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# Effectiveness of environmental taxes and environmental stringent policies on CO2 emissions: the European experience

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**Abstract**

The aim of this paper is to investigate the effectiveness of environmental taxes and environmental stringent policies in reducing $CO_2$ emissions in a panel of 20 European countries for the period 1995–2012. As mounting global environmental and climate challenges are becoming great cause for concern, environmental stringency policies and environmental taxes are becoming the cornerstones for a sustainable environment. Applying panel cointegration tests, we found a negative and a statistically significant relationship between environment taxes (disaggregated into total, energy and transport taxes) and $CO_2$ emissions on the one hand and also a negative and a statistically significant relationship between environmental policy stringent and $CO_2$ emissions on the other. The robustness of the evidence is also supported by a quantile regression model. The higher the environmental stringency policy, the lower the $CO_2$ emission. Similarly, the higher the revenue from total environmental tax, energy and transport tax, the higher the reductions in $CO_2$ emissions. Both these two policy instruments were effective in reducing $CO_2$ emissions. The positive impact of environmental tax on improving environmental quality should encourage policy makers to increase environmental tax as the current level of environmental tax is believed to be low relative to levels required to achieve climate change objectives and is also low relative to the social cost of carbon and relative to the prices of taxed fuels.

**Keywords** Cointegration · $CO_2$ emissions · Environmental policy stringency · Environmental taxes · Fossil energy · Renewable energy **JEL**

**Classification** H23 · Q2 · Q3 · Q4

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## 1 Introduction

One of the most important challenges facing the world is how to maintain environmental sustainability and how to reduce the detrimental effects of environmental degradation without jeopardising economic growth (Costa–Campi et al., 2017; Río, 2009; IPCC, 2018; Landrigan et al., 2017; World Bank, 2016). As succinctly put by Landrigan et al. (2017) "pollution is one of the great existential challenges" facing the world as global warming poses a fundamental threat not only to the natural ecosystems and economic development but also to human health (World Bank, 2016). The challenges facing the world regarding environmental sustainability, energy security and economic sustainability are enormous (Costa–Campi et al., 2017; Landrigan et al., 2017; Río, 2009; Tol, 2017). As the World Bank (2016) has eloquently put it, the negative impact of air pollution in terms of lost output and health is indeed a "sobering wake-up call" to act. It is therefore not surprising to see that reducing environmental degradation has become one of the most important environmental challenges facing the world. No matter how complex and how controversially the climate change debate is currently portrayed, nobody is disputing the fact that the world is facing significant environmental challenges and almost everybody seems to agree that there is an urgent need for reducing emissions (IPCC, 2018; Landrigan et al., 2017; Tol, 2009, 2017, 2018).

Environmental policy framework that protects the environment without jeopardising economic growth is now becoming one of the important policies for averting environmental degradation (IPCC, 2018; Landrigan et al., 2017; Río, 2009). This growing concern about environmental degradation is forcing many governments to seek, identify and implement the most appropriate policy for achieving lower pollution emissions and for maintaining economic growth that leads to improved social welfare (Borozan, 2019; IPCC, 2018; Lin and Li, 2011; Río, 2009; Speck, 2008; World Bank, 2016).

Currently, one of the most important policy instruments that is being implemented in the European Union (EU) to reduce greenhouse gas (GHG) emissions is carbon tax also commonly known as an Emissions Trading Scheme (ETS).[1] Carbon price is established in two ways. The first is where the government can levy a carbon tax on the distribution, sale or use of fossil fuels, based on their carbon content, and the second approach is through establishing a quota system called cap and trade (LSE, 2018). By putting a price on carbon where the price can act as an incentive for implementing emission reduction options, it is hoped that GHG emissions can be reduced (Baranzini et al., 2017; Cao, et al., 2019; European Commission, 2015; Haites, 2018; High-Level Commission on Carbon Prices, 2017; Tol, 2017). To the Climate Reality Project (2017), the single most important answer to our climate crisis and in particular to GHG emissions is to put a "meaningful price on carbon pollution". Similarly, to Tol (2017) the "First-best climate policy is a uniform carbon tax which gradually rises over time" (p. 431). The longer-term objective of carbon tax or ETS is not only to reduce GHG emissions but more importantly it is intended to eventually forge innovation in order promote a transition to a low-carbon economy (Martin et al., 2016).[2]

With the adaptation of the European Climate Change Program (ECCP) in 2000, a new climate policy has been ushered in the EU "… to help identify the most environmentally

[1] For an extensive discussion on ETS, see European Commission (2015).

[2] For e review of the literature on EU ETS, see Ellerman et al. (2016)

effective and most cost-effective policies and measures that can be taken at European level to cut greenhouse gas emissions” (European Commission, 2019, p. 1). The EU ETS works on the “cap-and-trade” principle where a government sets a cap for an allowable total amount of emissions over a certain period and issues tradable emission permits (European Commission, 2019). Under this system, an ETS establishes a cap either on total emissions or on emissions intensity, as measured by emissions per unit of gross domestic product (GDP, Haites, 2018). Within this system, the government provides allowances either freely or through an auction, equal to the level of the cap that gives polluting firms the flexibility to cut their emissions in the most cost-effective way (European Commission, 2019; Haites, 2018). According to European Commission (2019), ETS works by putting a limit on overall emissions from covered installations where this limit is reduced each year for the participating companies. Within this limit, companies are allowed to buy and sell emission allowances as they needed (European Commission, 2019). In EU, more than 1,500 national policies and measures have either been adopted, implemented or are being planned in to reduce greenhouse gas emissions, to achieve climate changes and to meet energy targets (European Environmental Agency, 2018). The introduction of the EU ETS, which covers carbon dioxide ( $CO_2$) emissions from some 11,500 heavy emitters in the power generation and manufacturing sectors, is considered to be as one of the most important and innovative initiatives taken by the EU (European Commission, 2019).

In contrast to the ETS, a carbon tax adds cost to all emissions equal to the level of the tax (Baranzini et al., 2017; European Commission, 2015; Haites, 2018). Unlike ETS, in a tax-based system there is no cap on emissions and agents are free to emit as much or as little as they like but they must pay the tax for these emissions. Under a carbon tax, it is the price that determines the level of emissions (Haites, 2018).[3] According to Baranzini et al. (2017) one of the advantages of carbon pricing is that allows “emitters to freely change their behavior to reduce their costs”. The carbon taxing system puts a price and the tax that must be paid on carbon measured in metric tons of carbon dioxide equivalent or $tCO_2e$ of a product or process (Hates, 2018; Partnership for Market Readiness, 2017). The carbon pricing mechanisms have three main categories: cap and trade i.e. ETS, carbon taxation or hybrid mechanisms that combine elements of both (Narassimhan, et al., 2018). Among these methods, carbon tax is considered to be the most effective instrument to curb carbon emissions as carbon tax is levied on the carbon content of fuels (Haites, 2018; Lin and Li, 2011; Schmalensee & Stavins, 2017; Tol, 2013). It is widely argued that by putting price on GHG emissions (carbon pricing) can be one of the most effective means of reducing emissions (Haites, 2018; High-Level Commission on Carbon Prices, 2017; Tol, 2013).

Energy tax is another policy instrument that is receiving a significant amount of attention to have a major impact on making the EU low-carbon an energy-efficient economy (Borozan, 2019). According to the OECD, an environmental tax is defined a tax whose base is “a physical unit, for example, a litre of petrol or a passenger flight that has a proven negative impact on the environment” (OECD, 2010). Environmental taxes are grouped into four categories: energy, transport, pollution and resource. Energy taxes include taxes on the production and use of energy products like petrol, diesel, gas and electricity (OECD, 2010). Transportation tax is tax levied on vehicles, ships and aircraft using public highways, rivers, and airports maintained by the government (OECD, 2010). Taxes on pollution consist of

[3] For an excellent review of the issues concerning carbon tax, see Baranzini et al. (2017).

taxes levied on the emission or discharge into the environment of noxious gases, liquids or other harmful substances while resource tax is the tax on exploitation of natural resources.

As carbon tax is based on the carbon content or $CO_2$ emission of fossil fuel, it is the best policy instruments that gives more focus on the reduction of $CO_2$ emissions relative to energy tax (Lin and Li, 2011). As Lin and Li (2011) further argue, compared to energy tax, carbon tax can "… promote energy saving as well as the development of alternative fuels, with more significant mitigation effects" (p. 5138).

To strength further the fight against pollution and to be a hub for an energy efficient and low-carbon economy, in October 2014 the European Council adopted the 2030 Climate and Energy Framework where the Council endorsed a binding EU target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990 (European Commission, 2019). Moreover, the Council also adopted a target of at least 32% share for renewable energy and equally at least 32.5% improvement in energy efficiency (European Commission, 2019). As Rio (2009) rightly argues, as these three targets are interrelated, success in them could make it easier for meeting the GHG mitigating targets of EU countries.

Apart from these market-based instruments, the EU is also using non-market instruments such as stringent environmental policies to make sure that the EU is a low-carbon and an energy efficient economy. Both environmental stringency policies and environmental taxes are becoming the cornerstones for combating environment degradation and promoting energy efficiency. Against these backdrops, the aim of this paper is to assess the extent to which environmental taxes and stringent environmental policies are effective in mitigating environmental degradation by applying a heterogeneous panel cointegration tests for a group of twenty European countries for the period 1994–2012. [4] Numerous studies have investigated the determinants of environmental degradation but most of these studies have mainly concentrated on identifying some macroeconomic determinants with only a few considering policy instruments as determinants of environmental quality (for a review see, Shahbaz & Sinha, 2019; Tiba & Omri, 2017). In addition, even those who investigated the effects of environmental tax on emissions have mostly relied on simulation models that do not take into account the long-run cointegrating relationships between environmental tax, environmental stringency and $CO_2$ emissions (Freire-González and Ho, 2018; Morley, 2012).

We believe that this paper makes four contributions to the literature on the relationship between environmental degradation, environmental taxes and the stringency of environmental policy. First, we use environmental taxes disaggregated into three categories: total, energy and transport. Second, as a proxy for our measure of environmental regulation, we use the newly OECD developed country-specific and internationally comparable measure of environmental policy stringency (see OECD, 2016). Third, to the best of our knowledge this is the first attempt to assess whether these two environmental policy instruments are effective in reducing $CO_2$ emissions in these countries. Fourth, in order to check the robustness of our results, we applied panel quantile regression method that has the advantage of providing a relatively more accurate estimates since the estimates are made at different quantiles of the distribution of $CO_2$ emissions rather than on the average relationships (Koenker, 2004).

[4] Environmental stringency policy index are available up to 2012 for all 20 countries under consideration.

The rest of the paper is structured as follows. The next section briefly reviews some of the related literature followed in Sect. 3 by a discussion on the data and the methodology used. Section 4 provides a discussion on the results of the empirical evidence. Section 5 presents a summary and concluding remarks.

## 2 Literature review

### 2.1 Pollution and environmental taxes

Pollution has a negative externality and market forces alone do not provide solutions to its adverse effects (Pigou, 1920). As proposed by Pigou (1920), environmental taxes are intended to internalize the negative externalities by polluters. Thus, governments are required to avert the adverse effects of pollution by imposing environmental taxes and by implementing stringent environmental rules and regulations (Costa–Campi et al. 2017; Haites, 2018; Landrigan et al., 2017; Pigou, 1920; Tol, 2017).

The primary aim of environmental taxes is to induce behavioural changes on businesses to use greener technologies and on consumers to use eco-friendly energy to reduce emission levels (Aydin & Esen, 2018; Borozan, 2019; European Environment Agency, 2005; ILO, 2014). It is hoped that by imposing taxes on carbon, fuel-intensive products can be replaced so that the structure of production and consumption of energy changes towards more eco-friendly products (Mardones & Cabello, 2019). Apart from bringing behavioural changes in favour of cleaner production and consumption of energy that improve environmental quality, environmental taxes, as postulated by the "double dividend" hypothesis, have also the potential for raising funds for governments where there is the possibility of recycling these funds for correcting other distortions in the economy (Pearce, 1991). For instance, revenues from environmental taxes can be used to reduce a distortionary tax (such as wages) and reduce existing inefficiencies in the economy (Freire-González, 2018). Fundamentally, unlike other taxes an environmental tax can wholly or partially correct a distortion from a pre-existing environmental externality by internalizing an environmental externality (Freire-González, 2018; Pearce, 1991). As Pearce (1991) further argues: "While most taxes distort incentives, an environmental tax corrects a distortion, namely the externalities arising from the excessive use of environmental services" (p. 940). Thus, according to the "double dividend" hypothesis, an environmental tax can simultaneously improve environmental quality (the "green dividend") and achieve a less distortional tax (the "blue dividend") where the environmental tax revenue is recycled to reduce existing tax such as income taxes, which distort labour supply and saving decisions (Fullerton & Wu, 1998; Goulder, 1995). The recycled revenues can stimulate improved performance in the economy such as generating more employment (Angelis, et al., 2019; Ciaschini, et al. 2012).

A further disentangling of the "double dividend" hypothesis also reveals that environmental taxes can generate not only double but also multiple dividends to the economy. For instance, according to Karydas and Zhang (2019) there are three social and economic dividends associated with environmental tax reform (ETR): I first dividend relates to an increase in environmental quality where environmental taxes can lead to an emissions-free economy. The second dividend, as mentioned above, enhances welfare by reducing tax distorting and recycling the tax revenues to generate welfare improvement such as creating more employment. The third dividend relates to the "induced innovation hypothesis" or the "induced technical change" (Karydas & Zhang, 2019) where environmental tax revenues can also be recycled to promote renewable technology by subsidizing the development of renewable energy projects, energy-saving technologies and energy-efficient technology (see Baranzini et al., 2000; Mardones & Cabello, 2019).[5] Thus, environmental taxes have multiple benefits including the following identified by Borozan (2019): (i) negative externalities can be corrected, for instance, by carbon tax that can reduce emissions and reduce fossil energy consumption; (ii) environmental impacts can be reduced by decreasing energy consumption; (iii) energy security can be enhanced when domestic production of energy supply is increased by promoting renewables which can lead to less dependence on imported energy; and (iv) environmental taxes can increase government revenue to be recycled for other benefits.

Nevertheless, despite the enormous potential benefits that environment tax can bring, it must not be forgotten that there several negative aspects associated with environmental taxation (Borozan, 2019; Lin and Li, 2011). In the first place, these taxes can increase the cost of production and weaken international competitiveness. Since environmental taxes are not uniform across countries, governments may not be willing to impose higher taxes on pollutants as these governments believe that these taxes can undermine their international competitiveness. Moreover, there is also the possibility that polluters may shift the increased cost to consumers through higher prices (Lin and Li, 2011). Since these costs disproportionately affect low-income people, it is always feared that these taxes can exacerbate income inequality (see Oueslati et al., 2017). If this happens, energy taxes can end up only in increasing fiscal revenue and not improving environmental quality (Lin and Li, 2011; ILO, 2014).

## 2.2 Environmental policy stringent and pollution

Concerning the effects of stringent environmental policies on the environment, it is believed these policies have the potential of minimizing the adverse effects of pollution by promoting innovation in clean technologies and by discouraging the development of "dirty" technologies (Ambec et al. 2017; Cohen and Tubb, 2017; Dechezleprêtre & Sato, 2017). Proponents of this view believe that stringent environmental rules and policies can partly mitigate environmental degradation and can also give incentives for using cleaner energy production and consumption (Ambec et al. 2017; Cohen and Tubb, 2017; Dechezleprêtre & Sato, 2017; van Leeuwen & Mohnen, 2017; Ramanathan, et al., 2017). According to the Porter Hypothesis (Porter & van der Linde, 1995), a carefully designed environmental policy can help industries to adopt environmentally friendly technologies that can reduce emissions (Dechezleprêtre & Sato, 2017; Ramanathan, et al., 2017). Further, Lagreid and Povitkina (2018) argue that nation states by "… means of laws and regulations they have the power to shape the behavior of firms operating on their territories and guide choices of their citizens" (p. 40).

[5] For review of the literature, see Hafstead and Williams III (2018).

## 2.3 Brief review of the empirical evidence

Empirical evidence on the effectiveness of environmental taxes in reducing $CO_2$ emissions is not conclusive.[6] For instance, for a group of European countries Morley (2012) found a significant negative relationship between environmental taxes and pollution. Equally, Miller and Vela (2013) also found that environmental taxes lead to higher reductions in $CO_2$ emission. For Finland, Lin and Li (2011) and for France, Millock et al. (2004) found that carbon tax were effective in reducing $CO_2$ emissions. Alfsen et al. (1995) also found that environmental taxes reduce emissions. For Japan, Nakata and Lamont (2001) found that environmental taxes reduce carbon emissions, and when environmental taxes were implemented, there was a shift towards the use of energy with lower emissions. In China, Lu, et al. (2010); Guo, et al. (2014); Xu and Long, (2014); Yang et al. (2014); Zhang et al. (2016) also found that environmental taxes reduce carbon emissions. For some European countries, Lin and Li (2011) also found that $CO_2$ taxes and $CO_2$ emissions were negatively related. Similarly, Chen et al. (2017), Lu, et al. (2010), Meng, et al. (2013), Miller and Vela (2013), Rapanos and Polemis (2005), Wissema and Dellink (2007), Xu and Long (2014), Yang et al. (2014) also found that environmental taxes negatively affect pollution emissions. Berkhout et al. (2004); Filipovic et al. (2015) found that energy taxes lead to a decrease in energy consumption and GHG emissions or an increase in energy efficiency. For a group of EU countries, Borozan (2019) also found that energy tax as % of GDP significantly increases energy consumption in lower energy-consuming EU countries, while at higher quantiles, it leads to a decrease in energy consumption, but not significantly. Moreover, carbon taxes and GHS ETS have contributed to the reduction in emissions from business as usual perspective (Haites, 2018).

In contrast to the above studies who found that environmental taxes negatively affect pollution emissions, Laganathan, et al. (2014) for Malaysia; and Radulescu, et al. (2017) for Romania found environmental taxes were ineffective in reducing $CO_2$ emissions. Similarly, Agostini, et al. (1992), Bruvoll and Larsen (2004), Gerlagh and Lise (2005) and Lin and Li (2011) did not find that environmental taxes helped to reduce $CO_2$ emissions. This is also true for a group of 18 European countries where Hotunluoglu and Tekeli (2007) found that carbon taxes were not effective in reducing emissions. Morley (2012) did not find any significant relationship between energy taxes and energy consumption.

Coming to the empirical relationship between environmental stringency policy and environmental quality, the evidence is not conclusive. While several studies have indicated that environmental regulations can induce innovation in clean technologies and can discourage the development of "dirty" technologies, others studies have found no evidence to support these claims (see Ambec et al. 2017; Cohen and Tubb, 2017; Dechezleprêtre & Sato, 2017; van Leeuwen & Mohnen, 2017). For instance, in the case of Chinese industries, Wang and Shen (2016) found that environmental regulations have significant positive effects on clean production industries. Similarly, Liu et al. (2018) for China have found that environmental regulations were negatively related to energy consumption. Shapiro and Walker (2018) also found that the changes in environmental policies account for most of the reduction of air pollutions emissions that the USA experienced in the period 1990–2008. Similarly, de Angelis et al (2019) found that the OECD stringency index they used to

[6] For an excellent summary of the empirical literature, see Aydin and Esen (2018); Freire-González (2018); Timilsinas (2018).

account for environmental regulation was negatively and significantly related to $CO_2$ emissions. In contrast,

**Table 1** Descriptivestatistics

| variables | stats | obs | mean | Std.dev | min | max |
|---|---|---|---|---|---|---|
| ss | Environmentalpolicystringencyindex | 360 | 2.07 | 0.83 | 0.52 | 4.41 |
| rr | Renewableenergy(shareintotalenergyconsumption) | 360 | 11.49 | 11.09 | 0.79 | 51.55 |
| cc | $CO_2$percapita | 360 | 8.29 | 2.14 | 4.38 | 13.71 |
| ff | Fossilfuel(shareintotalenergyconsumption) | 360 | 75.65 | 16.96 | 31.00 | 98.53 |
| yy | RealGDPpercapita | 360 | 37,661 | 18,839 | 6,539 | 91,617 |
| $yy^2$ | RealGDPpercapitasquared | 360 | | | | |
| ty | Totalenvironmentaltaxas%ofGDP | 360 | 2.62 | 0.66 | 1.55 | 5.30 |
| ti | Totalenvironmentaltaxas%oftotalrevenuesfromtaxesandsocialcontributions(includingimputed socialcontributions) | 360 | 6.93 | 1.47 | 4.16 | 10.78 |
| tx | Totalenvironmentaltaxas%oftotalrevenuesfromtaxesandsocialcontributions(excludingimputed socialcontributions) | 360 | 7.11 | 1.55 | 4.33 | 11.44 |
| ey | Energytaxas%ofGDP | 360 | 1.83 | 0.42 | 0.91 | 3.01 |
| ei | Energytaxas%oftotalrevenuesfromtaxesandsocialcontributions(includingimputedsocialcontribu tions) - | 360 | 4.86 | 1.09 | 2.73 | 7.93 |
| ex | Energytaxas%oftotalrevenuesfromtaxesandsocialcontributions(excludingimputedsocialcontribu tions) - | 360 | 4.99 | 1.13 | 2.77 | 8.52 |
| vy | Transporttaxas%ofGDP | 360 | 0.69 | 0.44 | 0.11 | 2.20 |
| vi | Transporttaxas%oftotalrevenuesfromtaxesandsocialcontributions(includingimputedsocialcontri butions) - | 360 | 1.82 | 1.07 | 0.32 | 4.51 |
| vx | Transporttaxas%oftotalrevenuesfromtaxesandsocialcontributions(excludingimputedsocialcontri butions) - | 360 | 1.87 | 1.11 | 0.32 | 4.66 |

mean,Std.dev.,minandmaxdenotethemean,standarddeviation,minimumandmaximumvaluesoftheseries.Intheempiricalanalysis,allthevariablesareinlogs

Zhang (2016); Hao et al. (2018) found that environmental regulations were not effective in reducing pollution in China. Equally, Li (2019) did not find that environmental regulations promoted technical progress in the Chinese industrial sector.

In the backdrop of these inconclusive outcomes, undertaking an empirical study to investigate the role of environmental tax and stringent environmental policies on $CO_2$ emission may add some light on the ongoing debate between environmental degradation, environmental stringency and environmental taxes.

## 3 Materials and method

### 3.1 Data

In this paper, we use a balanced annual panel data covering the period from 1995 to 2012 for 20 European countries (see Table 1). Real GDP per capita and fossil energy consumption are from World Development Indicators (2018). Renewable energy and environmental policy stringency (EPS) index are from OECD (2016, 2018). Disaggregated environmental taxes are from Eurostat database (2018). The environmental taxes used in this paper are classified into three: (1) total environmental taxes, (2) energy taxes and (3) transport taxes each defined as % of GDP and also as a share of overall total tax revenue (OECD, 2018).[7] The choice of the countries is based on the availability of complete set of data for 1995 to 2012 for all the variables under consideration. While the other data are available beyond 2012, EPS data are only available up to 2012 for all countries; only four European countries have EPS data up to 2015.

According to the OECD, environmental taxes are those whose base is a physical unit, for example, a litre of petrol or a passenger flight, that has a proven negative impact on the environment. Environmental taxes can be split into four categories: energy; transport; pollution; and resource. Energy taxes include taxes on the production and use of energy products like petrol, diesel, gas and electricity. Transportation tax is tax levied on vehicles, ships and aircraft using public highways, rivers and airports maintained by the government.[8] Environmental taxes are measured as % of GDP and as % of overall total tax revenues. Environmental taxes as % of overall total tax revenues are further disaggregated into taxes which include and exclude social security contributions. Social contributions are paid on a compulsory or voluntary basis by employers, employees and self- and non-employed persons. In 2017, the total environmental tax revenue in the EU-28 (i.e. revenue from environmental taxes collected by governments in all EU Member States) amounted to EUR 368.8 billion; this figure represents 2.4% of the EU-28 gross domestic product (GDP) and 6.1% of the total government revenues from all taxes and social security contributions in the EU (EEA, 2018). A substantial amount of the environmental tax is accounted for by energy tax amounting to 76.9% of the total environmental tax revenue in 2017, transport tax accounted for 19.8% and pollution and resources environmental tax accounting only for 3.3% of the total environmental tax revenue (EEA, 2018).

[7] For a detailed explanation, see OECD (2018).

[8] As data on pollution taxes and resources taxes are not available for the sample period, we have excluded them from our analysis.

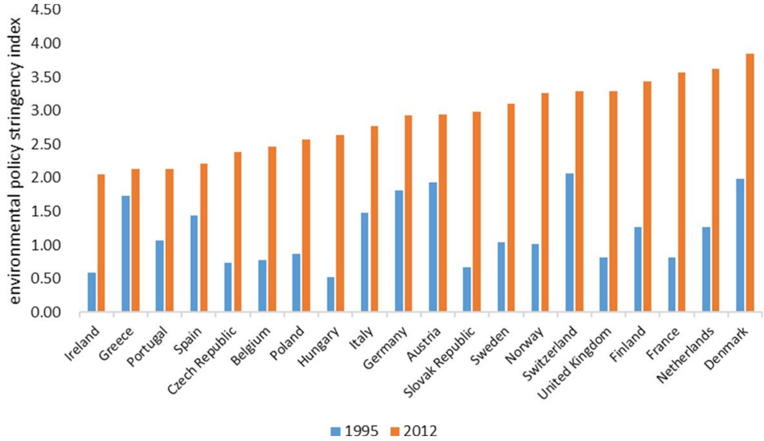


**Fig. 1** Environmental policy stringency index, 1995–2012

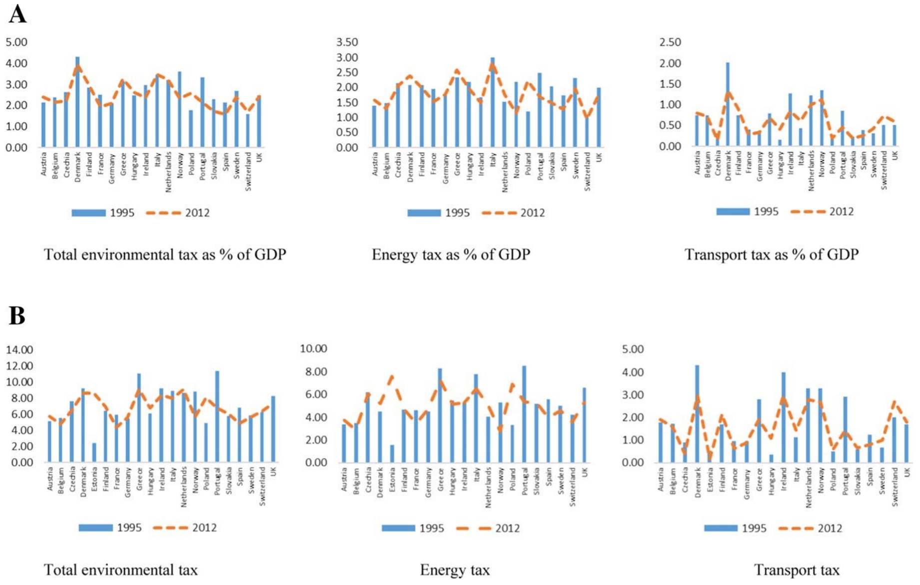


**Fig. 2** **A** Total environmental tax as % of GDP, energy tax as % of GDP and transport tax as % of GDP, **B** the above three taxes are measured as % of total revenues from all taxes and social contributions (excluding imputed social contributions)

The environmental policy stringency index used in this paper is the one recently developed by OECD (2016) which based on the measurement of stringency defined as the implicit or explicit cost of environmentally harmful behaviour. OECD derives this index by aggregating of information on selected environmental policy instruments that are primarily related to climate and air pollution. A higher value represents a more stringent policy where 6 denotes most stringent policies (see Botta and Kozluk, 2014; OECD, 2016). As can be seen from Fig. 1, in terms of the environmental stringency policy index, Denmark has the highest and Ireland the lowest. For all countries, the index has substantially increased over the years.

Background statistics for all the variables are presented in Table 1. $CO_2$ emissions exhibit a considerable cross-country variation from as low as 4.38 metric tons per capita in Portugal to as high as 13.71 metric tons per capita in Denmark. This is also true for renewable energy which ranges from as low as 0.79% in UK in 1995 to 51.55% of total energy consumption in Norway. The consumption of fossil fuel is the lowest in Sweden and the highest in Denmark. In terms of real GDP per capita, Portugal has the lowest and Switzerland the highest.

Environmental taxes also show considerable variations. As can be seen from Fig. 2, in 2012, total environmental tax as % of GDP varies from as high as 3.97% in Denmark to as low as 1.57% in Spain. Equally in 2012 the highest energy tax as % of GDP of 2.84% was recorded in Italy while the lowest of 0.96% was in Switzerland. Transport tax also varies considerably from as high as 1.35% of GDP in Denmark to as low as 0.14% of GDP in Czechia. More importantly, only in few of these twenty countries environmental taxes (total, energy and transport) as % of GDP have increased between 1995 and 2012. For instance, only in Austria, Finland, Greece and Poland total environmental tax as % of GDP increased while in eleven countries total environmental tax and transport tax (as % of GDP) declined, while energy tax as % of GDP fell in 14 countries.

The declining trends in environmental tax as % of GDP can be explained by some factors. According to ILO (2014) since energy demand has the tendency to grow more slowly than income, inevitably the share of taxes paid on energy decrease as the economy expands. Secondly, energy taxes may have affected energy demand where increasing energy taxes may have resulted in reduction of the tax base. In the third place, public authorities may be unwilling to raise environmental tax as they fear that this tax increase may increase energy costs that can affect industries and households that may also undermine international competitiveness.

These worrying trends are becoming a cause for concern as energy taxes are reported to have fallen short the threshold potential that can improve environmental and climate changes (OECD, 2018). Environmental taxes are not growing as fast as GDP growth. To some, a low environmental tax rate may be encouraging firms to pay this low tax rate and continue to pollute (Mardones and Flores, 2018). Haites also believes that "Most tax rates are low relative to levels thought to be needed to achieve climate change objectives" (Haites, 2018, p. 955). The ILO is also of the opinion that the ETRs in their current forms are "… too insignificant to address climate change or other environmental challenges" (2014, p. 27). As Haites (2018) argues further, "tax rates are low relative to the social cost of carbon and relative to the prices of taxed fuels" (p. 961).

Even though measuring the impact of the various market and non-markets policies on environmental quality are hard to measure, we can infer from the commonly used indicators such as $CO_2$ intensity ($CO_2$/GDP) to measure whether there was any change the degree of "greenness" in the overall economy(ILO, 2014). In 2017, total GHG emissions were 20.7% (1082 million tonnes $CO_2$ equivalents, OECD, 2019) below 1990 levels. Data between 1995 and 2014 show that C $O_2$ emissions per kg per PPP $ of GDP declined by more than 62%. In all the 20 countries under consideration, $CO_2$ emissions per kg per PPP $ of GDP declined by more than 50% with Slovak Republic, Poland, Denmark and Hungary registering more than 70% decline with the least of 52.4% for Greece.

### 3.2 T he model

In this paper, we augment the standard EKC (Environmental Kuznets Curve) model by including environmental policy stringency index and environmental taxes as determinants of environmental quality. The EKC links GDP per capita to C $O_2$ emissions per capita and postulates a concave or an inverted U-shaped relationship where environmental quality worsens with the rise in income up to a peak, after which environmental quality starts to improve with economic growth (de Angelis, 2019). The EKC reveals a major contradiction between economic growth and the environment: economic development may be environmentally beneficial in the long run but it can irreversibly damage the environment in the short run (de Angelis, 2019). The substantial majority of the empirical investigation centres on testing the validity of the inverted U-shaped relationship but despite this extensive research no consensus has been reached (see Shahbaz & Sinha, 2019).

In this paper in line with the standard EKC model, a panel model is specified as follows:

$$lnco_{it} = \alpha_{it} + \delta_{it} + \beta_1 lnet_{it} + \beta_2 lnss_{it} + \beta_3 lnyy_{it} + \beta_4 (lnyy_{it})^2 + \beta_5 lnff_{it} + \beta_6 lnrr_{it} + \varepsilon_{it} \qquad (1)$$

where $co_{it}$ represents $CO_2$ emissions per capita, $yy_{it}$ is real GDP per capita, $(yy_{it})^2$ is the square of real GDP per capita ( $yy_{it}$), $et_{it}$ is environment tax, s $s_{it}$ is a measure of the stringency of environmental policy, $ff_{it}$ is the share of fossil energy consumption in total energy consumption, $rr_{it}$ is the share of renewable energy consumption in total energy consumption and $\varepsilon_{it}$ is the error term which assumed to be independently and identically distributed with zero mean and constant variance. The subscripts $i$ denotes country ($i$ = 1, 2 … 20), and $t$ indicates the time span (1995–2012), respectively. The variables are assumed to be integrated of order 1, i.e. I(1) and the parameters $\alpha_{it}$ and $\delta_{it}$ are individual entities and time effects, respectively, while $\beta_1 \ldots \beta_6$ are slope coefficients. The transformation of the variables into natural logarithms avoids heteroscedasticity and the coefficients can be interpreted as long-run elasticities.

The real GDP per capita (lnyy) and its square term $[(lnyy_{it})^2]$ are used to test for the validity of the EKC hypothesis where different shapes of the ECK can be inferred with different implications for environmental sustainability. Regarding the coefficients $\beta_3$ and $\beta_4$ in Eq. (1), five possible C $O_2$-income relationships can be identified: (a) $\beta_3 = \beta_4 = 0$ implies no relationship between per capita $CO_2$ emissions and per capita GDP; (b) $\beta_3 > 0$ and $\beta_4 = 0$ suggests a monotonically increasing linear relationship where environmental quality gets worse as income increases. In contrast, in (c) $\beta_3 < 0$ and $\beta_4 = 0$ implies a monotonically decreasing linear relationship where environmental quality gets better as income increases. (d) $\beta_3 < 0$ and $\beta_4 > 0$ implies a U-shaped curve where environmental quality improves with the rise in income up to a certain point after which environmental quality worsens with economic growth. In the case of (e), when $\beta_3 > 0$ and $\beta_4 < 0$ there is an inverted U-shaped curve where environmental quality worsens with the rise in income up to a peak, after which environmental quality can improve with economic growth.[9]

[9] Of course, there are many studies that have also tested using cubic relations, ${}_1lnyy_{it} + {}_2(lnyy_{it})^2 + {}_3(lnyy_{it})^3$ and they are extensively reviewed in Shahbaz and Sinha (2019); Mardani, et al. (2019)

## 4 Results and discussion

Our empirical analysis for estimating the relationship between $CO_2$ emissions, three categories of environmental taxes and environmental policy stringency is carried out in three steps. First, we test for unit roots in order to determine the integration properties of the series. In the second step, if the series are found to be stationary in their first difference i.e. I(1), we test for the long-run equilibrium relationship among the variables by applying the panel cointegration test developed by Pedroni (1999, 2001, 2004). In third stage, we estimate the long-run coefficients by applying the fully modified ordinary least square (FMOLS) developed by Pedroni (2004) and the dynamic ordinary least square (DOLS) developed by Kao and Chiang (2000).

### 4.1 Panel unit root tests

For testing the integration properties of the data, we applied five unit root tests that have varying assumptions using two types of models that include a constant only and a constant and a deterministic trend. The five unit root tests include Levin, Lin and Chu (LLC); Im, Pesaran and Shin (IPS, 2003); Maddala and Wu (1999), Breitung (2000) and Fisher-type tests using ADF. The basic difference of these unit root tests emanates from the assumptions they make regarding the following AR(1) process for panel data:

$$y_{it} = r_i y_{it-1} + X_{it} d_i + e_{it} \tag{2}$$

where $i = 1, 2, \ldots, N$ cross-section units or series, that are observed over periods, $t = 1, 2, \ldots, T_i$. The $X_{it}$ represent the exogenous variables in the model, including any fixed effects or individual trends, $\rho_i$ are the autoregressive coefficients, and the errors $\varepsilon_{it}$ are assumed to be mutually independent (Pedroni, 1999). In testing for unit roots, two assumptions can be made about $\rho_i$. Both the LLC and the Breitung tests assume that there is a common unit root process so that $\rho_i$ is identical across cross sections. In contrast, the IPS, Fisher-ADF and Fisher-PP tests assume $\rho_i$ to vary freely (Pedroni, 1999). The IPS, the Fisher-ADF and the PP tests all allow for individual unit root processes so that they may vary across cross sections. In contrast to the IPS test which is a parametric and asymptotic test, Maddala and Wu (1999) propose a nonparametric test whose value does not depend on different lag lengths in the individual ADF regressions. The IPS, ADF and PP tests have the null hypothesis that all cross-section series have a common unit root (Ouedraogo, 2013, p. 641).

The results of these unit root tests are presented in Table 2, and they show that all the series are panel non-stationary in levels but when we applied panel unit root tests to the first difference of these variables, we can reject the null hypothesis of unit root for each of the variables at the conventional level of significance.

### 4.2 Panel cointegration

Having established that all the series were non-stationary and integrated of order 1, $I(1)$, we applied the panel cointegration test developed by Pedroni (1999, 2004) and Kao (1999).[10] The cointegrating relationship is estimated using the residuals $\varepsilon_{it}$ in Eq. (2). The

[10] More on this see Pedroni (2019).

**Table 2** Panel unit root tests

| | LLC | Breitung | IPS | ADF | PP |
|---|---|---|---|---|---|
| cc | − 0.295 | 7.615 | 1.547 | 39.794 | 48.294 |
| Δcc | − 16.844*** | − 5.973*** | − 16.308*** | 237.059*** | 312.611*** |
| ff | − 2.940*** | 5.213 | − 2.127** | 68.352*** | 39.555 |
| Δff | − 12.955*** | − 6.265*** | − 11.858*** | 182.918*** | 243.557*** |
| rr | − 2.802*** | 5.102 | 0.497 | 44.157 | 47.301 |
| Δrr | − 14.313*** | − 6.048*** | − 11.564*** | 180.919*** | 234.461*** |
| ss | − 1.307* | − 1.823** | − 0.318 | 44.329 | 45.073 |
| Δss | − 10.358*** | − 7.376*** | − 8.283*** | 131.785*** | 205.052*** |
| yy | 1.887 | 7.514 | 4.121 | 29.244 | 7.910 |
| Δyy | − 9.592*** | − 4.992*** | − 5.741*** | 97.871*** | 149.890*** |
| $yy^2$ | 2.089 | 7.414 | 4.117 | 28.788 | 8.000 |
| $\Delta yy^2$ | − 9.618*** | − 4.989*** | − 5.738*** | 97.826*** | 149.532*** |
| ei | − 0.778 | 0.960 | − 0.041 | 46.721 | 20.879 |
| Δei | − 9.531*** | − 7.535*** | − 8.189*** | 131.028*** | 160.320*** |
| ex | − 0.526 | 1.281 | 0.226 | 45.960 | 20.872 |
| Δex | − 9.473*** | − 7.611*** | − 8.133*** | 130.200*** | 153.550*** |
| ey | 0.511 | 2.557 | 0.666 | 44.031 | 35.742 |
| Δey | − 10.066*** | − 7.533*** | − 7.832*** | 125.630*** | 158.946*** |
| ti | − 0.529 | 1.806 | − 1.762** | 67.295*** | 44.984 |
| Δti | − 10.752*** | − 6.955*** | − 8.570*** | 136.270*** | 182.516*** |
| tx | − 0.177 | 2.219 | − 1.581* | 67.365*** | 43.640 |
| Δtx | − 10.581*** | − 7.0111*** | − 8.513*** | 135.394*** | 179.933*** |
| ty | 0.111 | 1.948 | − 0.514 | 55.738** | 44.764 |
| Δty | − 9.457*** | − 7.401*** | − 7.613*** | 122.912*** | 175.815*** |
| vi | − 1.049 | 0.490 | 0.464 | 37.439 | 45.862 |
| Δvi | − 15.400*** | − 9.969*** | − 11.192*** | 171.064*** | 206.183*** |
| vx | − 0.787 | 0.566 | 0.273 | 38.360 | 45.188 |
| Δvx | − 15.355*** | − 9.844*** | − 11.382*** | 173.755*** | 206.419*** |
| vy | − 2.043 | − 0.378 | − 1.544 | 54.174* | 55.544** |
| Δvy | − 13.710*** | − 8.645*** | − 9.868*** | 152.930*** | 200.456** |

***, ** and * denote rejection of the null hypothesis of unit root at 1%, 5% and 10% significant levels, respectively. Δ = denotes first difference. For the definition of the variables, see Table 1 null hypothesis of no cointegration ($\rho i = 1$) is tested via the following unit root test on the residuals:

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + m_{it} \tag{3}$$

Pedroni (1999) proposes seven different statistics based on two groups of cointegration tests to examine stationarity of the residuals ($\varepsilon_{it}$). The first four statistics, namely $v$-statistic, panel ρ-statistic, panel PP-statistic and panel ADF, which are known as panel cointegration statistics are based on the within approach and all assume common autoregressive coefficients (within-dimension). The remaining three statistics, namely group rho-statistic, group $\rho$-statistic and group ADF-statistic, are group panel cointegration

**Table 3** Residual panel cointegration test

| A. Pedroni Residual Cointegration test | | | | | | |
|---|---|---|---|---|---|---|
| Method | no trend | with trend | no trend | no trend | no trend | no trend |
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic |
| | Model 1: cc ss ti yy $yy^2$ rr ff | | Model 2: cc ss ei yy $yy^2$ rr ff | | Model 3: cc ss vi yy $yy^2$ rr ff | |
| Panel v-Statistic | −0.497 | −1.624 | −0.455 | −1.717 | −0.574 | −1.949 |
| Panel rho-Statistic | 2.948 | 3.933 | 2.682 | 3.951 | 3.506 | 4.346 |
| Panel PP-Statistic | −7.462*** | −10.598*** | −9.109*** | −9.968*** | −6.458*** | −10.502*** |
| Panel ADF-Statistic | −6.882*** | −9.318 | −7.520*** | −8.767*** | −7.293*** | −10.300*** |
| Group rho-Statistic | 4.222 | 5.199 | 4.089 | 5.278 | 4.838 | 5.204 |
| Group PP-Statistic | −12.236*** | −15.932*** | −13.371*** | −14.553*** | −13.067*** | −19.346*** |
| Group ADF-Statistic | −8.079*** | −10.269*** | −9.002*** | −9.799*** | −8.356*** | −11.305*** |
| | Model 4: cc ss tx yy $yy^2$ rr ff | | Model 5: cc ss ex yy $yy^2$ rr ff | | Model 6: cc ss vx yy $yy^2$ rr ff | |
| Panel v-Statistic | −0.532 | −1.637 | −0.427 | −1.690 | −0.650 | −2.039 |
| Panel rho-Statistic | 2.959 | 3.938 | 2.699 | 3.932 | 3.530 | 4.455 |
| Panel PP-Statistic | −7.443*** | −10.667*** | −9.166*** | −9.965*** | −6.424*** | −10.718*** |
| Panel ADF-Statistic | −6.621*** | −9.304*** | −7.541*** | −8.793*** | −7.236*** | −10.216*** |
| Group rho-Statistic | 4.237 | 5.229 | 4.108 | 5.276 | 4.861 | 5.280 |
| Group PP-Statistic | −12.359*** | −16.037*** | −13.488*** | −14.61***2 | −13.635*** | −19.230*** |
| Group ADF-Statistic | −7.736*** | −10.183*** | −9.015*** | −9.733*** | −8.303*** | −11.276*** |
| | Model 7: cc ss ty yy $yy^2$ rr ff | | Model 8: cc ss ey yy $yy^2$ rr ff | | Model 9: cc ss vy yy $yy^2$ rr ff | |
| Panel v-Statistic | −0.754 | −1.989 | −0.566 | −1.866 | −0.675 | −1.989 |
| Panel rho-Statistic | 3.171 | 3.891 | 2.932 | 3.855 | 3.473 | 3.891 |
| Panel PP-Statistic | −7.946*** | −11.051*** | −7.851*** | −9.896*** | −6.714*** | −11.051*** |
| Panel ADF-Statistic | −8.388*** | −10.442*** | −7.463*** | −9.164*** | −6.856*** | −10.442*** |
| Group rho-Statistic | 4.618 | 5.220 | 4.488 | 5.225 | 4.906 | 5.220 |
| Group PP-Statistic | −12.239*** | −16.434*** | −12.464*** | −16.452*** | −15.233*** | −16.434*** |

)

**Table 3** continued

| A.P(edroniResidualCointegrationtest | | | | | | |
|---|---|---|---|---|---|---|
| Method | notrend | withtrend | notrend | notrend | notrend | notrend |
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic |
| GroupADF -Statistic | − 8.860*** | − 10.928*** | − 8.363*** | − 10.103*** | − 8.261*** | − 10.928*** |

| B.Kaoresidualcointegrationtest | |
|---|---|
| model | ADFt -statistics |
| ccsstiyy yy$^2$rrff | − 6.202*** |
| ccsseiyy yy$^2$rrff | − 6.245*** |
| ccssviyy yy$^2$rrff | − 6.365*** |
| ccsstxyy yy$^2$rrff | − 6.192*** |
| ccssexyy yy$^2$rrff | − 6.245*** |
| ccssvxyy yy$^2$rrff | − 6.362*** |
| ccsstyyy yy$^2$rrff | − 6.245*** |
| ccsseyyy yy$^2$rrff | − 6.245*** |
| ccssvyyy yy$^2$rrff | − 6.342*** |

***denoterejectionofthenullhypothesisofnocointegrationat1%significantlevel.Forthedefinitionofthevariables,seeTable 1

**Table 4** Long-run coefficients

A. Long-run coefficients: Model excluding environmental taxes, dependent variable $CO_2$ emission per capita (cc)

| Independent variables | Coefficient |
|---|---|
| ss | − 0.020*** |
| yy | 5.742*** |
| $yy^2$ | − 0.241*** |
| rr | − 0.085*** |
| ff | 1.787*** |

B. Long-run coefficient: Model excluding environmental policy stringency index (dependent variable $CO_2$ emission per capita, cc)

| | Energy tax | | transport tax | | total environmental tax | |
|---|---|---|---|---|---|---|
| Taxes excluding social service contribution | ex | − 0.082*** | vx | 0.001** | tx | − 0.033 |
| | yy | 5.108*** | yy | 5.807* | yy | 3.193** |
| | $yy^2$ | − 0.214*** | $yy^2$ | − 0.246 | $yy^2$ | − 0.119** |
| | rr | − 0.049*** | rr | − 0.067*** | rr | − 0.062*** |
| | ff | 1.747*** | ff | 1.730*** | ff | 1.669*** |
| Taxes including social service contribution | ei | − 0.080*** | vi | − 0.005** | ti | − 0.040 |
| | yy | 5.038*** | yy | 6.020* | yy | 3.297** |
| | $yy^2$ | − 0.211*** | $yy^2$ | − 0.256 | $yy^2$ | − 0.124** |
| | rr | − 0.049*** | rr | − 0.067*** | rr | − 0.061*** |
| | ff | 1.747*** | ff | 1.730*** | ff | 1.675*** |
| Total environmental taxes | ey | − 0.095*** | vy | 0.015** | ty | − 0.055 |
| | yy | 6.730*** | yy | 3.939 | yy | 5.283** |
| | $yy^2$ | − 0.292*** | $yy^2$ | − 0.156 | $yy^2$ | − 0.221** |
| | rr | − 0.056*** | rr | − 0.065*** | rr | − 0.068*** |
| | ff | 1.757*** | ff | 1.754*** | ff | 1.716*** |

***, ** and * denote significant levels at 1%, 5% and 10%, respectively. For the definition of the variable, please see Table 1

statistics which are based on the between approach, and they assume individual autoregressive coefficients (between-dimension). According to Pedroni (2004), the group ρ-statistic is the most powerful followed by the panel ρ- and the ADF-statistic, and the group ADF is the strongest (Ozturk, et al., 2010). The null hypothesis is that there is no cointegration, while the alternative hypothesis is that there is cointegration between variables (Ouedraogo, 2013). Pedroni (2004) has also studied the small sample size properties for the seven statistics and finds that in terms of power, for smaller samples ($N =$

20) the group $\rho$-statistic is the most powerful, followed by the panel ρ- and panel ADF-statistics (see Acaravci & Ozturk, 2010).

Results of the panel cointegration tests are presented in Table 3, and these tests show that the null hypothesis of no panel cointegration is rejected by four out of the seven cointegration tests developed by Pedroni (2004) and the cointegration test developed by Kao (1999). According to the Pedroni (1999) test, the null hypothesis of no cointegration is not rejected by the panel *v-, panel rho- and group rho*-statistics but our empirical evidence

**Table 5** FMOLS and DOLS estimation results long-run estimates; dependent variable, $CO_2$ per capita

| independent variable | coefficient | | independent variable | coefficient | | independent variable | coefficient | |
|---|---|---|---|---|---|---|---|---|
| | FMOLS | DOLS | | FMOLS | DOLS | | FMOLS | DOLS |
| Energy taxes | | | | | | | | |
| ss | − 0.020*** | − 0.095*** | ss | − 0.019*** | − 0.094*** | ss | − 0.014*** | − 0.080*** |
| ex | − 0.079*** | − 0.087*** | ei | − 0.076*** | − 0.043 | ey | − 0.082*** | 0.194*** |
| yy | 4.904*** | 1.458** | yy | 4.731*** | 1.339** | yy | 6.730*** | 0.519 |
| $yy^2$ | − 0.203*** | − 0.058* | $yy^2$ | − 0.194*** | − 0.052 | $yy^2$ | − 0.291*** | − 0.01 |
| ff | 1.815*** | 0.493*** | ff | 1.816*** | 0.480*** | ff | 1.816*** | 0.445*** |
| rr | − 0.057*** | − 0.011 | rr | − 0.057*** | − 0.015 | rr | − 0.063*** | − 0.037* |
| *Transport taxes* | FMOLS | DOLS | | FMOLS | DOLS | | FMOLS | DOLS |
| ss | − 0.018*** | − 0.113*** | ss | − 0.018*** | − 0.111*** | ss | − 0.023*** | − 0.095*** |
| vx | − 0.014* | − 0.057*** | vi | − 0.019 | − 0.051** | vy | 0.001* | 0.008 |
| yy | 6.374*** | 0.815 | yy | 6.523*** | 0.795 | yy | 5.052* | 0.897 |
| $yy^2$ | − 0.269*** | − 0.024 | $yy^2$ | − 0.276** | − 0.023 | $yy^2$ | − 0.206 | − 0.030 |
| ff | 1.762*** | 0.550*** | ff | 1.763*** | 0.539*** | ff | 0.001* | 0.448*** |
| rr | − 0.081*** | − 0.010 | rr | − 0.080*** | − 0.012 | rr | − 0.077*** | − 0.026 |
| *Total environmental taxes* | FMOLS | DOLS | | FMOLS | DOLS | | FMOLS | DOLS |
| ss | − 0.020*** | − 0.093*** | ss | − 0.019*** | − 0.091*** | ss | − 0.024*** | − 0.073*** |
| tx | − 0.047** | − 0.018 | ti | − 0.052*** | 0.026 | ty | − 0.039* | 0.254*** |
| yy | 3.947*** | 1.200* | yy | 3.969*** | 1.253* | yy | 5.903*** | 1.037 |
| $yy^2$ | − 0.155*** | − 0.045 | $yy^2$ | − 0.156*** | − 0.047 | $yy^2$ | − 0.252*** | − 0.038 |
| ff | 1.755*** | 0.483*** | ff | 1.757*** | 0.457*** | ff | 1.780*** | 0.359*** |
| rr | − 0.079*** | − 0.018 | rr | − 0.078*** | − 0.021 | rr | − 0.083*** | − 0.046** |

***, ** and * denote significant levels at 1%, 5% and 10%, respectively. For the definition of the variables, see Table 1 indicates that null hypothesis of no cointegration is rejected by the relatively powerful tests: the group ρ-statistic, the panel ρ- and the ADF-statistic (Ozturk, et al., 2010).

### 4.3 Panel long-run relationship

Since we found a long-run relationship among the variables, we apply the fully modified (FMOLS) and the dynamic OLS (DOLS) panel cointegration methods developed by Pedroni (1999, 2000). The FMOLS and the DOLS correct for endogeneity and serial correlation in long-run relationships associated with ordinary pooled OLS. DOLS applies leads and lags of different variables in the cointegrating equation and uses a parametric approach while FMOLS uses a non-parametric approach (Pedroni, 2000; Ouedraogo, 2013). The coefficient estimates provide long-run impacts of the explanatory variables on $CO_2$ emissions. Since all the variables are measured in natural logarithms, the estimated coefficients from the long-run cointegration relationship can be interpreted as long-run elasticities.

Before we present results of the full model, in order to test the independent effects of the environmental policy stringency index, we first estimated the models without the environmental tax variables but including $CO_2$ emission per capita, environmental policy stringency index, fossil energy consumption, renewable energy consumption and income. As Table 4A shows, with environmental tax variables excluded from the models, the environmental policy stringency index (*ss*) shows a negative and a statistically significant relationship with $CO_2$ emissions. Thus, independently from environmental taxes, we find that the environmental policy stringency index has a negative impact on $CO_2$ emissions. The higher the environmental policy stringency index, the lower the $CO_2$ emissions. Our results are consistent with de Angelis et al. (2019) who also found that the environmental policy stringency variable was negatively and significantly related to $CO_2$ emissions.

In a similar vein, when we dropped the environmental policy stringency index variable but included all the environmental tax variables with all the other variables, as Table 4B shows, we found a negative and a statistically significant relationship between $CO_2$ emissions and energy tax on the one hand and a statistically significant relationship between transport tax and $CO_2$ emissions on the other. The relationship between $CO_2$ emissions and total environmental tax was negatively but not significantly significant.

We now turn to the complete model (Eq., 1), where we include all the variables. As can be seen from Table 5, we still found a negative and a statistically significant relationship between environmental policy stringency (ss) and $CO_2$ emissions (cc). The fact that we found a negative and a statistically significant relationship between $CO_2$ emissions and environmental stringency indicates that the higher the stringency of environmental policy, the lower the $CO_2$ emissions. The robustness of these results is also supported by the DOLS method. The coefficients of the DOLS estimates are, however, substantially higher than the FMOLS estimates.[11] These two methods indicate that increasing the stringency of environmental policy is an effective policy instrument for reducing $CO_2$ emissions in these countries.

[11] Even though DOLS and FMOLS are expected to derive similar parameter estimates asymptotically, it is not clear which approach works better in small sample cases (see Nguyen and Kakinaka, 2019). However, as Kao and Chiang (2000) argue provides the least bias compared to FMOLS. However, in small samples Stock and Watson (1993) suggest that DOLS performs relatively more efficiently than FMOLS (see Nguyen and Kakitana, 2019).

Coming to the relationship between $CO_2$ emissions and environmental tax, we also observe that there is a negative and a statistically significant relationship between the three types of environmental taxes and $CO_2$ emissions. Table 5 shows that energy tax (ex, ei and ey) is negatively related to $CO_2$ emissions. For instance, a 1% increase in energy tax (ex, ei and ey) reduces $CO_2$ emissions with the range of 0.076–0.082%. Similarly, Table 5 shows that transportation tax (vx, vi and vy) is negatively related to $CO_2$ emissions. A 1% increase in environmental transport tax reduces $CO_2$ emissions between 0.014 and 0.019%. Only when transport tax measured as % GDP (*vy*) is the coefficient is positive but not statistically significant. Finally, Table 5 shows that the coefficients of the total environmental tax (tx,ti and ty) are negatively related to $CO_2$ emissions. For instance, a 1% increase in total environmental taxes reduces $CO_2$ emissions within the range of 0.039–0.052%. Overall, the evidence indicates that all the three categories of environmental taxes have a negative impact of $CO_2$ emissions. However, judging from the size of the coefficients of the three types of the environmental tax (total, energy and transport), we observe that the coefficient of the energy tax is higher than the coefficients of the total and the transport taxes, respectively, implying that energy tax has the largest impact on reducing $CO_2$ emissions., With respect to the impact of renewable energy consumption (rr), Table 5 also shows that renewable energy consumption has a negative and a significant effect on $CO_2$ emissions, indicating that a 1% increase in renewable energy consumption reduces $CO_2$ emissions between 0.057 and 0.083% in the long run. Although the value is very small, the sign is as expected. Our findings are consistent with the latest finding of Nguyen and Kakinaka (2019) for high-income countries and with Jin and Kim (2018) for a group nuclear energy generating countries. Our results are also consistent with López-Menéndez et al. (2014) for 27 European Union countries who found that there was a significant impact of renewable energy on $CO_2$ emissions. Similarly, our results are also consistent with Shafiei and Salim (2014) who found renewable energy consumption reduces $CO_2$ emissions in OECD countries. Dogan and Seker (2016) have also found that renewable energy mitigates carbon emissions in the European Union.

As can be seen from Table 5, judging from the size of the coefficients of the environmental taxes and the environmental policy stringency variables, for total environmental tax and energy tax, we found that the coefficients of these two variables are higher than the coefficient of the environmental policy stringency variable. Table 5 also shows that the coefficient of renewable energy variable is higher than the coefficient of the environmental policy stringency variable. Thus, even though both environmental policy stringency and renewable energy are contributing to the reduction in $CO_2$ emissions, there is no denying the fact that promoting renewable energy is relatively more effective in reducing $CO_2$ emissions than making environmental policies more stringent. Renewable energy is not only at the forefront of the global energy transition but also at the forefront of promoting environmental sustainability.

As Table 5 indicates, increases in fossil energy consumption (ff) increases $CO_2$ emissions. Dogan and Seker (2016) have also found that non-renewable energy consumption increases $CO_2$ emissions in the European Union. The policy implications of our finding are that in order to mitigate $CO_2$ emissions, these 20 European countries should keep on increasing the share of renewable energy consumption and at the same time reduce the share of non-renewable energy consumption consistent with the European 2030 Strategy of reducing primary energy consumption and achieving a consistent share of renewable energy in the final energy consumption.

Coming to the evidence concerning the EKC hypothesis, Table 5 shows that all the coefficients of the yy variable are positive and all its square $(yy^2)$ are negative. As the ECK postulates, there is an inverted U-shaped relationship where per capita $CO_2$ emissions first increase and then reach a peak point and finally continue to decline.

## 4.4 Robustness checks

To confirm further the robustness of our estimation results, we estimated our model using quantile regression which provides a more comprehensive investigation for model estimation at different quantiles (Koenker, 2004). Unlike the traditional regression which focuses on the mean, the quantile regression is able to describe the entire conditional distribution between $CO_2$ emission and its determinants throughout the conditional distribution by specifying certain quantile points. The advantage of quantile regression is that it allows us to detect the possibility that the effects of the $CO_2$ determinants can differ across the conditional distribution of $CO_2$ with particular emphasis on countries with low, intermediate and high levels of $CO_2$ (see Borozan, 2019).

**Table 6** Quantile regression estimates

| Taxes | variable | quantiles q10 | q20 | q30 | q40 | q50 | q60 | q70 | q80 | q90 |
|---|---|---|---|---|---|---|---|---|---|---|
| Energy | ss | −0.080*** | −0.089*** | −0.127*** | −0.093*** | −0.040 | −0.016 | −0.005 | −0.017 | −0.091** |
| | ei | −0.233*** | −0.302*** | −0.264*** | −0.234*** | −0.140*** | −0.095*** | −0.082*** | −0.026 | 0.152 |
| | rr | −0.110*** | −0.086*** | −0.066*** | −0.070*** | −0.085*** | −0.098 | −0.097*** | −0.084*** | −0.009 |
| | ff | 0.793*** | 0.819*** | 0.653*** | 0.517*** | 0.474*** | 0.383*** | 0.353*** | 0.240 | −0.004 |
| | ss | −0.087*** | −0.098*** | −0.126*** | −0.083*** | −0.048* | −0.019 | −0.007 | −0.026 | −0.094* |
| | ex | −0.265*** | −0.336*** | −0.268*** | −0.248*** | −0.159*** | −0.100*** | −0.089*** | −0.056 | 0.086 |
| | rr | −0.103*** | −0.086*** | −0.062*** | −0.073*** | −0.082*** | −0.098 | −0.097*** | −0.069 | 0.015 |
| | ff | 0.814*** | 0.836*** | 0.654*** | 0.519*** | 0.470*** | 0.387*** | 0.355*** | 0.290 | 0.078 |
| | ss | −0.003 | −0.045 | −0.099** | −0.073 | −0.037 | −0.033 | −0.021 | −0.056 | −0.097*** |
| | ey | 0.158** | 0.235** | 0.115 | 0.045 | −0.007 | 0.026 | 0.052 | 0.124 | 0.326*** |
| | rr | −0.127*** | −0.103*** | −0.085 | −0.090*** | −0.083*** | −0.093*** | −0.091*** | −0.085*** | −0.035 |
| | ff | 0.539*** | 0.474*** | 0.546*** | 0.503*** | 0.482 | 0.411*** | 0.396*** | 0.152 | −0.031 |
| Transport | ss | −0.031** | −0.048** | −0.126** | −0.087 | −0.089*** | −0.057** | −0.060 | −0.050 | −0.076* |
| | vi | −0.040 | −0.041 | −0.048 | −0.057 | −0.092** | −0.084*** | −0.075 | −0.022 | 0.042 |
| | rr | −0.118*** | −0.098*** | −0.058* | −0.072*** | −0.083*** | −0.092*** | −0.077*** | −0.076* | 0.028 |
| | ff | 0.674*** | 0.616*** | 0.681*** | 0.597*** | 0.582*** | 0.546*** | 0.545*** | 0.315 | 0.113 |
| | ss | −0.031* | −0.047 | −0.126*** | −0.088* | −0.088*** | −0.061** | −0.058* | −0.050 | −0.074* |
| | vx | −0.039** | −0.042 | −0.049 | −0.061 | −0.091*** | −0.083*** | −0.073* | −0.024 | 0.043 |
| | rr | −0.118*** | −0.098*** | −0.059** | −0.075*** | −0.082*** | −0.091 | −0.078*** | −0.077 | 0.028 |
| | ff | 0.670*** | 0.618*** | 0.68*** | 0.595*** | 0.591*** | 0.548*** | 0.545 | 0.317 | 0.110 |
| | ss | −0.017 | −0.051 | −0.077* | −0.050 | −0.049 | −0.042 | −0.024 | −0.005 | −0.043 |
| | vy | 0.008 | 0.052 | 0.063 | 0.044 | −0.004 | −0.036 | −0.031 | 0.017 | 0.054 |
| | rr | −0.129*** | −0.111*** | −0.097*** | −0.089*** | −0.080*** | −0.095*** | −0.086*** | −0.088 | 0.011 |
| | ff | 0.591*** | 0.563*** | 0.421*** | 0.436*** | 0.490*** | 0.443 | 0.435*** | 0.137 | 0.086 |

**Table 6** (continued)

| Taxes | variable | quantiles q10 | q20 | q30 | q40 | q50 | q60 | q70 | q80 | q90 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total environmental | ss | −0.051*** | −0.061* | −0.136*** | −0.082** | −0.035 | −0.029* | −0.019 | −0.038 | −0.079 |
| | ti | −0.130* | −0.167 | −0.186 | −0.175** | −0.108*** | −0.089*** | −0.089* | 0.058 | 0.172** |
| | rr | −0.114 | −0.095*** | −0.062*** | −0.071*** | −0.097*** | −0.102*** | −0.098*** | −0.078*** | −0.013 |
| | ff | 0.721*** | 0.710*** | 0.686*** | 0.591*** | 0.505*** | 0.428 | 0.391*** | 0.119 | −0.101 |
| | ss | −0.048** | −0.062 | −0.132*** | −0.079** | −0.039 | −0.037* | −0.023 | −0.040 | −0.078* |
| | tx | −0.118 | −0.169 | −0.178 | −0.158** | −0.128*** | −0.104** | −0.099*** | 0.038 | 0.173* |
| | rr | −0.115*** | −0.099*** | −0.065*** | −0.071*** | −0.096*** | −0.102*** | −0.097*** | −0.078*** | −0.011 |
| | ff | 0.706*** | 0.703*** | 0.676*** | 0.587*** | 0.520*** | 0.442 | 0.399*** | 0.163 | −0.104 |
| | ss | −0.002 | −0.036 | −0.077** | −0.043 | −0.053 | −0.031 | −0.019 | −0.039 | −0.072** |
| | ty | 0.330*** | 0.321 | 0.227** | 0.191** | 0.096 | 0.075 | 0.093 | 0.203** | 0.257*** |
| | rr | −0.144*** | −0.125*** | −0.105*** | −0.112*** | −0.072*** | −0.089*** | −0.090*** | −0.076 | −0.003 |
| | ff | 0.299*** | 0.354*** | 0.405*** | 0.381*** | 0.461*** | 0.388 | 0.367*** | −0.036 | 0.014 |

***, ** and * denote significant levels at 1%, 5% and 10%, respectively. For the definition of the variables, see Table 1

Results of this test are presented in Table 6 and highlighted several important findings. In the first place, these results unveil significant heterogeneity in the $CO_2$ responses across the different quantiles. As can be seen from Table 6, all the coefficients of the environmental policy stringency variable (ss) are negative with varying levels of significance. All the coefficients of the environmental policy stringency are negative at all quantiles. The relationship between environmental policy stringency and C $O_2$ emissions seems to be an inverted N relationship. The impact is relatively larger and statistically significant up to the 40th quantile; between the $50^{th}$ and the 80th quantiles, the size of the coefficient falls but rises at 90th quantile. Generally, the evidence seems to imply that higher environmental stringent policies decrease C $O_2$ emission in countries that have lower $CO_2$ emissions.

All the coefficients of the energy tax variable measured as % of overall total tax revenue (ei and ex*)* with the exception of the 90th quantile are negative and statically significance (except the q80th quantile). In contrast, except the median quantile (q50) all the quantiles of the energy tax per capita (ey) variable are positive but most of the coefficients are not statistically significant.

Regarding total environmental tax, the coefficient (ti) measured as % of overall total tax revenues (including or excluding imputed social contributions) is negative and statistically significant up to the 70th quantile. In contrast, when total environmental tax as % of GDP are used, almost all the coefficients are positive with q10, q30, q40, q80 and q90 statistically significant. But the median quantile (50th quantile) for energy tax (ey) and transport tax (vy) are negative but not statistically significant while the median quartile of total environmental tax as % of GDP (ty) is positive but not statistically significant.

As can be seen from Table 6, when environmental tax as share of total tax revenue is used, higher environmental tax decreases $CO_2$ emissions in lower $CO_2$ emission countries which may suggest that it is countries with relatively lower $CO_2$ emissions that are effectively using their environmental tax to reduce $CO_2$ emissions. The overall evidence seems to imply that an increase in environmental tax and stricter environmental policy is more effective in countries with lower $CO_2$ emissions.

Only environmental tax as % of GDP is not consistent with the results shown in Table 5 Morley (2012) found that environmental tax relative to total tax revenue was relatively more significant than environmental tax relative to GDP. Abdullah and Morley (2014) also found that environmental tax relative to total tax was more significant that tax relative to GDP. Borozan (2019) also found that an increase in energy tax (as % of GDP) increases energy consumption in lower energy-consuming EU countries in particular in lower energy-consuming countries.

All the coefficients of the renewable energy consumption except at the 90th quantile are negative and mostly statistically significant especially up to the 70th quantiles In contrast, the coefficients of the fossil energy consumption are mostly positive and statistically significant up to the 70th quantile. Both for renewable energy consumption and fossil energy consumption, the impact is higher for low $CO_2$ emission countries than for other countries.

Both from the long-run coefficients presented in Table 5 and from the quantile regression presented in Table 6, the coefficient of the environmental tax variable is greater than the coefficient of the environmental policy stringency variable. Furthermore, the coefficient of the energy tax variable is substantially greater than the coefficient of the transport tax variable and also higher than the total environmental tax variable. Environmental energy taxes seem to be more efficient than both environmental policy stringency and environmental transport taxes. The quantile regression results for the renewable and the fossil energy consumption are also consistent with the results from the FMOLS and DOLS estimates presented in Table 5.

## 5 Concluding remarks

As mounting global environmental and climate challenges are becoming of a great concern, market-based and non-market instruments are now used to solve this fundamental threat to the environmental. Environmental stringency policies and environmental taxes are becoming the cornerstones for challenging this environmental existential challenge. The aim of this paper was to examine the effectiveness of both stringent environmental policies and environmental taxes in reducing $CO_2$ emission in 20 European countries for the period 1995–2012. Our empirical results indicate a negative and a statistically significant relationship between environmental policy stringency and $CO_2$ emissions suggesting that countries with strong environmental stringent policies exhibit higher reductions in $CO_2$ emissions. The higher the environmental stringency policy, the lower the $CO_2$ emissions. We also found a negative and a statistically significant relationship between three types of environmental taxes (total, energy and transport) and $CO_2$ emissions implying that countries with higher revenues from total environmental tax, energy tax and transport tax also show higher reductions in $CO_2$ emissions. Our evidence has important implications for environmental policy as they indicate that environmental stringency, total environmental tax, energy tax and transport tax are effective in reducing $CO_2$ emissions. Our results support the validity of the first part of the “double dividend” (DD) hypothesis which postulates that environmental tax improves environmental quality and that environmental tax can be used to combat environmental degradation. The environmental performance of a country is related to its environmental stringent policies and to its environmental taxes suggesting that the simultaneous increase in environmental tax coupled with higher stringent environmental policies can be effective instruments for reducing $CO_2$ emissions. Furthermore, in order to mitigate $CO_2$ emissions, these 20 European countries should not only keep on increasing the share of renewable energy but they should also decrease the share of non-renewable energy in total energy consumption.

Currently, trends in the growth of environmental taxes are becoming a cause for concern as the threshold potential where environmental taxes can improve environmental and climate changes is not achieved (ILO, 2014). Energy taxes are well below where they should be to reflect climate costs and this may encourage firms to pay the low tax rate and still continue to pollute. It is reported that most tax rates are low relative to levels thought to be needed to achieve climate change objectives (ILO, 2014). It is further claimed that these environmental taxes are too insignificant for addressing climate change and/or other environmental challenges as they are low relative to the social cost of carbon and relative to the prices of taxed fuels (Haites, 2018). In order to advance our understanding of the effectiveness of environmental stringency and environmental taxes in reducing $CO_2$ emissions, further research is needed from other countries.

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