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RESEARCH ARTICLE

The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: new insights from QARDL approach

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Abstract
This novel research is an argumentative subject which was needed to be addressed and to fill this gap, the author examined the effect of financial development, information and communication technology, and institutional quality on CO2 emission in Pakistan by using quantile autoregressive distributed lag (QARDL) model. The data were obtained for the period from 1995Q1 to 2018Q4. In the long run, GDP and institutional quality have a positive impact on CO2 emission when this emission is already high, which shows that if the GDP and institutional quality increases, the CO2 emission also increases. Moreover, financial development and ICT has a negative impact on CO2 emission irrespective of emission level that whether it is high or low in the country, which shows that if financial enhancement and ICT increases, carbon emission decreases. The study also supported the EKC hypothesis in Pakistan.

Keywords Financial development · Information · And communication technology · Institutional quality · CO2 emission

Introduction

Due to increased environmental pollution and exhaustion of resources all over the world, the policymakers and scholars' attention has turned towards the identification of the determinants causing environmental pollution. Several researchers have measured environmental degradation by using different proxies depending upon the selected variables, e.g., CO2 emission (Karasoy 2019; Tsaurai 2019; Sharif et al. 2019b) and ecological footprint (Sabir and Gorus 2019; Rudolph and Figge 2017, Charfeddine and Mrabet 2017; Tang et al. 2018). Researches (Sharif et al. 2017; Li and Yang 2016; Ramachandra and Mahapatra 2015; Friedl and Getzner 2003) proposes that these environmental concerns are initiated due to the emission of atmospheric greenhouse gases (GHG). But, the concentration of CO2 emission (CO2_EMS) is assumed to be the main GHG and the most vital root of global warming and variation in climate (Ullah et al. 2018). Maintenance of the required quantity of CO2_EMS is one of the key focus of today's practitioners and researchers who are making efforts for reducing the CO2_EMS and are trying to improve the quality of life on earth. Many research studies evaluated the impact of various factors affecting CO2_EMS, e.g., tourism (Ben Jebli et al. 2019), financial development

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(FDV) (Raheem et al. 2019), globalization (Lv and Xu 2018), urbanization (Ali et al. 2019a), renewable energy, (Sharif et al. 2019a), institutional quality (INSQ) (Salman et al. 2019), information and communication technology (ICT) (Danish et al. 2018), and economic growth (ECO_GRO) (Dutt 2009).

The concept of ECO_GRO and CO2_EMS can be well explained with the help of the Environmental Kuznets Curve (EKC). Kuznets (1955) presented the EKC which elucidates the association between ECO_GRO and CO2_EMS. It explains that as ECO_GRO increases and CO2_EMS also increases at early stages, but this CO2_EMS decreases as the economy reaches a threshold of economic development. This notion was further authenticated by Grossman and Krueger (1995), Lucas et al. (1992), Stern (2004), Friedl and Getzner (2003), Dinda and Coondoo (2006), Nohman and Antrobus (2005), Leitão (2013), and Shahbaz et al. (2012). Similarly, Choi et al. (2012) empirically tested the association between CO2_EMS and ECO_GRO in the context of EKC in developed economies. The results showed an early positive relationship between ECO_GRO and CO2_EMS, but later as the ECO_GRO increases, the CO2_EMS reduces in countries like China and Japan. It showed that ECO_GRO is the major reason for the decline in CO2_EMS.

So, it means that when ECO_GRO is in its early phases, the natural resources are in abundance with limited waste generation, but during the phase of industrialization and development, the depletion of natural resources increases which results in a significant positive relationship between ECO_GRO and ENV_DEG, but as the country gets in the developed phase of improved technology and information system, it diminishes the depletion of resources and results in a better environment (Panayotou 2003).

Further, it was also explained by Raheem et al. (2019) that the ECO_GRO can also be achieved by developed and state of the art ICT. The ICT plays an imperative role in the ECO_GRO of any country in this modern globalized era. Today, FDI and foreign trade mostly depend on Internet sources. The Internet is integral for ECO_GRO (Salahuddin and Alam 2016; Erumban and Das 2016). Environmental sustainability and ECO_GRO can be achieved through the ICT sector (Filos 2010). However, it was also postulated in numerous studies that although ICT is very important for ECO_GRO and sustainable development, it also deteriorates the environmental quality because of the toxic emission which occurs in the processing and engineering of equipment utilized in ICT. More specifically, advanced ICT equipment utilizes high energy during operations. As ICT is getting more advanced, it is consuming high energy that results in enhanced CO2_EMS. Previous studies explained the relationship between ICT and CO2_EMS. According to these studies, ICT utilizes energy (Salahuddin and Alam 2015; Sadorsky 2012) and results in high CO2_EMS (Hamdi et al. 2014).

Moreover, Schumpeter (1911) recognized a relationship between ECO_GRO and financial development by emphasizing the significance of the financial system in the development of ECO_GRO. A successful financial system of an economy works as an engine for it and reduces information and communication costs. (Goldsmith 1969). The developed financial system aids in the efficient allocation of resources which enhances ECO_GRO, and results in reduced depletion of resources, which ultimately results in less environmental degradation (Frankel and Rose 2005). Moreover, FDV has a significant effect on the consumption of energy. (e.g., Shahbaz and Lean, 2012; Islam et al. 2013) which results in reduced CO2_EMS (Tamazian et al. 2009). A well-built financial system results in a low cost of borrowing which enhances investment activities and also reduces the CO2_EMS by enhancing the efficiency of the energy sector (Shahbaz et al. 2010; Tamazian and Rao 2010). According to Raheem et al. (2019), the low cost of borrowing enables the state to involve in healthy environmental projects. If healthy projects, i.e., less harmful for the environment are not undertaken, this will increase industrial pollution. As stated by Jensen (1996) that one more reason for testing FDV, though negative, is that it improves ECO_GRO, but it may increase industrial pollution which results in ENV_DEG.

After the pivotal task by Williamson (1989) and North (1990), the work on institutional economics has generally recognized that INSQ is one of the most important factors for growth in GDP. Inefficiently funding in the private sector by weak institutions contributes to corruption, weak environmental protocols, and deficient bureaucratic methods (Asoni 2008). Concerning the environment, INSQ has recently attracted the attention of policymakers, scientists, and economists. Olson (1996) noted that the efficient and impartial institutions of government can play an important role in fostering fruitful cooperation among market dealers. So, the rule of law now becomes a decisive element in resolving environmental concerns. Robust rule of law is therefore essential to enforce control procedures on CO2_EMS, and businesses would not be reluctant to do so. By contrast, if weaknesses persist in INSQ, the organizations would simply overlook the CO2_EMS control measures by evading the externalities of the environment that are associated with growth procedures. (Welsch 2004).

The importance of Pakistan in the global arena is undeniable. According to Gupta and Goldar (2005), Pakistan is falling under the cluster of flourishing economies. The exports and imports have reached 20.09 billion and 44.03 billion US dollars, respectively, from July to April 2019, and the position of Pakistan has improved to 136th in 2019 against 147th in 2018 in the index of easiness of doing business which results in the attraction of foreign investors (Economic Survey of Pakistan 2018_19). The figures for 2018–2019 as per Pakistan rice exports reached record (2019) shows that rice export has attained a record of 4.5 million tones. However, as per the criterion of air pollution, Pakistan approached to top 10 in the list of most polluted countries, but at the same time, it has a significant increase in ECO_GRO during the current years (Lahiani 2018). In Pakistan, the CO2_EMS from the combustion of fuel was recorded as 183.4 million tons (IEA, 2019). However, CO2_EMS per capita in Pakistan varied considerably in current years, it tended to upsurge during 1999–2018, and in 2018, it reaches 0.980 metric tons. (Pakistan CO2 emissions per capita n.d..

Therefore, the most challenging job in this research was to present a realistic vision of the relationship between variables under consideration to provide ways for formulating strategies that would help policymakers to make effective decisions. Substantial attention has been given while choosing the most appropriate methodology. Previously, standard and well-established methods were utilized to examine the associations without focusing on and differentiating the intensity of CO2_EMS. Hence, no proper policy recommendations can be based on the results of such models. According to the best of our knowledge, this research can be regarded as one of the few systematic quantitative studies using the quantile autoregressive distributed lag model (QARDL) to examine the relationship between CO2_EMS and FDV, ICT, and INSQ in Pakistan.

Professionals in previous studies have focused on the execution of applicable approaches to tackle the gaps, but the utilization of the QARDL in this effort has made it distinctive from the prior work. The QARDL approach proposed by Cho et al. (2015) is a unique and elite way to test the validity of long-term relationship over different quantiles and present an econometric framework which is more flexible and reliable to scrutinize the nexus between the variables of our concern. This recent econometric methodology allows us to investigate concurrently long-run relationships and short-run dynamics between ICT, FDV and INSQ (independent variable) and ENV_DEG (dependent variable) across quantiles of the conditional distribution of CO2_EMS. It also considers any potential asymmetric and nonlinear linkages of CO2_EMS to variation in ICT, FDV, and INSQ.

Some studies also find lack of proof related to cointegration between time series due to conventional econometric practices, like the Johansen cointegration test and the linear ARDL model, but the QARDL model permits the presence of fluctuating cointegration coefficients in the short-term according to quantile, while the variables carry on to move collectively in the long-term (Xiao 2009). Further, the QARDL model is superior to other available nonlinear models, e.g., nonlinear autoregressive distributed lag (NARDL) (Shin et al. (2014). All these reasons make the QARDL the most suitable among all to get more accurate results of asymmetric and nonlinear linkages between FDV, ICT, INSQ, and CO2_EMS in Pakistan.

Literature review

The relationship between ECO_GRO and ENV_DEG has achieved a great deal of attention by researchers of this era. Kuznets (1955) presented a curve (EKC) that explains the relationship between ECO_GRO and ENV_DEG. The EKC theory was explained by Beckerman (1992) that it is primarily about the impact of ECO_GRO on ENV_DEG. Beckerman (1992) has done an extensive level of research about the impact of ECO_GRO on ENV_DEG and found a negative association between them. Anderson (1992) conducted explanatory research on the relationship between the per capita income (ECO_GRO) and ENV_DEG. According to him, it is possible to alleviate this trade-off by suitable policies. Saidi and Hammami (2015) explored that there is a significant relationship between ECO_GRO, usage of resources, and environment. They found that the usage of energy resources may have economic benefits but it harms the environment in the long run due to CO2_EMS. Selden and Song (1994) found out the same results in the context of EKC.

Dutt (2009) analyses ECO_GRO and CO2_EMS relationship in the context of EKC by adding some more aspects like strong socio-economic and political conditions and high investment in the education sector. The outcomes depict that these factors contribute to CO2_EMS. Further, according to the findings, out of total countries, only 15% have shown the decline in CO2_EMS; whereas, the remaining 85% of the countries have shown an increase in CO2_EMS due to rise in income. A study by Qasim et al. (2015) shows the validation of the EKC theory for Pakistan. By using data from 1980 to 2013, the analysis showed a significant inverse relationship between ECO_GRO and ENV_DEG in Pakistan. According to Dhrifi (2018), CO2_EMS increases as per capita income increases.

The expansion of the financial sector may also help in lowering the investment cost in environmental projects. Regulating and monitoring the CO2_EMS is a costly project which is only possible if the financial sector is developed and able to provide low costs finance for such projects (Cline 1992; Revkin 2000). The developed and strong financial system of a country enhances ECO_GRO and reduces CO2_EMS (Frankel and Romer 1999). They also suggested that higher FDV boost R&D activities which accelerate ECO_GRO and reduces ENV_DEG. Further, 1% rise in FDV decreases CO2_EMS by 0.006%.

FDV improves FDIs and other financial aspects of the country which in turn results in more environmentally friendly projects even if they are expensive. Claessens and Feijen (2007) also explained the role of financial sector development in improving environmental quality. A decade ago, Kumbaroglu et al. (2008) explained how the FDV persuades technological development in the energy sector which results in reduced CO2_EMS. Zakaria and Bibi (2019) explained that countries which are in the developing phase, the environmental regulators would do better if they are developed financially.

This results in the technological developments and structured markets that are aimed for a better environment, i.e., reduction in CO2_EMS.

Dasgupta et al. (2004) found that a well-developed financial system might be a source to enhance the incentives to the firm to reduce the CO2_EMS. Tamazian et al. (2009) analyzed the effect of ECO_GRO and FDV on CO2_EMS for developed countries like the USA and Japan. The results support that both factors help in reducing CO2_EMS. FDV is not the cause of environmental pollution in China. The same was found out by Jalil and Feridun (2010). They explained the impact of FDV and ECO_GRO on ENV_DEG in China, and the results showed that as the FDV increases, CO2_EMS decreases. Bad financial conditions do not necessarily have a deteriorating influence on the environment. But on the contrary, Bello and Abimbola (2010) suggest a positive relationship between FDV and CO2 emissions in Nigeria. Tsaurai (2019) researched to discover the role of FDV on CO2_EMS. They also found a positive effect of FDV on CO2_EMS. Enkvist et al. (2010) examined that while countries were facing a global crisis in their financial systems, CO2_EMS was also at risk at that time. Seetanah et al. (2019) conducted a study to investigate the impact of ECO_GRO and FDV on CO2_EMS. The study results postulate that FDV has an insignificant influence on CO2_EMS.

Tamazian and Rao (2010) used the GMM estimation methodology to examine the significance of INSQ to environmental quality for the period of 1993 to 2004. For this study, they considered 24 transition countries. The study's empirical results showed the significance of INSQ in enhancing the environmental quality of selected countries. Panayotou (1997) claimed that INSQ plays an imperative role in augmenting the quality of a country's environment even when a country's economic level is low. This ensures that effective institutions can help to reduce the environmental cost of enhanced economic development while allowing countries to minimize emissions. Also, Gagliardi (2008) concluded that the quality of better institutions would help discourage manipulation, strengthen team working relationships, and allow agents to integrate externalities. So, better INSQ can, therefore, provide detailed strategies for boosting economic development and the advancement of environmental quality. (Subramanian 2007).

Lau et al. (2014) discovered the role of INSQ between the association of growth and CO2_EMS in Malaysia. The findings indicated that effective and unprejudiced domestic institutions are very crucial for economic progress to mitigate carbon emissions. Abid (2017) used the 1990–2011 dataset to integrate institutional quality for 41 EU and 58 Middle East and African (MEA) countries into the growth emission model. He claimed that INSQ is important in the selected countries for boosting economic growth and simultaneously reducing CO2_EMS. Bhattacharya et al. (2017) examined the role of institutional quality from 1991 to 2012 in 85 emerging and developed economies in improving economic growth and reducing CO2_EMS. The outcomes indicated that the investigated institutions are imperative in enhancing economic progress and fighting carbon emissions. Ali et al. (2019b) explained the impact of INSQ on CO2_EMS in developing counties. The results of the study show that as the INSQ improves, the CO2_EMS reduces in the long-term.

Moreover, Sarkodie and Adams (2018) concluded that in South Africa, INSQ decreases CO2_EMS by 0.1%. Salman et al. (2019) also found that well-organized and unbiased national institutions play a very significant part in increasing economic growth and decreasing CO2_EMS. In an economy, to enhance environmental quality, sound and effective environmental rules are perhaps one of the main determinants (Ibrahim and Law 2015). Quality organizations should, therefore, be seen as the contributors in delivering sound regulations, as if implemented successfully that will help in reducing the environmental challenges in the global economy. (Lau et al. 2014). Strong policies and better law and regulation implications enable the country to flatten the EKC and reduce ENV_DEG along with achieving higher ECO_GRO (Jones and Manuelli 2001).

Several pieces of research have examined the association between ICT, energy consumption, ECO_GRO, and CO2_EMS. However, two thoughts have been put forward for the nexus between ICT and CO2_EMS. One of the research group stated that ICT improves the environmental quality by reducing CO2_EMS (Al-Mulali et al. 2015a; Ozcan and Apergis 2017; Moyer and Hughes 2012). Whereas, another research group claimed that the use of the Internet enhances energy consumption, thus, results in an increase of CO2_EMS. (Lee and Brahmasrene 2014; Salahuddin and Gow 2016; Danish et al. 2018

Al-Mulali et al. (2015a) examine the impact of Internet usage on CO2_EMS by using data from 77 countries. The results of the study show that Internet use decreases CO2_EMS in developed countries, but on the other hand, there is no significant impact of internet use in increasing CO2_EMS in developing countries. Ozcan and Apergis (2017) used panel data to evaluate the influence of Internet usage on CO2_EMS in emerging economies. Empirical outcomes indicate that Internet usage reduces CO2_EMS in emerging economies. Zhang and Liu (2015) examine ICT industry contribution to CO2_EMS for different regions of China using STRIPAT model. The study results disclose that ICT is effective in minimizing CO2_EMS.

The second research group stated that ICT use is destroying the environment by discharging a large amount of CO2_EMS. Raheem et al. (2019) identified the impact of ICT and FDV on CO2 in G7 countries. The results show that ICT has a positive influence on CO2_EMS in the long run. Similarly, Salahuddin et al. (2016) calculated the impact of ICT and economic growth on CO2_EMS across OECD countries. The result indicates that an increase of 1% in Internet use raises CO2_EMS by 0.16%. Lee and Brahmasrene (2014) analyzed the association between internet usage, ECO_GRO, and CO2_EMS for the Association of Southeast Asian Nations (ASEAN) from 1991 to 2009. The results showed that the usage of the Internet has a positive influence on both CO2_EMS and ECO_GRO. Recently, Danish et al. (2018a) approximated the effect of ICT on CO2_EMS in emerging economies and incorporated a unique methodology to calculate the effect of ICT economic growth interaction on CO2_EMS. The study suggests that the use of the Internet and mobile poses a threat to the quality of the environment.

Asongu (2018) investigated the effect of ICT on CO2_EMS for 44 sub-Saharan African nations. The outcomes showed that ICT and CO2_EMS are related positively; however, more advanced usage of ICT decreases CO2_EMS and hence results in a better environment. Majeed (2018) also empirically tested the impact of ICT on CO2_EMS in developing countries. The study runs an analysis of 132 developing and developed countries to test the relationship of ICT with CO2_EMS for the period of 1980–2016. The result showed that ICT has a favorable influence on developed countries; however, the impact was contrary to the developing countries.

Methodology

To investigate the nonlinear relationship between ICT, financial development, INSQ, ECO_GRO, and CO2_EMS, we imply the QARDL model, which is presented by Cho et al. (2015). This QARDL is an extension of the ARDL model and it allows testing the nonlinear relationship and asymmetries between the ICT, financial development, INSQ, ECO_GRO, and CO2_EMS. The equation for the model is as follows.

$$\begin{aligned} \mathrm{CO2}_t = \mu &+ \textstyle\sum_{i=1}^{p} \upsilon_{\mathrm{CO2}i}\mathrm{CO2}_{t-i} + \sum_{i=0}^{q} \upsilon_{\mathrm{GDP}i}\mathrm{GDP}_{t-i} \\ &+ \textstyle\sum_{i=0}^{r} \upsilon_{\mathrm{GDP}^2 i}\mathrm{GDP}^2{}_{t-i} + \sum_{i=0}^{s} \upsilon_{\mathrm{FDV}i}\mathrm{FDV}_{t-i} \\ &+ \textstyle\sum_{i=0}^{U} \upsilon_{ICTi}\mathrm{ICT}_{t-i} + \sum_{i=0}^{v} \upsilon_{\mathrm{INSQ}_i}\mathrm{INSQ}_{t-i} + \varepsilon_t \end{aligned} \tag{1}$$

where ε_t is explained as the $CO2_t - \mathrm{E}[\mathrm{CO2}_t/\gamma_{t-1}]$ with γ_{t-1} as the smallest ϑ-field caused by $\{\mathrm{CO2}_t, \mathrm{GDP}_t, \mathrm{GDP}^2{}_t, \mathrm{FDV}_t, \mathrm{ICT}_t, \mathrm{INSQ}_t, \mathrm{CO2}_{t-1}, \mathrm{GDP}_{t-1}, \mathrm{GDP}^2{}_{t-1}, \mathrm{FDV}_{t-1}, \mathrm{ICT}_{t-1}, \mathrm{INSQ}_{t-1}\}$ and p, q, r, s, u, and v are the lag orders designated by the Schwarz information criterion (SIC). In Eq. (1) INSQ, ICT, FDV, GDP^2, GDP, and CO2 are institutional quality, information and communication technology, financial development, gross domestic product along with its square and CO2 emission. Cho et al. (2015) extended the model into QARDL model; the quantile context of our Eq. (1) is QARDL (p, q, r, s, u, v)

$$\begin{aligned} Q_{CO2_t} = \mu(\tau) &+ \textstyle\sum_{i=1}^{P} \upsilon_{\mathrm{CO2}i}(\tau)\,\mathrm{CO2}_{t-i} + \sum_{i=0}^{q} \upsilon_{\mathrm{GDP}i}(\tau)\mathrm{GDP}_{t-i} \\ &+ \textstyle\sum_{i=0}^{r} \upsilon_{\mathrm{GDP}^2 i}(\tau)\mathrm{GDP}^2{}_{t-i} + \sum_{i=0}^{s} \upsilon_{\mathrm{FDV}i}(\tau)\mathrm{FDV}_{t-i} \\ &+ \textstyle\sum_{i=0}^{U} \upsilon_{\mathrm{ICT}i}(\tau)\mathrm{ICT}_{t-i} + \sum_{i=0}^{v} \upsilon_{\mathrm{INSQ}_i}(\tau)\mathrm{INSQ}_{t-i} + \varepsilon_t(\tau) \end{aligned} \tag{2}$$

where, $\varepsilon_t(\tau) = \mathrm{CO2}_t - Q_{\mathrm{CO2}_t}(\tau/\delta_{t-1})$ (Kim and White 2003) and $0 > \tau < 1$ shows quantile. In the error term, due to the possibility of serial correlation, the model of QARDL in Eq. (2) can be written:

$$\begin{aligned} Q_{\Delta\mathrm{CO2}_t} = \mu &+ \rho\mathrm{CO2}_{t-1} + \kappa_{\mathrm{GDP}}\mathrm{GDP}_{t-1} + \kappa_{\mathrm{GDP}^2}\mathrm{GDP}^2{}_{t-1} \\ &+ \kappa_{\mathrm{FDV}}\mathrm{FDV}_{t-1} + \kappa_{\mathrm{ICT}}\mathrm{ICT}_{t-1} + \kappa_{\mathrm{INSQ}}\mathrm{INSQ}_{t-1} \\ &+ \textstyle\sum_{i=1}^{P} \upsilon_{\mathrm{CO2}i}\Delta\mathrm{CO2}_{t-i} + \sum_{i=0}^{q} \upsilon_{\mathrm{GDP}i}\Delta\mathrm{GDP}_{t-i} \\ &+ \textstyle\sum_{i=0}^{r} \upsilon_{GDP^2 i}\Delta GDP^2{}_{t-i} + \sum_{i=0}^{s} \upsilon_{\mathrm{FDV}i}\Delta\mathrm{FDV}_{t-i} \\ &+ \textstyle\sum_{i=0}^{U} \upsilon_{\mathrm{ICT}i}\Delta\mathrm{ICT}_{t-i} + \sum_{i=0}^{v} \upsilon_{\mathrm{INSQ}_i}\Delta\mathrm{INSQ}_{t-i} \\ &+ \varepsilon_t(\tau) \end{aligned} \tag{3}$$

According to QARDL model, Eq. (3) can be rewritten as per Cho et al. (2015) for ECM reparametrization form:

$$\begin{aligned} Q_{\Delta\mathrm{CO2t}} = \ &\mu(\tau) \\ &+ \rho(\tau)\left(\mathrm{CO2}_{t-1} - \beta_{\mathrm{GDP}}(\tau)\mathrm{GDP}_{t-1} - \beta_{\mathrm{GDP}^2}(\tau)\mathrm{GDP}^2{}_{t-1} - \beta_{\mathrm{FDV}}(\tau)\mathrm{FDV}_{t-1} - \beta_{\mathrm{ICT}}(\tau)\mathrm{ICT}_{t-1} - \beta_{\mathrm{INSQ}}(\tau)\mathrm{INSQ}_{t-1}\right) \\ &+ \textstyle\sum_{i=1}^{P} \upsilon_{\mathrm{CO2}i}(\tau)\Delta\,\mathrm{CO2}_{t-i} + \sum_{i=0}^{q} \upsilon_{\mathrm{GDP}i}(\tau)\Delta\mathrm{GDP}_{t-i} + \sum_{i=0}^{r} \upsilon_{\mathrm{GDP}^2 i}(\tau)\Delta\mathrm{GDP}^2{}_{t-i} + \sum_{i=0}^{s} \upsilon_{\mathrm{FDV}i}(\tau)\Delta\mathrm{FDV}_{t-i} \\ &+ \textstyle\sum_{i=0}^{U} \upsilon_{\mathrm{ICT}i}(\tau)\Delta\mathrm{ICT}_{t-i} + \sum_{i=0}^{v} \upsilon_{\mathrm{INSQ}_i}(\tau)\Delta\,\mathrm{INSQ}_{t-i+\varepsilon_t(\tau)} \end{aligned} \tag{4}$$

Table 1 Results of descriptive statistics

Variables	CO2	GDP	ICT	INSQ	FDV
Mean	0.210	237.423	7.979	13.868	11.805
Minimum	0.161	199.154	0.008	13.128	9.234
Maximum	0.244	302.637	18.455	14.650	15.142
Std. Dev.	0.022	29.819	7.542	0.383	1.374
Skewness	−0.214	0.343	0.085	0.003	−0.132
Kurtosis	3.708	2.843	3.179	2.939	2.445
Jarque-Bera	7.412	5.550	13.373	15.523	17.509
Probability	0.025	0.062	0.001	0.000	0.000

Source: Author Estimation

The delta method has been utilized to gauge the cumulative short-run effect of the past CO2_EMS on current CO2_EMS and it is measured through $\upsilon_{CO2.}$ On the other hand, the cumulative short-run influence of past and current GDP, GDP^2, FDV, ICT, and INSQ on the contemporaneous level of CO2_EMS is measured through $\upsilon_{GDP*} = \sum_{i=1}^{q} \upsilon_{GDPi}$, $\upsilon_{GDP^2*} = \sum_{i=1}^{r} \upsilon_{GDP^2_i}$, $\upsilon_{FDV*} = \sum_{i=1}^{s} \upsilon_{FDVi}$, $\upsilon_{ICT*} = \sum_{i=1}^{u} \upsilon_{ICTi}$,, $\upsilon_{INSQ*} = \sum_{i=1}^{v} \upsilon_{INSQ_i}$. The parameter ρ in Eq. (4) should be significantly negative. The long-run co-integrating parameter for GDP, GDP^2, FDV, ICT, and INSQ is β, for which following formula has been utilized

$$\beta_{GDP*} = -\frac{\beta_{GDP}}{\rho} \beta_{GDP^2*} = -\frac{\beta_{GDP^2}}{\rho}, \quad \beta_{FDV*} = -\frac{\beta_{FDV}}{\rho} \beta_{ICT*} = -\frac{\beta_{ICT}}{\rho} \beta_{INSQ*} = -\frac{\beta_{INSQ}}{\rho}$$

In this research, the Wald test was used to study statistically the short-run and long-run asymmetric impacts of GDP, GDP^2, FDV, ICT, and INSQ on CO2_EMS, e.g., for ρ, the parameter for speed of adjustment, the null hypothesis will be $\rho_*(0.05) = \rho_*(0.10)$, $\rho_*(0.15)$. $\rho_*(0.95)$. A similar pattern was used for β_{GDP}, β_{FDV}, β_{ICT}, β_{GDP^2} and β_{INSQ} parameters and for specific lags, i.e., υ_{CO2}, υ_{GDP}, υ_{ICT}, υ_{GDP}^2 and υ_{INSQ}, the short-term parameters.

Results and discussion

The present study examines the impact of GDP, FDV, ICT, and INSQ on CO2_EMS in Pakistan. In doing so, the proxies used for the data are, e.g., GDP/capita for GDP, the number of internets and mobile users for ICT, domestic credit by financial sector (% of GDP) for FDV, CO2_EMS metric tons per capita for CO2_EMS, and economic freedom index for INSQ. The data was obtained in annual frequency for the period of 1995–2018 from the World Bank. Moreover, INSQ is measured by the economic freedom index, and the data is collected from the website of Freedom House Report. Besides, the data is further converted to quarterly data using the match-sum method, as used by Shahbaz et al. (2018), Sharif et al. (2019a), and Aziz et al. (2020). The quadratic match sum method is useful as it convert the data using amendments for seasonal deviations as data is transformed from low to high frequency by dropping the point-to-point data deviations (Mishra et al. 2019; Sharif et al. 2020; Batool et al. 2019).

Table 1 shows the descriptive statistics of GDP, FDV, ICT, INSQ, and CO2_EMS. CO2_EMS has a mean value of 0.210 which lies between 0.161 and 0.244. GDP has a mean value of 237.423 and lies between 199.154 and 302.637. ICT has a mean value of 7.979 and lies between 0.008 and 18.455. INSQ has a mean value of 13.868 which varies from 13.128 to 14.650. Lastly, FDV has a mean value of 11.805 which varies from 9.234 to 15.142. The Jarque-Bera test results shown in Table 1 are significant for all variables, i.e., GDP, FDV, ICT, INSQ, and CO2_EMS. It shows that data is not normally distributed which is a prerequisite for the quantile regression analysis.

Table 2 shows the test results of the Augmented Dickey-Fuller (ADF) and ZA unit root test. These tests are used to determine the structural breaks along with the stationary feature of the time series data. In this analysis, the results show that all variables, i.e., GDP, FDV, ICT, and CO2_EMS are nonstationary at level, but at first differences, they are all stationary. So the results show that all variables have a unique integration order.

The results for the QARDL model (presented in Table 3) of our study indicate that the estimated parameter of dependency

Table 2 Results of unit root test

Variables	ADF (level)	ADF (Δ)	ZA (level)	Break year	ZA (Δ)	Break year
CO2 Emission	− 5.048***	− 7.372***	− 0.843	1998 Q03	− 7.382***	2007 Q01
GDP	− 1.216	− 11.844***	− 1.482	2012 Q01	− 6.235***	2012 Q04
ICT	− 0.748	− 5.379***	− 1.973	2012 Q04	− 7.284***	2009 Q02
IQ	− 1.382	− 6.038***	− 2.372	2009 Q04	− 5.029***	2016 Q03
FD	1.094	− 7.382***	− 1.385	2008 Q01	− 8.448***	2010 Q04

The values in the table specify statistical values of the ADF and ZA test. The asterisks ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively

Table 3 Results of quantile autoregressive distributed lag (QARDL) for CO2

Quantiles (τ)	$\mu_*(\tau)$	$\rho_*(\tau)$	$\beta_{GDP}(\tau)$	$\beta_{GDP}{}^2(\tau)$	$\beta_{ICT}(\tau)$	$\beta_{IQ}(\tau)$	$\beta_{FD}(\tau)$	υ_{CO2}	υ_{GDP}	$\upsilon_{GDP}{}^2$	υ_{ICT}	υ_{IQ}	υ_{FD}
0.05	15.853	(0.015)***	4.092	− 0.370	− 0.195***	1.412	1.165	0.080	58.804	− 5.300	0.040	0.416	0.045
	(12.724)	(0.004)	(25.231)	(2.045)	(0.039)	(5.964)	(6.087)	(0.130)	(37.983)	(3.516)	(0.024)	(0.337)	(0.132)
0.10	10.771	−0.131***	0.322	− 0.030	− 0.130***	0.112	0.075	0.243**	58.916	− 5.348	− 0.044**	0.214	− 0.013
	(10.960)	(0.027)	(0.333)	(0.024)	(0.037)	(0.088)	(0.181)	(0.120)	(37.412)	(3.461)	(0.022)	(0.314)	(0.132)
0.20	2.632	− 0.045***	0.259	− 0.027	− 0.078	0.077	−0.241***	0.122	71.803**	− 6.543**	0.004	0.064	0.026
	(6.028)	(0.011)	(0.381)	(0.039)	(0.059)	(0.205)	(0.076)	(0.111)	(27.520)	(2.552)	(0.030)	(0.216)	(0.077)
0.30	2.146	− 0.033***	0.296	− 0.032	− 0.143	0.050	− 0.405***	0.157*	71.061**	− 6.457*	− 0.004	− 0.128	− 0.025
	(5.698)	(0.008)	(0.478)	(0.059)	(0.040)	(0.224)	(0.090)	(0.088)	(29.351)	(2.717)	(0.027)	(0.161)	(0.060)
0.40	1.852	− 0.006***	1.353	−0.138	− 0.518	0.274	− 1.501***	0.316***	48.746*	− 4.387*	0.000	− 0.054	− 0.050
	(6.221)	(0.002)	(11.909)	(1.314)	(0.348)	(2.256)	(0.364)	(0.083)	(26.252)	(2.430)	(0.027)	(0.158)	(0.055)
0.50	0.441	− 0.063***	0.051	− 0.006	−0.018	0.054	− 0.040***	0.283***	38.485*	− 3.446*	0.007	− 0.024	− 0.026
	(6.589)	(0.020)	(0.259)	(0.029)	(0.044)	(0.086)	(0.010)	(0.099)	(20.797)	(1.928)	(0.023)	(0.144)	(0.051)
0.60	− 0.598	− 0.070***	0.008	−0.001	− 0.004	0.091	− 0.026***	0.259***	20.722	− 1.805	0.002	0.037	− 0.012
	(5.573)	(0.022)	(0.197)	(0.031)	(0.046)	(0.062)	(0.007)	(0.086)	(24.027)	(2.217)	(0.017)	(0.101)	(0.066)
0.70	− 3.758	− 0.054***	0.224***	− 0.019***	− 0.044	0.117***	−0.239***	0.235*	15.903	− 1.364	− 0.008	0.058	− 0.017***
	− 5.915	(0.014)	(0.045)	(0.005)	(0.032)	(0.024)	(0.053)	(0.120)	(27.121)	(2.498)	(0.022)	(0.117)	(0.008)
0.80	− 4.436	− 0.047***	0.320***	−0.028***	− 0.035***	0.130***	− 0.440***	0.167	6.173	− 0.441	− 0.021***	0.059	−0.065***
	− 9.653	(0.014)	(0.076)	(0.007)	(0.010)	(0.030)	(0.101)	(0.137)	(38.819)	(3.556)	(0.004)	(0.158)	(0.013)
0.90	10.890	− 0.107***	0.389***	− 0.035***	−0.065***	0.188***	− 0.093***	0.122	5.745	− 0.356	− 0.004***	0.210	− 0.097***
	− 17.427	(0.027)	(0.091)	(0.007)	(0.021)	(0.096)	(0.028)	(0.194)	(59.503)	(5.446)	(0.001)	(0.258)	(0.020)
0.95	− 21.785	− 0.392***	0.191***	− 0.017***	− 0.039***	0.040	− 0.028***	0.289	47.217	− 4.434	− 0.045***	0.268	0.219
	− 18.789	(0.162)	(0.053)	(0.009)	(0.011)	(0.032)	(0.008)	(0.130)	(64.078)	(5.865)	(0.012)	(0.248)	(0.052)

The table reports the quantile estimation results. The t-statistics are between brackets. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Source: Author Estimations ρ is highly significant with the negative sign at all quantiles. This is the sign of reversion to the long-term equilibrium nexus between GDP, FDV, ICT, and CO2_EMS. Further, the beta coefficient (β) shows the relationship between the dependent (CO2_EMS) and independent (GDP, FDV, ICT, and INSQ) variables in the long-term. The results show that βGDP is significantly positively related to CO2_EMS at high quantiles. It means that in the long-term, when CO2_EMS is already high, the CO2_EMS further increases as the GDP increases, whereas βGDP^2 is also significant but negative at high quantiles. This shows the presence of the EKC curve in Pakistan which was also supported by (Nazir et al. 2018; Qasim et al. 2015). The βICT has a negative significant relationship with CO2_EMS at low quantiles, i.e., 0.05–0.10. It means that when the CO2_EMS is already low in the country, the overall CO2_EMS emission further decreases with the increase in ICT. At the same time, the results are also showing that ICT has the same significant negative relationship at high quantiles, i.e., 0.85–0.95, which indicates that even when the CO2_EMS is at high intensity in Pakistan, the effect will be the same as that of low quantile, i.e., the overall CO2_EMS emission decreases with the increase in ICT. This inverse relationship was supported by Ozcan and Apergis (2017) and Salahuddin and Gow (2016).

Further, βINSQ shows that there is a positive relationship of INSQ with CO2_EMS at high quantiles (0.70–0.90), which indicates that, when the CO2_EMS is already at the high level in Pakistan, it increases further as the INSQ improves. The same was supported by Ibrahim and Law (2015) concerning trade in the country, i.e., trade will have a negative influence on the quality of environment in those countries who have poor institutions. At last, the βFDV shows that at the majority of quantiles, there is a significant negative relationship between CO2_EMS and FDV. This indicates that most of the time, the stronger FDV in the country will result in the reduction of CO2_EMS. This result was supported by Dasgupta et al. (2004) and Zakaria and Bibi (2019).

Now, the short-term analysis shows that present CO2_EMS are significantly and positively influenced by their previous levels in Pakistan at low, middle, and upper-middle quantiles. The present and previous changes in GDP has a positive significant effect; whereas, GDP^2 has a negative significant impact on present CO2_EMS at quantiles (0.20–0.50). Moreover, in the short-term, previous and present changes in ICT has a negative significant impact on present CO2_EMS levels at quantile (0.10) and (0.80–0.90), whereas FDV shows the same impact at quantile (0.70–0.90). The previous and present changes in INSQ has no significant impact on present CO2_EMS in the short-term.

The Wald test outcomes are presented in Table 4. The Wald test helps to test the parameter constancy across the eleven quantiles. Furthermore, according to Cho et al. (2015), the Wald test also confirms the nonlinearities in short-run and long-run parameters for estimating locational asymmetries. The null hypothesis acceptance shows that no asymmetries and nonlinearities are found in the relationships. In our study, the Wald test rejects the null hypothesis related to all independent variables of our study in the long run, i.e., GDP, FDV, ICT, and INSQ, whereas all the null hypothesis except INSQ and FDV are again rejected in the short run also. The outcomes ascertain that all the variables, i.e., GDP, ICT, INSQ, FDV, and CO2_EMS represent the nonlinear and asymmetric association, but INSQ and FDV show linear and symmetric link in short-term dynamics.

Table 4 Results of the Wald test for the constancy of parameters

Variables	F-statistics (*P* value)
ρ*	5.094*** (0.000)
β_{GDP}	9.482*** (0.000)
β_{GDP^2}	6.338*** (0.000)
β_{ICT}	11.482*** (0.000)
β_{INSQ}	8.329*** (0.000)
β_{FDV}	9.418*** (0.000)
υ_{CO2}	4.822*** (0.000)
υ_{GDP}	5.294*** (0.000)
υ_{GDP^2}	0.210 (0.999)
υ_{ICT}	5.958*** (0.000)
υ_{INSQ}	2.258 (0.441)
υ_{FDV}	1.458 (0.561)

Source: Authors Estimation

Conclusion and policy implications

This study was conducted to assess the impact of FDV, ICT, and INSQ on CO2_EMS in Pakistan by using the QARDL model. We have taken a sample for the period from 1995Q1 to 2018Q4. This recent econometric methodology (Cho et al. 2015) allows us to instantaneously investigate the long-run relationship and short-run dynamics by taking into account any potential asymmetric and nonlinear linkages between ICT, FDV, INSQ (independent variable) and CO2_EMS (dependent variable).

The results for the QARDL model indicate that the estimated parameter ρ is highly significant with a negative sign at all quantiles. In the long run, if the GDP and INSQ increase, the CO2_EMS also increases but only at high quantiles, which means that if the CO2_EMS is already high in the country, even then the CO2_EMS will further increase if the GDP and INSQ increases. However, at low quantiles, i.e., when CO2_EMS is low in the country, the results show no significant relationship between GDP, INSQ, and CO2_EMS. But the results of the other two independent variables (FDV and ICT) show a significant negative impact on CO2_EMS at almost all quantiles for FDV, and at low and high quantiles for ICT in the long run, which means that, if FDV and ICT increases, the CO2_EMS decreases irrespective of its level that whether it is high or low in the country. Further, the presence of the EKC curve in Pakistan was also validated.

As the results showed that FDV and ICT has a negative significant impact on CO2_EMS, therefore it is further suggested that the Pakistan government shall encourage more implementation of those credit policies which guarantee the loans taken by the financial sector that must be used towards the environmentally friendly projects that reduce CO2_EMS. Statistical results prove this to some extent. Moreover, the encouraging impact of ICT on CO2_EMS shows that residents of Pakistan should use smarter energy as well as energy-efficient ICT devices in true spirit. The increase in CO2_EMS in Pakistan might because of less investment in renewable energy. Pakistan is far behind the use of renewable energy to its maximum capacity. Although there is an improvement in recent years, but the utilization of ICT technologies like online banking, online purchasing, and other smartphone applications as well as the effective consumption of electricity and promotion of more ICT devices development will further reduce CO2_EMS. Further, with enriched financial systems and strict monetary guidelines, the investment shall be made in clean energy projects and owners of businesses shall be encouraged to adopt green technology, i.e., cleaner manufacturing technologies with the help of ICT. Dependence on traditional energy means shall be minimized, and utilization of contemporary sensors and the latest machinery specifically in construction works reduces CO2_EMS in Pakistan.

It is also important to strengthen the institutions and enable them to work efficiently. Effective operations of institutions would result in the proper implementation of laws and regulations which helps to fight corruption, which if steadily monitored, will reduce CO2_EMS in the country. Business sectors in Pakistan do not have enough resources to invest in the projects of healthy environmental programs because of the weak institutional structures. Therefore, stronger financial and economic development in the future is necessary to reduce CO2_EMS. Stokey (1998) stated that CO2_EMS can be reduced if the strategies to reduce it are implemented at the early stages.

Moreover, the results support the EKC curve which shows that at the early stages, the economic growth might result in increased CO2_EMS, but in the long-term, expensive environmentally friendly machinery and equipment will reduce CO2_EMS. This is further supported by the results of ICT and FDV which can further be achieved by averting needless cost of transportation and combining the effective businesses and households' management. For illustration, the availability of cell phones and transportation costs can be reduced, and savings can be used in other investments that can improve the financials.

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