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RESEARCH ARTICLE

Does digitalization matter in green preferences in nexus of output volatility and environmental quality?

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Abstract
The fact is that output volatility and carbon dioxide (CO2) emissions move together over the period. This empirical study examines the dynamic effect of output volatility on CO2 emissions using the advance nonlinear panel autoregressive distributed lag (ARDL) approach. The empirical analysis is executed for ten high emitters Asian countries covering the period from 1990 to 2019. The findings reveal that positive change in output volatility increases CO2 emissions and negative change in output volatility decreases CO2 emissions in the long run in Asia. The results also show that digitization also positively impacts environmental quality in Asia due to green globalization. The findings are also robust and similar in an alternative indicator of the environment. An important policy is that reducing volatility in output is a suitable way of environmental sustainability, particularly for Asian countries.

Keywords Output volatility · CO2 emissions · Digitalization · Asia

Introduction

The present and future well-being of the competitive economy depends on the stability of its economic system. A predictable economic environment is necessary for economic growth, capital mobility, investment, and energy consumption. Conversely, economic uncertainty hinders major economic factors like output growth, employment, capital flows, and investment (Montiel and Servén 2006). Therefore, worldwide, the stability of the economy remains one of the central policy objectives. In the mid of 1980s, the obstinate reduction in volatility is noticed in the USA and several other regions of the world that captured the consideration of several researchers to recognize the fundamental reasons behind the obstinate decline in volatility. Meanwhile, the research work which is done by Kydland and Prescott (1982), Nelson and Plosser (1982), King et al. (1988), and Long Jr and Plosser (1983) started a debate among policymakers and economists about the foundations of fluctuations in macroeconomics. Iseringhausen and Vierke (2019) noted that initially, the labor force's government role and demographic factors were assumed as important factors of stability in macroeconomics in the OECD countries. Afterward, the studies associated output volatility with trade openness (Mohey-ud-Din and Siddiqui 2018, financial performance (Majeed and Noreen 2018), environment (Majeed and Mazhar 2019a, b), the uncertainty of terms of trade (Hakura 2009), population (Mobarak 2005), inflation volatility (Majeed and Noreen 2018), and economic growth Badinger 2009; Ozturk and Acaravci 2013).

Recently, the study done by Majeed and Mazhar (2019a, b) reported that climatic degradation is a fundamental factor of output volatility. The study also pointed out that ecosystem changes significantly contribute to influencing uncertainty in economic conditions. The increase in climatic shocks and

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environmental degradation results in increasing uncertainties of production by affecting the productivity of agriculture in agricultural regions. Additionally, drought, extreme climatic conditions, losses in major crops like wheat and maize, and reduction in arable land increase the output and production uncertainty in the agricultural sector (WESS 2013). The degradation of the environment in the case of air pollution hampers both human capital and natural resources that increase the development instability by deteriorating the productivity of capital (Gwangndi et al. 2016).

By applying nonlinear econometric methods, the study carries new understandings on the nexus between output volatility and environmental degradation. Currently, the interest of researchers is increasing towards spatial analysis in the climatic and regional sciences. As regions and countries are not entirely independent, they have closely collaborated, and their collaboration is crucial to integrate with the econometric analysis for attaining the correct results (Fingleton and Le Gallo 2008). In Kolb's (2011) view, the speedy rise in economic incorporation has produced many prospects for disseminating the benefits all over the worldwide economy along with allocating the uncertainties and risks with the world. In this respect, Antonakakis and Badinger (2012) contended that along with increasing economic dependence, economic growth and its volatility spillover from international economies to the domestic economies.

Abate (2016) reported that macroeconomic instability of a country not only dampens the development of its own economy but also spillovers to economies of other countries and impedes its growth rates by producing the instabilities in production and consumption that disrupt physical and human investment; thus, it also influenced the environment. Florax and Van der Vlist (2003) noted that economic instability has also badly affected environmental quality as a worldwide challenge in the last few decades. Chiefly, the whole world has perceived the global issue of climatic change and numerous other issues of environment that result in increasing resource wars in the form of oil wars, water wars, and diamond wars both at national and international levels. These environmental issues like greenhouse gas emissions, soil erosion and exhaustion, and deforestation do not only respect the border of the country, it also flourishes directly to the nearer localities (Pereira 2015).

Moreover, Ramirez and Loboguerrero (2002) noted that economies are connected with each other through numerous channels like technological and knowledge diffusion, digitalization, capital outflows and inflows, environmental, economic, and political policies that exert possible spillover regional and cross border impacts. The shocks are easily transmitted through globalization from one region to another region. Most importantly, trade openness also affects regional environmental quality. Under the objective of promoting trade internationally, the regulatory authorities usually overlook the implementation of environmental protection rules that result in deteriorating the quality of the environment (Managi and Kumar 2009). The use of information and communication technology (ICT) has transformed human society altogether. It has become an important contributor to the growth of developed and emerging economies (Jin and Cho 2015; Salahuddin and Alam 2016; Erumban and Das 2016; Xinmin et al. 2020; Usman et al. 2021; Su et al. 2021). Moreover, the role of ICT is not limited to one or two sectors of the economy but spreads to banking and finance (Agboola 2006; Osabuohien 2008; Hafeez et al. 2018), education (Sanchez et al. 2011), health care (Honka et al. 2011; Shiferaw and Zolfo 2012; Chaabouni and Saidi 2017), energy (Ozturk 2010; Ishida 2015; Salahuddin and Alam 2016), and industries (Wang et al. 2010). Though the beneficial impacts of ICT are quite a lot, its hazardous effects are also under discussion particularly its role in polluting the environment (Danish et al. 2018; Chen et al. 2019).

The previous study does not highlight the output volatility and environmental nexus. Some studies, for instance, Antonakakis and Badinger (2012) and Lin and Kim (2013), reported the output volatility and economic growth for developed and developing economies. Similarly, Gavin and Hausmann (1998) assess the macroeconomic volatility and economic development for Latin Americans, while Ullah et al. (2020) elaborate on the relationship between GDP volatility and CO2 for Pakistan. A key objective of the study is that we examine the asymmetric impact of output volatility on CO2 for Asian economies. Thus the asymmetric impact of output volatility on environmental pollution is a novel contribution to the environmental and economic literature. There is a lack of literature on this topic as only one study offers the empirical investigation of output volatility-environmental degradation nexus by employing panel data technique (Majeed and Mazhar 2019a, b). According to our knowledge, the current study is the first one that investigates the asymmetric effects of output volatility on environmental degradation. This study is more important for the policymakers as well as authorities for environmental quality. In the next sections, we have covered the literature, model and methodology, results and discussion, and conclusion of the study.

Literature review

The theoretical background associated with macroeconomic volatility of business cycles can be drawn back to the earlier twentieth century when the economists of different schools of thought anticipated various sources of output volatility. The comprehensive debate on the issue of the business cycle started after the occurrence of the great depression. Keynes figured out the sticky nature of prices and wages that limit the speedy regulation of macroeconomic equilibrium and the factors of demand-side tend to create instabilities in output.

Furthermore, the Sun-spot theory and the real business cycle (RBCs) theory determine the contribution of the environment in macroeconomic instability. The RBCs school of thought describes that technological productivity and innovations shocks are the fundamental causes behind fluctuations in the business cycle. Likewise, the pioneer of Sun-spot theory Jevons (1878) elaborates sunspots as the fundamental source of economic instability. According to this theory, Sunspots fluctuate the weather of the earth that directly affects the productivity of output by producing structural changes in the agricultural sector. These structural changes have transferred to each sector of the economy, thus also affect the quality of the environment as well the health of the economy. A total of 1.34 billion Chinese lives in vulnerable and highly vulnerable area (He et al. 2018; Zuo et al. 2020; He et al. 2021). The minimization of construction and demolition waste is an imperative approach to tackle challenges of waste management (Yuan et al. 2021; He et al. 2021). Government subsidy has less impact on waste reduction as an incentive policy (Liu et al. 2020). To control CO_2 emission, a carbon tax is encouraging to use electric vehicles for better environment (Li et al. 2020).

The intrinsic linkages of growth stability and environmental quality can be figured out through intergenerational equity and ecological modernization theories. Streamflow and sediment load dynamics are primarily instigated by an increase in temperature (Tian et al. 2020; Zhao et al. 2020; Zuo et al. 2020). The ecological modernization theory ruminates the productivity of the environment as natural capital like capital and labor productivity. The theory recommends the better usage of natural resources using green and clean technologies to have stable and higher growth rates. Also, the consequences of intergenerational equity theory recommend that stability of growth can be attained by concentrating on social impartiality between future, present, and past generations with the effective utilization of services of the ecosystem. This argument is also supported by Gavin and Hausmann (1998) and Badinger and Breuss (2008). Similarly, the "value belief norms theory," "the environmental Kuznets curve hypothesis," and "the environmental transition theory" reveal the role of time frame, priorities of people for a higher quality of the environment, and education that tend to achieve sustainable growth after a time lag. The environmental transition theory reveals that at the initial level of transition, the economy's structure converges to the industrial sector from the agricultural industry; the demand for urban infrastructure and energy raises that result in more carbon emissions. Then, when the per capita income of cities or economies rises, the emphasis is averted towards higher protection of the environment.

Just like environmental transition theory, the environment Kuznets curve hypothesis postulates that at initial levels of growth, carbon emission rises as much attention is given to development. But, after achieving the highest level, the economic development-carbon emissions nexus becomes negative because people start demanding a better quality environment. In the end, the value belief norm theory reveals how the psychology of the environment influences the quality of the environment. According to the followers of this belief, environmental preservation and environmental degradation are initiated by people's values and beliefs they have about the services of the ecosystem, like if they provide more value to the environment, then they will ruminate themselves more responsible for pollution-related activities. Resultantly, pro-environmental kind of behavior is encouraged; otherwise, individuals do not consider their accountability for environmental issues. Thus, theoretical literature suggests that economic growth or output volatility is interconnected with the environment.

Based on the theoretical background, policymakers and researchers tried numerous empirical exercises to investigate the impact of output volatility on the environment. Volatility is not good for economic growth, because it adversely affects investment, saving, growth, distribution of income, and poverty. Similar findings are also funded by Inter-American Development Bank (1995), Flug et al. (1998), and Gavin and Hausmann (1998). In the case of UAE, Darrat et al. (2005) found the presence of volatility reducing the influence of financial expansion in the long run. The findings conclude that monetary policy and technological progress contribute more significantly in bringing variations in output. Conversely, fiscal policy also affects the stability of growth but at a smaller magnitude (Hondroyiannis and Papapetrou 2000). In the case of Greek economy, Chapsa et al. (2011) found the causal linkage between inflation uncertainty and output uncertainty. In case of South Africa, Bhoola and Kollamparambil (2011) noted that monetary policy contributes in the alleviation of output volatility. In case of Indian economy, Ghosh (2013) found financial deepening, government expenditure, and institutional quality as instability-reducing factors. Generally, these results conclude that country-specific issues play a leading role in mounting/waning output instability in the country. Another strand in literature investigated the influences of demographics, financial development, government expenditure, remittances, trade openness, and democracy on output volatility (Mobarak 2005; Bejan 2006; Bugamelli and Paterno 2011; Iyidogan and Turan 2017; Majeed and Noreen 2018; Iseringhausen and Vierke 2019). These studies reported that along with domestic components, external factors of the economies like remittances and trade openness contribute more dominantly in explaining instability in output.

Gounder and Saha (2007) noted that variations of GDP per capita are initiated by production uncertainties in the manufacturing and agriculture sector and adversely affect the environment. Ullah et al. (2020) found the harmful influence of output instability on the environment. Maddison (2006) and You et al. (2019) reported the strong influences of carbon emissions of neighboring countries on the carbon emissions of local country. The developed countries transfer their pollution to the developing economies through "pollution trading" that challenge environmental protections by permitting polluters to transfer their pollution emissions by selling and purchasing their right of pollution to each other. Samreen and Majeed (2020) also found the existence of a significant and positive influence of pollution emissions of neighboring economies on pollution emission of local economies. Zhao et al. (2021) reported that domestic environmental structure is largely exaggerated by the income per capita, biocapacity, and environmental footprint of neighboring countries. In their views, an upsurge in awareness regarding ecological diffusion and protection of cleaner technological production and capital flows mainly influences the domestic environmental footprint. Abildtrup et al. (2013) concluded the negative influence of the use of land on supply cost of water both within the supplied region and the surroundings and nearby region. Abate (2016) reported the negative influence of instability on GDP per capita; however, Daud and Podivinsky (2011) discovered negative influence of debt on GDP per capita. On other hand, Stanca (2010) reported that welfare is very crucial because of aggregate economics and analogous social circumstances of neighboring countries. In crux, theoretical and empirical literature suggests that output volatility or macroeconomic volatility is bad for economic factors.

Model, methods, and data

Recent theoretical and empirical research suggests that a volatile output leads to significantly decrease investment and economic growth, harms the distribution of income, and increases poverty. Majeed et al. (2021) noted that output volatility negatively affects each sector of the economy, i.e. agriculture, industrial, and services sectors; it also affects environmental quality. Based on the literature, output volatility is considered one of the important factors of economic growth as well environment (Badinger and Breuss 2008; Lin and Kim 2013, Ullah et al. 2020). The basic model is:

$$CO_{2,it} = \beta_0 + \beta_1 OV_{it} + \beta_2 ICT_{it} + \beta_3 Trade_{it} + \beta_4 GE_{it} + \mu_{it} \quad (1)$$

Equation (1) is the Asian economies CO2 model, where $CO_{2,\ it}$is the carbon emission to Asia which is assumed to depend on the output volatility denoted by OV_{it}, where t indicates the time period from 1990 to 2019 and i represents cross-sections from 1, 2, …10. We expect an estimate of β_1 to be negative. Equation 1 gives us the long-run effects of exogenous variables on CO2 emissions. We also used the ICT, trade, and government expenditure variables as control variables in the analysis. We also evaluate the short-term effects; therefore, we need to include the short-run dynamic adjustment process into Eq. (1). The model is:

$$\begin{aligned}\Delta CO_{2,it} = {} & \pi + \sum_{p=1}^{n1} \pi_{1p} \Delta CO_{2,it-p} + \sum_{P=0}^{n2} \pi_{2p} \Delta OV_{it-p} \\ & + \sum_{p=0}^{n3} \pi_{3p} \Delta ICT_{it-p} + \sum_{p=0}^{n4} \pi_{4p} \Delta Trade_{it-p} \\ & + \sum_{p=0}^{n5} \pi_{5p} \Delta GE_{it-p} + \beta_1 CO_{2,it-1} + \beta_2 OV_{it-1} \\ & + \beta_3 ICT_{it-1} + \beta_4 Trade_{it-1} + \beta_5 GE_{it-1} + \mu_{it} \quad (2)\end{aligned}$$

where "Δ" represents the first difference, π is a constant term, β_1 and β_5 are the long-run coefficients estimates, $\pi_{1p}$and π_{5p} are the short-run coefficients estimates, and μ_{it} is an error term. Equation (2) gives us short- and long-term coefficient estimates of the linear panel ARDL model. However, for the validity of long-run effects, a cointegration must be established and Pesaran et al. (2001) revealed the F test and ECM or t-test to establish cointegration. One of the assumptions of the panel ARDL model is that variables could be a mixture of I(0) and I(1). While nonlinear approach decomposes the output volatility variables into two partial sums, a positive partial sum ($OV^{+}{}_{it}$) is supposed to capture positive changes of output volatility, and a negative partial sum ($OV^{-}{}_{it}$) is supposed to capture the negative changes. Under this modern approach, a positive and negative change of output volatility is not expected to have symmetric effects on CO2 emissions. We are following the Shin et al. (2014) approach to decompose the output volatility variable in panel form which is as follows:

$$OV^{+}{}_{it} = \sum_{n=1}^{t} \Delta OV^{+}{}_{in} = \sum_{n=1}^{t} \max\left(\Delta OV^{+}{}_{in}, 0\right) \quad (3)$$

$$OV^{-}{}_{it} = \sum_{n=1}^{t} \Delta OV^{-}{}_{in} = \sum_{n=1}^{t} \min\left(\Delta OV^{-}{}_{in}, 0\right) \quad (4)$$

where $OV^{+}{}_{it}$ is the partial sum of positive changes and reflects an increase in output volatility, while $OV^{-}{}_{it}$ is the partial sum of negative changes and reflects a decrease in output volatility. We re-formulated Eq. (2) into a new error correction formats as follows:

$$\Delta CO_{2,it} = \pi + \sum_{p=1}^{n1}\pi_{1p}\Delta CO_{2,it-p} + \sum_{P=0}^{n2}\pi_{2p}\Delta OV^{+}{}_{it-p} + \sum_{p=0}^{n3}\pi_{3p}\Delta OV^{-}{}_{it-p} + \sum_{P=0}^{n2}\pi_{4p}\Delta ICT_{it-p} + \sum_{p=0}^{n3}\pi_{5p}\Delta Trade_{it-p} + \sum_{p=0}^{n4}\pi_{6p}\Delta GE_{it-p} + \beta_1 CO_{2,it-1} + \beta_2 OV^{+}{}_{it-1} + \beta_3 OV^{-}{}_{it-1} + \beta_6 ICT_{it-1} + \beta_7 Trade_{it-1} + \beta_7 GE_{it-1} + \mu_{it} \quad (5)$$

The nonlinear ARDL panel model adopted in this study is assembled by incorporating long-term and short-term nonlinear terms of output volatility and followed the Shin et al. (2014) approach. Unlike the linear version of the panel ARDL, the nonlinear equation is referred to as asymmetric panel ARDL that allows us asymmetric responses of output volatility on CO2 emissions. We also estimate the nonlinear panel ARDL through the pooled mean group (PMG) or mean group (MG) estimators, and after that, we assess the appropriate estimators through the Hausman test. This approach is the workhorse of the modern time series dataset. The main edge of this approach is that it allows us to incorporate the nonlinear variables in our analysis and estimates the short and long run in a single step.

The study uses CO2 emissions as a dependent variable measured in kilotons. For robust analysis, we also used GHEs emissions. Output volatility variable is used as an independent variable and the remaining three factors used control variables in our analysis. The independent variables selection is based on study of Majeed et al. (2021). The data on CO2 emissions, GHEs, ICT, trade, and government expenditure are obtained from the World Bank. The dataset on years of schooling is provided by Barro and Lee (2010). Our study uses annual data for 10 Asian economies (China, India, Iran, Japan, Malaysia, Saudi Arabia, Thailand, Turkey, UAE, and Vietnam) from 1990 to 2019, and the selection of time frame is based on data availability. All variables are converted into natural logarithm, except ICT form for consistent and robust estimates. Table 1 gives information about variables definitions and data sources. The detailed descriptive analysis and correlation matrix are also given in Table 2. The next section has also reported the results of the ARDL and NARDL models.

Results and discussion

Before estimating the model, as a preliminary analysis, stationarity properties of the data have been tested by using Levin–Lin–Chu (LLC), Im–Pesaran–Shin (IPC), and augmented Dickey–Fuller (ADF). In Table 3, the results of LLC tests confirm that output volatility and carbon emissions are stationary at the first difference; however, all other variables of the model are stationary at I(0). The remaining two tests are also reported in the mixed order of integration. In order to proceed with regression analysis, ARDL and NARDL estimation techniques have been used. Table 4 provides the ARDL and NARDL estimates for carbon emissions. The long-run coefficient of output volatility variable is statistically insignificant; it suggests that output volatility exerts no significant influence on pollution emissions in the long run. However, in the short run, the coefficient estimate of output volatility is positive and statistically significant at the 10 percent level. The coefficient estimate shows that due to 1% upsurge in output volatility, pollution emissions increase by 0.402% in the short run.

The influence of ICT on pollution emissions is significant at 10% level in the long run; however, the short-run coefficient estimate of this variable is statistically insignificant. The negative estimate of ICT proposes that a 1% increase in ICT results in decreasing pollution emissions by 0.09% in the long run. The coefficient of trade is also statistically significant only in the short run at 10% level. The coefficient estimate of this variable is negative which postulates that due to an increase in trade, the pollution emissions reduce by 1.308%. In precise, both variables ICT and trade result in reducing pollution emissions in the long run. However, GE is positively associated with pollution emissions in the long run at 10% level of statistical significance but the estimate of this variable is again statistically insignificant in the short run. The positive association suggests that due to the upsurge in GE, pollution emissions also increase by 0.05%. In case of ARDL, the

Table 1 Variables description

Variables	Symbol	Definition	Data source
Carbon dioxide emissions	CO_2	Carbon dioxide emissions (Kilotons)	World Bank
Greenhouse gas emissions	GHEs	Total greenhouse gas emissions (kt of CO2 equivalent)	World Bank
Output volatility	OV	The standard deviation of GDP per capita (Constant, 2010 US$)	Author's calculations
Information and Communication Technology	ICT	Proxy of mobile cellular subscriptions (per 100 people)	World Bank
Trade openness	Trade	Trade (% of GDP)	World Bank
Government expenditure	GS	General government final consumption expenditure (% of GDP)	World Bank

Table 2 Descriptive analysis and correlation matrix

	CO2	GHEs	OV	ICT	Trade	GE
Descriptive analysis						
Mean	12.87	13.22	1.043	2.285	4.157	13.53
Std. Dev.	1.328	1.223	1.066	3.054	0.673	4.935
Min	9.234	11.00	0.776	0.787	2.741	5.465
Max	16.10	16.40	3.867	5.360	5.395	34.15
Correlation matrix						
CO2	1.000					
GHEs	0.970	1.000				
OV	0.371	0.222	1.000			
ICT	0.203	0.082	0.790	1.000		
Trade	−0.555	−0.580	0.176	0.360	1.000	
GE	0.265	0.144	0.143	0.098	−0.204	1.000

estimate for ECM (−1) is statistically significant and negative at 10% level. The coefficient −0.153 indicates that within 1 year, almost 15% disequilibrium of carbon emissions will be adjusted back towards long-run equilibrium.

In this study, an asymmetric association between output volatility and pollution emissions has also been investigated. To perform this task, the output volatility has been decomposed into negative and positive partial sum to dig out the asymmetric influence of output volatility on carbon emissions in selected countries of Asia. The short-run and long-run asymmetry in the association are examined using the Wald test. The coefficient estimate of Wald test confirms the existence of long-run asymmetry in the association between output volatility and carbon emissions at 1% level of significance. However, the Wald test does not confirm this association in the short run.

The long-run results show that the asymmetry in the influence of positive shock (OV_positive) and negative shock (OV_negative) in output volatility on pollution emissions in selected Asian countries is statistically significant. The long-run coefficient of positive change in output volatility is statistically significant at 5% level associated with a positive sign. The estimate confirms that one unit positive shock in output volatility upsurges pollution emissions by approximately 0.619% in the long run. Conversely, a unit negative change in output volatility results in decreasing pollution emissions by approximately 0.108% in the long run, and the influence of this estimate is statistically significant at 5% level. The results of long-run estimates confirm that the influence of positive shock in output volatility on pollution emissions in selected Asian countries is stronger than the reducing impact of a unit negative shock in output volatility. The results are similar with Ullah et al. (2020), who found that increase in GDP volatility has harmful effects on the environment, while a decrease in GDP volatility has a favorable impact on the environment. Similarly, Sohail et al. (2021) noted that policy uncertainty and output volatility raise the non-renewable energy consumption that is a key source of CO2 emissions. A positive shock of output volatility has a positive effect on carbon pollution, suggesting that volatility raises the non-renewable consumption of energy in economic activities. Another interesting finding is that higher output volatility is affecting the environment more than lower output volatility. The short-run coefficient estimate of positive shocks in output volatility is statistically insignificant; however, the coefficient estimate of negative shocks in output volatility is also statistically insignificant in the short run. There is still large controversy, whether it is a negative or positive effect on CO2 emissions. The negative impact of output volatility on CO2 emissions thus confirms that more unstable economies are more likely to grow faster due to the extra use of dirty energy consumption that leads to more energy consumption. A similar finding is already found by Ullah et al. (2020) for Pakistan, who noted that GDP stability increases CO2 emissions.

As long as other variables are concerned, ICT is negatively associated with pollution emissions in the long run at 1% level of significance. However, the coefficient estimate of this variable is statistically insignificant in the short run. The influence of trade on pollution emissions is significant at 10% level in the short run; however, the long-run coefficient estimate of this variable is statistically insignificant. The negative estimate of trade proposes that a 1% increase in trade has to decrease

Table 3 Panel unit root tests

	LLC I(0)	I(1)	Decision	IPS I(0)	I(1)	Decision	ADF I(0)	I(1)	Decision
CO2	−1.029	−6.810***	I(1)	−1.330	−4.691***	I(1)	0.464	−11.66***	I(1)
GHEs	−3.219***		I(0)	−1.612	−5.747***	I(1)	−0.279	−15.12***	I(1)
OV	−0.873	−7.364***	I(1)	−1.398	−8.602***	I(1)	0.428	−13.40***	I(1)
ICT	−7.228***		I(0)	−6.645***		I(0)	−10.10***		I(0)
Trade	−2.587**		I(0)	−1.556	−8.116***	I(1)	−0.058	−12.10***	I(1)
GE	−2.747***		I(0)	−3.683***		I(0)	−4.951***		I(0)

Table 4 ARDL and NARDL estimates of CO2

	ARDL Coefficient	S.E	t-Stat	Prob.*	NARDL Coefficient	S.E	t-Stat	Prob.*
Long run								
OV	−0.010	0.057	0.166	0.868				
OV_POS					0.619***	0.061	10.19	0.000
OV_NEG					−0.108***	0.015	6.987	0.000
ICT	−0.090***	0.016	5.598	0.000	−0.059***	0.006	9.425	0.000
TRADE	−1.308***	0.204	6.413	0.000	−0.027	0.062	0.427	0.670
GE	0.050***	0.017	3.021	0.003	0.026***	0.009	2.706	0.008
Short run								
D(OV)	0.402*	0.232	1.733	0.085				
D(OV_POS)					0.169	0.216	0.782	0.435
D(OV_POS(−1))					0.326**	0.129	2.518	0.013
D(OV_NEG)					−0.006	0.023	0.264	0.792
D(ICT)	0.027	0.039	0.677	0.499	−0.001	0.042	0.021	0.983
D(TRADE)	−0.109	0.065	1.663	0.098	−0.032*	0.016	1.940	0.054
D(TRADE(-1))					0.059	0.069	0.863	0.389
D(TRADE(-2))					−0.015	0.054	0.268	0.789
D(GE)	−0.002	0.011	0.207	0.836	0.006	0.008	0.708	0.480
D(GE(−1))					0.008	0.009	0.886	0.377
C	0.758*	0.437	1.733	0.085	3.207***	1.018	3.152	0.002
Diagnostic								
ECM (−1)	−0.153*	0.090	1.669	0.107	−0.274***	0.087	3.147	0.002
F-test	7.689***				8.975***			
	0.122				1.021			
Log likelihood	488.1				493.9			
Wald-SR					1.235			
Wald-LR					6.684***			

Note: asterisks three, two, and one are for 1%, 5%, and 10% level of significance

pollution emissions by 0.032% in the short run. In the long run, coefficient estimate of government spending is positive and statistically significant at 1% level. The coefficient estimate shows that due to 1% upsurge in government spending, pollution emissions increase by 0.026% in the long run. However, the short-run coefficient of the government spending variable is statistically insignificant; it suggests that government spending exert no significant influence on pollution emissions in the short run.

As far as the ECM coefficient of NARDL is concerned, the coefficient estimate for ECM (−1) is statistically significant and negative at a 1% level. The coefficient −0.274 indicates that within one year, almost 27% disequilibrium of pollution emissions will converge back towards long-run equilibrium. While log-likelihood is also shown, the goodness of fit and F-test are also reported the Cointegration. To check the robustness of our model, we have used GHEs as the dependent variable and investigated the effect of output volatility on greenhouse emissions. The robust analysis is shown in Table 5; the study has a similar coefficient estimated for focused and controlled variables using ARDL and NARDL techniques.

Conclusion and policy

Output volatility is a serious and controversial concern of policymakers across the Asian economies as it negatively affects the economy of each sector. This paper gives us an empirical assessment of output volatility and CO2 emissions relationship in the light of an advance econometric framework. This study also used the GHEs for alternative proxied for robust analysis. This study provides evidence on the dynamic effect of output volatility on CO2 emissions using panel data of 10 economies over the period 1990 to 2019. For analysis, we used ICT, trade, and government spending as control variables. The analysis has been carried out by using both symmetric ARDL and asymmetric ARDL panel data models for the sake of comparison and extended the analysis. These models estimate through MG and PMG, while on the basis

Table 5 ARDL and NARDL estimates of GHEs (robustness model)

	ARDL Coefficient	S.E	t-Stat	Prob.*	NARDL Coefficient	S.E	t-Stat	Prob.*
Long run								
OV	0.441***	0.042	10.42	0.000				
OV_POS					0.561***	0.037	15.04	0.000
OV_NEG					−0.190***	0.072	2.637	0.010
ICT	−0.009	0.006	1.559	0.121	−0.010*	0.005	1.857	0.065
TRADE	−0.079***	0.030	2.641	0.009	−0.139	0.027	5.190	0.000
GE	0.003	0.004	0.751	0.454	0.010**	0.004	2.274	0.024
Short run								
D(OV)	0.160	0.153	1.045	0.297				
D(OV(−1))	0.216	0.310	0.698	0.486				
D(OV_POS)					0.023	0.183	0.125	0.900
D(OV_POS(−1))					0.165	0.425	0.387	0.699
D(OV_NEG)					−0.001	0.005	0.220	0.826
D(ICT)	0.004	0.034	0.107	0.915	0.008	0.034	0.224	0.823
D(ICT(-1))	−0.022	0.021	1.034	0.303	0.001	0.023	0.023	0.982
D(TRADE)	0.020	0.021	0.958	0.339	0.116**	0.055	2.098	0.037
D(TRADE (−1))	0.032	0.028	1.152	0.251	0.012	0.068	0.176	0.861
D(GE)	0.013	0.008	1.633	0.104	0.010*	0.006	1.661	0.101
D(GE (−1))	−0.011	0.014	0.743	0.459	−0.005	0.012	0.445	0.657
C	4.920**	1.875	2.624	0.009	5.372**	2.146	2.502	0.013
Diagnostic								
ECM (−1)	−0.361**	0.138	2.609	0.010	−0.399**	0.157	2.540	0.012
F-test	5.655***				7.689***			
Hausman test	1.235				1.001			
Log likelihood	574.7				571.8			
Wald-SR					1.235			
Wald-LR					7.688***			

Note: asterisks three, two, and one are for 1%, 5%, and 10% level of significance

of Hausman specification tests, the results of preferred PMG models are only reported.

The results from the estimated coefficients of ARDL and NARDL model reported three types of relationships between output volatility and pollution emissions in selected Asian countries. These results include short-run association, long-run association, and the speed of convergence to attain equilibrium. The empirical results for ARDL model show that output volatility has a significant increasing effect on pollution emissions in the short run, but output volatility has an insignificant influence on pollution emissions in the long run. However, the empirical results of NARDL model suggest that the influence of positive shock in output volatility on pollution emissions in selected Asian economies is significantly different (both in magnitude and direction) from that of negative shocks in the long run. The results for long-run asymmetries suggest that positive shock in output volatility has a significant positive influence on pollution emissions, while negative shock in output volatility has a significant reducing influence on pollution emissions. However, the coefficient estimates of positive shocks and negative shocks in output volatility are statistically insignificant in the short run. Thus output volatility is also behaved asymmetrically in the environment and fact pronounced. On the other hand, additional results in terms of the control variables suggest that a negative effect of ICT and trade on pollution emissions and positive effect of government spending on pollution emissions in the long run in both regressions; however, in the short run, the effect of all these variables on pollution emission is statistically insignificant in case of ARDL, Trade exerts a positive influence on pollution emissions in case of NARDL. Our robust analysis gives us similar estimates for ARDL and NARDL. The remaining control variables, ICT and trade, also carry correct signs, and findings are similar to the theory and empirical insights.

The empirical analysis gives us evidence in the provision of the need for commitments regarding the achievement of sustainable development goals (SDGs) that can support offsetting pollutant emissions across and within Asian economies. The countries should work together for achieving this common goal and providing incentives for investment and diffusion of green and clean technologies. The national and sub-national authorities should also strengthen the execution of environmental policies to improve environmental quality. The restrictions on dirty industrial and agricultural productivity in highly polluted Asian economies could also be beneficial for avoiding negative environmental externalities. Our empirical analysis also enforced the importance of output stability as well as economic certainties because economic disturbance in one country can also affect many other countries. The regulatory authorities should also play their role to minimize the economic uncertainties by improving the environment. Therefore, Asian governments should more focus on adopting ICTs for reducing CO_2 emissions to upsurge inclusive development. Governments of these countries should increase Research and Development (R & D) expenditures, which would help in developing ICT products that are conducive to the environment. Besides, authorities should levy heavy taxes on the industries that are emitting CO_2 and other greenhouse gasses during the production process. During the analysis, this study did not include other relevant new CO2 determinants such as stock market volatility, price volatility, and exchange volatility. Future empirical studies can extend this work in the added stock market volatility, price volatility, and exchange volatility variables in the model.

Availability of data and material The datasets/ materials used and/or analyzed for present manuscript are available from the corresponding author on reasonable request.

Author contribution Carlos Samuel Ramos Meza stipulated the idea. Rinat Zhanbayev, Hazrat Bilal, Mubbashra Sultan, and Zehra Betul Pekergin have done the data acquisitions, analysis, and written the whole draft. Carlos Samuel Ramos Meza and Hafiz Muhammad Arslan read and approved the final version.

Declarations

Ethical approval Not applicable.

Consent to Participate I am free to contract any of the people involved in the research to seek further clarification and information.

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