Environmental Science ▌and Pollution Research

Do environmental taxes and environmental stringency policies reduce CO2 emissions? Evidence from 7 emerging economies

--Manuscript Draft--

Manuscript Number:	ESPR-D-20-08127R1
Article Type:	Research Article
Corresponding Author Secondary Information:	
Authors:	Yemane Wolde-Rufael, PhD
	Eyob Mulat-Weldemeskel, PhD
Funding Information:	
Abstract:	Environmental tax and environmental policy stringency are becoming central policy instruments for combating environmental degradation but there is lack of studies that assess their combined effectiveness in mitigating emissions especially for emerging economies. We address this important gap by assessing the effectiveness of these two policy instruments in reducing CO_2 emission in a panel of 7 emerging economies for the period 1994-2015. We believe that this is the first attempt to apply these two important policy instruments in the same framework for testing their effectiveness in reducing CO_2 emissions in these 7 emerging economies. We apply a heterogeneous panel data considering cross-sectional dependence and slope heterogeneity tests by using the Augmented Mean Group (AMG) which is efficient, unbiased and produces consistent estimates. We found an inverted U–shaped relationship between CO_2 emissions and environmental policy stringency suggesting that it takes time for environmental policy stringency to be effective. We also found a unidirectional causality running from environmental policy stringency to CO_2 emission. CO_2 emission was negatively and significantly related to total environmental tax with causality running from total environmental tax to CO_2 emission thus supporting the 'green dividend' hypothesis of improving environmental quality. In contrast, CO_2 emission and energy taxes were not causality related but CO_2 emission was negatively and significantly related to energy taxes. Robustness checks using the FMOLS also show that both environmental policy stringency and environmental taxes can be effective in mitigating CO_2 emissions.

Question	Response

Do environmental taxes and environmental stringency policies reduce CO₂ emissions? Evidence from 7 emerging economies

Yemane Wolde-Rufael
Eyob Mulat-Weldemeskel

Abstract

Environmental tax and environmental policy stringency are becoming central policy instruments for combating environmental degradation but there is lack of studies that assess their combined effectiveness in mitigating emissions especially for emerging economies. We address this important gap by assessing the effectiveness of these two policy instruments in reducing CO_2 emission in a panel of 7 emerging economies for the period 1994-2015. We believe that this is the first attempt to apply these two important policy instruments in the same framework for testing their effectiveness in reducing CO_2 emissions in these 7 emerging economies. We apply a heterogeneous panel data considering cross-sectional dependence and slope heterogeneity tests by using the Augmented Mean Group (AMG) which is efficient, unbiased and produces consistent estimates. We found an inverted U–shaped relationship between CO_2 emissions and environmental policy stringency suggesting that it takes time for environmental policy stringency to be effective. We also found a unidirectional causality running from environmental policy stringency to CO_2 emission. CO_2 emission was negatively and significantly related to total environmental tax with causality running from total environmental tax to CO_2 emission thus supporting the 'green dividend' hypothesis of improving environmental quality. In contrast, CO_2 emission and energy taxes were not causality related but CO_2 emission was negatively and significantly related to energy taxes. Robustness checks using the FMOLS also show that both environmental policy stringency and environmental taxes can be effective in mitigating CO_2 emissions.

Key words: CO_2 emissions; emerging economies; environmental policy stringency; environmental taxes; green dividend; panel causality; panel cointegration

Introduction

Environmental degradation has become one of the greatest threats facing humanity as it adversely affects not only human health but also economic growth (World Bank 2016). As emissions levels are constantly rising, the IPCC (2018) warns that we are confronted by 'painful environmental problems' sooner than expected. Despite this alarming warning however, "the climate crisis continues unabated as the global community shies away from the full commitment required for its reversal" (UN, 2020, p. 50). The UN further warns that "if the world does not act now, and *forcefully* [emphasis added], the catastrophic effect of climate change will be far greater than the current pandemic (COVID-19)" (UN, 2020, p. 50). This dire warning comes from the fact that global warming is increasing, with the year 2019 being the second warmest on record causing massive wildfires, hurricanes, droughts, floods and other climate disasters across all continents (UN, 2020). What is more worrying is that while the Paris Agreement (2015) calls for limiting global warming to 1.5°C, the world is way off track to meet this target at the current level of nationally determined contributions (UN, 2020). With the drive for fast economic growth, energy consumption has increased with its attendant evils of increasing atmospheric carbon dioxide emissions that cause climate change and global warming. The energy sector accounts more than two-thirds of total green gas emissions and more than 80% of CO_2 emissions (IEA, 2019). CO_2 emission is considered to be the driving force of global warming and climates change. Global energy-related CO_2 emissions have increased from 20,521 million tonnes of CO_2 in 1990 to around 32,840 million tonnes in 2017 (IEA, 2020).

Between 1990 and 2017, the total CO_2 emissions (kt) of the 7 emerging economies under consideration increased by more than a 55% but their share in the world total CO_2 emissions (kt) declined marginally from 6.0% in 1990 to 5.8% in 2017. The largest increase of almost of threefold, was recorded in Turkey. Turkey is a high resource intensity country with the share of renewable energy in total energy consumption declined significantly by almost 55% between 1990-2017 (World Bank, 2020). This was followed by South Korea where total CO_2 emissions (kt) more than doubled between 19990 and 2917, making Korea the eighth largest emitter of CO_2 emissions in the world (World Bank, 2020). Korea's energy mix is dominated by fossil fuels and the share of renewables is the lowest in the OECD accounting for only 2.7% of total energy consumption in 2017 (World Bank, 2020). In South Africa, a highly fossil-dependent economy, total CO_2 emissions increased by around 73% for the same period. In contrast, in Czech Republic, Greece, Hungary and Poland total CO_2 emissions declined. The decline in CO_2 emissions, for instance, in Czech Republic can be attributed to the way the country has managed to decouple many environmental pressures from its economic growth and from

improve environmental infrastructure (OECD, 2018a). In the case of Greece, progress in decoupling air pollutant emissions from GDP has been made with improving the conservation status of natural habitats. The energy mix of Greece has shifted towards cleaner fuels, but the economy strongly relies on fossil fuels with renewable energy accounting for only 17.2% of total energy consumption (World Bank, 2020). All these 7 countries have lower than the world average of renewable energy consumption in total final energy consumption (World Bank, 2020).

The increase in CO_2 emissions has several ramifications for economic growth, human health and environmental degradation (IEA, 2019). Irrespective of the decrease or increase in CO_2 emissions in these 7 countries, still climate change caused by increased emissions, has harmful and irreversible effects on economic growth and human life. Many empirical studies show that CO_2 emission has a detrimental effect on economic growth and on the quality of the environment (Ahmed, et al. 2020; Purcel, 2020; Sarkodie and Strezov 2019; Shahbaz and Sinha 2019; Tiba and Omri 2017). Thus, reducing CO_2 emissions prevents the adverse effects of global warming and can have a positive impact on the quality of the environment and economic growth.

All these eminent threats of global warming and climate changes definitely require an effective energy policy to combat their adverse effects. Recognizing these eminent threats and also recognizing that markets forces alone do not provide solutions to environmental problems (Pigou 1920), environmental taxes and stringent environmental policies are now becoming the cornerstones of environmental sustainability and a panacea for reducing CO_2 emissions. Nevertheless, the paper recognizes that these two policy instruments are among the many policy instruments available for addressing the adverse effects of global warming and climate change. Equally, we also recognize that these two policy instruments are not in themselves sufficient to reduce the harmful effects of CO_2 emissions. For instance, according to OECD there are more than 3,200 environmental instruments, of which more than 2,800 are in force. Carbon tax and emission trading system (ETS) are among the most efficient policy instruments for cutting greenhouse gas emissions[1]. It is widely argued that by putting price on greenhouse gas (GHG) emissions (carbon pricing) can be one of the most effective means of reducing emissions (Haites, 2018; IBRD, 2017; Tol, 2013). 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). Carbon tax is considered to be the most effective instrument for curbing carbon

---

[1] ETS works by putting a limit on overall emissions from covered installations where this limit is reduced each year for the participating companies. 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).

emissions as carbon tax is levied on the carbon content of fuels (Haites, 2018; Lin and Li, 2011; Schmalensee and Stavins, 2017; Tol, 2013). All these measures are intended to encourage firms to seek eco-friendly technologies so that fossil fuels are replaced by renewable energy for an eventually a carbon-free society.

In conjunction with several environmental regulations, promoting renewable energy is at the heart of environmental policy. The development of green technologies both nationally and through international cooperation is becoming a cornerstone of energy policy and also the best hope for sustainable development and emission free society. Several researches are being undertake to replace conventional technologies by eco-friendly technologies (IEA, 2019). Environmentally sustainable production and consumption of energy is now one of the stated goals of the UN Sustainable Development Goals. As global warming is a global problem, and encouraging collaboration on green technology innovation that address global climate change or regional pollution is becoming an important international energy policy agenda. Furthermore, even though global climate conventions are not binding, several countries are a party to the Paris Agreement that have pledged a joint intervention agreement to combat climate change (Neves, et al. 2020). This agreement became effective in 2020 to fight climate change globally by limiting global average temperatures to 2_0C above pre-industrial levels (United Nations, 2015). Effective collaboration and adherence to international conventions and treaties is fundamental to combating global warming and climate change.

The aim of this paper is to assess the effectiveness of environmental taxes and stringent environmental policy in reducing CO_2 emissions in a panel of 7 emerging economies that include Czech Republic, Greece, Hungary, Korea, Poland, South Africa and Turkey for the period 1994-2015. Even though our study does not include the major emerging countries such as Brazil, China and India, still these seven countries constitute major important players in emerging economies and also in the world economy. Our strategy is to exploit not only the data on total environmental tax but also on energy tax, where among the list of the emerging countries, only for these 7 countries is a complete set of data on both total environmental tax, energy tax and environmental policy stringent available for the period 1994-2015. By doing so we hope to test the 'green dividend' hypothesis that total environmental tax and energy tax can play an important role in improving environmental quality in these 7 emerging countries.

To the best knowledge of the current authors, there is no study that sets these two instruments in the same framework to assess their effectiveness in reducing CO_2 emissions. However, there are several studies that

separately assessed the effectiveness of either environmental tax or environmental policy stringent. For instance, Aydin and Esen 2018; Freire-González 2018; Shahzad 2020; Timilsinas 2018) assessed the effectiveness of environmental taxes in reducing CO_2 emissions while the effectiveness of environmental policy stringency was assessed by Ambec et al. 2013; Cohen and Tubb 2018; Dechezleprêtre and Sato 2017; van Leeuwen and Mohnen 2017; Wang and Shen 2016; Wolde-Rufael and Mulat-Weldemichael 2020). Despite these extensive studies none of them combined both environmental taxes and environmental policy stringency in the same framework to test the combined effectiveness of these policy instruments in mitigating CO_2 emissions (see Shahzad 2020). None of these papers also tested the effectiveness of these two instruments using both consumption-based and territory-based CO_2 emission. As these studies do not include both policy instruments in the same framework to assess their effectiveness in mitigating CO_2 emissions, we believe that a shift in focus towards assessing the effectiveness of policy instruments such as environmental rules and regulations and environmental taxes in mitigating CO_2 emissions can advance our understanding the nexus between environmental policies and CO_2 emission (Khan et al. 2019; Wolde-Rufael and Mulat-Weldemichael 2020). Moreover, we believe that the potential importance of environmental taxes and strict environmental rules and regulations in combating emissions necessitates not only further research but also the application of a relatively new econometric technique that addresses cross-sectional dependence, slope homogeneity and homogeneous causality.

We address this important gap in the literature by throwing some insights into how environmental stringency policies and how environmental taxes affect the mitigation efforts of these 7 emerging economies. By highlighting the potential importance of these two policy instruments in the mitigating strategies of these emerging economies, the paper attempts to make some contributions to the debate on the relationship between environmental degradation, environmental policy stringency and environmental taxes. First, to the best of our knowledge, this is the first attempt to assess the simultaneous effectiveness of environmental stringency and environmental taxes on the environmental quality of the 7 emerging economies. Second, as the effectiveness of environmental policy stringent and environmental tax on carbon emissions adjusted for international trade has not been investigated for these economies, we fill this gap by using the consumption-based carbon emissions data developed by Peters et al. (2011). Unlike the territory-based CO_2 emissions which do not include emissions embodied in international trade, the consumption-based carbon emissions are estimated based on the domestic use of fossil fuels plus the embodied emissions from imports less exports (Liddle 2018). As international trade

plays an important role in these emerging economies, CO_2 emissions adjusted for international trade may be relatively more important than territorial-based CO_2 emissions. Third, for measuring the stringency of environmental policies, we use the newly developed and 'internationally-comparable measure of environmental stringency', the environmental policy stringency index developed by OECD (2016). As our fourth contribution, since the true relationship between CO_2 emissions and environmental policy stringency can be non-monotonic, we model our empirical study in a non-linear framework that includes the square of environmental policy the stringency index to test our hypothesize that relationship between environmental policy stringency and CO_2 emissions is an inverted U-shaped. It takes time for the stringency regulations to be effective (Neves, et al. 2020). Further, in order that our outcome does not dependent on one measure of environmental tax, unlike many previous studies that attempted to test the effectiveness of environmental tax on CO_2 emissions, we distinguish between total environmental tax and energy tax measured as (i) as % of GDP, (ii) as % of total tax revenue and (iii) as real tax per capita. For our empirical test, we apply a heterogeneous panel data considering cross-sectional dependence and slope heterogeneity tests using the Augmented Mean Group (AMG) which is efficient, unbiased and produces consistent estimates.

We organize the rest of the paper as follows. In section 2 we briefly review the related literature. In section 3 we present the data and the methodology we used. Section 4 provides a discussion on our empirical findings while section 5 presents a summary and concluding remarks.

A brief review of the literature[2]

Environmental taxes and environmental degradation

Since the seminal work of Pigou (1920) which highlighted that environmental degradation has negative externalities and that these externalities should not be left to the market alone to provide solutions, environmental taxes and stringent environmental rules and regulations have become two of the most important policy instruments for addressing environmental degradation (Haites 2018; Pigou 1920; Tol 2009, 2017, 2018). The ultimate objective of environmental tax is not only to bring revenues for the state but fundamentally to

---

[2] For an excellent summary of the impact of environmental tax on energy consumption and environmental quality, see Shahzad (2020).

bring about behavioral changes on businesses to use environmentally friendly technologies and on consumers to consume less pollutant products so that the harm to the environment is reduced (Aydin and Esen 2018; Borozan 2019; European Environment Agency 2005; ILO 2014; Pigou 1920; Shahzad 2020; Wolde-Rufael and Mulat-Weldemeskel 2020). To many, a carbon tax can change the structure of production and consumption in favor more environmentally-friendly production and consumption of energy related products (Mardones and Baeza 2018; Shahzad 2020; Tol 2018). These proponents further believe that environmental-related taxes can reduce emissions as well as promote green technological innovations, energy efficiency and cleaner and healthier environment (Shahzad 2020). An early study by Ligthart and Van Der Ploeg (1999) showed that environment tax can achieve multiple objectives such as greener environment as well as bolster economic growth, reduce unemployment and cut labor taxes (see Shahzad 2020).

The dual role of environmental tax, as postulated by the 'double dividend' hypothesis(Pearce, 1991) is also to improve environmental quality, the 'green dividend' as well as achieve a less distortional tax, the 'blue dividend' (de Angelis et al. 2019; Ciaschini et al. 2012; Goulder 1995; Karydas and Zhang 2019). Furthermore, as Pearce (1991) 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). The 'double dividend' hypothesis also predicts that environmental taxes can raise revenues to be recycled for correcting other distortions in the economy (Pearce 1991).

However, environmental taxes can also increase the cost of production for firms and can undermine their international competitiveness (see Mulatu 2018). Moreover, firms can shift the increased cost of environmental tax to consumers that can hurt low income people and exacerbate income inequality (Fremstad and Paul 2019; Lin and Li 2011; Oueslati et al. 2017; Shahzad 2020). If firms shift the increased cost of environmental tax to consumers, environmental tax may undermine the fight against environmental degradation and end up instead of only adding to the fiscal revenue of the state (Lin and Li 2011; ILO 2014; Vehmas 2005).

Empirical evidence on the effectiveness of environmental tax in mitigating environmental degradation is mixed with some studies supporting the effectiveness of environmental tax in reducing emissions while others find no evidence to support the claim that environmental taxes improve environmental quality (see Aydin and Esen 2018; Freire-González 2018; Shahzad 2020; Timilsinas 2018). Among those who found that environmental taxes reduce CO_2 emissions include (Haites 2018; Lin and Li 2011; Miller and Vela 2013; Morley 2012). In addition to the above, Nakata and Lamont (2001) for Japan also found that environmental taxes reduce carbon emissions and also lead to the use of energy with lower emissions. Filipovic et al. (2015);

8

Morley (2012) also found that energy taxes can decrease energy consumption as well as reduce GHG emissions. For China, Guo et al. (2014); Lu et al. (2010); Xu and Long (2014); Yang et al. (2014); Zhang et al. (2016) also found that environmental taxes can reduce carbon emissions. Applying quantile regression, Borozan (2019) found that energy tax increases energy consumption in lower energy-consuming EU countries but at higher quantiles, energy tax insignificantly reduces energy consumption. Similarly, for a group of 15 European countries Aydin and Esen (2018) also found that environmental taxes reduce emissions and promote technological innovation. According to Sen and Vollebergh (2018) for a group of OECD countries, a one euro increase in energy taxes reduces carbon emissions from fossil fuel consumption by 0.73 percent. Similarly, for group of OECD countries and China, He et al. (2019) found that environmental taxes reduce pollutant emissions. According to Hashmi and Alam (2019) a 1% increase in environmental tax revenue per capita reduces CO_2 emissions by 0.033% in OECD countries.

While the above studies found that environmental taxes were effective in reducing emissions and improving environmental quality, other studies have not found that environmental taxes are effective in reducing environmental degradation. For instance, for a group of 18 European countries Hotunluoglu and Tekeli (2007) did not find that carbon taxes reduce emissions. Equally, Loganathan, et al. (2014) for Malaysia; Radulescu et al. (2017) for Romania did not find that environmental taxes reduce CO_2 emissions. Similarly, Gerlagh and Lise (2005) and Lin and Li (2011) did not find that environmental taxes were effective in reducing CO_2 emissions. Liobikienè, et al. (2019) also did not find that energy taxes influence GHG emissions in EU countries.

Environmental policy stringency and environmental degradation

Another policy instrument that is being implemented to combat environmental degradation is stringent environmental policy and regulations. The purpose of stringent policies is to make pollution and other environmental services more costly in order to change the behavior of both producers and consumers towards more environmental-friendly products (Neves, et al. 2020; OECD 2016). This is done by imposing restrictions on polluting agents to increase the cost of polluting activities and make them less attractive (Neves, et al. 2020). Since the seminal work of Porter and van der Linde (1995), the debate between environmental regulation and environmental outcomes has been at the forefront of the regulation-environmental-outcome nexus (see Mulatu 2018). To Porter and van der Linde (1995), a carefully designed environmental policy can help industries to

adopt environmentally friendly technologies which can lead to reduction in emissions (Dechezleprêtre and Sato 2017; Ramanathan et al. 2017). Ambec et al. (2013); Cohen and Tubb (2018); Dechezleprêtre and Sato (2017) also believe that stringent environmental policies can minimize the adverse effects of pollution by promoting environmentally friendly technologies and by discouraging environmentally 'dirty' technologies. Thus, like environmental taxes, stringent environmental rules and regulations have the ability to potentially change the behavior of producers and consumers towards eco-friendly production and consumption of energy products (Lagreid and Povitkina 2018).

Nevertheless, it is also possible that the cost of environmental stringency policies can hinder firms from adopting environmentally friendly investments that prevent them from seeking innovations that can improve environmental quality (see Mulatu 2018; Wolde-Rufael and Mulat-Weldemeskel 2020). To circumvent these additional costs and also avoid these stringent environmental policies, as the Pollution Haven Hypothesis (Porter and van der Linde 1995) pustulates, firms in developed countries can export their production of environmentally 'dirty' goods to countries with relatively weak environmental rules and regulations (Levinson and Taylor 2008; Mulatu 2018). The 'race to the bottom hypothesis' also predicts that developing countries may lower their environmental standards in order to enhance their international competitiveness and attract foreign capital (Kim and Rhee 2019). However, as development progresses and developing countries themselves became more environmentally stringent, these countries can implement their own stringent environmental rules and regulations that can promote clean and environmentally friendly technologies (Dechezleprêtre and Sato 2017; Ramanathan et al. 2017). Thus, at an early stage of the development process, environmental regulations may not have an impact on improving environmental quality but at a later stage they can improve environmental quality (Ferris et al. 2019). Hence, as it takes time for environmental regulation to be effective, we hypothesize an inverted U-shaped relationship between environmental policy stringency and CO_2 emissions in the 7 economies under consideration.

Regarding the empirical evidence on the relationship between environmental quality and environmental policy stringency, similar to the relationship between environmental taxes and environmental quality, the evidence is also not conclusive. Ambec et al. (2013); Cohen and Tubb (2018); Dechezleprêtre and Sato (2017); van Leeuwen and Mohnen (2017) found that environmental regulations can lead to innovation in clean technologies and can discourage the development of 'dirty' technologies thereby minimizing environmental degradation. For instance, in the case of China, Wang and Shen (2016) found that environmental regulations

10

positively affect clean production industries. Similarly, Liu et al. (2018) found that environmental regulations were negatively related to energy consumption. Again, for China Wang et al. (2019) also found that environmental regulations have a positive impact on ecological efficiency. According to Yin et al. (2015) environmental regulations reduce CO_2 emission in China. Shapiro and Walker (2018) also argue that most of the reductions of air pollution emissions that occurred in the USA between 1990 and 2008 were due to environmental policies. In a similar vein, for a group of OECD countries de Angelis et al. (2019) also found that CO_2 emissions were negatively and significantly related to environmental stringency. Similarly, according to Cole et al. (2005) environmental regulations have been successful in reducing pollution intensity in UK industries. Song et al. (2020) also found that environmental regulation can directly alleviate environmental pollution in China. Similarly, Pei, et al (2019) also found that environmental regulations could potentially reduce carbon emissions. Danish et al. (2020) also found that environmental regulations are helpful in reducing pollution in BRICS countries. Similar to Danish et al (2020) Wolde-Rufael and Mulat-Weldemeskel (2020) also found that environmental stringency reduces CO_2 emissions.

In contrast to the above, Hao et al. (2018); Zhang (2016) found that environmental regulations were not effective in reducing pollution in China. Equally, Li (2019) also found that environmental regulations did not promote technical progress in the Chinese industrial sector. Wang and Wei (2020) also found that environmental policy stringency did not make an appreciable effect on CO_2 reductions (see Wolde-Rufael and Mulat-Weldemeskel 2020).

The 'green paradox'

While many believe that environmental regulations and environmental taxes can provide solutions to environmental externalities, there are others who are skeptical about the effectiveness of these policy instruments in mitigating environmental externalities. According to the proponents of the 'green paradox' (Sinn 2008), there is a fear that such policies can produce unintended and undesirable consequences that can exacerbate environmental degradation (Jansen et al. 2015). To the advocates of the 'green paradox' these imperfect carbon emission mitigation policies, instead of reducing carbon emissions they can lead to the opposite effect of increasing emissions (Jansen et al. 2015; Sinn 2008). Sinn (2008) argues that environmental regulations only address the demand side of the externalities: the consumption of fossil energy without addressing the supply side of fossil production. To Sinn (2008): "If suppliers do not react, demand reductions by

a subset of countries are ineffective …, [and] if suppliers feel threatened by a gradual greening of economic policies …; they will extract their stocks more rapidly, thus accelerating global warming" (p. 360). The central tenet of Sinn (2008) argument is that there is a time lag between environmental policy announcement and its implementation. This lag enables fossil resources owners to anticipate that increases in environmental taxes can reduce demand for their fossil resource. Consequently, these environmental regulatory policies prompt these resource owners to extract more resources rapidly. Environmental regulations make fossil fuel producers fear that their assets will become worthless, consequently they increase production of fossil fuel more quickly thereby accelerating and exacerbating global warming instead of reducing it (Jansen et al. 2015; Sinn 2008; van der Ploeg and Withagen 2015). Thus, the efforts of fossil consuming countries to reduce global warming can be undermined by fossil owners. However, the empirical evidence on the Green Paradox is not conclusive, see (van der Werf and Di Maria 2012; (Zhang et al. 2017). It is for this and other similar reasons that pollution is not only one of the 'greatest existential challenges' (Landrigan et al. 2018) but also one of the 'hardest to tackle for governments all over the world' (van der Werf and Di Maria, 2012).

In contrast to the above, there are others who contend that environmental regulation initially increases CO_2 emissions, the 'green paradox' but at a later stage, environmental degradation helps to reduce CO_2 emissions. Thus, a U-shaped trend is anticipated between CO_2 emissions and environmental degradation where initially the 'green paradox' dominates but later followed by the 'emission reduction effect' (Min 2018). For a group of OECD and emerging countries, Wang and Wei (2020) found the possibility of a 'Green Paradox' occurring in response to strict environmental regulation policies. Wang and Wei (2020) are of the opinion that strict level of environmental regulation in emerging economies will cause 'green paradox' effects and that can hinder economic development.

Against the backdrop of the above complex issues and inconclusive evidence, undertaking an empirical assessment that investigates whether the environmental performance of a country can be related to its environmental policy stringency and to its environmental taxes may add some light on the ongoing debate between environmental degradation, environmental taxes and environmental policy stringency.

Material and methods

The paper uses a balanced annual panel data covering the period 1994-2015. The choice of countries and period is based on the availability of data for both environmental taxes and environmental policy stringent

index (EPS) for the 7 emerging economies. As previously stated, among the list of the emerging countries only for Czech Republic, Greece, Hungary, Korea, Poland, South Africa and Turkey is a complete set of data available for the period 1994-2015[3]. Data on environmental taxes and environmental policy stringency index are from OECD database (2018) and from Wang and Wei (2020)[4]. Data on real GDP per capita, fossil energy and renewable energy come from the World Development Indicators (2018). Consumption and territory--based CO_2 emissions per capita are from Peters et al. (2011).

Background statistics for all the variables are presented in Table 1. Environmental policy stringency index (EPS) ranges from 0 (not stringent) to 6 (highest degree of stringency). According to the OECD (2016) stringency is defined as the "… implicit or explicit cost of environmentally harmful behavior" (p. 5). The indicator focuses on upstream sectors, such as energy and transport and their effects on air and climate policies (OECD 2016). According to the OECD, an environmental tax is defined a tax whose base is "a physical unit, for example, a liter of petrol or a passenger flight that has a proven negative impact on the environment" (OECD, 2018b).

As can be seen from Table 1, CO_2 emissions exhibit a considerable cross-country variation from 5.46 metric tons per capita in Turkey to 12.77 metric tons per capita in Korea. In term of real GDP per capita, South Africa has the lowest and Greece the highest.

[Table 1 about here]

In terms of the environmental policy stringency index, as can be seen from Fig. 1a, South Korea has the highest while South Africa the lowest. Except for South Africa and Greece, for all the remaining five countries the index has substantially increased over the period under consideration. Environmental taxes also show some variations. As can be seen from Fig 1b, total environmental taxes as % of GDP varies from 4.04% in Turkey to 2.60% in Poland.

[Fig. 1 about here]

---

[3] For Brazil, China, India, Indonesia and Russia there are data on EPS for 1990-2015 but not environmental taxes for the whole period.
[4] Wang and Wei (2020) extrapolated some of the missing data (2013-2015) for Czech Republic, Greece, Hungary and Poland.

The model

In this paper even though our primary aim is not to test the validity of the EKC (Environmental Kuznets Curve), we augment our model by including environmental policy stringency index and environmental taxes as determinants of environmental quality to the standard EKC model as follows:

$$co_{2it} = \alpha_{it} + \beta_1 yy_{it} + \beta_2(yy_{it})^2 + \beta_3 ss_{it} + \beta_4(ss_{it})^2 + \beta_5 tax_{it} + \beta_6 ff_{it} + \beta_7 rr_{it} + \varepsilon_{it} \tag{1}$$

where co_2 is consumption-based CO_2 emissions per capita, yy_{it} is real GDP per capita, $(yy_{it})^2$ is squared real GDP per capita, ss_{it} is environmental policy stringency index, $(ss_{it})^2$ is the squared of the environmental policy stringency index, tax_{it} is environment tax (total and energy), ff_{it} is fossil energy consumption as % of total energy consumption, rr_{it} is renewable energy consumption as % of total energy consumption and ε_{it} is the error term. Total environmental and energy taxes are each measured: (i) as % of GDP, (ii) as % of total tax revenue and (iii) as real tax per capita (OECD, 2018). Eq.1 is estimated for six models, three models using the three measures of total environmental tax and three models using the three measures of energy tax. To avoid heteroscedasticity and to interpret the coefficients as long-run elasticities, all variables in the lower case indicate that they are logarithmically transformed variables.

Results and discussion

For estimating the relationship between environmental quality, environmental taxes and environmental policy stringency we use the Augmented Mean Group (AMG) estimator developed by Eberhardt and Bond (2009), Bond and Eberhardt (2013). This estimator does not require any pre-testing procedure of unit root or cointegration and allows the examination of the parameters of non-stationary variables (Destek and Sarkodie 2019). The AMG procedure also takes into account cross-sectional dependence and country-specific heterogeneity among countries (Danish et al. 2019; Destek and Sarkodie 2019). For testing the causal relationship among the variables, we use the heterogeneous panel Granger non-causality test proposed Dumitrescu and Hurlin (2012).

Cross-section dependence unit root test

14

Testing for cross-dependence (CD) has become a prerequisite for testing for cointegration as ignoring cross-section dependency can lead to bias and size distortions (Pesaran 2006). Results of the CD tests are presented in Table 2. As can be seen from Table 2, according to the Pesaran (2004) CD test, the null hypothesis of no cross-section dependence for five out of the six is rejected, but for the other three tests namely, the Breusch-Pagan LM, the Pesaran scaled LM and the Bias-corrected scaled LM, tests the null hypothesis is not rejected. Since the majority of the CD tests did not reject the null hypothesis of no cross-section independence, we conclude that the series are cross-sectionally related.

[Table 2 about here]

Slope homogeneity test

Despite the possible dependence across countries, still countries can maintain their own independent policies and it is therefore crucial to test for cross-country heterogeneity. Results of applying the Pesaran and Yamagata (2008) slope homogeneity test are presented in Table 3 and they show that there is a country-specific heterogeneity among these economies.

[Table 3 about here]

Panel long-run estimates

In this section, we first report the AMG long-run estimation results for the linear models without including the squared of the environmental policy stringent variable (ss^2). Table 4 shows that there is a positive and a statistically significant relationship between CO_2 emissions (cc) and environmental policy stringency (ss) implying that higher CO_2 emissions are associated with relatively low level of environmental policy stringency. South Africa and Turkey should make their environmental policy more stringent as these two countries have a relatively low EPS index while they are among the top pollutant countries. In these linear models, the relationship between total environmental tax and CO_2 emissions is negative but not statistically significant. In contrast, the relationship between energy tax and CO_2 emissions is negative and statistically significant.

[Table 4 about here]

15

Since the true relationship between environmental policy stringency and CO_2 emissions could be non-monotonic, models that do not allow for non-monotonicity will lead to a downward bias in the estimated relationship (Kim et al. 2020). Thus, to assess whether CO_2 emissions and environmental policy stringency are a non-monotonically related, we estimate the models by including the square of the environmental policy stringency ($ss2$). Results of these tests are presented in Table 5. As can be seen from the Table, the ss variable is significantly positive, while its square ($ss2$) is significantly negative for all models suggesting an inverted U-shaped or concave relationship between CO_2 emissions and environmental policy stringency. This implies that initially strict stringent environmental policy may lead to environmental degradation but after a threshold point is reached, environmental stringency policy may lead to reduction in CO_2 emissions suggesting that the more stringent the environmental regulation is, the lesser the increases in CO_2 emissions. Our evidence is in line with Ouyang et al. (2019) who found an inverted U-shaped relationship between environmental policy stringency index and $PM_{2.5}$ emissions for 30 OECD countries. Our evidence is also in line with the findings of Guo et al. (2018) and Wang et al. (2019) for China even though they did not use the same environmental policy stringency we used in this paper. Wenbo and Yan (2018) also found a significant inverted U-shaped curve relationship between environmental regulation and CO_2 emissions in China. Similarly, Zhou et al. (2019) also found an inverted U-shaped relationship between $PM_{2.5}$ and environmental regulations for 277 Chinese cities. Chen et al (2020) have also found an inverted U-shaped relationship between environmental regulations and CO_2 emissions in the Chinese iron and steel industry. Our evidence is also in line with Wolde-Rufael and Mulat-Weldemeskel (2020) who found an inverted U-shaped relationship between environmental policy stringency index and CO_2 emissions for BRIICTS countries (Brazil, Russia, India, Indonesia, China, Turkey and South Africa). Song et al. (2020) and Zhang et al (2020) have also found a U-shaped relationship between environmental regulation and green product innovation for China. Our evidence together with the above indicates that regulations take time to be effective (Neve, et al, 2020). In this respect, our evidence gives credence to the Environmental Kuznets Curve (EKC) hypothesis between environmental policy stringency and CO_2 emissions.

[Table 5 about here]

Turning to the relationship between CO_2 emissions and environmental tax, Table 5 shows that the relationship is negative but not statistically significant when total environmental tax is measured in per capita terms (*tpx*, column 1) but when total environmental tax is measured as % of total taxes (*trx*, column 2) and also

when measured as % of GDP (*tyx*, column 3), CO_2 emission is negatively and significantly related to total environmental tax. A 1% increase in total environmental tax decreases CO_2 emission between 0.060 and 0.087%. Similarly, the relationship between CO_2 emissions and the three measures of energy tax (*epx, erx, eyx*) is negative and statistically significant where a 1% increase in energy tax decreases CO_2 emissions between 0.112 and 0.140%. Our evidence is in line with Lu et al. (2010); Guo et al. (2014); Xu and Long (2014); Yang et al. (2014); Zhang et al. (2016) who found that environmental taxes can reduce carbon emissions. Our evidence is also in line with Hashmiand and Alam (2019) who found that a 1% increase in environmental tax revenue per capita reduces CO_2 emissions by 0.033% in OECD countries. Similarly, our evidence is also in line with Ulucak, Danish and Kassouri (2020) who found that environmental tax reduces CO_2 emissions. Equally our evidence is also in line with He et al. (2020) who found that a significant reduction in greenhouse gas emissions through the imposition of energy taxes. Further, similar to our finding, Neves et al (2020) also found that environmental tax contributes to decreasing CO_2 emissions in the long-run.

Coming to the relationship between CO_2 emissions and renewable energy consumption, we found a negative but not statistically significant relationship between CO_2 emissions (*cc*) and renewable energy consumption (*rr*) in models that include total environmental tax (columns 1 to 3). In contrast, in models that include energy tax (columns 4-6), we found negative and statistically significant relationship between CO_2 emissions (*cc*) and renewable energy consumption (*rr*). Our evidence is similar to the findings of Saidi and Omri (2020) for Czech Republic and Koc and Bulus (2020) for Korea but contrary to Saidi and Omri for Korea who found that renewable energy increases CO_2 emissions. Pata (2018) did not find that renewable energy contributes to CO_2 emission reductions in Turkey. Danish et al. (2019) for South Africa did not find that renewable energy had any impact of CO_2 emissions.

The relationship between CO_2 emissions (*cc*) and fossil energy consumption (*ff*) was positive and statistically significant. Our evidence is in line with most studies (see Adewuyia, and Awodumi 2017; Jebli and Kahia, 2020). For instance, Bulut (2017) for the case of Turkey found that CO_2 emissions were positively and significantly related to CO_2 emissions. For the case of South Africa Banday and Aneja (2019) found a unidirectional causality running from non-renewable energy to CO_2 emission.

Concerning the EKC hypothesis, Table 5 shows the coefficients of the income (*yy*) and the square of income (*yy2*) variables show the correct sign but are not statistically significant. The relationship between CO_2

emissions and economic growth is also divergent in these 7 countries. For instance, Lază, et a. (2019) found that the effects of the three polynomial terms in GDP were not statistically significant for Czech Rep., Hungary and Poland. However, using a quadratic function shows that the effect of the two GDP terms is statistically significant in Czech Republic and Hungary showing an inverted-U-shaped relationship that confirms the Environmental Kuznets Curve. In the case of Korea, Koc (2020) did not find support for the EKC hypothesis. For Greece, a recent study by Kotroni et al. (2020) found that the relationship between per capita GDP and CO_2 emissions did not support the EKC hypothesis while and earlier study by Acaravci and Ozturk (2010) confirmed an EKC- pattern in Greece in the 1960-2005 period. For South Africa, Danish et al (2020) found support for the EKC.

The significant positive relationship between CO_2 emissions and fossil energy consumption may highlight the dilemma between promoting economic growth and safeguarding their environmental quality these countries are facing (Wolde-Rufael and Mulat-Weldemeskel 2020). Unlike in the past, these countries should be more cautious not to endanger their environmental quality at the expense of fast economic growth. There is a need to balance fast economic growth with protecting the environment. The empirical evidence presented in this paper indicates that there is a need for these countries to make their environmental rules and regulation more stringent and also to make their environmental taxes more effective. A long-term goal of environmental sustainability in these countries should strive to promote more renewable energy by promoting green technology, alter their energy mix towards fossil-free economy and increase energy efficiency (Wolde-Rufael and Mulat-Weldemeskel 2020). There is evidence to indicate that energy efficiency is crucial for the reduction of CO_2 emission (Akram, et al. 2020).

Robustness checks

For robustness checks, we applied the FMOLS estimator[5]. As this estimator requires that the data are stationary and cointegrated, we carried out several first-generation unit root tests and cointegration tests using the Pedroni (1999, 2004) and Kao (1999) panel cointegration tests. Results of the unit root and panel cointegration tests indicate that the series were difference stationary and cointegrated[6]. The long-run FMOLS

---

[5] According to the popular Pesaran (2004) CD test, the null hypothesis of no cross-section dependence, except for one of the six models, for all the variables in the remaining five models, and for all the models the null hypothesis of no-cross dependence is rejected. Thus, we can use the first generation of unit root and cointegration tests.
[6] Results available for the authors.

estimates are presented in Table 6. Concerning the relationship between CO_2 emissions and environmental policy stringency, similar to the AMG estimates, we found an inverted U-shaped relationship.

[Table 6 about here]

As can be seen from Table 6, the relationship between CO_2 emissions and total environmental taxes is negative but not statistically significant. In contrast, similar to the AMG estimates, we find a negative and a statistically significant relationship between energy taxes and CO_2 emissions. In line with the AMG estimates, the FMOLS estimates also show that there is a positive and statistically significant relationship between CO_2 emissions and fossil energy consumption; and a negative and statistically significant relationship between CO_2 emissions and renewable energy consumption. Coming to the evidence concerning the EKC hypothesis, Table 6 shows the coefficients of the income (yy) and the square of income (yy^2) variables show the correct sign and they are statistically significant and thus there is support for EKC by the FMOLS estimator but not by the AMG estimator.

In summary, both for the AMG and the FMOLS estimates we found that the coefficient of the energy tax is greater than the coefficient of the total environmental tax. Energy taxes are relatively more effective than total environmental tax in reducing CO_2 emissions[7]. Our overall findings highlighting the crucial role environmental taxes and environmental policy stringency can play in achieving environmental targets. While this may be encouraging, it is hard to tell whether the current level of environmental tax is sufficient to achieve climate change objectives as environmental tax rates may be low relative to the social cost of carbon emissions (Haites, 2018). In these countries, the environmental tax rate has not changed very much over the last few years. Further, these countries have not reached the turning point of the environmental policy stringent Kuznets Curve. As Fig 1B, shows the environmental policy stringent index has declined in recent years. There is no doubt that effective measures to combat global warming cannot be solved by these two policy instruments nor by individual countries themselves alone. Adhering to and strengthening international agreements and conventions and strengthening them through international collaboration in green technology is an important path towards addressing the challenges of global warming.

---

[7] All these tests were carried out using the consumption-based CO_2 emissions. When we used the territory-based CO_2 emissions form Peters et al. (2011) and the World Bank, World Development Data CO_2 emissions per capita, we found no evidence of a U-shaped relationship between the territory-based emissions CO_2 and environmental policy stringency. Results available from the authors.

Causality tests

The above analyses do not indicate the direction of causality among the variables. In this section we carry test of causality by applying the Dumitrescu and Hurlin (2012) panel Granger causality test. Since our main concern is the relationship between CO_2 emissions, environmental stringency policy and environmental taxes, we concentrate on these causal relationships. Results of the causality tests are presented in Table 7. As can be seen from the Table, there is a unidirectional causality running from environmental policy stringency to CO_2 emissions. There is also a bi-directional causality between total environmental tax (measured as % of GDP) and CO_2 emissions but a unidirectional causality from total environmental tax measured as % of total tax revenue and per capita total environmental tax. Thus, total environmental tax causes CO_2 emissions. In contrast, we found no causality between energy tax and CO_2 emissions. Similarly, there was a unidirectional causality from total environmental tax to environmental policy stringency. There was also a unidirectional causality from per capita energy tax to environmental policy stringency. We also found a unidirectional causality from environmental policy stringency to renewable energy and from energy tax to renewable energy. However, we did not find any causality running in any direction between CO_2 emissions and income; between renewable energy and CO_2 emissions; and between fossil energy and CO_2 emissions.

[Table 7 about here]

Concluding remarks

As there is a lack of study that examines the combined effectiveness of environmental policy stringency and environmental taxes on mitigating CO_2, this paper attempted to address this gap for 7 emerging economics for the period 1994-2015. Our evidence indicates a unidirectional causality running from environmental policy stringency to CO_2 emissions (adjusted for international trade). We also found an inverted U–shaped relationship between environmental policy stringency and CO_2 emissions suggesting that initially strict environmental policy does not lead to reductions in CO_2 emissions but after a certain threshold is reached, environmental policy stringency leads to improvement in environmental quality. We also found a negative relationship between CO_2 emissions and total environmental taxes where causality runs from total environmental taxes to CO_2 emissions. Even though we found no causality running between energy taxes and CO_2 emissions, CO_2 emissions were negatively and significantly related to energy tax. The evidence seems to suggest that environmental policy stringent and environmental taxes can be two effective policy instruments in

20

combating negative environmental externalities. Stringent environmental policy and environmental taxes can lead to CO_2 emissions reduction indicating that the environmental performance of a country may be related to its stringent environmental policies and to its environmental taxes highlighting their crucial role in environmental externalities. The policy implication is that making environmental rules and regulations more stringent and increasing environmental taxes can be two effective instruments for reducing CO_2 emissions. However, these two instruments alone are not in themselves sufficient to reduce the harmful effects of energy consumption and CO_2 emissions. Our finding has further highlighted the significance of the dilemma of promoting economic growth and safeguarding the environment. Reducing overall emissions while maintaining high levels of economic development should be the core guiding principle towards sustainable development for these emerging economies. These countries should create a balance between promoting economic growth and safeguarding their environmental quality. An effective policy of making their environmental rules and regulation more stringent and at the same time promoting renewable energy, altering the energy mix towards fossil-free economy and increasing energy efficiency should be their long-term goal of caring for the environment. Our finding of a negative relations between CO_2 emissions and environmental tax on the one hand, and a positive relationship between CO_2 emissions and fossil energy on of the other suggests that the most effective ways of mitigating CO_2 emissions is to reduce fossil fuel consumption by promoting renewable energy. All these countries have lower than the world average of renewable energy consumption in total final energy consumption. Increased utilization of renewable energy overtime not only reduces emission but it can promote sustainable energy supply for a zero-emission strategy. These countries should also develop incentives for their citizens to consume more eco-friendly goods and services. Attracting foreign direct investment that promotes innovative green technology and renewables should also help in their quest for sustainable energy development and better environmental quality. These countries have to develop their abilities to imitate the green technology from developed countries and cooperate among themselves for clean technologies. CO_2 emissions is a global problem and it needs also global solution. Thus, these countries should actively engage themselves in global cooperation to be able to mitigate pollution. Increasing energy efficiency and developing renewable energy should be a pathway for clean growth in the future.

Acknowledgments

REFERENCES

Adewuyia, A O and Awodumi, OB. (2017). Renewable and non-renewable energy-growth-emissions linkages: Review of emerging trends with policy implications. Renewable and Sustainable Energy Reviews. 69:275-291

Akram R, Majeed MT, Fareed Z, Khalid F, Ye H (2020). Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: evidence from nonlinear panel autoregressive distributed lag model. Environ Sci Poll Res 27, 18254–18268

Acaravci, A., Ozturk, I. (2010), On the relationship between energy consumption, CO2 emissions and economic growth in Europe. Energy, 35, 5412-5420

Ahmed, A U. et al. (2020). Pollutant Emissions, Renewable Energy Consumption and Economic Growth: An Empirical Review from 2015-2019. J. Environ. Treat. Tech. Volume 8, Issue 1, Pages: 323-335

Ambec S, Cohen A, Elgie S, Lanoie P (2013). The Porter Hypothesis at 20: Can environmental regulation enhances innovation and competitiveness? Rev Environ Econ Policy 7:2–22

de Angelis EM, Giacomo MD, Vannoni D (2019) Climate change and economic growth: The role of environmental policy stringency. Sustainability 11:(8), 2273

Aydin C, Esen Ö (2018) Reducing CO_2 emissions in the EU member states: Do environmental taxes work? J Environ Plan Manag. DOI:10.1080/09640568.2017.1395731

Banday, UJ and Aneja, R (2019). Renewable and non-renewable energy consumption, economic growth and carbon emission in BRICS Evidence from bootstrap panel causality. International Journal of Energy Sector Management 14: 248-260

Bond S, Eberhardt M (2013) Accounting for Unobserved Heterogeneity in Panel Time Series Models. Nuffield College, University of Oxford, Mimeo.

Borozan D (2019) Unveiling the heterogeneous effect of energy taxes and income on residential energy

    consumption. Energy Policy 129:13-22

Botta E, Koźluk T (2014). Measuring environmental policy stringency in OECD countries: A composite index

    approach, OECD Economics Department Working Papers, No. 1177, OECD Publishing, Paris.

    https://www.oecd-ilibrary.org/economics/measuring-environmental-policy-stringency-in-oecd-

    countries_5jxrjnc45gvg-en. Accessed March 2017.

Bulut U (2027) The impacts of non-renewable and renewable energy on CO2 emissions in Turkey.

    Environmental Science and Pollution Research volume 24, pages15416–15426(2017)

Chen Y, Fan X, Zhou Q. (2020) An Inverted-U Impact of Environmental Regulations on Carbon Emissions in

    China's Iron and Steel Industry: Mechanisms of Synergy and Innovation Effects. Sustainability 2020,

    12, 1038; doi:10.3390/su12031038

Ciaschini M, Pretaroli R, Severini F, Socci C (2012) Regional double dividend from environmental tax reform:

    an application for the Italian economy. Res Econ 66:273–283

Cohen, MA, Tubb A (2018) The Impact of Environmental Regulation on Firm and Country Competitiveness: A

    Meta-analysis of the Porter Hypothesis. J Asso Environ Res Economists 5:371–399

Cole MA, Elliot RJR, Shimamoto, K (2005) Industrial characteristics, environmental regulations and air

    pollution: an analysis of the UK manufacturing sector. J Environ Econ Manag 50:121–143

Danish, Baloch, MA, Mahmood N, Zhang JW (2019) Effect of natural resources, renewable energy and

    economic development on CO2 emissions in BRICS countries. The Scie Total Environ 678:632-638

Danish, et al. (2020) Mitigation pathways toward sustainable development: Is there any trade-off between

    environmental regulation and carbon emissions reduction? Sustainable Development 28:813–822

Dechezleprêtre A, Sato M (2017) The impacts of environmental regulations on competitiveness. Rev Environ

Econ Policy 11:183–206

Destek MA, Sarkodie SA (2019) Investigation of environmental Kuznets curve for ecological footprint: The role

of energy and financial development. Sci Total Environ 650: 2483:2489

Eberhardt, M., & Teal, F. (2009). A Common Factor Approach to Spatial Heterogeneity in Agricultural

Productivity Analysis (CSAE Working Paper, WPS/2009-05). Centre for the Study of African

Economies, Department of Economics, University of Oxford.

European Environmental Agency (EEA) (2005) Market-based instruments for environmental

policy in Europe, Technical report No 8/2005, Copenhagen, Denmark

http://reports.eea.europa.eu/technical_report_2005_8/en/EEA_technical_

report_8_2005.pdf). Accessed 12 October 2018

European Commission (2019). First European Climate Change Programme.

https://ec.europa.eu/clima/policies/eccp/first_en Accessed August 2019

Ferris A, Garbaccio R, Marten A, Wolverton A (2019) The Impacts of Environmental Regulation on the U.S.

Economy. Oxford Research Encyclopedia of Environmental Science. Accessed March (2019)

Filipović S, Golušin M (2015) Environmental taxation policy in the EU-New methodology approach. J Clean

Prod 88:308–317

Freire-González J (2018) Environmental taxation and the double dividend hypothesis in CGE modelling

literature: A critical review. J Policy Model 40:194–223

Freire-González J, Ho MS (2018) Environmental fiscal reform and the double dividend: Evidence from a

Dynamic General Equilibrium Model. Sustainability 10(2), 501; https://doi.org/10.3390/su10020501

Fremstad A, Paul M (2019) The impact of a carbon tax on inequality. Ecol Econ 163:88–97

Gerlagh R, Lise, W (2005) Carbon taxes: A drop in the ocean, or a drop that erodes the stone? The effect of

carbon taxes on technological change. Ecol Econ 54:241-260

Goulder, LH (1995) Environmental taxation and the double dividend: a reader's guide. Inter Tax Publ Fina

2:157–183

Guo Z, Zhang X, Zheng Y, Rao, R (2014) Exploring the impacts of a carbon tax on the Chinese economy using

a CGE model with a detailed disaggregation of energy sectors. Energy Econ 45:455-462.

Haites E (2018) Carbon taxes and greenhouse gas emissions trading systems: what have we learned? Climate

Policy 18:955-966

Hashmi R, Alam K (2019) Dynamic relationship among environmental regulation, innovation, CO2 emissions,

population, and economic growth in OECD countries: A panel investigation. J Clean Prod 231:1100-

110

Hao YU, Deng H, Lu Z, Chen H (2018) Is environmental regulation effective in China? Evidence from city-

level panel data. J Clean Prod, 188:966-976

He P, Chen L, Zou X, Li S, Shen H, Jian, J (2019) Energy Taxes, Carbon Dioxide Emissions, Energy

Consumption and Economic Consequences: A Comparative Study of Nordic and G7 Countries

Sustainability 2019, 11, 6100; doi:10.3390/su11216100

He P, Ning J, Yu Z, Xiong H, Shen H, Jin, H (2019). Can environmental tax policy really help to reduce

pollutant emissions? An empirical study of a panel ARDL model based on OECD countries and China.

Sustain 11. https://doi. org/10.3390/su11164384

Hotunluoğlu H, Tekel R (2007) Analysis and effects of carbon tax: Does carbon tax reduce emissions? Sosyo

Ekonomi Temmuz 2:107-125

IBRD, International Bank for Reconstruction and Development and International Development Association /

The World Bank (2027) Report of the High-Level Commission on Carbon Prices (2017).

https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f26b3c91f1bb0de2e41a/150 5227373770/CarbonPricing_EnglishSummary.pdf

IEA, International Energy Agency, (2019).

file:///G:/PAPERS%20SUBM/7EMERGFINALPAPERMAY/CO2_Emissions_from_Fuel_Combustion_2019_Highlights.pdf

IEA (2019). CO2 Emissions from Fuel Combustion: Overview An essential tool for analysts and policy makers

Statistics report — July 2020. https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

IEA. (2020). CO2 Emissions from Fuel Combustion 2019 Highlights

https://webstore.iea.org/co2-emissions-from-fuel-combustion-2019-highlights

ILO (2014) The double dividend and environmental tax reforms in Europe. EC-IILS joint discussion paper

series No. 13. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---inst/documents/publication/wcms_194183.pdf. Accessed June 2018.

IPCC et al. (2018) Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the

impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland.

Jebli, MB and Kahia M. 2020. The interdependence between CO2 emissions, economic growth, renewable and

non-renewable energies, and service development: evidence from 65 countries. Climate Change. https://link.springer.com/article/10.1007%2Fs10584-020-02773-8

Jensen S, Mohlin K, Pittel K, Sterner T (2015) An Introduction to the Green Paradox: The Unintended

Consequences of Climate Policies. Rev Environ Econ Policy 9: 246-265

Karydas C, Zhang L (2019) Green tax reform, endogenous innovation and the growth dividend. J Environ Econ Manag 97: 58–181

Khan Z, Sisi Z, Siqun, Y (2019) Environmental regulations an option: Asymmetry effect of environmental regulations on carbon emissions using non-linear ARDL. Energ Sour, Part A: Recov, Utiliz, and Enviro Effec 41: 137–155

Kim DH, Wu, YC, Lin, SC (2020) Carbon dioxide emissions and the finance curse. Energy Econ 88, 104788

Kim Y, Rhee DE (2019) Do stringent environmental regulations attract foreign direct investment in developing countries? Evidence on the "race to the top" from cross-country panel data. Emerg Mark Fina Trade 55:2796–2808

Koc, S & Gokay Canberk Bulus, G C. (2020). Testing validity of the EKC hypothesis in South Korea: role of renewable energy and trade openness: Environmental Science and Pollution Research volume 27, pages 29043–29054

Koc, S & Gokay Canberk Bulus Environmental Science and Pollution Research 27:29043–29054

Kotroni E, Dimitra Kaika D, Zervas, E (2020) Environmental Kuznets Curve in Greece in the Period 1960-2014. International Journal of Energy Economics and Policy, 10(4), 364-370.

Lagreid OM, Povitkina M (2018) Do political institutions moderate the GDP-CO_2 relationship? Ecol Econ 145:441–450

Landrigan PJ et al (2018) Commission on pollution and health. (2017). The Lancet 391: 462–512

Levinson A, Taylor MA (2008) Unmasking the Pollution Haven Effect. Inter Econ Rev 49:223-254

Liddle B (2018) Consumption-based accounting and the trade-carbon emissions nexus. Energy Econ 69:71-78

van Leeuwen G, Mohnen, P (2017) Revisiting the Porter hypothesis: an empirical analysis of Green innovation for the Netherlands. Econ Inno New Tech 26:63-77

Ligthart JE, Van Der Ploeg F (1999) Environmental Policy, Tax Incidence, and the Cost of Public Funds.

Environ Res Econ 13: 187–207

Liobikienè G, Butkus M, and Matuzevičiûtè. (2020) Contribution of Energy Taxes to Climate Change

Policy in the European Union (EU). Resources 2019, 8, 63; doi:10.3390/resources8020063

Li C (2019) How does environmental regulation affect different approaches of technical progress? Evidence

from China's industrial sectors from 2005 to 2015. J of Cleaner Prod 209:572-580

Lin B, Li X (2011). The Effect of carbon tax on per capita CO_2 emissions. Energy Policy 39:5137–5146

Liu Y, Li Y, Yin X (2018) Environmental regulation, technological innovation and energy Consumption-a

cross-region analysis in China. J Clean Prod 203:885-897

Loganathan N, Shahbaz M, Taha R (2014) The link between green taxation and economic growth on CO_2

emissions: fresh evidence from Malaysia. Renewable and Sustainable

Lu C, Tong Q, Liu X (2010)The impacts of carbon tax and complementary policies on Chinese Economy.

Energy Policy 38:7278-7285

Mardani A, Streimikiene D, Cavallaro F, Loganathan N, Khoshnoudi M (2019) Carbon dioxide (CO_2) emissions

and economic growth: A systematic review of two decades of research from 1995 to 2017. Scie Total

Environ 649:31-49

Mardones C, Baeza, N (2018) Economic and environmental effects of a CO_2 tax in Latin American countries.

Energy Policy 114:262-273

Miller, S, Vela, MA (2013) Are environmentally related taxes effective? Inter-American Development Bank

Working Paper No. IDB-WP-467 https://publications.iadb.org/en/publication/11334/are-
environmentally-related-taxes-effective. Accessed June 2018

Min W (2018) Spatial Effect of Environmental Regulation on Carbon Emissions. Meteoro & Environ Res 9: 57-

61

Morley, B (2012) Empirical evidence on the effectiveness of environmental taxes. Appl Econ Lett 19:1817-

1820

Mulatu, A (2018) Environmental regulation and international competitiveness: a critical review. Inter J Glob

Environ Issues 17: 41-63

Nakata, T, Lamont, L (2001) Analysis of the Impacts of Carbon Taxes on Energy Systems in Japan. Energy

Policy 29:159–166

OECD (2016) How stringent are environmental policies?

http://www.oecd.org/eco/greeneco/how–stringent–are–environmental–policies.htm

Accessed May 2017

OECD Environmental Performance Reviews: Czech Republic (2018a)

https://www.oecd.org/environment/czech-republic-2018-9789264300958-en.htm

OECD (2018b) Taxing Energy Use 2018: Companion to the Taxing Energy Use Database,

OECD   Publishing, Paris, https://doi.org/10.1787/9789264289635-en. Accessed March (2019)

OECD Environmental Performance Reviews: Greece 2020.

https://www.oecd.org/environment/oecd-environmental-performance-reviews-greece-2020-cec20289-
en.htm

OECD Environmental Performance Reviews: Korea 2017. https://www.oecd-

ilibrary.org/environment/oecd-environmental-performance-reviews-korea-2017/executive-

summary_9789264268265-6-en

Oueslati, W. Zippererb Z, Rousselière D, Dimitropoulos, A (2017) Energy taxes, reforms and income

inequality: An empirical cross-country analysis. Inter Econ, 150:80-95

Ouyang X, Shao Q, Zhu H, He H, Xiang, C, Wei, G (2019) Environmental regulation, economic growth and air

pollution: Panel threshold analysis for OECD countries. Sci Total Environ 657:234-241

Ozcan B, Tzeremes PG, Tzeremes NG (2020) Energy consumption, economic growth and environmental

degradation in OECD countries. Econ Model 84:203-213

Özokcu S, Özdemir Ö (2017) Economic growth, energy, and environmental Kuznets curve. Renew Sust Energ

Rev 72:639-647

Pata, U K. (2028). Renewable energy consumption, urbanization, financial development, income and CO2

emissions in Turkey: Testing EKC hypothesis with structural breaks. J of Cleaner Prod 187, 20 June

2018, Pages 770-779

Pearce D (1991) The role of carbon taxes in adjusting global warming. The Econ J 101:938-948

Pei Y, Zhu Y, Liu S, Wang, X and Cao Y. (2019) Environmental regulation and carbon emission: The mediation

effect of technical efficiency. J. of Clean Prod 236:117599.

Pesaran MH, Yamagata T, (2008) Testing slope homogeneity in large panels. J. Econ. 142,50–93

Peters GP, Mix JC, Weber CL, Edenhofer, O (2011) Growth in emission transfers via international trade from

1990 to 2008. PNAS 108:8903–8908

Pigou A C (1920). The Economics of Welfare. 4th edition 1938. London: Weidenfeld andNicolson

Porter, ME, van der Linde, C (1995) Toward a new conception of the environment–competitiveness

relationship. J of Econ Pers 9:97–118

Purcel, AA. (2020) New insights into the environmental Kuznets curve hypothesis in developing and transition

economies: a literature survey. Environmental Economics and Policy Studies 22, 585–631

Radulescu M, Sinisi CI, Popescu C, Iacob, SE (2017). Environmental tax policy in Romania in the context of the EU: Double Dividend Theory. Sustainability, 9(11), 1986; https://doi.org/10.3390/su9111986

Ramanathan R, He O, Black A, Ghobadian A, Gallear D (2017) Environmental regulations, innovation and firm performance: A revisit of the Porter hypothesis. J Clean Prod 155: 79-92

Saidic S, Omri, A. (2020).Reducing CO2 emissions in OECD countries: Do renewable and nuclear energy matter? Progress in Nuclear Energy.126, 103425

Sarkodie SM, Strezov V (2019) A review on Environmental Kuznets Curve hypothesis using bibliometric and meta-analysis. Sci Total Environ 649:128-145

Sen S, Vollebergh, H (2018) The effectiveness of taxing the carbon content of energy consumption. J Environ Econ Manag 92:74-99

Shahbaz M, Sinha A (2019) Environmental Kuznets curve for CO2 emissions: a literature Survey. J Econ Stud 46:106-168

Shahzad, U (2020) Environmental taxes, energy consumption, and environmental quality: Theoretical survey with policy implications. Env Scie and Poll Rese https://doi.org/10.1007/s11356-020-08349-4

Shapiro J, Walker R (2018) Why is Pollution from US Manufacturing Declining? The Roles of environmental regulation, productivity and trade. American Economic Review 108:3814–3854

Song M, Wang S, and Zhang, H. (2020). Could environmental regulation and R&D tax incentives affect green product innovation? J. of Clean Prod 258, 120849

Song Y, Yang T, Li Z, Zhang X, Zhang M.(2020) Research on the direct and indirect effects of environmental regulation on environmental pollution: Empirical evidence from 253 prefecture-level cities in China. J. of Clean Prod 269, 122425

Tiba S, Omri A (2017) Literature survey on the relationships between energy, environment and economic

growth. Renew Sust Energ Rev 69:1129-1146

Timilsinas GR (2018) Where is the carbon tax after thirty years of research? IMF, Development Economics,

Development Research Group, WPS8493

http://documents.worldbank.org/curated/en/209041530236682559/pdf/WPS8493.pdf. Accessed 15

August (2019)

Tol RSJ (2009) The economic effects of climate change. J Econ Persp 23:29–51

Tol RSJ (2017) The structure of the climate debate. Energy Policy 104:431–438

Tol RSJ (2018) The Economic Impacts of Climate Change. Rev Environ Econ Policy 12:4-25

United Nations, Transforming our world: the 2030 Agenda for Sustainable Development, 2015.

UN (2020). The Sustainable Development Goals Report 2020

The-Sustainable-Development-Goals-Report-2020.pdf

Ulucak, R Danish and Kassouri, Y. (2020) An assessment of the environmental sustainability corridor:

Investigating the non-linear effects of environmental taxation on CO2 emissions. Sustainable

Development 28:1010–1018

van der Ploeg F, Withageny C (2015) Global Warming and the Green Paradox: A Review of Adverse Effects of

Climate Policies. Rev of Enviro Econ Policy 9: 285–303

Van der Werf E, Di Maria, C (2012) Imperfect Environmental Policy and Polluting Emissions: The Green

Paradox and Beyond. Inter Rev Environ Reso Econ 6: 153–194

Vehmas J. (2005) Energy-related taxation as an environmental policy tool—the Finnish experience 1990–2003.

Energy Policy 33: 2175–2182

Wang H, Wei, W (2020) Coordinating technological progress and environmental regulation in CO_2 mitigation:

The optimal levels for OECD countries & emerging economies. Energy Econ 87: 104510

Wang Y, Shen N (2016) Environmental regulation and environmental productivity: The case of China. Renew Sust Energ Rev 62:758-766

Wang S, Sun X, Song M (2019) Environmental regulation, resource misallocation, and ecological efficiency. Emer Mark Fina Trade 1-20 DOI: https://doi.org/10.1080/1540496X.(2018)1529560.

Wang, Y, Zuo Y, Li W, Kang Y, Chen W (2019) Does environmental regulation affect CO_2 emissions? Analysis based on threshold effect model. Clean Tech Environ Policy 21:565–577

Wenbo G, Yan C (2018) Assessing the efficiency of China's environmental regulation on carbon emissions based on Tapio decoupling models and GMM models. Energy Reports 4: 713-723

Wolde-Rufael, Y. and Mulat-Weldemeskel, E (2020). Environmental policy stringency, renewable energy consumption and CO_2 emissions: Panel cointegration analysis for BRIICTS countries. Inter J Green Energy 17 - Issue 10

World Bank (2016) The cost of air pollution: Strengthening the economic case for action. The World Bank and Institute for Health Metrics and Evaluation University of Washington, Seattle https://openknowledge.worldbank.org/handle/10986/25013. Accessed December 2017

World Bank (2018) World Development Indicators. Accessed June (2018)

Xu, S C, Long, RY (2014) Empirical Research on the Effects of Carbon Taxes on Economy and Carbon Emissions in China. Environ Eng and Manag J 13:1071–1078

Yang M, Fan Y, Yang F, Hu H (2014) Regional disparities in carbon Dioxide reduction from China's uniform carbon tax: A Perspective on Interfactor/Interfuel Substitution. Energy 74:131–139

Ying J, Zheng M, Chen, J (2015) The effects of environmental regulation and technical progress on CO_2 Kuznets curve: An evidence from China. Energy Policy 77: 97-108

Zhang X, Guo, Z, Zheng, Y, Zhu J, Yang J (2016) A CGE Analysis of the Impacts of a Carbon Tax on

Provincial Economy in China. Emerg Market Fina Trade 52:1372–1384

Zhang K, Zhang ZY, Liang Q (2017) An empirical analysis of the green paradox in China: From the perspective

of fiscal decentralization. Energy Policy 103: 203-211

Zhang H (2016) Exploring the impact of environmental regulation on economic growth, energy use, and CO2

emissions nexus in China. Nal Haza 84:213–231

Zhou Q, Zhang, X, Shao, Q, Wang, X (2019) The non-linear effect of environmental regulation on haze

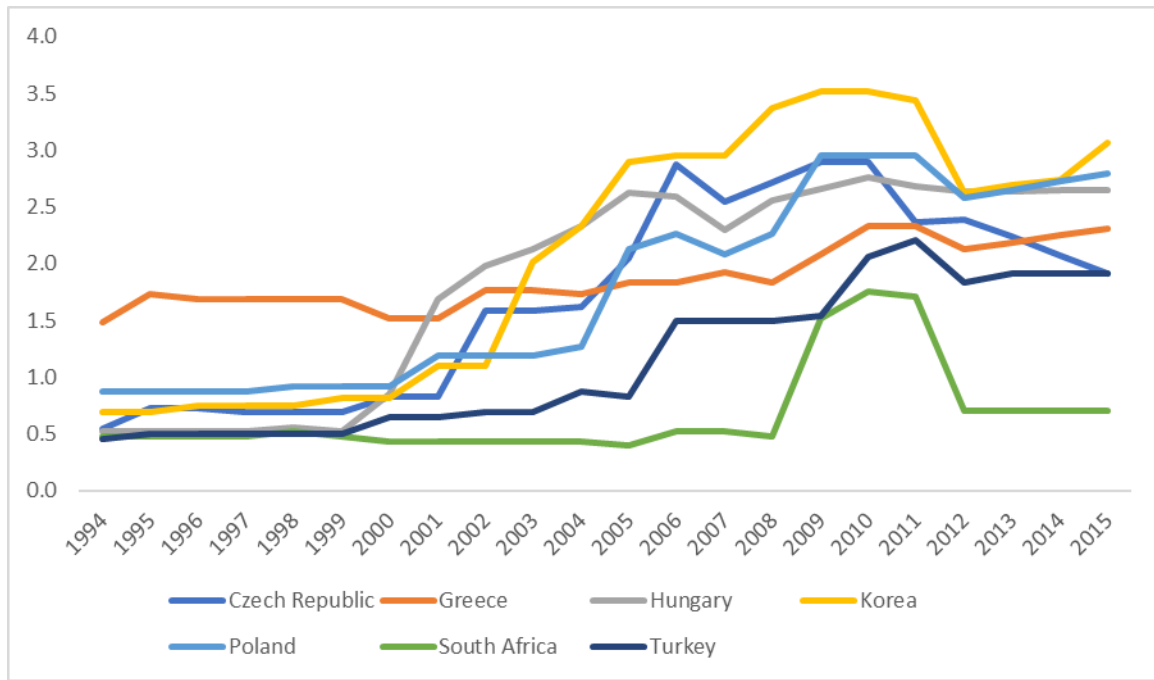pollution: Empirical evidence for 277 Chinese cities during 2002–2010. J Environ Manag 248: 109274

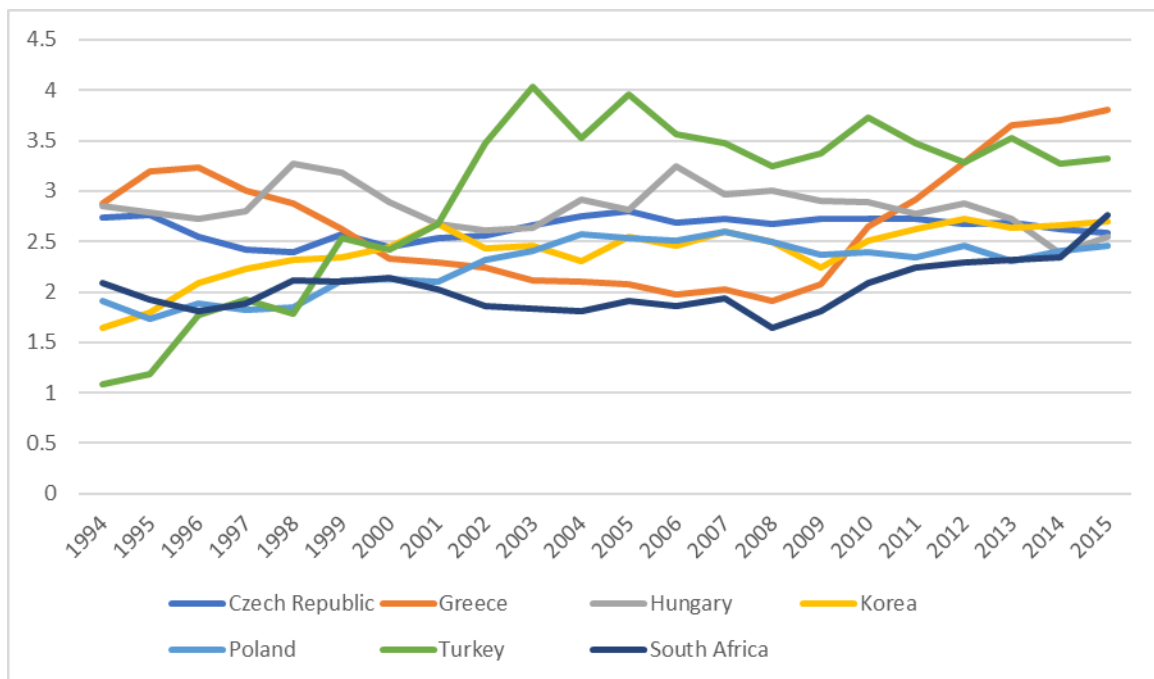Figure

Fig 1a Environmental policy stringency index

Fig 1b Total environmental tax as % of GDP

Table

Table 1: Descriptive statistics

variables	Obs	Mean	Std. Dev.	Min	Max	source
Consumption-based CO_2 per capita	154	8.13	2.54	3.45	12.77	Peters et al. (2011)
Environmental policy stringency	154	1.59	0.89	0.40	3.52	OECD
Total environmental tax per capita	154	512.41	205.01	122.1	973.19	OECD
Energy tax per capita	154	391.89	150.32	98.78	728.91	OECD
Total environmental tax as % of GDP	154	2.54	0.53	1.08	4.04	OECD
Energy tax as % of GDP	154	1.98	0.47	0.72	3.23	OECD
Total environmental tax as % of total tax revenue	154	8.92	2.44	4.73	16.96	OECD
energy tax as % of total tax revenue	154	6.89	1.88	3.29	12.9	OECD
Fossil energy consumption as % of total energy consumption	154	86.44	6.04	68.19	96.32	WDI
Renewable energy consumption as % of total energy consumption	154	9.9	5.89	0.44	24.24	WDI
Real GDP per capital in $USA	154	14,055	6,356	5,564	30,055	WDI

Notes: OECD (2018); WDI, World Bank (2018).

Table 2: Cross-section dependence test

model	Breusch-Pagan LM		Pesaran scaled LM		Bias-corrected scaled LM		Pesaran CD	
	statistic	p value	statistic	p value	statistic	p value	statistic	p value
cc ss ss^2 tpx ee yy yy^2	70.412***	0.000	7.624***	0.000	7.458***	0.000	1.318	0.187
cc ss ss^2 trx ee yy yy^2	58.077***	0.000	5.721***	0.000	5.554***	0.000	1.383	0.167
cc ss ss^2 tyx ee yy yy^2	70.463***	0.000	7.632***	0.000	7.466***	0.000	1.296	0.195
cc ss ss^2 epx ee yy yy^2	75.086***	0.000	8.346***	0.000	8.179***	0.000	1.283	0.200
cc ss ss^2 erx ee yy yy^2	74.082***	0.000	8.191***	0.000	8.024***	0.000	1.716*	0.086
cc ss ss^2 eyx ee yy yy^2	75.133***	0.000	8.353***	0.000	8.186***	0.000	1.270	0.204

Variable definition.

cc = trade adjusted CO_2 per capita
ss =   environmental policy stringency index
ss^2 =   the square of environmental policy stringency
tpx =   total environmental tax per capita index
trx =   total environmental tax as % of total tax revenue
tyx =   total environmental tax as % of GDP
epx =   energy tax per capita
erx =   energy tax as % of total tax revenue
eyx =   energy tax as % of GDP
ff   =   fossil energy consumption as % of total energy consumption
rr   =   renewable energy consumption as % of total energy consumption
yy =   real GDP per capital $US
yy^2 =   the square of real GDP per capital $US

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

Table 3: Pesaran and Yamagata slope homogeneity

model	test	
	$\bar{\Delta}$	$\bar{\Delta}_{adj}$
cc ss ss^2 tpx ee yy yy^2	3.268***	3.494***
cc ss ss^2 trx ee yy yy^2	3.099***	3.312***
cc ss ss^2 tyx ee yy yy^2	3.410***	3.645***
cc ss ss^2 epx ee yy yy^2	3.369***	3.601***
cc ss ss^2 erx ee yy yy^2	3.716***	3.972***
cc ss ss^2 eyx ee yy yy^2	3.663***	3.916***

Notes: *** denotes rejection of the null hypothesis of slope homogeneity for the analyzed variables at 1% statistical significance. For the definition of the variables, see Table 2.

Table 4: AMG results linear estimation, dependent variable cc (CO_2 per capita)

variable	model 1	model 2	model 3	model 4	model 5	model 6
			coefficients			
ss	0.049***	0.079***	0.054***	0.062***	0.072***	0.064***
tpx	-0.024					
trx		-0.087*				
tyx			-0.032			
epx				-0.108***		
erx					-0.145***	
eyx						-0.111***
ff	0.650**	0.657**	0.650**	0.759**	0.737*	0.755**
rr	-0.184**	-0.180**	-0.184**	-0.187***	-0.193**	-0.185***
yy	0.625	1.988	0.444	-2.066	0.003	-2.090
yy^2	0.036	-0.056	0.043	0.186	0.059	0.181

Notes: ***, ** and * denote significant levels at 1%, 5% and 10% respectively. For the definition of the variables, see Table 2.

Table 5: Long-run AMG non-linear estimates, dependent variable cc (CO_2 per capita)

variables	model 1	model 2	model 3	model 4	model 5	model 6
ss	0.132**	0.140*	0.135*	0.099**	0.065*	0.086**
ss^2	-0.118**	-0.103**	-0.116**	-0.071**	-0.035	-0.057***
tpx	-0.051					
trx		-0.087**				
tyx			-0.060**			
epx				-0.112***		
erx					-0.140***	
eyx						-0.118***
ff	0.909***	0.990***	0.914***	0.976***	1.065***	0.980***
rr	-0.114	-0.096	-0.114	-0.128*	-0.116*	-0.125*
yy	3.000	4.273	2.746	0.015	0.753	-0.292
yy^2	-0.086	-0.176	-0.077	0.074	0.014	0.082

Notes: ***, ** and * denote significant levels at 1%, 5% and 10% respectively. For the definition of the variables, see Table 2.

Table 6: FMOLS long-run estimates, dependent variable cc (CO_2 per capita)

	model 1		model 2		model 3		model 4		model 5		model 6
variable	coefficient	variable	coefficient	variable	coefficient	variable	coefficient	variable	coefficient	variable	coefficient
ss	0.024**	ss	0.025**	ss	0.023**	ss	0.017*	ss	0.017*	ss	0.017*
ss^2	-0.034*	ss^2	-0.040*	ss^2	-0.035*	ss^2	-0.045*	ss^2	-0.051**	ss^2	-0.045*
tpx	-0.016	trx	0.001	tyx	-0.020	epx	-0.042**	erx	-0.038**	eyx	-0.044**
ff	0.587***	ff	0.530***	ff	0.585***	ff	0.488***	ff	0.427**	ff	0.486**
rr	-0.186***	rr	-0.198***	rr	-0.185***	rr	-0.184***	rr	-0.192***	rr	-0.183**
yy	5.245**	yy	4.734***	yy	5.290**	yy	4.675**	yy	4.629***	yy	4.740**
yy^2	-0.245**	yy^2	-0.222**	yy^2	-0.248**	yy^2	-0.214**	yy^2	-0.215**	yy^2	-0.219**

Notes: ***, ** and * dente significant levels at 1%, 5% and 10% respectively. For the definition of the variables, see Table 2.

Table

Table 7: Dumitrescu and Hurlin (2012) panel Granger causality test

null hypothesis	W-bar	Z-bar	p value	decision	null hypothesis	W-bar	Z-bar	p value	decision
ddss↛dcc	2.538	2.877	0.080	uni	dtpx↛dyy	1.514	0.961	0.380	no
dcc↛dss	0.751	-0.465	0.700	no	dyy↛dtpx	9.386	3.670	0.160	no
dff↛dcc	0.505	-0.926	0.300	no	dtrx↛dyy	1.552	1.032	0.320	no
dcc↛dff	4.030	2.685	0.120	no	dyy↛dtrx	2.314	2.457	0.060	uni
drr↛dcc	1.191	0.357	0.800	no	dtyx↛dyy	1.466	0.872	0.380	no
dcc↛drr	2.162	2.174	0.060	uni	dyy↛dtyx	6.798	2.617	0.180	no
dyy↛dcc	2.831	1.099	0.380	no	depx↛dyy	2.314	2.459	0.020	uni
dcc↛dyy	1.811	1.518	0.200	no	dyy↛depx	8.898	3.261	0.320	no
dtpx↛dcc	1.765	1.432	0.100	uni	derx↛dyy	1.899	1.682	0.060	uni
dcc↛dtpx	14.104	7.617	0.140	no	dyy↛derx	1.454	0.849	0.380	no
dtrx↛dcc	2.112	2.080	0.040	uni	deyx↛dyy	2.232	2.304	0.060	uni
dcc↛dtrx	9.589	3.840	0.180	no	dyy↛deyx	1.413	0.772	0.560	no
dtyx↛dcc	2.131	2.117	0.080	bi	dtpx↛drr	12.239	6.057	0.120	no
dcc↛dtyx	14.234	7.726	0.080		drr↛dtpx	1.095	0.178	0.860	no
depx↛dcc	1.571	1.067	0.240	no	dtrx↛drr	10.633	4.713	0.120	no
dcc↛depx	8.858	3.228	0.400	no	drr↛dtrx	0.645	-0.665	0.480	no
derx↛dcc	1.678	1.269	0.120	no	dtyx↛drr	13.923	7.465	0.080	uni
dcc↛derx	5.855	3.083	0.040	uni	drr↛dtyx	0.493	-0.949	0.460	no
deyx↛dcc	1.818	1.531	0.120	no	depx↛drr	10.046	4.221	0.200	no
dcc↛deyx	5.287	2.470	0.120	no	drr↛depx	0.631	-0.691	0.580	no
dtpx↛dss	2.797	3.361	0.000	uni	derx↛drr	10.748	4.809	0.180	no
dss↛dtpx	0.826	-0.326	0.780	no	drr↛derx	0.482	-0.970	0.360	no
dtrx↛dss	3.106	3.939	0.000	uni	deyx↛drr	7.354	1.969	0.500	no
dss↛dtrx	0.532	-0.875	0.480	no	drr↛deyx	0.291	-1.326	0.280	no
dtyx↛dss	2.889	3.534	0.000	uni	dtpx↛dff	8.171	2.653	0.320	no
dss↛dtyx	0.771	-0.428	0.720	no	dff↛dtpx	12.670	6.417	0.120	no
depx↛dss	21.892	14.133	0.020	uni	dtrx↛dff	21.292	13.631	0.000	bi
dss↛depx	9.527	3.788	0.320	no	dff↛dtrx	17.776	10.689	0.020	
derx↛dss	10.066	4.238	0.180	on	dtyx↛dff	12.280	6.091	0.080	bi
dss↛derx	0.302	-1.307	0.240	no	dff↛dtrx	21.139	13.503	0.000	
deyx↛dss	11.744	5.642	0.200	no	depx↛dff	8.658	3.061	0.300	no
dss↛deyx	0.583	-0.780	0.560	no	dff↛depx	25.044	16.770	0.020	uni
dff↛dss	9.365	3.652	0.260	no	derx↛dff	1.450	0.842	0.400	no
dss↛dff	6.253	1.049	0.640	no	dff↛derx	0.683	-0.593	0.680	no
drr↛dss	2.681	0.901	0.500	no	deyx↛dff	10.867	4.908	0.140	no
dss↛drr	2.617	3.025	0.000	uni	dff↛deyx	17.905	10.797	0.000	uni
dyy↛dss	0.460	-1.010	0.420	no	dff↛dyy	1.357	0.667	0.460	no
dss↛dyy	0.887	-0.212	0.800	no	dyy↛dff	2.571	0.756	0.540	no
dff↛drr	3.200	4.115	0.020	uni	drr↛dyy	10.352	4.478	0.380	no
drr↛dff	1.385	0.720	0.520	no	dyy↛drr	14.411	7.874	0.180	no

Notes: uni = unidirectional, bi = bidirectional, d = first difference. For the definition of the variables, see Table 2.