the environment. Moreover, Cheng (2019) ar-gued that to successfully achieve the target of low CO_2 emissions and energy-saving functions of fscal expenditure, it is imperative to clarify the responsibilities at diferent levels of government. The second group of studies, which include Millimet (2003), Batterbury and Fernando (2006), Sigman (2014), and Fell and Kafne (2014), is more pessimistic regarding the role of FD in afecting environmental quality. For instance, Millimet (2003) argued that in the process of decen-tralization, countries compromise on the environmental quality because of the weak local environment due to increased authorization of the lower unit of the state. Similarly, Sigman (2014) argued that the free- rider behavior among jurisdictions deteriorates the environmental quality due to an increasing degree of FD. Studies on the role of FD on environmental degradation in the case of China are scant. Only K. Zhang et al. (2017) have investigated the role of FD on CO_2

emissions. However, the study tests the green paradox by analyzing the impact of FD on CO2 emissions via environmental policies. The estimation strategy of our study difers from that of Zhang et al. (2017). We intend to empirically test the direct impact of FD on environmental degradation in China by controlling eco-innovation, GDP, and trade.

To sum up, the role of FD on CO2 emissions shows ambiguous results in the extant literature. The present study ofers new insights into the role TI,Gl and DGP as key determinants.

Table 1 Description of Variables and Sources

CO	Carbon Emissions	Metric tons	Global Carbon Atlas, 2019
2**t**			
			http://www.globalcarbonatlas.org/en/CO2-emissions
FD	Sub-national expenditure as ratio of total	Percentage	International Monetary Fund, 2019
2**t**			
	federal expenditure		https://data.imf.org/?sk=1C28EBFB-62B3-4B0C-AED3-048EEEBB684F
	(Fiscal Decentralization)		
GDP	Gross Domestic Product	Constant US Dollars, 2010	Word Development Indicators, 2019
i, t			
			https://databank.worldbank.org/source/world-development-indicators#
			advancedDownloadOptions
TI	Technological innovation	% of all technologies	Organisation for Economic Co-operation and Development, 2019
i, t			
			https://stats.oecd.org
GL	Economic Globalization Index	Index based on FDI, trade, and	Gygli et al. (2019): Revised KOF globalization Index. (https://doi.org/10.
t			
		portfolio investment	1007/s11558-019-09344-2_

Table 2
Results of Unit Root Test

Variables	Level I(0) Intercept	Intercept and Trend	First Difference I(1) Intercept	Intercept and Trend
Carbon Emissions	−3.1310	−4.0924	−5.0263***	−6.0429***
GDP	−3.0975	−2.5404	−6.0621***	−7.3158***
Globalizations	0.6570	−0.7957	−4.5855**	−4.8933*
Fiscal Decentralization	−3.3982	−3.5120	−6.5849***	−12.4625***
Technological innovation	−4.0015	−4.6144	−6.0746***	−6.6200***
Structural Breaks at Intercept		**Structural Breaks at Intercept and Trend**		
2008Q3–2012Q3		2008Q2–2010Q2		
2008Q2–2010Q1		2006Q2–2007Q3		
2014Q1–2016Q3		2010Q2–2012Q3		
2008Q1–2011Q1		2009Q2–2012Q2		
2005Q4–2011Q2		2010Q1-2012Q3		

Note: ***, **, and * indicate 1%, 5%, and 10% significance level, respectively.

Table 3
Results of Cointegration Tests

Bayer–Hanck Cointegration (Without Structural Breaks) Test	Statistic	Critical value at 5%
Engle-Granger-Johansen (EG-J)	55.387***	10.419
Engle-Granger-Banerjee-Boswijk (EG-J-Ba-Bo)	58.139***	19.888
Maki Cointegration (With Structural Breaks)		
Model	**Test Statistics**	**Structural Breaks**
Level shifts with Trend	−6.276*	2007Q3–2008Q3–2010Q3
Regime Shifts	−11.490***	2007Q1–2009Q2–2014Q1
Regime Shifts and Trend	−9.233***	2008Q1–2010Q3–2014Q3

Note: ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

To analyze the impact of FD on CO2 emissions in the presence of control variables such as TI, GDP, and economic globalization for China over the 2005Q1–2018Q4 period, the empirical equation is modeled as:

$$CO_{2,it} = FD_t + TI_t + GDP_t + GDPS_t + GL_t + t,$$

where COrepresents carbon dioxide emissions, FD denotes fscal decentralization, TI is technological innovation, GL represents economic globalization, and GDP stands for gross domestic product. Following Batterbury and Fernando (2006), Cheng (2019), Fell and Kafne (2014), Fredriksson and Millimet (2002), Konisky (2007), Millimet (2003), and Sigman (2014), FD is included as a core variable in the regression. The literature on the sign of the coefcient of FD is ambiguous. The theoretical rationale for the negative association be-tween

FD and CO_2emissions is that by authorizing the lower unit of the state, countries can successfully implement policies related to im-proving environmental quality. By contrast, FD increases COemissions due to the free-rider problem among jurisdictions, that is, the greater is the fscal expenditure authority granted to lower units of the state, the greater is the probability of deterioration in environmental quality (Cheng, 2019). Hence, the nature of the relationship between FD and COemissions is ambiguous and requires further investigation.

Following Ulucak and Khan (2020) and Li et al. (2020), we in-troduce TI as an explanatory variable in equation 1. TI promotes wider use of sustainable energy systems, thereby transforming the industrial structure and reducing CO_2 emissions. Therefore, we expect a negative impact of eco-innovation on COemissions, that is, =<0. In TIthe literature, GDP is considered as the most infuential factor re-sponsible for COemissions. Increase in economic activities result in growing demands for energy, and hence, negatively afects the environmental quality, that is, =>0. Moreover, we include the GDP square term of GDP in equation 1 to test the presence of the EKC hy-pothesis. Similarly, international trade is considered as one of the persistent causes of environmental degradation. Following Zhang et al. (2017) and Li et al. (2020), we introduce GL as an ex-planatory variable in equation 1. We expect a positive impact of GL on *CO*2.

CO_2emissions, that is, =>0. The data sources, descriptions, GL and units of variables used in equation 1 are presented in Table 1.

3.2. Empirical methodology

3.2.1. Unit root tests

Till a cointegration test is performed, the order of the integration must be checked by examining the unit root tests. The period con-sidered for our study includes global transitions that cause structural breaks. Traditional unit root tests such as ADF, DF-GLS, and KPSS do not consider structural breaks and may lead to incomplete findings (Alola and Kirikkaleli, 2019). Given these concerns, we use a unit root test of two endogenous breaks proposed by Narayan and Popp (2010). The benefit of this method is that structural breaks do not influence the data process, unlike conventional unit root tests.

Table 4
Long-run Estimates

Variables	**Coefficients$_{CCR}$** [Standard Error]	**Coefficients$_{FMOLS}$** [Standard Error]	**Coefficients$_{DOLS}$** [Standard Error]
Fiscal Decentralization (FD)	−0.25*** [0.066]	−0.256*** [0.075]	−0.272*** [0.094]
Globalization (GL)	0.149*** [0.037]	0.157*** [0.034]	0.179*** [0.037]
Technological innovation (TI)	−0.326*** [0.081]	−0.307*** [0.088]	−0.313*** [0.121]
GDP	0.863*** [0.158]	0.824*** [0.192]	0.874*** [0.113]
GDP-Square	−0.211*** [0.072]	−0.238*** [0.076]	−0.261*** [0.064]
Constant	−0.354*** [0.008]	−0.341*** [0.081]	−0.363*** [0.094]

Note: ***, **, and * denote 1%, 5%, and 10% significance level, respectively. FMOLS is fully modified ordinary least squares, DOLS is dynamic ordinary least squares, and CCR is canonical cointegrating regression.

Table 5
Robust Regression Analysis

Variables	**Coefficients$_{RR}$**[Standard Error]
Fiscal Decentralization (FD)	−0.236*** [0.055]
Globalization (GL)	−0.134*** [0.0467]
Technological innovation (TI)	−0.371*** [0.064]
GDP	0.792*** [0.172]
GDP-Square	−0.179*** [0.062]
Constant	−0.393*** [0.152]

Note: ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

3.2.2. Cointegration techniques

After the stationarity check, Bayer and Hanck's (2013) test is em-ployed to investigate the cointegration relationship among the chosen variables. This recently updated approach to cointegration ofers a more accurate outcome by combining many separate test results, such as the test of Engle and Granger (1987), Johansen (1991), Boswijk (1994), and Banerjee et al. (1998). The Fishers' equations for the Bayer–Hanck method are formulated as below:

$$EG\ JOH = 2[\ln(PEG) + \ln(PJOH)],$$

The probability values for each single cointegration test as men-This study uses CCR, FMOLS, and DOLS methods to estimate the tioned above are denoted by P, PPand P. The structure of long-run coefcients empirically (See Table 4). The results of all three EGJOH, BO, BDM. Fisher statistics determines how the underlying variables are coin-approaches are consistent with each other. It is evident that FD, TI, tegrated. As a next step, we use the Maki test of cointegration, devel-GDP, and GL are infuential factors in explaining CO2 emissions in oped by Maki (2012), and consider multiple structural breaks to explore China. The variable FD negatively afects cCOemissions, which in the long-term equilibrium relationship between COemissions and its plies that the green paradox does not hold in the case of China. The

possible determinants, namely, FD, TI, GL, and GDP. According to coefcient of TI is negative and signifcant in the case of all three es-Murthy and Ketenci (2017), the Maki cointegration test has good size timation methods. This implies that the strategy of TI is helpful in and power properties relative to other cointegration tests that also in-abating CO2emissions in China. The existence of the EKC hypothesis is tegrate structural breaks (e.g., Hatemi-J, 2008; Gregory and Hansen, evident from the switch of sign from positive to negative for the Frequency Domain Causality Test

Table 6

Frequency Domain Causality Test

Causality from Controlled Variables to Green Growth	Long-run $\omega = 0.75$ Wald Statistic(P-Values)	Medium-run $\omega = 1.50$ Wald Statistic(P-Values)	Short-run $\omega = 2.50$ Wald Statistic(P-Values)
GDP CO_2	6.750**	5.115*	4.190
	(0.034)	(0.092)	(0.1230)
GDPS CO_2	5.292*	4.859*	4.496
	(0.070)	(0.096)	(0.105)
GL CO_2	17.468***	13.527***	8.536**
	(0.000)	(0.001)	(0.014)
FD CO_2	6.854**	8.367**	6.423**
	(0.032)	(0.015)	(0.040)
TI CO_2	5.061*	5.654*	8.671**
	(0.079)	(0.059)	(0.013)

Note: ***, **, and * denote 1%, 5%, and 10% significance level, respectively. ω represents frequency.

3.2.3. Robustness check

The present study also employs DOLS, CCR, and FMOLS tests propose by Saikkonen (1992) and Stock and Watson (1993), Park (1992), and Phillips and Hansen (1990), respectively, to detect the long-run effects of FD, TI, GL, and GDP on CO2 emissions in China while using GDP and renewable energy use as controlled variables for China. Phillips and Hansen (1990) developed the semi-parametric approach FMOLS to avoid the correlation problem and emphasized that FMOLS test is asymptotically unbiased and efficient. Park (1992) developed CCR, another method similar to FMOLS, which is applied for investigating cointegration vectors in a model where the order of the integration of time series variables are I(1). The main difference between FMOLS and CCR estimators is that FMOLS estimator concentrates the transformation of both data and parameters, whereas the CCR estimator focuses only on data transformation (Wu et al., 2018). The DOLS estimator includes leads and lags to overcome simultaneity and small sample biases. Specifically, both DOLS and FMOLS estimators manage the problem endogeneity and serial correlation by coping with nuisance parameters (Yildirim and Orman, 2018). To capture the causal effects, this study also employs the spectral BC causality test developed and suggested by Breitung and Candelon (2006) to capture the causal effects of FD, TI, GL, and GDP on CO2 emissions in China. The spectral BC test was initially developed by Geweke (1982) and Hosoya (1991).

4. Results and discussions

The findings of the unit root test demonstrate that after the first difference, all variables are stationary (see Table 2). They further depict the structural breaks for each time series. The same order of integration of variables enables us to employ Bayer–Hanck and Maki cointegration tests (see Table 3).

To test the cointegration among variables presented in model 1, this study uses Bayer–Hanck and Maki cointegration tests. Substantial evidence exists for a long-run relationship between CO2 emissions and FD, TI, GDP, and GL. The significant test statistics at the level and regime shifts while using the Maki cointegration method confirming our claim of the stable long-run relationship among variables. This study uses CCR, FMOLS, and DOLS methods to estimate the long-run coefficients empirically (See Table 4). The results of all three approaches are consistent with each other. It is evident that FD, TI, GDP, and GL are influential factors in explaining CO2 emissions in China. The variable FD negatively affects CO2 emissions, which implies that the green paradox does not hold in the case of China. The coefficient of TI is negative and significant in the case of all three estimation methods. This implies that the strategy of TI is helpful in abating CO2 emissions in China. The existence of the EKC hypothesis is evident from the switch of sign from positive to negative for the coefficients of GDP to GDP-Square. The coefficient of GL is positive and significant, which implies that an increase in the degree of GL results in growing demands for energy, and hence, is one of the main causes of environmental degradation.

To analyze the causal interaction between variables in model 1, this study uses a frequency domain causality test (see Table 6). We checked the causal relationship among variables at three different runs by using a frequency value of 0.75 for the long-run, 1.50 for the medium-run, and 2.50 for the short-run. The results suggest that FD, TI, and GL cause CO2 emissions in all three runs. However, GDP causes CO2 emissions only in the medium- to long-run. Hence, it can be argued that any policy shock in FD, TI, and GL has implications for CO2 emissions in the short- to long-run. Moreover, any policy shock in GDP changes CO2 emissions in the medium- to long-run.

4.2. Discussion

By employing various time series econometric methods, we found that FD, TI, GDP, and GL are influential factors in explaining CO2 emissions in China. The variable FD negatively affects CO2 emissions, which implies that the green paradox does not hold in the case of China. These results are similar to the findings of Cheng (2019), Fredriksson and Millimet (2002), Konisky (2007), and Levinson (2003). A high degree of FD is a prerequisite for improving the environment.

Hence, to successfully achieve the target of low CO2 emissions and energy-saving functions of fiscal expenditure, it is imperative to clarify the responsibilities at different levels of government. The coefficient of TI is negative and significant in the case of all three estimation methods. This implies that the TI helps reduce CO2 emissions in China. These results are analogous with the earlier findings of Li et al. (2020), Ulucak and Khan (2020), and Wang et al. (2020). TI helps create a more sustainable industrial structure, and hence, reduces CO2 emissions. The existence of the EKC hypothesis is evident from the switch of sign from positive to negative for the coefficients of GDP to GDP-Square. The EKC hypothesis is confirmed by the earlier studies such as Apergis and Ozturk (2015), Balsalobre-Lorente et al. (2019), Bhattacharya et al. (2016), Liddle (2018), and Ulucak and Khan (2020). At the initial stages of development, the environment deteriorates because of heavy infrastructure projects. However, after achieving a certain level of development, the environment improves with further increase in economic growth because more money can be spent to improve environmental quality. The coefficient of GL is positive and significant, which implies that an increase in the degree of GL results in growing demands for energy, and hence, is one of the main causes of environmental degradation. Therefore, GL is considered as one of the persistent causes of environmental degradation. These results support the earlier findings of Alola et al. (2019), Bhattacharya et al. (2016), Hasanov et al. (2018), Liddle (2018), and Ulucak and Khan (2020). This study uses the SSR method to check the robustness of results. The results of Table 5 are consistent with the outcomes derived from the CCR,

FMOLS, and DOLS methods.

5. Conclusions and policy recommendations

The increase in world output and economic activities because of advanced technologies has remarkably increased the use of fossil fuels, which is a severe threat to the environment. However, recently introduced environment-friendly technologies have shifted the economic structure from non-renewable energies to sustainable sources such as renewable energy. With the ushering in of industrial revolution 4.0, eco-friendly technologies have tremendously improved the environmental quality of advanced countries. These eco-friendly technologies have widespread implications for the environment and climate change. Hence, the importance of eco-friendly technologies has further increased in the industrial revolution 4.0. The high growth in CO2 emissions has drawn the attention of researchers to determine the influential factors of CO2 emissions.

Various studies have been conducted to ascertain the main causes of environmental degradation. However, unlike international trade, economic activities, and eco-innovation, the political structure of a country is often overlooked by scholars because of its indirect impact, which is difficult to evaluate, on emission reduction. This study examined the

impact of FD on CO2 emissions in the presence of GDP, GL, and TI in the case of China. Understanding the nexus between FD and CO2 emissions is important when formulating policies to achieve sustainable development.

The empirical estimation provides robust results: i) the variables CO2 emissions, FD, TI, GDP, and GL are co-trending in the longrun; ii) FD, TI, GDP, and GL are influential factors in explaining CO_2 emissions in China; iii) FD and TI are beneficial for reducing CO_2 emissions in China; iv) globalization and economic activities are harmful to environmental quality; v) any policy shock in FD, TI, and GL has implications for CO_2 emissions in the short- to long-run; and vi) any policy shock in GDP changes CO_2 emissions in the medium- to long-run. The findings of this study can help in designing policies related to FD and the environment in China. To manage deteriorating environmental quality, China needs to formulate policies to mitigate emission levels. Similar to Denmark and Sweden, promoting energy-efficient systems to transform the industrial structure to renewable energies is critically needed. Moreover, to smoothen the process, it is imperative to clarify the responsibilities at different levels of government to successfully achieve the target of low CO_2 emissions and energy-saving functions of fiscal expenditure. Focusing on environment-friendly technologies, which shift the economic growth drivers from non-renewable energies to sustainable sources such as renewable energy, is needed. These eco-friendly technologies have widespread implications for the environment and climate change. Moreover, China needs to switch its industrial and economic structure to promote TI. This study is limited to empirically examining the impact of FD on CO_2 emissions in the presence of some control variables such as TI, GL, and GDP. We found that FD, TI, GL, and GDP are important factors affecting CO_2 emissions in China. The results of this study can be extended to other countries, regions, and groups. Moreover, future research is required to identify the complementarities of FD in affecting CO_2 emissions.

Credit authorship contribution statement

Ya Cheng: Conceptualization, Methodology, Supervision, Writing - original draft. Usama Awan: Software, Data curation, Validation, Project administration, Writing - original draft. Shabbir Ahmad: Conceptualization, Writing - review & editing. Zhixiong Tan: Conceptualization, Software, Formal analysis, Visualization,Investigation, Writing - review & editing.

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