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The moderating role of environmental tax and renewable energy in CO_2 emissions in Latin America and Caribbean countries: Evidence from method of moments quantile regression

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ABSTRACT

This paper investigates the effectiveness of environmental tax and renewable energy in mitigating CO_2 emissions in 18 Latin America and Caribbean (LAC) countries for the period 1994–2018 after controlling for financial development, non-renewable energy and economic growth. We applied the recently novel panel Methods of Moments Quantile Regression (MMQR) with fixed effects, and to rigorously analyze the hypothesized relationship, we also applied a number of other conventional estimators including the augmented mean group (AMG), the Dynamic Ordinary Least Squares (DOLS) and the Driscoll and Kraay estimators. Our evidence shows that the effect of environmental tax and renewable energy on CO_2 emissions is heterogeneous with significant negative effect in higher emissions countries but insignificant effect in lower emission countries. Results from MMQR together with the other estimators show that environmental tax and renewable energy can reduce CO_2 emissions with the mitigation effect of renewable energy considerably higher than that of environmental tax. Granger causality test also reveals that environmental tax and renewable energy unidirectionally cause CO_2 emissions. We also found that environmental tax not only reduces CO_2 emissions but it also promotes renewable energy. The evidence indicates that environmental tax and renewable energy can be effective instruments for promoting environmental quality in LAC. Environmental sustainability in these countries can be promoted by increasing environment tax, investing in renewables and reducing non-renewable energy consumption.

1. Introduction

Over the past several years there has been a stark warning indicating that the world is heading towards a 'painful environmental problems' sooner than expected (IPCC, 2018). Global warming and its detrimental effects on the environment are two of the greatest environmental threats facing humanity (World Bank, 2016). According to WHO (2020a), WHO (2020b), air pollution kills an estimated 7 million people worldwide every year with 4.2 million deaths every year world-wide due to the exposure of ambient (outdoor) air pollution. 6% of global deaths are attributed to outdoor air pollution (WHO, 2020a). Moreover, apart from the human tragedy, the economic cost of the lack of mitigation is also daunting. For instance, according to Kahn et al. (2021), if the international community adheres to the recommendations of the Paris Agreement of limiting the temperature increase to 0.01 °C per annum, world real GDP per capita can be reduced by only about 1 percent by 2100. In contrast, if mitigation policies are not carried out and if there is a persistent increase in the average global temperature by 0.04 °C per year, by 2100 world real GDP per capita can be reduced by more than 7 percent. The tragedy is that while these deaths and economic costs can be significantly reduced by improving environmental quality (EEA, 2019), it is sad to see that the world community is "shying away from the full commitment required for its reversal" (p. 50) and that the world is 'way off track' for limiting global warming to 1.5 °C (RE21, 2020; UN, 2020).

The growing risks of climate changes and the failure of market forces to provide solutions to environmental externalities have prompted many countries, including LAC countries to implement environmental tax to mitigate emissions and to reduce fossil consumption. However, while the effectiveness of environmental tax on mitigating carbon emissions have been studied for a number of countries and regions, there is only scanty evidence for LAC countries. Our inclusion of the environmental tax variable is to partly address the "omitted variable bias" as many previous panel studies on the determinants of CO_2 emissions in LAC did not include environmental tax as a determinants of CO_2 emissions. Thus, the inclusion of environmental tax may also explain changes in carbon emissions as well as deal with omitted variables. Therefore, the aim of this paper is to fill this gap by applying the Machado and Silva (2019)

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developed Methods of Moments Quantile Regression (MMQR) with fixed effects for 18 LAC countries for the period 1994–2018. As the stages of economic development among LAC countries differ and as their emission levels are also heterogenous across these countries, the MMQR approach is deemed appropriate as it takes into account the conditional heterogeneous effects of the independent variables that influence the whole distribution rather than each determinant being a mean shifter (D'Orazio et al., 2020; Ike et al., 2020; Machado and Silva, 2019). Even though conventional panel long-run cointegration tests such as the Dynamic Ordinary Least Square (DOLS) and the Modified Ordinary Least Square (FMOLS) take into account the issues of cross-sectional dependence and endogeneity, they still fail to depict the full distributional impact of the regressors on the dependent variable (Ike et al., 2020; Koengkan et al., 2021; Koenker and Bassett, 1978; Lingyan et al., 2021). These standard panel long-run estimates only detect the medium levels of the regression coefficients but not the marginal effects of the independent variables at different levels of the conditional distribution of the dependent variable (see *inter alias*, Ike et al., 2020; Koengkan et al., 2021). Consequently, mean regression does not detect the relationship between the independent and the dependent variable throughout the conditional distribution of the outcome variables (Amengavi, 2021; Ike et al., 2020; Koengkan et al., 2021; Sarkodie and Strezov, 2019). In contrast, quantile regression (QR), by taking into account the distributional impact of the determinants of CO_2 emissions across different quantiles, enables us to detect, say, whether the impact of environmental tax and/or renewable energy is relatively more effective in countries with higher CO_2 emissions per capita than in countries with lower CO_2 emissions per capita. However, despite these novelties of the ordinary QR, it still does not deal with panel structure and hence it does not take into account the issue of unobserved heterogeneity and ignoring these unobserved effects can produce biased estimate (Baum and Hurn, 2021; Ike et al., 2020; Machado and Silva, 2019). In contrast, the MMQR approach overcomes this limitation by incorporating fixed effects to account for the distributional heterogeneity at different quantile distributions of the dependent variable (Ike et al., 2020; Machado and Silva, 2019). Additionally, by simultaneously treating endogeneity and heterogeneity, MMQR can offer estimates relating to the non-linear and asymmetric relationship among the variables (Amengavi, 2021; Gómez and Rodríguez, 2020; Lingyan et al., 2021). Further, unlike ordinary QR, MMQR estimates are more robust to outliers and they can provide estimates in the presence of endogenous and cross-sectionally related variables (Ike et al., 2020; Koengkan et al., 2021; Lingyan et al., 2021; Machado and Silva, 2019).

Apart from the MMQR estimates, in order to rigorously analyze the hypothesized relationship, we also subject our empirical evidence to a battery of other recently developed econometric estimators that include the AMG (Augmented Mean Group), the DOLS and the Driscoll and Kraay (1998) estimators. We also test the direction of Granger causality by applying the Dumitrescu and Hurlin (2012) approach. To our knowledge, this is the first paper that applies the above estimators to assess the effectiveness of environmental tax and renewable energy in mitigating CO_2 emissions in LAC. We hope that our approach, by taking into consideration endogeneity, heterogeneity and non-linear and asymmetric relationship among the variables may provide broader insights for environmental sustainability in LAC.

We structure the rest of the paper as follows. In Section 2 we briefly review the development of environmental tax and renewable energy in LAC countries, Section 3 discusses the related literature, Section 4 outlines the data and the methodology used. Empirical findings and discussions are presented in Section 5. The summary and concluding remarks are presented in Section 6.

2. Development of environmental tax and renewable energy in LAC countries

Like the rest of the world, LAC countries are not also immune from the vagaries of global warming and climate changes (van der Zwaan et al., 2016; Fuinhas et al., 2021; Román-Collado and Morales-Carrión, 2018). According to Reyer et al. (2017) by the end of this century, LAC will be severely affected by climate changes where the mean temperature is projected to increase up to 4.5 °C compared to the pre-industrial level. Moreover, according to Clark et al. (2016) by the year 2050, the possibility of reducing pollution in Latin America will be relatively lower than the rest of the world. Moreover, there is now a growing concern that LAC's rapid economic growth and the mismanagement of its natural resources are impacting negatively on the quality of the region's environment and is leading to more air pollution (ECLAC, 2014). This has led some areas of LAC to being more significantly and more intensely affected than other regions of the world (ECLAC, 2014).

Many LAC countries have now recognized that the worsening environmental conditions require fiscal mechanisms to reduce CO_2 emissions and many countries are implementing a series of tax measures to enhance their environmental protection (Washburn and Pablo-Romero, 2019). Following the example of some developed countries, the majority of these incipient environmental tax initiatives have focused on motor vehicles and the fuels used to operate them (OECD, 2021). Other efforts to promote renewables include tax incentives such as tax exemptions in income tax and through sales tax/value-added taxes or via tariffs (Silva et al., 2019). In some LAC countries Feed-In Tariffs are also employed to encourage the development of renewable energy (see Washburn and Pablo-Romero, 2019). This system is a long-term, guaranteed purchase agreements for green electricity at a price that can provide project developers a reasonable return on investment (Jacobs et al. 2013; Recalde, 2013). Nevertheless, LAC countries have been slow to implement environmentally related taxes (OECD, 2021) and revenue from environmentally related taxes in LAC amounted to 1.2% of GDP in 2019 compared to 2.1% for OECD (OECD, 2O21). Beyond taxes on fuel and the registration or use of vehicles, environmental taxes are still underdeveloped across the LAC region (OECD, 2O21). Moreover, despite these efforts, still the tax rate (US$/ton CO_2) in LAC is lower than that proposed by the World Bank to meet global targets for reducing CO_2 emission (Mardones and Baeza, 2018).

In contrast to environmental tax, LAC countries are becoming world leaders in renewable energy. Many Latin American countries have pledged a set of regional goals of reaching at least 70% of renewable energy in electricity by 2030 and have implemented formal targets for renewable energy (Jacobs et al., 2013). Renewable energy accounts for almost 28% of LAC total energy consumption while the world average is 18% (CEPAL, 2018, Washburn and Pablo-Romeo, 2019). The increasing share of renewable energy in total energy consumption reflects investment in renewable sources, were in some LAC countries the share of renewable energy investment accounts for more than 1% of GDP (Fuinhas et al., 2021). Investment in renewable energy technologies increased by 54% in 2018 amounting to US$ 18.1 billion in 2019 (Fuinhas et al., 2021). This has been made possible by the availability of expanded capital stock, access to funding promoted by the financial liberalization measures and also public-private participation in renewable energy development (Fuinhas et al., 2021). For instance, Ecuador, Bolivia, Brazil, Argentina, Chile, Peru, El Salvador and Costa Rica built several energy projects that use renewable sources such as solar and hydro-electric energy (Alvarado et al., 2019). In recent years, costs for renewable energy technologies have fallen to the extent that solar and onshore wind power no longer need financial support to compete with conventional power generation in a growing number of Latin American countries (Santiago et al., 2020). However, despite the fast growth of renewable energy in the LAC region, LAC still continue to be fossil-fuel dependent, either as producers or consumers (Santiago et al., 2020). Despite empirical evidence showing that renewable energy not only decreases CO_2 emissions in LAC but also reduces outdoor air pollution (Koengkan and Fuinhas, 2020; Koengkan et al., 2021; Vural, 2021); the productive structure of LAC is still very dependent on non-renewable energy consumption, which leads to significant increases in CO_2 emissions (Santiago et al. 2020). Nevertheless, many LAC countries are vigorously pursuing various energy policies to achieve sustainable development by promoting low-carbon development, by developing new environmentally friendly energy and green technology supported by fiscal mechanisms to reduce environmental degradation (Santiago et al., 2020).

3. A brief review of the related literature

3.1. The theoretical and empirical determinants of CO_2 emissions

As the determinants of CO_2 emissions are complex and varied (Alstine and Neumayer, 2021; Mardani et al., 2019; Shahbaz and Sinha, 2019; Tiba and Omri, 2017), in this section we shall concentrate on some of the most important determinants of CO_2 emission the literature has identified. Environmental degradation has become one of the perennial problems threatening humanity and several studies have been anxious to find the most important determinants of CO_2 emissions that can have significant impact on either improving or retarding environmental degradation. The most important challenge facing policy makers is how to mitigate environmental degradation without sacrificing economic and social development. Based on the Environmental Kuznets Curve (EKC) some believe that economic growth is the main cause of environmental degradation as well as a panacea to environmental degradation. According to this EKC hypothesis, in the early stages of economic growth, environmental degradation worsens with rising trend of fossil energy consumption. However, at higher stages of economic growth due to technological progress in energy technology that promotes environmentally friendly energy, emissions come down and environmental quality improves (Alstine and Neumayer, 2021; Shahbaz and Sinha, 2019). The EKC hypothesis predicts “inverted U-shaped” relationship between economic growth and CO_2 emissions. This hypothetical relationship was extensively researched and the conclusion that emerges is that there is no conclusive evidence as some find support for the inverted U-shaped relationship while others do not (Alstine and Neumayer 2021; Shahbaz and Sinha, 2019). Some believe that economic growth, by promoting less pollution-intensive technologies can address the issues of environmental degradation (Alstine and Neumayer, 2021). Further, with structural transformation, the share of industry will go down as the share of services goes up and these sectoral changes may favor less-polluting sectors (Alstine and Neumayer, 2021). Moreover, as income rises, population growth rates fall and this can lessen the pressure on the environment. The fundamental dilemma that developing countries are facing is to ‘grow now and clean up later (Alstine and Neumayer, 2021). A balance is required.

Early studies focused on testing the validity and shape of the EKC focus in terms of considering economic growth as the only determinant of environmental quality with little emphasis on other determinants of CO_2 emissions. Recently however the focus has been on the determinants of CO_2 emissions with a view to broaden policies to mitigate environmental degradation (Shahbaz and Sinha, 2019). The focus is shifting toward finding whether the environmental performance of a country can be related to its environmental policy such as implementing environmental taxes (Wolde-Rufael and Mulat-Weldemeskel, 2020). With this in mind, the empirical literature has identified around twenty determinants of CO_2 emissions that include variables such as renewable and non-renewable energy, foreign trade, foreign direct investment, globalization, natural resource, urbanization, green technology, human capital, literacy, democracy, corruption, financial development, income inequality, tourism etc. Since it is hard to include all of them in one model, the empirical studies include only few of these determinants. Following these studies and based on the scope of the paper, we divided the literature review in various sub-sections pertaining to environmental tax, renewable energy, non-renewable energy financial development, and income as follows:

3.2. Environmental tax and CO_2 emissions

It is now widely accepted that neither economic growth nor market forces can alone solve the fundamental problems of environmental externalities. Consequently, environmental taxation has become one of the most important policy instruments for addressing environmental externalities (European Environment Agency, 2016; Freire-González, 2018;; Freire-González and Ho, 2018; Goulder, 1995; Haites, 2018; ILO 2014; Pearce, 1991, Pigou 1920; Tol, 2017, 2018). According to the ‘double dividend’ hypothesis proposed by Pearce (1991), environmental tax serves two important purposes. First, as the ‘green dividend’ hypothesis postulates, environmental tax can improve environmental quality by making polluters pay for the pollution they create so that these taxes can induce them to take some remedial actions to reduce the damage they cause to the environment. Second, according to the ‘blue dividend’ hypothesis, the revenues from environmental tax can be recycled not only to correct environmental externalities but also to correct other distortions such as reducing labor tax (Pearce, 1991). Fundamentally however, the ultimate long-run objective of environmental tax is to inculcate behavioral changes so that businesses promote environmentally friendly technologies and consumers to consume these environmentally friendly products (European Environment Agency, 2016; 2020; Wolde-Rufael and Mulat-Weldemeskel, 2020). Eventually, it is hoped that environmental tax can change the structure of energy production and energy consumption towards less pollutant energy production and energy consumption. Additionally, it is also hoped that environmental tax can induce investment in green technology and promote energy efficiency that reduce emissions (Karmaker et al., 2021).

Despite the above positive attributes, it is also possible that environmental tax, by increasing the cost of production can adversely affect international competitiveness (Mulatu, 2018). Further, producers can shift the cost of environmental tax to consumers, and as these increased prices can disproportionately affect low-income people, it is possible that environmental tax can exacerbate income inequality (Fremstad and Paul, 2019; Oueslati et al., 2017). However, the more fundamental problem of environmental tax is the fear that it can exacerbate environmental externalities rather than solving them. According to the proponents of the ‘green paradox’ (Jensen et al., 2015; Sinn, 2008), environmental tax can generate unintended consequences that can undermine environmental quality rather than promote environmental sustainability. To Sinn (2008), if suppliers of fossil energy do not react, the “demand reductions by a subset of countries are ineffective” (p. 360). This so because, “If suppliers feel threatened by a gradual greening of economic policies …; they will extract their stocks more rapidly, thus accelerating global warming” (p. 360). As fossil producers anticipate that increases in environmental tax can reduce the demand for their fossil resources, they will step-up production more quickly and their actions can further deteriorate environment quality (Sinn, 2008). However, the empirical evidence so far is not conclusive (van der Ploeg and Withagen, 2015).

Coming to the empirical evidence of the effectiveness of environmental tax in reducing CO_2 emissions, the evidence is not conclusive (Bashir et al., 2020, 2021; Shahzad, 2020). Evidence which supports the effectiveness of environmental tax in mitigating emissions comes, among others, from Bashir et al., 2020; Chien et al., 2021 ; Ghazouani et al., 2021; Haites, 2018; Hao et al., 2021; He et al., 2019b; Miller and Vela, 2013; Morley, 2012; Safi et. al., 2021; Sen and Vollebergh, 2018 Ulucak et al., 2020; Wolde-Rufael and Mulat-Weldemeskel, 2020. In the case of Colombia, Calderón et al. (2016) and Cardenas et al. (2016) show that carbon tax has the potential for significant CO_2 reductions. In addition, others such as (Filipović and Golušin, 2015) also found that energy tax can decrease energy consumption as well as reduce GHG emissions. Similarly, Aydin and Esen (2018) for some European countries also found that environmental tax can reduce emissions and promote technological innovation.

In contrast to the above, there are other studies which found that environmental tax is not effective in reducing environmental degradation. For instance, Borozan (2019); Liobikienė et al. (2020); Hotunluoğlu and Tekel, 2007 for a group of European countries; Loganathan et al. (2014) for Malaysia; Radulescu et al. (2017) for Romania did not find that environmental tax reduces CO_2 emissions. Similarly, for three LAC countries, Mardones and Baeza (2018) found that carbon tax was not effective in mitigating emissions.

3.3. CO_2 emissions, renewable energy and fossil energy consumption

In the relationship between energy consumption and CO_2 emissions, the majority of the empirical literature uses aggregate energy consumption and fails to distinguish between renewable and non-renewable energy sources as separate determinants of CO_2 emission. Renewable energy and non-renewable energy may have different impacts on CO_2 emissions. In light of the prominence of renewable energy in mitigating environmental degradation and in light of the threats to the environment posited by fossil energy consumption as the main source of CO_2 emissions, and also to meet Goal 7 of the UN Sustainable Development of ensuring 'access to affordable, reliable, sustainable and modern energy for all', it is imperative that the role of energy sources as major determinants of environmental sustainability should be investigated. Empirical evidence also shows that disaggregating energy sources into renewable and non-renewable can exert heterogeneous impacts on CO_2 emissions (Chen et al., 2019; Yuping et al., 2021).

Concerning the role of renewable energy, the empirical evidence generally indicates that it is one of the most important energy sources for combating environmental degradation (Acheampong et al., 2019; Alola et al., 2019; Bahir et al., 2020; Frankfurt School-UNEP Centre, 2020; Hao et al., 2021; Inglesi-Lotz and Dogan, 2018; Khan et al., 2019; Koengkan et al., 2020; Oluoch et al., 2021; Sharif et al., 2019; Vural, 2021). According to REN21 (2020) renewable energy has cemented its position as the dominant source of energy where around 28% of global electricity is now coming from renewables, up from 19% in 2010. Renewable energy is also one of the pillars for combating emissions in LAC (Bersalli et al., 2020; Washburn and Pablo-Romeo, 2019). Empirical evidence also shows that renewable energy not only decreases CO_2 emissions in LAC but also reduces outdoor air pollution (Koengkan and Fuinhas, 2020; Koengkan et al., 2021; Vural, 2021).

In contrast to renewable energy, fossil or non-renewable energy sources is adding to GHG emissions that exacerbates global warming. Hanif (2017) has found that fossil fuel consumption, significantly contributes to environmental degradation in LAC. Equally, Koengkan et al. (2021) have also found that non-renewable energy use across Latin America is responsible for environmental degradation (increases in CO_2 emission). For other countries many have found that non-energy consumption exacerbates environmental degradation (see Erdogan et al., 2020).

3.4. CO_2 emissions and financial development

Financial development can have both positive and negative impact on CO_2 emissions (Shahbaz et al., 2021). If financial services promote renewable energy, then since renewable energy is less pollutant, renewable energy can have a positive impact on environmental quality. Financial development, can reduce investment costs and can provide better opportunities for firms to finance technological advances that can mitigate CO_2 emissions. On the other hand, if financial services promote fossil energy at the expense of renewable energy, and since fossil energy consumption increases CO_2 emission, financial services aggravate environmental degradation. Fossil or non-renewable energy sources is adding to GHG emissions that exacerbates global warming.

Numerous studies, such as Zaidi et al. (2019) argued that a developed financial system enhances environmental quality by providing funds/incentives for eco-friendly technologies and renewable energy infrastructures through the financial mechanism and/or transfer of technology from developed countries. In contrast, others argue that financial development increases environmental degradation by providing funds that enhances the acquisition of energy-intensive types of machinery such as automobiles, vehicles, and other applications. Coming to the relationship between environmental quality and financial development, there have been several studies but the empirical evidence is not conclusive (Petrović and Lobanov, 2021). For instance, (Acheampong, 2019; Al-mulali et al., 2015; Bashir et al., 2020; Jebli et al., 2020; Lv and Li, 2021; Shahbaz et al., 2021) found that financial development can improve environmental quality. In contrast, others including Ibrahim and Vo (2021); Sadorsky (2011); Shoaib et al. (2020) found that financial development deteriorates environmental quality. Xu et al. (2021) also found that financial development has a positive impact on CO_2 emissions when per-capita income is between $1100 and $8100 but a negative impact when per-capita income is less than $1100 or greater than $8100. Others such as Charfeddine and Kahia (2019); Dogan and Turkekul (2016) found that the impact of financial development on environmental quality is either neutral or is insignificant. Similarly, for Latin American countries, Adebayo et al. (2021) did not find that financial development impacts on CO_2 emissions.

4. Model and data

4.1. The basic model

The determinants of CO_2 emissions are complex and varied but for our current purpose we limit ourselves to include only environmental tax and renewable energy after controlling for financial development, non-renewable energy and economic growth as follows:

$$cc_{it} = \alpha_{it} + \beta_1 tax_{it} + \beta_2 rr_{it} + \beta_3 ff_{it} + \beta_4 bb_{it} + \beta_5 yy_{it} + \varepsilon_{it} \tag{1}$$

where cc_{it} is CO_2 emissions per capita, tax_{it} is environment tax, rr_{it} is renewable energy consumption, ff_{it} is non-renewable energy consumption, bb_{it} is bank credit to the private sector as% of GDP (proxy for financial development), yy_{it} is real GDP per capita and $\varepsilon_{\mathrm{it}}$ is the error term. We measure environmental tax: (i) as real environmental tax per capita; (ii) as% of GDP and (iii) as% of total tax revenues. Thus, Eq. (1) is estimated for three different models using the three different measures of environmental tax. All the data are in logs.

4.2. Data and descriptive statistics

We use a balanced annual panel data covering the period 1994–2018 for 18 LAC countries where a complete set of data is available only for 18 countries out of all the LAC countries: Argentina, Belsize, Bolivia, Brazil, Chile, Colombia, Dominican Republic, Ecuador, Guatemala, Guyana, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago and Uruguay. Data on environmental tax are from OECD database (OECD, 2020); real GDP per capita and bank credit are from the World Development Indicators (World Bank, 2020). Renewable energy (includes the consumption of energy from wood, waste, geothermal, wind, photovoltaic cells and solar energy sources) and non-renewable energy consumption (includes the aggregate consumption of coal and coal products, oil and natural gas measured in quadrillion of Btu) are from USA Energy Information Administration (IEA 2020) and CO_2 emissions per capita are from European Environment Agency Emissions Database for Global Atmospheric Research (Crippa et al., 2020).

Table 1 presents some background statistics for all the variables. Real environmental tax per capital (2015 USD PPP) varies from as low as 1.92 in Belsize to 392 in Paraguay. Trinidad and Tobago has the highest CO_2 emissions per capita as well as the highest GDP per capita while Nicaragua has the lowest CO_2 per capita as well as the lowest GDP per capita. Paraguay and Trinidad and Tobago have the highest and the lowest renewable as% of total energy. Bank credit to the private sector also varies considerably. Following Koengkan and Fuinhas (2021), we tested also for normality and Variance Inflation Factor (VIF) and we

Table 1
Descriptive statistics.

Variable names (in logs)	Data description	Obs.	Mean	Std. Dev.	Min	max	source
cc	CO_2 emissions per capita	450	0.627	0.800	−0.562	3.372	European Environment Agency
txp	Real environmental per capita	450	4.376	0.895	0.651	5.971	OECD (2020)
txr	Environmental tax as% of total tax revenues	450	1.484	0.877	−2.354	2.967	OECD (2020
txy	Environmental tax as% of GDP	450	−0.181	0.804	−3.612	1.094	OECD (2020
rr	Renewable consumption	450	−3.458	2.631	−10.127	1.536	EIA (2020)
ff	Non-renewable energy	450	−1.509	1.638	−5.560	2.181	EIA (2020)
bb	Bank credit to the private sector as% of GDP	450	36.174	17.819	9.503	94.72	World Bank (2020)
yy	Real GDP per capita	450	8.487	0.658	6.969	9.745	World Bank (2020)

found that the null hypothesis of normality is rejected and that there is low multicollinearity (available from the authors).

4.3. Methods: the panel quantile regression with fixed effects model

Our main empirical strategy is to apply the MMQR in order to detect the possibility that the effects of the determinants of CO_2 emissions can differ across the conditional distribution of CO_2 emissions that reflect the emissions levels of LAC countries. Following Machado and Silva (2019) and others (Amegavi, 2021; Anwar et al., 2021;Ike et al., 2020; Koengkan and Fuinhas, 2021; Koengkan et al., 2021; Sarkodie and Strezov, 2019), the conditional quantile of a random variable $Q_Y(\tau|X)$ can be is expressed as follows:

$$Y_{it} = \alpha_i + X'_{it}\beta + (\delta_i + Z'_{it}\gamma)\cup_{\mathrm{it}} \tag{2}$$

where Y_{it} is the dependent variable, X_{it} is an i.i.d endogenous variable, $(\alpha,\ \beta,\ \delta,\ \gamma)'$ are parameters to be assessed. The probability, $P\{\delta_i + Z'_{it} > 0\} = 1$. U_{it} is an i.i.d unobserved random variable distributed across individuals and is orthogonal to X_{it} satisfying the Machado and Silva (2019) moment conditions (see Ike et al., 2020; Koengkan, 2020; Machado and Silva, 2019). $i = 1 \ldots n$, denotes the individual i fixed effects and Z is a k-vector of known components of X (see Amengavi, 2021;Koengkan et al., 2021; Machado and Silva, 2019).

Following Amegavi (2021); Ike et al., al.(2020), Eq. (2) implies the following:

$$Q_Y(\tau|X_{it}) = (\alpha_i + \delta_i q(\tau)) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \tag{3}$$

Where $Q_Y(\tau|X_{it})$ is the quantile distribution of the dependent variable, Y_{it}. $\alpha_i(\tau) \equiv \alpha_i + \varepsilon_i q(\tau)$ is the scalar coefficient (Ike et al., 2020) and τ^{th} is the sample quantile (Amegavi, 2021; Ike et al., 2020; Machado and Silva, 2019). Z denotes a k-vector of known components of X_{it} which is normalized to satisfy the Machado and Silva (2019) moment conditions $E(U) = 0$ and $E(|U|) = 1$ (see Ike et al., 2020; Koengkan and Fuinhas, 2020).

The MMQR version of Eq. (4) which includes the relevant variables for our model is specified as follows:

$$Qcc_{it}(\tau_k|\alpha_i, x_{it}) = \alpha_i + \beta_{1\tau}tax_{it} + \beta_{2\tau}rr_{it} + \beta_{3\tau}bb_{it} + \beta_{4\tau}ff_{it} + \beta_{5\tau}yy_{it} \tag{4}$$

where the variables are defined before.

5. Empirical strategy and results

Our empirical strategy follows six steps. First, we test for cross-sectional dependence (CD) as a prerequisite for determining the integration properties of the data. Second, depending on the CD test, we test the integration properties of the data. Third, we test for panel cointegration. Fourth, the long-run coefficients are estimated by applying the Augmented Mean Group (AMG) estimator developed by (Eberhardt and Teal, 2009) and by Bond and Eberhardt (2013) where the test takes into account CD and country-specific heterogeneity among countries (Danish et al., 2019; Destek and Sarkodie, 2019). In addition to the AMG, we also apply the DOLS and the Driscoll-Kraay estimator which has the advantage of taking into consideration the issues of cross- sectional dependency and heteroscedasticity. Fifth, as our main empirical concern is to assess the impact of the dependent variables on the whole distribution of the dependent variable (CO_2 per capita), we estimate Eq. (4) by applying the MMQR method. Sixth, we test for causality by using the Dumitrescu and Hurlin (2012) approach.

5.1. Cross sectional dependence (CD) and slope homogeneity test

As ignoring CD test entails bias, size distortions and inconsistent results (Pesaran, 2006), it is imperative to check the existence of CD. This test is given by:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\tilde{\rho}_{ij} \tag{5}$$

where $\tilde{\rho}_{ij}$ denotes the pairwise correlation (Wolde-Rufael, 2014). Applying the above Pesaran (2006) CD test, Table 2 shows the data are cross-sectionally related implying that shocks in one LAC can be transmitted to another LAC.

However, despite the presence of CD relationship, these countries can also maintain their own independent dynamism and assuming homogenous slope coefficient can provide misleading results (Pesaran and Yamagata, 2008). It is therefore important to test the null hypothesis of homogeneous slopes. This test is given by:

$$\tilde{\Delta}adj = \sqrt{N\left(\frac{N^{-1}\tilde{S}(\tilde{z}_{it})}{\sqrt{var\left(\tilde{S}(\tilde{z}_{it}\right)}}\right)} \tag{6}$$

where the mean $E(\tilde{z}_{it}) = k$ and the variance. $\mathrm{var}(\tilde{z}_{it}) = 2k(T\text{-}k\text{-}1/T + 1)$ (see Wolde-Rufael, 2014).

Applying the above slope homogeneity test, Table 3 shows that there is a country-specific heterogeneity and that the regression parameters are not the same for each individual cross-sectional unit at 1% significant level. Thus, the MMQR is appropriate as it allows for heterogeneity (Koengkan et al., 2021).

5.2. Panel unit root test and panel cointegration

As our data are CD related, we apply the second generation of unit root tests that take into account the CD properties of the data (Pesaran, 2007). Applying the CADF and CIPS tests, Table 4 shows that all the series are difference stationary or I(1) except the *txp* and *txr* variables, which are I(0) but the first generation of unit root tests show that all the variables are difference stationary, I(1).

Having established the integration properties of the data, we carried out tests for cointegration by applying the Pedroni (1999, 2000) and the Kao (1999) cointegration tests but as our data a mixture of I(0) and I(1) variables and the time-span was short, we were not able to apply the Westerlund (2007) cointegration test. However, applying the Pedroni (1999, 2000) and the Kao (1999) tests, Table 5 shows that cointegration is strongly supported.

5.3. Panel long-run tests

Even though our primary aim is to assess the impact of the determinants of CO_2 emissions on the whole distribution of the dependent

Table 2
Bias-adjusted Cross-sectional dependence test.

Model 1				Model 2				Model 3				
variable	LM	LM adj.	LM CD	variable	LM	LM adj.	LM CD	variable	LM	LM adj.	LM CD	
cc	230.500***	6.049***	0.403	cc	237.300***	6.865***	0.662	txy	233.700***	6.444***	0.404	0.687***
txp	249.700***	8.547***	2.531***	txr	226.500***	5.711***	2.464***	cc	251.100***	8.71***6	2.649***	0.008***
rr	203.200***	2.732***	3.610***	rr	203.100***	2.709***	3.118***	rr	203.300***	2.759***	3.527***	0.000***
ff	235.300***	6.771***	1.156	ff	228.500***	5.93***9	1.732	ff	234.600***	6.698***	1.245	0.213***
yy	268.600***	11.140***	5.724***	yy	265.200***	10.690***	4.036***	yy	261.200***	10.240***	4.935***	0.000***
bb	241.300***	7.519***	1.710*	bb	255.400***	9.179***	1.399	bb	242.900***	7.745***	1.854**	0.064**

Notes: *** and ** denote significant levels at 1% and 10% respectively. *xtcsi* Stata 14 routine was used.

Table 3
Test for slope homogeneity.

	Model 1			Model 2			Model 3	
variable	$\ddot{\Delta}$	$\ddot{\Delta}_{adj}$	variable	$\ddot{\Delta}$	$\ddot{\Delta}_{adj}$	variable	$\ddot{\Delta}$	$\ddot{\Delta}_{adj}$
cc	13.418***	14.144***	cc	13.103***	13.812***	cc	13.433***	14.160***
txp	10.995***	11.589***	txr	11.503***	12.125***	txy	11.072***	11.671***
rr	12.292***	12.957***	rr	12.599***	13.280***	rr	12.313***	12.979***
ff	12.633***	13.316***	ff	12.633***	13.316***	ff	12.599***	13.280***
yy	18.145***	19.126***	yy	17.857***	18.823***	yy	17.963***	18.935***
bb	15.101***	15.918***	bb	15.081***	15.897***	bb	15.067***	15.882***

Notes: *** denotes rejection of null hypothesis of homogeneous slopes at 1%. *** denote significant levels at 1%. Significant evidence of slope heterogeneity. The test is carried out with *xthst* Stata 14 routine.

Table 4
Unit root test.

	CADF		CIPS			CADF		CIPS	
	level					first difference			
variable	No trend	With trend	No trend	With trend	variable	No trend	With trend	No trend	With trend
cc	32.955	31.470	0.053	1.235	Δcc	186.549***	150.035***	−6.490	−4.985***
txp	89.012***	54.095**	−1.655**	−1.254*	Δtxp	229.853***	188.039***	−8.426	−6.995***
txr	51.043***	33.626	−2.976***	−1.984**	Δtxr	202.678***	154.711***	−8.467	−6.884***
txy	81.536***	55.141**	−2.906***	−2.213	Δtxy	231.413***	186.175***	−8.649***	−7.368***
rr	26.207	53.007	−0.627	−0.227	Δrr	304.484***	259.897***	−9.726***	−8.270***
ff	34.098	41.369	−0.623	1.231	Δff	206.715***	170.305***	−7.130***	−4.949***
bb	42.487	58.812***	0.465	0.783	Δbb	156.849***	113.102***	–7.137***	−5.674***
yy	18.751	31.648	−0.305	0.783	Δyy	105.826***	72.722***	−3.434***	−2.667***

Notes: ***. ** and * denote rejection of the null hypothesis of unit root at 1%, 5% and 10% respectively. Δ = first difference.

Table 5
Panel cointegration test.

A. Pedroni						
	Model 1		Model 2		Model 3	
method	no trend Statistic	with trend Statistic	no trend Statistic	with trend Statistic	no trend Statistic	with trend Statistic
Panel v-Statistic	−0.025	−1.645	0.152	−1.439	0.011	−1.602
Panel rho-Statistic	1.228	2.617	1.130	2.545	1.217	2.597
Panel PP-Statistic	−3.485***	−2.536***	−3.627***	−2.683***	−3.497***	−2.557***
Panel ADF-Statistic	−3.972***	−3.194***	−4.123***	−3.292***	−3.986***	−3.219***
Group rho-Statistic	2.856	4.268	2.718	4.274	2.858	4.269
Group PP-Statistic	−4.508***	−3.151***	−4.249***	−3.319***	−4.518***	−3.151***
Group ADF-Statistic	−6.166***	−5.158***	−5.649***	−5.168***	−6.161***	−5.157***
B. Kao						
method		Model 1	Mode 2	Model 3		
Modified Dickey-Fuller t		−1.269*	−1.218	−1.304*		
Dickey-Fuller t		−1.377*	−1.327*	−1.413*		
Augmented Dickey-Fuller t		−2.506***	−2.512***	−2.543***		
Unadjusted modified Dickey-Fuller t		−3.196***	−2.955***	−3.259***		
Unadjusted Dickey-Fuller t		−2.400***	−2.262***	−2.445**		

Notes: ***, ** and * denote significant levels at 1%, 5% and 10% respectively.

Table 6

Long-run coefficient estimates.

AMG						Driscoll-Kraay						DOLS					
Model 1		Model 2		Model 3		Model 1		Model 2		Model 3		Model 1		Model 2		Model 3	
txp	−0.033*	txr	−0.023	txy	−0.033*	txp	−0.049***	txr	−0.033***	txy	−0.051***	txp	−0.028	txr	−0.043*	txy	−0.071***
rr	−0.088**	rr	−0.083*	rr	−0.088**	rr	−0.063***	rr	−0.067***	rr	−0.062***	rr	−0.215***	rr	−0.212***	rr	−0.211***
bb	0.082**	bb	0.083**	bb	0.084**	bb	−0.022	bb	−0.023	bb	−0.022	bb	0.017	bb	0.015	bb	0.012
ff	0.455***	ff	0.464***	ff	0.455***	ff	0.547***	ff	0.525***	ff	0.549***	ff	0.321***	ff	0.321***	ff	0.324***
yy	0.601***	yy	0.588***	yy	0.554***	yy	0.293***	yy	0.266***	yy	0.243***	yy	0.601***	yy	0.563***	yy	0.563***

Notes: ***, ** and * denote significant levels at 1%, 5% and 10% respectively.

Table 7

Results of the Method of Moments Quantile regression (MMQR).

quantiles variables	Location	Scale	q05	q10	q20	q30	q40	q50	q60	q70	q80	q90	q95
Model 1													
txp	−0.049	−0.013	−0.024	−0.03	−0.035	−0.039**	−0.043***	−0.047***	−0.053***	−0.057***	−0.063**	−0.070**	−0.074**
rr	−0.063	−0.026	−0.010	−0.022	−0.034	−0.042	−0.050**	−0.060***	−0.071***	−0.080***	−0.093**	−0.107**	−0.116**
bb	0.547	−0.066	−0.055	−0.047	−0.04	−0.035	−0.030	−0.024	−0.017	−0.011	−0.003	0.006	0.012
ff	−0.022	0.017	0.679***	0.648***	0.620***	0.598***	0.577***	0.554***	0.526***	0.503***	0.470***	0.436***	0.413***
yy	0.293	0.129	0.035	0.097	0.152	0.194***	0.234***	0.281***	0.335***	0.380***	0.444***	0.511***	0.555***
F/Wald test			976.98***	976.83***	977.13***	976.88***	976.76***	977.32***	977.12***	976.87***	976.76***	977.52***	976.83***
Model 2													
txr	−0.033	−0.012	−0.008	−0.015	−0.019	−0.024	−0.027	−0.032**	−0.037**	−0.041**	−0.046*	−0.053*	−0.057
rr	−0.067	−0.030	−0.003	−0.022	−0.033	−0.044	−0.053**	−0.064***	−0.077***	−0.088***	−0.101***	−0.118***	−0.129**
bb	0.525	−0.078	−0.064	−0.052	−0.045	−0.038	−0.032	−0.025	−0.017	−0.010	−0.001	0.010	0.016
ff	−0.023	0.019	0.689***	0.640***	0.612***	0.584***	0.561***	0.533***	0.500***	0.470***	0.436***	0.392***	0.365***
yy	0.266	0.127	0.000	0.079	0.125	0.169**	0.207***	0.253***	0.306***	0.353***	0.409***	0.480***	0.523***
F/Wald test			1140.1***	1140.05***	1140.12***	1140.11***	1140.06***	1140.26***	1140.38***	1140.14***	1140.06***	1140.26***	1140.05***
Model 3													
txy	−0.051	−0.014	−0.024	−0.03	−0.036	−0.041**	−0.045***	−0.050***	−0.056***	−0.060***	−0.067***	−0.074**	−0.078**
rr	−0.062	−0.026	−0.010	−0.022	−0.034	−0.042	−0.051**	−0.060***	−0.070***	−0.079***	−0.093**	−0.106**	−0.114**
bb	0.549	−0.065	−0.055	−0.047	−0.040	−0.035	−0.030	−0.024	−0.017	−0.012	−0.003	0.005	0.01
ff	−0.022	0.016	0.681***	0.649***	0.621***	0.600***	0.578***	0.555***	0.528***	0.506***	0.473***	0.439***	0.419***
yy	0.243	0.115	0.010	0.067	0.115	0.153**	0.192***	0.232***	0.279***	0.319***	0.377***	0.438***	0.473***
F/Wald test			1161.07***	1161.04***	1161.15***	1161.06***	1161.02***	1161.21***	1161.12***	1161.11***	1161.02***	1161.31***	1161.02***

Notes: ***, ** and * denote significant levels at 1%, 5% and 10% respectively.

Table 8
Dumitrescu and Hurlin Granger non-causality test results.

Null hypothesis	W-bar	Z-bar	p-value	decision
dtp ↛ dcc	9.004	3.680	0.000	dtp → dcc
dcc ↛ dtp	6.070	0.086	0.932	
dtr ↛ dcc	30.951	30.558	0.000	dtr
dcc ↛ dtr	10.609	5.645	0.000	↔
dty ↛ dcc	11.510	6.748	0.000	dcc dty → dcc
dcc ↛ dty	6.213	0.261	0.794	
drr ↛ dcc	10.957	6.071	0.000	drr → dcc
dcc ↛ drr	2.105	0.223	0.824	
dbb ↛ dcc	1.014	0.043	0.966	dcc → dbb
dcc ↛ dbb	16.510	12.872	0.000	
dff ↛ dcc	9.273	4.009	0.000	dcc
dcc ↛ dff	10.745	5.812	0.000	↔
dyy ↛ dcc	1.278	0.834	0.405	dff dcc → dyy
dcc ↛ dyy	1.682	2.046	0.041	
dtp ↛ drr	8.972	3.640	0.000	drr
drr ↛ dtp	14.586	10.515	0.000	↔
dtr ↛ drr	5.363	4.093	0.000	dtp dtr
drr ↛ dtr	8.130	2.609	0.009	↔
dty ↛ drr	1.482	1.445	0.149	drr drr → dty
drr ↛ dty	9.775	4.623	0.000	
dbb ↛ drr	25.836	24.294	0.000	drr
drr ↛ dbb	19.729	16.814	0.000	↔
dff ↛ drr	1.007	0.022	0.983	dbb drr → dff
drr ↛ dff	13.579	9.282	0.000	
dyy ↛ drr	10.350	5.327	0.000	drr
drr ↛ dyy	8.555	3.129	0.002	↔
dtp ↛ dbb	16.512	12.874	0.000	dyy dtp
dbb ↛ dtp	8.084	2.552	0.011	↔
dtr ↛ dbb	19.998	17.144	0.000	dbb dtr
dbb ↛ dtr	8.350	2.878	0.004	↔
dty ↛ dbb	15.597	11.754	0.000	dbb dty
dbb ↛ dty	7.559	1.909	0.056	↔
dbb ↛ dff	8.593	3.176	0.002	dty dbb → dff
dff ↛ dbb	1.335	1.003	0.316	
dyy ↛ dbb	4.928	11.784	0.000	dbb
dbb ↛ dyy	7.856	2.274	0.023	↔
dtp ↛ dff	0.968	−0.096	0.924	dyy dff → dtp
dff ↛ dtp	7.829	2.240	0.025	
dtr ↛ dff	0.779	−0.662	0.508	dff → dtxr
dff ↛ dtr	8.431	2.978	0.003	
dty ↛ dff	0.989	−0.034	0.973	dff → dty
dff ↛ dty	11.255	6.436	0.000	
dyy ↛ dff	0.972	−0.085	0.932	dff
dff ↛ dyy	1.311	0.934	0.351	↛
dtp ↛ dyy	8.867	3.511	0.000	dyy dtp
dyy ↛ dtp	7.679	2.056	0.040	↔
dtr ↛ dyy	7.646	2.016	0.044	dyy dtr
dyy ↛ dtr	8.357	2.886	0.004	↔
dty ↛ dyy	9.927	4.809	0.000	dyy dty
dyy ↛ dty	7.966	2.408	0.016	↔ dyy

Notes: d = first difference operator. ↛ = does not cause; → = unidirectional; ↔ = bidirectional. The optimum lag was selected by the AIC. For the definition of the variables, see Table 1. *xtgcause* routine in Stata 14 was used.

variable (CO_2 emissions) by applying the MMQR approach, for comparative purposes we first present the results of three traditional estimators: the AMG, the DOLS and the Driscoll & Kraay estimates.

Results of these tests are presented in Table 6. The AMG, DOLS and the Driscoll and Kraay results show that there is a negative and statistically significant relationship between CO_2 emissions and environmental tax. For instance, according to the AMG estimates, a 1% increase in environmental tax decreases CO_2 emissions per capita between 0.023% and 0.033%. Similarly, the DOLS estimator also shows a negative and statistically significant relationship, where a 1% increase in environmental tax reduces CO_2 emissions per capita between 0.028 and 0.071% (see, Table 6). Consistent with the two above estimates, the Driscoll and Kraay estimator also shows a negative and statistically significant relationship with a 1% increase in environmental tax reducing CO_2 emissions per capita between 0.033 and 0.051% (see Table 6). Our evidence is in line with other studies for other countries who found that environmental taxes can reduce carbon emissions (see, Bahir et al., 2020; Chien et al., 2021; Ghazouani et al., 2021; Hao et al., 2021; He et al. 2019; Wolde-Rufael and Mulat-Weldemskel, 2020; Zahan and Chuanmin, 2021). Our results indicate that there is no support for the ‘green paradox’ in LAC.

Regarding the relationship between CO_2 emissions and renewable energy consumption, similar to the relationship between CO_2 emissions and environmental tax, we also found a negative and statistically significant relationship in all the three estimators. According to the AMG, a 1% increase in renewable energy consumption leads between 0.083% and 0.088% reduction in CO_2 emissions per capita. Similarly, the DOLS estimators and the Driscoll and Kraay estimators also show a negative and statistically significant relationship between CO_2 emissions and renewable energy consumption. For instance, the DOLS estimator shows that a 1% increase in renewable energy consumption reduces CO_2 emissions per capita between 0.211 and 0.215% while the Driscoll and Kraay estimator shows that a 1% increase in renewable energy consumption reduces CO_2 emissions per capita between 0.062 and 0.067%. Our evidence is in line with other LAC studies that include Fuinhas et al. (2017); Koengkan and Fuinhas (2020); Koengkan et al. (2021); Vural (2021), and also in line with other recent studies that include Acheampong et al. (2019); Alola et al. (2019); Bashir et al. (2020); Hao et al. (2021); Inglesi-Lotz and Dogan (2018); Sharif et al. (2019).

Coming to the relationship between financial development and CO_2 emissions, only the AMG estimate shows that CO_2 emissions and financial development are positively and significantly related. The AMG estimator seems to indicate that financial development was detrimental to environmental quality in LAC. In contrast, the DOLS and the Driscoll & Kraay estimate show that there is no statistically significant relationship between financial development and CO_2 emissions. The results from the DOLS and the Driscoll and Kraay estimates are consistent with Adebayo et al. (2021) who found no significant impact of financial development on CO_2 emissions in LAC.

Similarly, we also found a positive and a statistically significant relationship between non-renewable energy and CO_2 emissions in all the estimators. This is in line with Koengkan et al. (2021) who found that fossil fuel consumption was positively related to CO_2 emissions for LAC countries.

5.4. Panel quantile regression results and discussion

For reasons discussed above, our main concern is to present estimates that reflect the heterogenous impact of the determinants of CO_2 emissions rather than the conditional mean of these estimates. The results of the MMQR test together with the Wald test that ascertain that all the coefficients of the regressors are not equal to zero (Koengkan and Fuinhas, 2021) are presented in Table 7. As can be seen from Table 7 the effect of environmental tax on CO_2 emissions is heterogeneous among LAC countries. The impact of environmental tax increases across the quantiles but the environmental tax coefficients for lower quantiles (5th, 10th and 20th) are negative but not statistically significant. As quantile regression arranges the data in ascending order based on the conditional distribution of the dependent variable, CO_2 emission per capita (Lingyan et al., 2021), Table 7 shows that in lower emission countries the role of environmental tax in the reduction emissions is not effective. In contrast, for higher emission countries there is a negative and statistically significant relationship between CO_2 emissions and the three measures of environmental tax in all quantiles (Models 1, 2 and 3). For instance, from the 40th up to the 95th percentiles, we found a negative and significant relationship between CO_2 emissions and environmental tax. This indicates that for countries with relatively higher CO_2 emissions per capita, the impact of environmental tax is relatively more effective than countries with lower emissions. For higher emission countries, the evidence validates the effectiveness of environmental tax in reducing

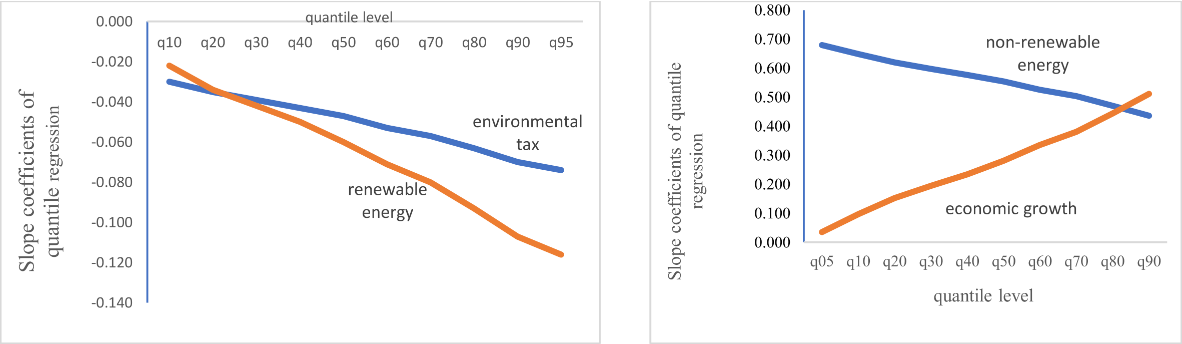

Fig. 1. A. Change in panel quantile regressions coefficients for environmental tax and renewable energy. B. Change in panel quantile regressions coefficients in non-renewable energy and economic growth.

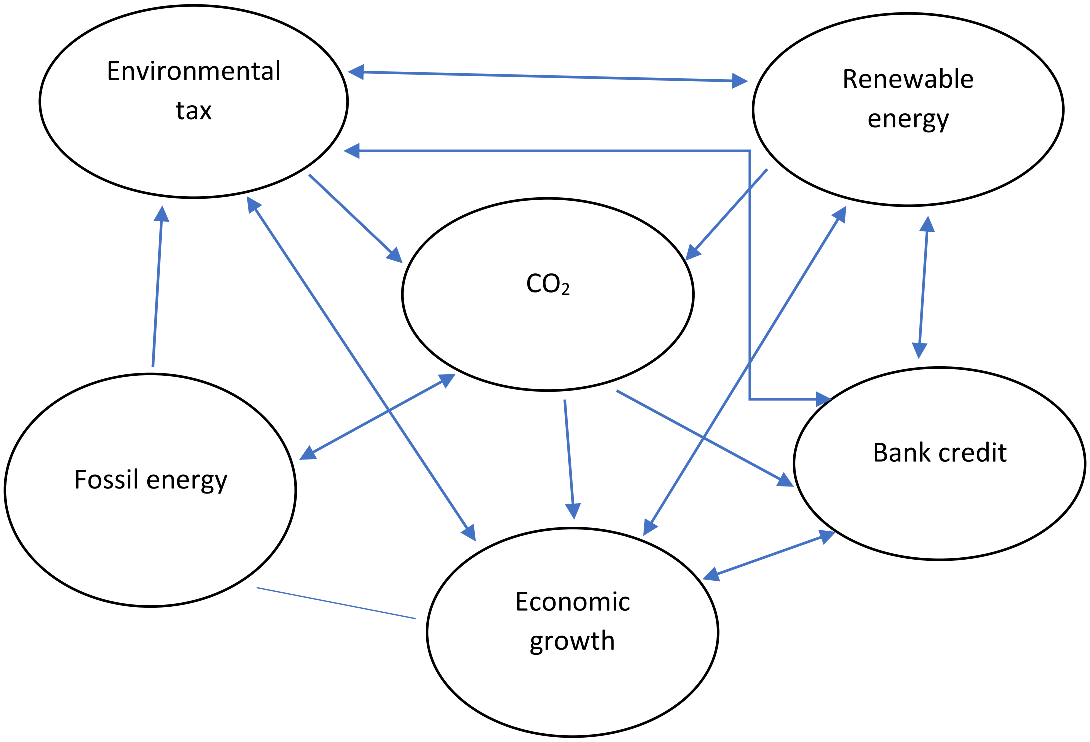

Fig. 2. Direction of causality between CO_2 emissions and its determinants.
Notes: → = unidirectional, ↔ = bidirectional, — no causality.

CO_2 emissions and is consistent with the quantile evidence presented in Bashir et al. (2020).

Similar to the environmental tax, Table 7 shows that the relationship between CO_2 emissions and renewable energy is also heterogeneous among LAC countries. As can be seen from Table 7, the impact of renewable energy increases in all quantiles. However, the relationship between CO_2 emissions and renewable energy is negative and significant only for higher quantiles (40th to the 95th). This indicates that the impact of renewable energy in reducing CO_2 emissions is more effective in higher carbon-emitting countries than in lower emitting countries. Again, as with the environmental tax, for countries with lower emission (5th, 10th, 20th and 30th percentiles), the relation between CO_2 and renewable energy consumption is statistically insignificant. This implies that impact of renewable energy consumption in mitigating CO_2 emissions in low emission countries is not as effective as in higher emission countries. One possible reason for the insignificant relation between CO_2 emissions and renewable energy consumption in these low emission countries could be that the investment and maintenance costs of renewable energy may be relatively higher for these countries relative to countries with high emission (Koengkan, 2020; Oluoch et al., 2021). Our evidence of a statistically significant negative relationship between CO_2 emissions and renewable energy is not in line with statistically insignificant MMQR negative relationship between CO_2 emissions and renewable energy found by Anwar et al. (2021) for ASEAN countries but is consistent with Alharthi et al. (2021) for MENA countries.

A graphical summary of the impact of the determinants of CO_2 emissions is depicted in Fig. 1. Fig 1A shows that both environmental tax and renewable energy are heterogeneous among LAC countries. The mitigation impact of environmental tax and renewable energy on CO_2 emissions increase across the quantiles. These results reveal important information that is no covered by the traditional mean based OLS regressions such as AMG, DOLS and FMOLS. The figure shows a non-linear relationship and that there is an asymmetric link between environmental tax and CO_2 emissions on the one hand and between renewable energy and CO_2 emissions on the other. As Fig. 1A depicts, these two policy instruments contribute to improving environmental quality in LAC.

Our MMQR results relating to the relationship between environmental tax and CO_2 emissions are similar to the quantile regression findings of Bashir et al. (2020); Zhou and Li (2019). What these results suggest is that in countries like Honduras, Guatemala and Nicaragua where CO_2 emissions per capita is relatively low, environmental tax and renewable energy are not effective in reducing emissions and these countries should strive to make these two policy instruments more effective for fighting environmental degradation. Fig 1A also shows that the renewable energy quantile coefficients are relatively larger than the environmental tax quantile coefficients in all the estimated results suggesting that renewable energy is relatively more effective than environmental tax in reducing emissions. This may be due to the fact that environmental tax was recently introduced in LAC countries. Nevertheless, the higher relative importance of renewable energy consumption in reducing CO_2 emissions may give credence to the ECLA (2018) claim that LAC countries are becoming world leaders in renewable energy. Overall, Fig. 1A shows that the contribution of both environmental tax and renewable energy increases with all quantiles and show that both these two policy instruments are effective in combating CO_2 emissions in high emissions countries. Again, as with the AMG, DOLS and Driscoll & Kraay results, the MMQR results, show that renewable energy is relatively more effective in reducing emissions than environmental tax.

Concerning the MMQR results for other variables, we found a positive and statistically significant relationship between CO_2 emissions and non-renewable energy consumption which is in line with Anwar et al. (2021). One important point to note is that the detrimental effect non-renewable energy consumption is less conspicuous in countries with relatively low emissions than in countries with high emissions. Moreover, as stated earlier, countries with lower emissions have relatively lower renewable energy coefficients. The relatively lower renewable energy coefficients and higher fossil energy coefficients suggest that these countries have to lower their fossil energy consumption and increase their use of renewable energy by investing in environmentally friendly technologies. Fig. 1B also shows that while the impact of fossil energy consumption on CO_2 emission decreases as we move up the quantiles, the impact of economic growth increases in all quantiles.

5.5. Results of heterogeneous panel causality test

As the above analyses do not indicate the direction of Granger causality among the variables, we tested the direction of causality by applying the Dumitrescu and Hurlin (2012) panel Granger causality test. Results of this test are presented in Table 8. As can be seen from Table 8, there is unidirectional causality from environmental tax to CO_2 emissions in model 1 and 3. In contrast, in model 2 we found bidirectional causality between CO_2 emissions and environmental tax. Nevertheless, the overall evidence indicates that environmental tax causes CO_2 emissions.

Concerning the causal relationship between the other determinants and CO_2 emissions, we found unidirectional causality from renewable energy consumption to CO_2 emissions; bidirectional causality between CO_2 emissions and non-renewable energy consumption; unidirectional causality from CO_2 emissions to financial development; and unidirectional causality from CO_2 emissions to GDP per capita.

As can be seen from Table 8, there is bidirectional causality between per capita environmental tax and renewable energy consumption (Model 1 and Model 2) but causality runs from renewable energy to environmental tax (in Model 3). Concerning the other causality results, we found bidirectional causality between economic growth and environmental tax; bidirectional causality between environmental tax and financial development; bidirectional causality between economic growth and renewable energy; bidirectional causality between economic growth and financial development; bidirectional causality between renewable energy and financial development. In contrast, we found unidirectional causality from financial development to non-renewable energy but no causality between economic growth and non-renewable energy.

Fig. 2 depicts the graphical summary of the above causal relationship between CO_2 emissions and its determinants.

6. Summary and concluding remarks

The aim of this paper was to assess the effectiveness of environmental tax and renewable energy in reducing CO_2 emission in 18 Latin America and Caribbean countries for the period 1994–2018 by applying the Methods of Moments Quantile Regression with fixed effects. For robustness checks, we also applied a number of other estimators including the augmented mean group (AMG), the Dynamic Ordinary Least Squares (DOLS) and the Driscoll and Kraay (1998) estimator. Our evidence indicates a heterogeneous impact of environmental tax on CO_2 emissions on the one hand and a similarly heterogeneous effect of renewable energy on CO_2 emissions on the other. Environmental tax and renewable energy decrease CO_2 emission in all quantiles but only statistically significant in higher quantiles (40th to 95th percentiles). The evidence indicates that the impact of environmental tax and renewable energy are relatively more effective in high emission countries than countries with lower emissions. The AMG and, DOLS and the Driscoll and Kraay (1998) estimators also show a statistically significant negative relationship between CO_2 emission and environmental tax on the one hand and a statistically significant negative relationship between CO_2 emission and renewable energy consumption on the other. In addition, we also found causality from environmental tax to CO_2 emission and from renewable energy to CO_2 emission. We also found bidirectional causality between environmental tax and renewable energy consumption suggesting that environmental-related taxes can not only reduce emission but they can also promote renewable energy. Our empirical evidence indicates that both environmental tax and renewable energy can be effective instruments for reducing CO_2 emission. Nevertheless, while both environmental tax and renewable energy can be effective policy instruments for reducing CO_2 emission, they cannot alone in themselves be sufficient to promote environmental sustainability. There should be other supportive environmental policies to complement and make these two policy instruments more effective in reducing CO_2 emission. The promotion of renewable energy should be reinforced by providing incentives such as tax reliefs and subsidies for green technologies. Firms that use environmentally unfriendly technology should be discouraged. As we found that fossil energy consumption exacerbates environmental degradation, LAC should reduce the use of fossil energy and alter their energy mix towards more renewable energy use. To reinforce behavioral changes on both businesses and consumers, there should also be environmental awareness and environmental participation of all citizens. There is also a need for sustainable resource management that supports both environmental sustainability and economic growth by making financial development conducive to promoting renewables and discouraging 'dirty' industries. The region's richness in natural resource has to some extent been a liability as it is not only detrimental to environmental sustainability but is also a source of inequality. The growing concern over the mismanagement of natural resource also needs to be addressed in order to minimize its detrimental effects on the ecosystem.

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