RESEARCH ARTICLE

Does green policy pay dividends?

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Abstract

While there is a near global consensus about the need to address climate change, most countries are hesitant to employ sufficiently stringent policies in fear of sacrificing economic growth. The objective of this research is to examine the impact of environmental policy on economic growth, using the OECD's Environmental Policy Stringency (EPS) index across 21 OECD countries from 1990 to 2014. An augmented Solow Model with the inclusion of variables to represent human capital, trade openness and the EPS index is used to assess whether policy stringency affects growth with empirical analysis comprised of a pooled mean group estimator, dynamic OLS, fixed effects and pooled OLS to estimate the short and long run effects. The results reveal that policy stringency negatively affects economic growth in the short run but pays dividends of positive growth in the long run. There appears to be a threshold level of the EPS, beyond which the dividend is realized in the long run. The results are expected to be of interest to policy makers who strive to address climate change without trading off economic growth.

Keywords Environmental policy · Economic growth · Pooled mean group estimation · Porter hypothesis

1 Introduction

Despite a near global consensus about the need to address climate change, most countries are reluctant to implement sufficiently strong policies in fear of sacrificing economic growth. While many global leaders dither, global warming

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continues with predicted increases between 3 and 5 °C unless significant measures are taken (IPCC 2018). Without meaningful policy action, the long run effects of climate may be catastrophic for many regions.

Since the United Nations Framework Convention on Climate Change (UNFCCC) opened for signature at the Earth Summit in Rio de Janeiro in 1992, regularly held meetings have provided a venue to assess progress toward climate change mitigation. In 1997, 192 countries agreed to gradually combat climate change by signing the Kyoto Protocol. More recently, in 2015, 196 countries signed the Paris Agreement to address global warming with respect to the mitigation, adaption and financing required to limit the increase in global temperature to 1.5 °C by the end of this century (Sutter and Berlinger 2015). From the Kyoto Protocol in 1997 to the Paris Agreement in 2015, policy initiatives have neither been sufficiently comprehensive nor prevalent enough to slow climate change at a global level. This research examines the effect of environmental policy on short run and long run economic growth of OECD countries.

Although numerous studies have investigated the impact of individual environmental policies on economic growth within countries, the number of studies examining the effect of environmental policies on economic indicators across countries is more limited (Bhattacharya et al. 2016; Halkos and Psarianos 2016; Rubashkina et al. 2015; Albrizio et al. 2014). Several studies estimate economic growth models with mixed findings about the impact of policies to limit CO_2 emissions on economic growth (Soytas and Sari 2009; Ricci 2007), thus fueling a general perception among cautious policymakers that efforts to reduce greenhouse gas emissions will be detrimental to economic growth. Such findings have led most countries on a recent trajectory toward minimal or no efforts to reduce their emissions (Nordhaus 2018).

There exists evidence to suggest that efforts to reduce greenhouse gas (GHG) emissions can be detrimental to GDP growth and employment in the short run (Liu et al. 2018; Maji 2015; Weyant 1993), given such reductions often involve capital costs. However, it may be the case that environmental policy pays dividends in the long run, in the form of economic growth. Sweden, for instance, the first country to implement a carbon tax system in 1991, and now with the world's highest carbon tax has seen their GDP growth outpace the European average (Frank 2018; World Bank 2016). In line with the Porter hypothesis (Porter 1991; Porter and van der Linde 1995), these results and others (Lu et al. 2010) suggest that firms tend to find alternative production methods by changing or substituting technology thereby reducing CO_2 emissions without sacrificing GDP and employment in the long run. This research estimates the short and long run effects of environment control policy on the economic growth of OECD nations.

The analysis in this study is grounded in the augmented Solow Model (Solow 1956) with the inclusion of a measurement for policy stringency. Panel data variables include the environmental policy stringency index (OECD 2018) and other non-stationary macroeconomic control variables which are analysed with cointegration and error-correction models using the Pooled Mean Group (PMG) and Dynamic OLS (DOLS) estimators for OECD countries from 1990 to 2014.

Pooled OLS, Dynamic OLS and fixed effects estimators are applied to check the robustness of the short run and long run results derived from the PMG.

The results suggest that although pro-environmental policy adversely affects economic growth in the short run, it pays dividends in the long run. Overall, the countries with more stringent environmental policies benefit from higher economic growth in the long run. A threshold analysis reveals that countries implementing environmental policy above an empirically determined threshold level tend to benefit from positive economic growth in the long run while the others suffer from both short and long run negative growth. Additional analysis reveals that stakeholders in the countries with more stringent environmental policies tend to change their behavior as evidenced by lower energy–GDP, CO_2–energy and CO_2–GDP ratios compared to the countries with less stringent environmental policies.

The main contributions of this research include support for the Porter hypothesis and a strong argument for more stringent environmental policy to incentivize economic agents to use energy more efficiently and to increase renewable energy use, thereby contributing to GDP growth in the long run. Conversely, the results imply that relatively weak environmental policy fails to sufficiently incentivize stakeholders and only leads to costs in both the short and long run. Another significant contribution of this paper is consideration of the impact of policy in the short and long run, undertaken in few other papers. The findings will be of interest to policy makers who strive to pursue green initiatives without sacrificing economic growth.

The remainder of this paper is organized as follows. Section 2 presents a review of the relevant literature, followed by Sect. 3, which explains the theoretical background of the empirical model. In Sect. 4, the data, variables and methods of analysis are described, followed by the results and discussion of the findings in Sect. 5, and concluding remarks in Sect. 6.

2 Literature review

The literature most relevant to this analysis consists of research on the effects of environmental policy and regulation on economic growth and other economic indicators. This review covers the empirical research on the Porter hypothesis, on the effects of environmental taxes and regulation, and the literature on the effects of renewable energy use on economic growth. In addition, a few studies using the OECD's environmental policy stringency (EPS) index to examine the impact of policy on some economic indicators are covered.

2.1 The Porter hypothesis

Nearly 30 years ago, Michael Porter stated that, "strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it" (Porter 1991, p. 168). The Porter hypothesis (PH) asserts that well-designed environmental policies can stimulate innovations thereby benefitting firms through productivity gains and possibly end user product value (Porter 1991; Porter

and van der Linde 1995). Many theoretical and empirical studies have endeavoured to test the hypothesis with mixed results. The PH has been disaggregated into a "weak" and a "strong" version with the weak version addressing the relationship between regulation and technological innovation without commenting on whether or not the innovation is a benefit to the firms (Ambec et al. 2013; Jaffe and Palmer 1997). The "strong" version hones in on whether the net benefit of the innovation is positive thereby increasing the firms' productivity and competitiveness.

Several studies have found support for the weak PH that environmental policy has a positive impact on innovation. For instance, Jaffe and Palmer (1997) found environmental policy to result in a significant rise in research and development (R&D) among manufacturing industries in the U.S. With OECD survey data for over 4000 firms, Lanoie et al. (2011) found a positive association between environmental regulation and environmental innovation but a negative association with business performance. Van Leeuwen and Mohnen (2017) found strong support for the weak version of the PH and some support for the strong version using data on the Netherlands, and De Vries and Withagen (2005) examined the association between environmental policy and patent applications in Europe and North America with mixed findings.

The results are quite mixed when testing the strong version of the PH. Berman and Bui (2001) found support for the strong version in the US petroleum refining industry while Alpay et al. (2002) found a positive effect on productivity but a negative impact on profit in the Mexican processed food sectors. Several studies found environmental regulation to have a negative impact on productivity in the U.S. and Canada (Gollop and Roberts 1983; Smith and Sims 1985; Gray 1987; Barbera and McConnell 1990; Dufour et al. 1998; Gray and Shadbegian 2003).

Ambec et al. (2013) found that most studies of the PH did not consider its dynamic qualities, thus ignoring the time needed for innovations to lead to a reduction in inefficiencies and costs. Lanoie et al. (2008) introduced 3 and 4-year lags between changes in regulations and resulting changes in productivity and found modest long-term gains in seventeen Quebec manufacturing sectors.

Most recently, the OECD's environmental policy stringency index was used to test the Porter hypothesis with time-series cross-sectional data for 14 countries (Martínez-Zarzoso et al. 2019). They focused on six economic sectors, reporting limited evidence for the weak version, with a positive effect on patent applications and R&D expenditures in some companies. They also found support for the strong version with a positive effect on total factor productivity, but with substantial differences among countries.

2.2 Environmental taxes and regulations

Given the environmental stringency index includes carbon tax and cap and trade policies among others, a brief review of the literature on the impact of such policies on economic growth and other economic indicators is relevant to this research.

There is a healthy body of literature examining the impact of environmental taxes and regulations, including but not limited to carbon tax schemes and cap and trade programs. Elgie and McClay (2013) examined the effect of British Columbia's

carbon tax[1] and found that the provincial economy slightly outperformed the rest of the Canadian economy. Murray and Rivers (2015) examined the impact of the tax using both empirical analysis and simulation models, and found negligible effects on the economy, though some emissions intensive sectors faced challenges. Beck et al. (2015) examined the distributional effects of British Columbia's carbon tax and found the tax to be quite progressive with below-median income households experiencing a smaller burden than above-median households do. The impact of a proposed carbon tax on Saskatchewan's[2] resource intensive economy was examined with a Computable General Equilibrium (CGE) model (Liu et al. 2018). Their modelling indicated a reduction in green house gas (GHG) emissions and a contraction in the economy. Other research has used CGE models to assess the impact of carbon taxes on individual economies (Zhang et al. 2016; Van Heerden et al., 2016; Allan et al. 2014). Zhang et al. (2016) assessed the economic impacts of a carbon tax on three provinces in China and found negative impacts which they stated could be reduced with revenue recycling polices. Lu et al. (2010) modelled the impact of a proposed carbon tax on the Chinese economy finding minimal negative effects on economic growth. Lin and Jia's (2018) model of a carbon tax on China found that a tax with a high tax rate on energy and energy intensive industries would not significantly harm economic growth.

Nong's (2018) CGE model revealed that additional tax levies on petroleum and coal were negatively associated with GDP in Vietnam. Van Heerden et al. (2016)'s CGE model illustrated a negative impact on GDP in South Africa which could be reduced with different revenue recycling methods. Allan et al. (2014) examined the impact of a carbon tax in Scotland under different assumptions about revenue recycling and found the possibility of a double dividend—lower GHG emissions and a rise in economic activity. The economic impacts of taxes on electricity under different scenarios was examined for Spain with a CGE model by Freire-González and Puig-Ventosa (2019) with results indicating that restricting taxation to non-renewable sources had positive outcomes for both the environment and economic growth.

Bosquet (2000) researched the effect of environmental tax reform that moved the tax burden from economic 'goods' such as employment, income and investment, to economic 'bads', such as pollution, resource depletion and waste. They synthesized simulations from 59 studies globally with results suggesting some gains in employment.

The impact of a cap and trade system was examined by Dechezleprêtre et al. (2018) for the EU for the period 2005 to 2012. They found that the emissions trading system resulted in a reduction in GHG emissions and a statistically significant increase in revenue and fixed assets of the regulated firms, suggesting that the firms' increased investment spending led to productivity gains. Further, they found that no one country or sector suffered a decline in revenue, fixed assets, employment or profits (Dechezleprêtre et al. 2018). The authors note that the stringency of the

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[1] British Columbia (BC), Canada implemented the first comprehensive revenue-neutral tax on carbon in North America in 2008.

[2] Saskatchewan is one of Canada's ten provinces.

EU emissions trading system has been relatively weak thus far which may partly account for positive economic results.

Research on the environmental Kuznets curve hypothesis revealed that regulatory policies in the mid twentieth century, such as the Clean Air Act of 1956, were associated with the turning point on the inverted-U curve, where emissions began to fall as per capita GDP continued to rise, suggesting a positive association between environmental policy and economic growth (Amar 2021).

Past research examined the impact of some general environmental taxes on economic growth. Hassan et al. (2020a, 2020b) examined the relationship between both energy-based taxes and more general environmental taxes, and economic growth with panel data on 31 OECD countries from 1994 to 2003. They found that energy-based taxes negatively affected economic growth in the short run with the magnitude of the effect varying with the country's degree of dependence on polluting energy. The results also suggest that increasing energy-based taxes were more likely to have a positive effect on economic growth when the initial wealth level in the country was high. The results from their study on the association between general environmental taxes, measured with environmentally related tax revenue, and growth reveal a negative association in both the short and long run. However, for countries with relatively higher initial levels of GDP, environmental policies tended to promote economic growth.

2.3 Renewable energy and economic growth

Several studies have researched the effect of renewable energy use, which is often associated with environmental policy, on GDP and economic growth with mixed results. For instance, Maji (2015) examined the impact of clean energy on Nigeria's economic growth with data from 1971 to 2014. A negative relationship was found between clean nuclear energy use and economic growth in the long run, while a positive relationship was reported for the short run. Taghvaee et al. (2017) found that renewable energy had no significant effect on economic growth in Iran from 1981 to 2012. The authors noted that the results may be due to the very small role of renewable energy in total energy consumption in Iran.

Using the structural vector autoregressive model and data for Denmark, Portugal, Spain and the U.S, Silva et al. (2012) studied the effect of rising shares of renewable energy use on GDP for the years 1960–2004. While all four counties have different levels of economic and social development, their investments in renewable energy are similar. The results suggest a negative impact on GDP per capita for all countries, except the US. Research on the Middle East and North African (MENA) countries found evidence to suggest a positive association between renewable energy use, particularly renewable electricity generation, and economic growth (Dees and Auktor 2018).

Bildirici and Gökmenoğlu (2017) find Granger causality from hydropower energy consumption to economic growth for G7 countries with panel data from 1961 to 2013, suggesting a key role for hydro energy in sustainable economic growth. Bhattacharya et al. (2016) investigated the impact of renewable energy use on the

economic growth of the 38 top renewable energy-consuming countries with panel data from 1991 to 2012. The long run output elasticities suggest a positive and significant effect of renewable energy consumption on GDP for over half of the countries. Most of the countries experiencing the positive effect had a significant shift toward renewable energy from 1991 to 2012.

Halkos and Psarianos (2016) included a measure of abatement, proxied by renewable electricity production, in a neoclassical growth model to test the Environmental Kuznet's Curve hypothesis with panel data for 43 countries. They found a negative association between abatement and emissions as economic growth increased suggesting that renewable energy is associated with positive economic growth.

2.4 OECD's environmental policy stringency

A few studies have used the OECD's EPS index to examine the impact of environmental policy on economic indicators. For instance, the effect of policy stringency was examined for OECD countries over a 20-year period as stringency increased, with findings of minimal effects on economic indicators with more technologically advanced industries realizing productivity gains and less technologically advanced firms experiencing productivity losses (Albrizio et al. 2014). Their results suggest that the variance in economic effects across countries is not due to the stringency of policies but related more to barriers to entry and levels of competition (Albrizio et al. 2014).

The EPS index was used to evaluate the Pollution Haven Hypothesis (PHH), which proposes that countries with stronger environmental policies tend to lose competitiveness and exports (Koźluk and Timiliotis 2016). They concluded that the overall effects of environmental polices on trade patterns were very small over the 20-year period with some industries coming out ahead and others losing. A similar study used the EPS index to confirm a positive relationship between more stringent environmental policies and a country's export of environmental goods and services due to the effect of the policies on market size (Sauvage 2014).[3]

In sum, past research reveals that the impact of environmental policy on a country or region's economy may be either positive, negative or close to neutral. Most past research has focused on specific policies such as a carbon tax with various customizations typically involving different amounts of revenue recycling. Some research has been conducted using the OECD's EPS index to examine the impact of varying stringencies of environmental policy, but none of the research to our knowledge has examined economic growth.

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[3] Martínez-Zarzoso et al. (2019) used the EPS index to test the Porter Hypothesise described in 2.1.

3 Methodology

3.1 Model

An augmented Mankiw et al. (1992) economic growth model is applied, which is an extended version of the Solow (1956) model including human capital as an additional variable.

The Cobb–Douglas production function can be written as,

$$Y_t = A_t K_t^\alpha H_t^\beta L_t^{1-\alpha-\beta} \tag{1}$$

where, A is technology, K is physical capital, H is human capital, L is labour force. Note that 'A' includes technological progress such as policy changes in the energy sector, but technological change does not occur in the short run. Thus 'A' is constant in the short run, and α, β, and 1-α-β are the shares of capital, human capital, and labour in total output, respectively. Equation (1) in the long run takes the following form,[4]

$$Y_t = A_t^\delta K_t^\alpha H_t^\beta L_t^{1-\alpha-\beta-\delta} \tag{2}$$

δ is the growth share of technological progress that incurs costs in the short run, however, pays dividends in the long run. δ is the parameter of interest in this study.

By taking the logarithm, the equation becomes

$$lnY_t = \alpha lnK_t + \beta lnH_t + (1 - \alpha - \beta - \delta)lnL_t + \delta lnA_t \tag{3}$$

And for the empirical model, we can write

$$lnY_{i,t} = \alpha lnK_{i,t} + \beta lnH_{i,t} + (1 - \alpha - \beta - \delta)lnL_{i,t} + \delta lnA_{i,t} + \Upsilon Z_{i,t} + \varepsilon_{i,t} \tag{4}$$

where Z includes other economic growth indicators, Υ is the growth share of the other economic growth indicator variables, subscript i represents cross-section, and ε represents the error term. Environmental policy stringency is a proxy for 'A' in Eq. (4) both in the short and long run. The rationale for A being measured by the level of environmental policy stringency is grounded in the assumption that environmental policy provides incentives for firms to reduce emissions and generally produce in a cleaner manner, but at the same time, firms strive to maximize profit. Thus, it is expected that countries with a higher EPS index will experience greater technological progress compared to countries with a lower EPS index.

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[4] The Solow Model assumes that both technology and labour grow at a constant rate. This formulation of technology is referred to as labour-augmenting. In essence, technology is making labour more effective. Solow's economic growth model can be written as follows (see Zhao 2019):

$$Y_t = K_t^\alpha \left(A_t L_t\right)^{1-\alpha}$$

Further, we assume that technology does not only make labour more efficient, it can also contribute to the productivity of capital. So, 'A' in our theoretical discussion is a separate long-run variable.

3.2 Data and variables

The main data sources for this study include the OECD Environment Statistics (2018), World Bank database (2017), Penn World Tables (Feenstra et al. 2015) and the International Labour Organization database (2018). As explained in the previous section, a Solow type economic growth model with the addition of a variable to represent the level of environmental policy stringency is used for empirical analysis. The level of policy stringency is measured with the Environmental Policy Stringency (EPS) Index, developed and available in OECD Environment Statistics (OECD 2018).

The EPS index is a composite indicator focusing on air and climate polices in the key upstream sectors of energy and transport (OECD 2016; Botta and Koźluk 2014). While there have been other attempts at constructing indicators of environmental policy (van den Bergh and van Veen-Groot (2001) the EPS is the most comprehensive, to date, providing measures for OECD countries across time. The structure of the index includes both market-based and non-market-based policies, equally weighted.[5] For the market-based policies, equal weight is assigned to the following four categories: taxes, trading schemes, feed-in-tariffs, and deposit and refund schemes. For the non-market-based policies, equal weight is assigned to standards and research subsidies. The indictor ranges from zero to six, where zero indicates no policy instrument and six indicates the most stringent policies (OECD 2016).

As with all indexes, the EPS has limitations. The first limitation is its relatively narrow focus on air and climate policies, thus excluding water, biodiversity, natural resources and waste. Second, some important policy instruments for air and climate have been excluded, such as tax incentives for environmentally sustainable investment, land use regulations and labelling requirements. The third limitation is the challenge of dealing with the issue of site specificity and the challenge of assessing and comparing the stringency of polices across countries (OECD 2016).[6] Fourth, by nature of an index being an aggregate measure, it is challenging to identify situations when individual polices affect economic growth differently. For instance, a pricing policy, such as a carbon tax, may affect economic growth differently than a non-pricing policy, such as a subsidy.

Despite the limitations, the strength of the EPS is evidenced by statistically significant Spearman rank correlations with five other proxies of environmental policy stringency[7] (OECD 2016). See Appendix 1 for specification of the variables and data sources.

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[5] See Martínez-Zarzoso et al. (2019) for a concise explanation of the components of the EPS index.

[6] See Brunel and Levinson (2016) for more discussion on the challenges of developing a useful and accurate measure of environmental policy stringency.

[7] Five proxies for environmental policy stringency include: CLIMI (European Bank of Reconstruction and Development), World Economic Forum's Executive Opinion Survey, Energy Prices (Sato et al. 2015), Environmental Patents (share) and Landfilled waste (share, Sauvage 2014; OECD 2016).

3.3 Methods

The Im et al. (2003) method is used to test the panel data for unit roots. The test results confirm that all data is I(1) series. The Pedroni test for panel co-integration is then applied to the results revealing cointegration. Subsequently, the Mean Group (MG) (Pesaran and Smith 1995) and Pooled Mean Group (PMG) (Pesaran et al. 1999) estimators are used to estimate the growth model (Eq. 4) given that the panel data are non-stationary and cointegrated (Blackburne and Frank 2007; Pesaran et al. 1999).

For this estimation, the number of time series observations (number of years, *T*) must be greater than the number of groups (number of cross-sections, *N*), which is satisfied. The PMG estimator involves both pooling and averaging. This estimator allows the intercepts, short run coefficients, and error variances to differ across groups, but constrains the long run coefficients to be the same. The PMG method not only provides the long run and short run relationships but also provides an error-correction coefficient measuring the degree of adjustment between the short run and long run.

In addition to the PMG estimator, pooled OLS and fixed effects are applied to re-examine the short run impact of environmental control policy on economic growth. In this case, the first-difference of all variables is used to ensure that the variables are stationary.

The sample is divided into two sub-groups based on the threshold level of the EPS index, which is 1.92 according to Hansen's (1999) method for determining thresholds. Group 1 consists of the countries with an EPS index value greater or equal to 1.92 and group 2 consists of the countries with an EPS index value less than 1.92. For robustness, we apply dynamic OLS regressions (DOLS) proposed by Stock and Watson (1993) using the full and sub-samples. DOLS considers the role of "lags" and "leads" of the first difference of integrated variables of cointegrating regression models. We specified a fixed lag and lead length of 1 for the annual observations.

Further analysis is conducted to gain a deeper understanding of the estimation results. Here, country level data for energy use, CO_2 emissions and GDP growth are examined for both country groups (Group 1 and Group 2) and for two time periods (before and after 2000). It is worth noting that the Kyoto Protocol was adopted in 1997, with the intention of being effective by 2005. However, the countries who signed on to the protocol started applying environmental policies around 2000, which is evident in the data (see Appendix 2).

Finally, a fixed effects model is used to estimate the impact of environmental policy on CO_2–energy, energy–GDP, and CO_2–GDP ratios by country group. The estimation results provide insight into the findings from the PMG, Pooled OLS and the fixed effects estimators.

4 Results

4.1 Descriptive statistics

The initial data set consists of macroeconomic data for 23 OECD countries for the years 1990 to 2014, however, Iceland and Luxembourg are excluded due to the lack

Table 1 Sample OECD countries, by policy stringency group

Group 1: more stringent	Group 2: less stringent
Austria, Denmark, Finland, France, Germany, Netherland, Italy, Spain, Sweden, Switzerland	Australia, Belgium, Canada, Greece, Ireland, Japan, South Korea, Norway, Portugal, UK, USA

Table 2 Descriptive statistics

Variable	Obs	Mean	SD	Min	Max
Full sample					
Lypc	483	10.39	0.271	9.40	11.06
Llab	483	9.21	1.18	7.18	11.95
Lk	483	25.80	1.20	23.43	28.83
Hk	483	3.15	.371	1.94	3.72
Open	483	70.20	34.22	16.01	196.4
EPS index	483	1.84	0.881	0.375	4.13
Sub-sample	Group 1				
Lypc	230	10.42	.248	9.58	10.96
Llab	230	9.50	1.39	7.79	11.95
Lk	230	26.18	1.41	24.03	28.83
Hk	230	3.23	.417	1.94	3.72
Open	230	60.40	25.12	16.01	124.24
EPS index	230	2.00	0.827	0.582	4.07
Sub-sample	Group 2				
Lypc	207	10.33	0.264	9.40	10.76
Llab	207	9.23	0.665	8.28	10.15
Lk	207	25.63	0.769	23.99	26.95
Hk	207	3.08	0.316	2.43	3.67
Open	207	72.13	33.65	32.21	163.99
EPS index	207	1.75	0.925	0.375	4.13

[a]lypc is log of per capita GDP; llab is log of labour force; lk is log of physical capital formation; hk is human capital measured by the average years of post-secondary schooling for the population between 25 and 64 years; open is the trade GDP ratio; EPS index is the Environmental Policy Stringency index

[b]Group 1 consists of countries with an EPS index ≥ 1.9208, Group 2 consists of countries with an EPS index < 1.9208

of EPS index data. The growth model is estimated for the full sample and the two country groups. As described above, the 21 countries are divided into 2 groups according to the threshold value of the EPS index of 1.92, over the 25 years. Thus, group 1 is associated with relatively more stringent environmental policy and group 2 with relatively less stringent environmental policy, as shown in Table 1.

The descriptive statistics for the total sample and the sub-samples of the two country groups are presented in Table 2. There is minimal difference in the mean

Table 3 Panel unit root tests (Z-t-tilde-bar)

Series	Level	First difference
Lypc	−0.1573 (0.438)	−8.7842 (0.000)
Llab	4.3111 (1.00)	−10.6021 (0.000)
Lk	2.4587 (0.993)	−10.7402 (0.000)
Hk	5.1987 (1.00)	−11.8476 (0.000)
Open	1.7443 (0.960)	−11.6950 (0.000)
EPS index	3.820 (0.999)	−11.5495 (0.000)

p values are in parentheses

Table 4 Results of Pedroni test for Panel co-integration among variables

	Full-sample	Group 1	Group 2
Modified Phillips–Perron test	3.152 (0.000)	3.316 (0.000)	2.837 (0.002)
Phillips–Perron test	2.005 (0.022)	2.021 (0.022)	0.105 (0.458)
Augmented Dickey–Fuller test	2.141 (0.016)	2.305 (0.011)	0.553 (0.290)

[a]H_0 No cointegration; H_a all panels are cointegrated

[b]p values are in parentheses

values of most variables between the two country groups except for the EPS index, where the mean is 2 for group 1 countries and 1.75 for group 2 countries (See Appendix 1 for variable descriptions and data sources).

On average, group 1 and group 2 countries use very similar levels of labour, capital, and human capital. Although group 2 countries implement relatively more liberalized trade policy and group 1 countries implement relatively more consistent environmental policy, as indicated by the standard deviation.

Correlation statistics reveal a positive association ($r = 0.53$) between the EPS index and per capita real GDP (log) for the entire sample, with the correlation for group 1 countries ($r = 0.71$) being substantially higher than for group 2 countries ($r = 0.46$).

4.2 Results of the unit root test

Given the unbalanced nature of the panel data set, the Im–Pesaran–Shin method is used for the unit root test with the results shown in Table 3. The results confirm all variables are non-stationary at level but are stationary at the first difference.

4.3 Results of the cointegration test

The results for the Pedroni test are illustrated in Table 4, including the modified Phillips–Perron test, the Phillips–Perron test and the Augmented Dicky–Fuller test. The results reject the null hypothesis of no co-integration, thus a long run relationship

exists among all variables in the panel for the full and sub-samples. Cointegration test results reveal that all the empirical models are cointegrated.

4.4 Results of the pooled mean group (PMG) and dynamic OLS (DOLS) estimation

The growth model is estimated using the PMG estimator providing both short run and long run results. The short run results are reported from the fixed effects and OLS estimations, in addition to the PMG (short run) estimator. The coefficient of EPS on per-capita GDP growth, in the short run under the PMG estimator, is quite similar to that of the fixed effects estimator, as shown in Table 5. Note that all variables are in first difference form for the short run (Table 5) and in level form for the long run (Table 6).

The results in Table 5 suggest that more stringent environmental policy results in costs in the short run. The coefficient of EPS is negative and statistically significant in the fixed effects, pooled OLS and PMG (short run) estimates. The coefficients are –0.015, –0.012 and –0.017 for the full sample, country groups 1 and 2, respectively. The interpretation of these coefficients is that for a one unit increase in the EPS index, per capita GDP growth decreases by 1.49%, 1.19% and 1.71% for the full sample, country groups 1 and 2, respectively.[8]

To estimate the long run effect of the EPS index on CO_2 emissions we estimated the empirical model using both Mean Group (MG) and Pooled Mean Group (PMG) estimators. Hausman test results for the full sample ($\chi^2 = 1.19$; $p = 0.946$), group 1 ($\chi^2 = 4.84$; $p = 0.436$), and group 2 ($\chi^2 = 0.17$; $p = 0.999$) indicate that the Pooled Mean Group estimator is a more suitable estimator than the Mean Group estimator for this empirical model. We report the PMG estimation results in Table 6, which show that labour, capital and trade liberalization are positive and significant factors for GDP per capita growth in the long-run. Human capital is statistically significant and positive only for group 2. The error correction coefficient is negative and statistically significant for all three estimations, indicating stability of the empirical model. The speed of adjustment is represented by the coefficients of -0.143 for the total sample, -0.198 for group 1 countries and -0.268 for group 2 countries. These coefficients indicate that, on average, approximately 20 and 27% of disequilibrium is adjusted in each period (year) for group 1 and group 2, respectively. The magnitude of the error correction coefficients of the sub-samples suggest that a complete adjustment takes approximately 4–5 years while the coefficient for the full sample suggests that the speed of adjustment is approximately two years longer.

To address the main objective of the research, the impact of the EPS index is assessed in the long run. The estimations indicate that the EPS index is a significant determinant for economic growth. For the full sample, the EPS index is positive with a value of 0.06, indicating that environmental policy stringency contributes to per capita GDP growth in the long run by close to 6% for each one unit increase in

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[8] Given that the dependent variable is in log form and EPS is not in log form, we need to subtract 1 from the exponent of the coefficient and then multiply the value by 100 to determine the effect of EPS on the growth of per capita GDP.

Table 5 Short run results (dependent variable: d.lypc)

Variable	Fixed effects			Pooled OLS			PMG (short run)		
	Full sample	Group 1	Group 2	Full sample	Group 1	Group 2	Full sample	Group 1	Group 2
d.lnlab	0.160 (0.068)***	0.141 (0.078)*	0.249 (0.134)*	0.185 (0.066)*	0.130 (0.051)**	0.334 (0.163)**	0.035 (0.191)	−0.205 (0.315)	0.256 (0.178)
d.lnk	0.250 (0.014)***	0.243 (0.024)***	0.245 (0.019)***	0.245 (0.015)***	0.240 (0.025***)	0.238 (0.025)***	0.166 (0.022)***	0.185 (0.036)***	0.033 (0.021)
d.hk	0.051 (0.190)	−0.771 (0.492)	0.199 (0.209)	0.340 (0.135)	−0.412 (0.243)	0.546 (0.129)***	0.460 (0.599)	0.058 (0.903)	0.483 (0.522)
d.open	0.0005 (0.0002)**	0.001 (0.0003)**	0.0001 (0.0003)	0.0006 (.0002)***	0.001 (0.0004)**	0.0002 (0.0004)	0.0004 (0.0009)	0.00004 (0.0004)	0.0005 (0.001)
d.EPS	−0.015 (0.004)***	−0.012 (0.005)**	−0.017 (0.005)***	−0.015 (0.004)**	−0.012 (0.004)**	−0.017 (0.006)**	−0.014 (0.004)***	−0.015 (0.004)***	−0.005 (0.004)
Constant	0.017 (0.003)***	0.028 (.007)***	0.015 (0.004)***	0.0125 (0.002)***	0.023 (0.003)***	−0.008 (0.003)***	0.271 (0.080)***	0.580 (0.154)***	−0.842*** (0.162)
Observ. (N)	479	225	254	479	225	254	479	225	243
No. of groups	21	10	11				21	10	11
F-Stat	85.42***	40.31***	47.07***	86.83***	49.87***	50.95***			
R^2	0.47	0.49	0.49	0.47	0.49	0.47			
Sigma_u	0.0074	0.0038	0.0094						
Sigma_e	0.0231	0.0225	0.0235						
Rho	0.0932	0.0277	0.1391						
Country FE	Yes	Yes	Yes	No	No	No			
Time FE	Yes	Yes	Yes	No	No	No			

Robust standard errors in parentheses

***, ** and *denotes level of significance at 1%, 5% and 10%, respectively

Table 6 Long run results (PMG and DOLS)

Variable	Pooled mean group (PMG)			Dynamic OLS (DOLS)		
	Full sample	Group 1 (above threshold-old)	Group 2 (below threshold-old)	Full sample	Group 1 (above threshold-old)	Group 2 (below threshold-old)
Dependent: lypc						
Lnlab	0.390 (0.030)***	0.072 (0.031)***	0.382 (0.097)***	−0.133 (0.021)***	−0.123 (0.013)***	−0.324 (0.033)***
Lnk	0.181 (0.015)***	0.263 (0.018)***	0.327 (0.023)***	0.171 (0.019)***	0.148 (0.012)***	0.370 (0.033)***
Hk	0.052 (0.054)	0.045 (0.078)	0.377 (0.037)***	0.238 (0.019)***	−0.003 (0.030)	0.228 (0.030)***
Open	0.005 (0.0004)***	0.004 (0.0007)***	0.003 (0.0003)***	0.002 (0.0003)***	0.003 (0.0004)***	0.002 (0.0003)***
EPS	0.061 (0.008)***	0.080 (0.014)***	−0.029 (0.004)***	0.087 (0.008)***	0.137 (0.012)***	−0.048 (0.011)***
Error correction (ec)	−0.143 (0.038)***	−0.198 (0.024)***	−0.268 (0.044)***			
Constant	0.271 (0.080)***	0.499 (0.079)***	−0.842 (0.163)***	6.24 (0.306)***	7.303 (0.206)***	
Observations	479	225	243	437	205	232
No. of countries	21	10	11			
F-stat				59.08***	103.16***	49.83***
R^2				0.75	0.89	0.81

[a]Robust standard errors in parentheses; ***, ** and * denotes level of significance at 1%, 5% and 10%, respectively

[b]Hausman test results for full sample ($\chi^2 = 1.19$; $p = 0.946$), Group 1 ($\chi^2 = 4.84$; $p = 0.436$), and Group 2 ($\chi^2 = 0.17$; $p = 0.999$) indicates that the Pooled Mean Group estimator is a more suitable than Mean Group estimator for our empirical model. Threshold EPS (1.9208) is determined by Hansen (1999) method

Table 7 Key ratios by country group

Indicators	Full sample	Group 1	Group 2
CO_2–energy ratio			
1990–2014	100,138	53,533	134,937
1990–2000	82,083	53,433	130,534
2001–2014	89,903	53,611	138,397
Energy–GDP ratio			
1990–2014	6.09e-08	1.26e-08	9.72e-08
1990–2000	4.18e-08	1.49e-08	9.16e-08
2001–2014	5.06e-09	1.07e-08	1.02e-07
CO_2–GDP ratio			
1990–2014	0.0002706	0.0002414	0.0002925
1990–2000	0.0002758	0.0002904	0.0003343
2001–2014	0.0002492	0.0002032	0.0002597

the EPS index. When the model is run separately for the two groups, the results are different with the coefficient of EPS index being positive (0.08) for the relatively more stringent group 1 countries and negative for the less stringent group 2 countries (-0.03). These findings imply that if the EPS exceeds the threshold level, it has a positive effect on per capita GDP growth (an increase of 8.33% for each unit increase in the EPS index), however, if the EPS index is below the threshold level then it adversely affects GDP growth (a decrease of 2.85% for each unit increase in the EPS index). Thus, in the long run, environmental policy appears to pay dividends of economic growth to those countries with more stringent environmental policies, contrary to the short run, when it is costly.

For robustness, we estimate the same empirical model using the dynamic OLS (DOLS) estimator for the full and sub-samples with the long-run results presented in Table 6. DOLS results for the short run, and the lags and leads of variables are not reported here, however, are available upon request. The estimations using DOLS show that environment policy stringency significantly increases the GDP of the OECD countries in the long run. Group 1 countries receive a greater benefit ($+0.137$) from their more stringent policy compared to the full sample of OECD countries ($+0.087$). Group 2 countries with relatively less stringent policy are not able to benefit from their policy. This result is consistent with the PMG results.

4.5 Why does a rise in environmental policy stringency affect the two country groups differently?

The results suggest that environmental policies pay dividends to group 1 countries while they adversely affect the economic growth in group 2 countries. What are some possible reasons for these results? To address this question some key ratios are computed to gain insight into the results. The ratios of CO_2–energy, energy–GDP and CO_2–GDP are estimated for each country group for the full period 1990–2014,

Table 8 Results of fixed effects model regression of environmental policy on CO_2–energy–GDP and CO_2–GDP ratios by group of countries

Dependent	Independent	
	Group 1	Group 2
ln(CO_2/energy)		
lEPS	− 0.027 (0.008)***	0.050 (0.006)***
Constant	10.307 (0.413)***	10.891 (0.538)***
Wald-statistics	11.17	68.15
ln(energy/GDP)		
lEPS	− 0.408 (0.020)***	− 0.287 (0.011)***
Constant	− 18.364 (0.400)***	− 19.138 (0.362)***
Wald-statistics	404.32	631.95
ln (CO_2/GDP)		
lEPS	− 0.431 (0.025)***	− 0.237 (0.012)***
Constant	− 8.062 (0.020)***	− 8.247 (0.299)***
Wald-statistics	302.42	417.46

lEPS is log of the EPS index; ln(CO_2/energy) is the log of CO_2–energy ratio; ln(energy/GDP) is the log of energy–GDP ratio; ln(CO_2/GDP) is the log of CO_2–GDP ratio

as well as for the sub-periods, 1990–2000 and 2001–2014, as shown in Table 7 (see Appendix 1 for a description of the calculation and data sources of the ratios).

The CO_2–energy ratio indicates the quantity of CO_2 emissions per unit of energy generation with a low ratio indicating a larger proportion of renewable energy use. On the other hand, the energy–GDP ratio indicates the amount of energy used to produce a dollar's worth of GDP. A relatively lower ratio implies that energy is used more intensively (efficiently) to produce GDP, with the reverse being true as the ratio rises. The CO_2–GDP ratio is the combination of the previous two ratios which demonstrates the amount of CO_2 released to produce a dollar's worth of GDP. A relatively low ratio suggests either a higher degree of energy efficiently or a substitution of a green source of energy for a dirty source.

The estimated CO_2–energy ratio for group 1 countries is 53,533 compared to 134,937 for group 2 countries for the entire sample period, as shown in Table 7. This ratio is more than 2.5 times greater for group 2 countries than group 1 countries. Furthermore, this ratio remains stable in group 1 countries while it increases over time in group 2 countries. This suggests that group 1 countries use relatively more green sources of energy than group 2 countries. The energy-GDP and the CO_2–GDP ratios depict a similar picture. The estimates of these two ratios imply that group 2 countries use energy less efficiently, thereby releasing more CO_2 emissions to produce each dollar's worth of GDP compared to those in group 1.

To examine how the EPS index is related to the three ratios, simple regression models, by country groups, are run using the fixed effects estimator, where the ratios are dependent variables and EPS index is the explanatory variable. The results, as shown in Table 8, indicate that the EPS index is statistically significant in all six regressions ($p < 0.01$). Note that the relationship between the EPS index and the CO_2–energy ratio is negative for group 1 and positive for group 2, confirming the

contention that more stringent policy has incentivized the stakeholders in group 1 countries to use more green energy compared to the group 2 countries, thus offering a reasonable explanation for the difference in CO_2–energy ratios in Table 7.

The relationship between the EPS index and the energy-GDP ratio vis-a-vis CO_2–GDP ratio is found to be negative for both country groups (see Table 8). However, the degree of negative association varies with the magnitude being much higher (1.4 times to 1.8 times higher) for the group 1 countries compared to the group 2 countries. The difference in the size of the EPS coefficients in both the energy–GDP regression (group $1 = -0.408$ for group $2 = -0.28$) and the CO_2–GDP regression (group $1 = -0.408$ and group $2 = -0.237$) imply that more stringent policy plays a significant role in reducing these three critical ratios, which not only helps to reduce GHG emissions but also contributes to increasing GDP growth, at least in the long run. These results support the findings of the economic growth model in both the short and long run, as shown in Tables 5, 6.

5 Discussion

The widely held view that environmental policy is costly to firms, thereby reducing their profitability leads to a sentiment of dread when the topic arises (Palmer et al. 1995). This is in stark contrast to the Porter Hypothesis (Porter 1991; Porter and van der Linde 1995) which contends that environmental regulation may provide an incentive for firms to innovate, realize productivity gains, and in many cases reduce their costs. For instance, Cohen and Tubb (2018), in their meta-analysis, found that a positive association between regulation and productivity is more likely at the state, region or country level, rather than the firm or industry level.

The current findings indicate that environmental regulations negatively affect economic growth in a sample of OECD countries, irrespective of level of policy stringency. However, in the long run, a positive association is found between policy stringency and economic growth for the full sample. This positive relationship also holds for the subsample of group 1 countries, with relatively more policy stringency, but not for group 2 countries, with relatively less policy stringency. Thus, the long run results offer support for the Porter hypothesis. It is reasoned that when policy stringency increases, the benefits of innovation exceed the costs of regulation for stakeholders, resulting in positive economic growth in the long run. On the other hand, when the policy stringency is relatively weak, as in the case of group 2 countries, the costs of regulation do not sufficiently incentivize stakeholders to invest in innovative technologies.

Thus, environmental regulation and technological innovation may be considered complementary in the long run providing the policy is sufficiently stringent. Nevertheless, changing behaviour and innovation on the part of stakeholders typically takes time and consequently in the transition period or short run, environmental policy may have negative consequences on output growth.

Several studies (Abdullah 2013; Dasgupta et al. 1999; Bovenberg and Smulders 1994; Omri 2013) find that taxing carbon has a positive effect on reducing GHG emissions without harming GDP. Some of the findings also suggest that under

some conditions sustainable growth is feasible and optimal. The results of this current research are in line with these findings. To achieve this goal, government needs to implement an effective environmental policy. Carbon tax policies, for example, can take many shapes and forms in terms of the amount of tax and the degree and type of revenue recycling (Zhang et al. 2016; van Heerden et al. 2016). For instance, research on British Columbia's revenue neutral carbon tax (Bernard et al. 2018; Yamazaki 2017; Murray and Rivers 2015; Beck et al. 2015; Elgie and McClay 2013) suggests that at the very least, it does not result in a fall in either GDP or employment. Furthermore, it is a highly progressive tax and there is a complete pass-through of the carbon tax into the price over time, implying that consumers ultimately bear the cost of the carbon tax and are thereby incentivized to reduce their consumption of fossil fuel, which they do. Similar results have been found in research for cap-and-trade policies. For instance, Dechezleprêtre et al (2018) observed that investment in new technologies leads to productivity gains in many EU countries with cap-and-trade policies. The current research results are in line with these findings.

While carbon taxes and cap-and-trade schemes can be cost-effective methods for reducing GHG emissions, neither are sufficient to reduce all emissions. Considerations for effective policy include, but are not limited to, the quality of government institutions and business cycles. The quality of government institutions can be assessed by the degree of efficiency a government illustrates in enforcing environmental policies as well as the type of policies which are sometimes politically driven, and thereby perhaps less effective (Runar et al. 2017). In regard to business cycles, the effectiveness of specific policies can be affected by the phase of a country's business cycle such that the same policy for renewable energy consumption may lead to different economic growth outcomes when implemented during varying phases in the business cycle (Bildirici and Gökmenoğlu 2017).

Future policy development should attempt to coordinate environmental policies such that they are complementary. More is not necessarily better when it comes to GHG reducing policies. For instance, adding a non-pricing policy, such as a subsidy, to a carbon price may undermine the effectiveness of the carbon price policy (Ragan 2017). An important role for governments is to cooperate to ensure that policies work together coherently.

6 Conclusion

A macroeconomic analysis of OECD countries with panel data from 1990 to 2014 utilizes an augmented Solow Model with the inclusion of the OECD's Environmental Policy (EPS) index to examine the effect of environmental policy of economic growth. The results suggest that although environmental policy adversely affects economic growth in the short run, the policy pays dividends of economic growth in the long run. It appears that countries with more stringent environmental policies benefit from higher economic growth in the long run. Stakeholders in the countries with more stringent policies tended to use energy more efficiently and to use more renewable energy compared to countries with relatively less stringent polices.

There are limitations to this research that need to be acknowledged. First are the limitations associated with using a policy index as a measure of policy stringency. While some type of aggregate policy measure is required to examine the effects of policy on economic and other outcomes, the perfect index does not and may not ever exist. The challenges of measuring the stringency of environmental policies goes much further than those related to data collection, as is well articulated by Brunel and Levinson (2016). The main challenges are conceptual problems such as the issues surrounding multidimensionality, simultaneity, industrial compositions and capital vintage (see Brunel and Levinson 2016).

Second are the limitations associated with the EPS index, as briefly discussed in Sect. 3 (OECD 2016). The EPS index focuses on air and climate policies thereby excluding important areas such as water and biodiversity, for instance. In addition, not all policy instruments for air and climate are considered in the index. Despite these and other limitations of the EPS index, it is considered a reasonable proxy for environmental policy stringency as evidenced by its statistically significant correlation with similar measures.

Third, it is important to note that this analysis is restricted to 21 OECD countries, thereby providing a reasonable picture of the developed world. The results may be quite different for emerging and developing countries, a topic for future research. Future research may also consider the impacts of policy stringency on specific industry sectors and how a country's industrial composition is related to how it is impacted by policy stringency, as has been alluded to in past research (Albrizio et al. 2014; Sauvage 2014).

Finally, the results are expected to be relevant to policy makers tasked with addressing climate change without forfeiting economic growth. While policy ought to consider the current business cycle in the short run and the overall quality of government institutions to enforce regulations, the most important recommendation is to focus on the long run and be prepared for the short run costs associated with sufficiently stringent policy. Further, policy needs to take a broad lens and consider all environmental policy and regulations to ensure they work together coherently.

Appendix 1

See Table 9.

Table 9 Variable definitions and data sources

Variable	Description	Source
Lab	Labour force, 15 +	International Labour Organization
K	Gross capital formation (constant 2010 US$)	World Bank
Hk	Average year of schooling among population between 25 and 64 years	The Penn World Table
Open	Trade percentage of GDP	World Bank
EPS	Environmental Policy Stringency index (EPS); the value ranges between 0 and 6	OECD Environment Statistics (database)
CO_2	CO_2 emissions (kilo ton)	World Bank
Ener	Energy use (kg of oil equivalent)	World Bank
N-pop	National population (number)	World Bank
GDP	GDP at chained PPPs (in mil. 2011US$)	Penn World Table
CO_2-Energy ratio	Ratio = (mean of CO_2 for countries) /(mean Ener for countries) CO_2-energy ratio indicates how much CO_2 emissions are released to generate one unit of energy	Calculated with data from sources as identified above
Energy-GDP ratio	Ratio = (mean Ener for countries)/(mean GDP for countries) The energy–GDP ratio indicates how much energy is used to produce a dollar worth of GDP	Calculated with data from sources as identified above
CO_2-GDP ratio	Ratio = (CO_2/energy ratio) × (energy/GDP ratio) This ratio demonstrates how much CO_2 is released to produce a dollar's worth of GDP	Calculated with data from sources as identified above

Appendix 2

See Fig. 1.
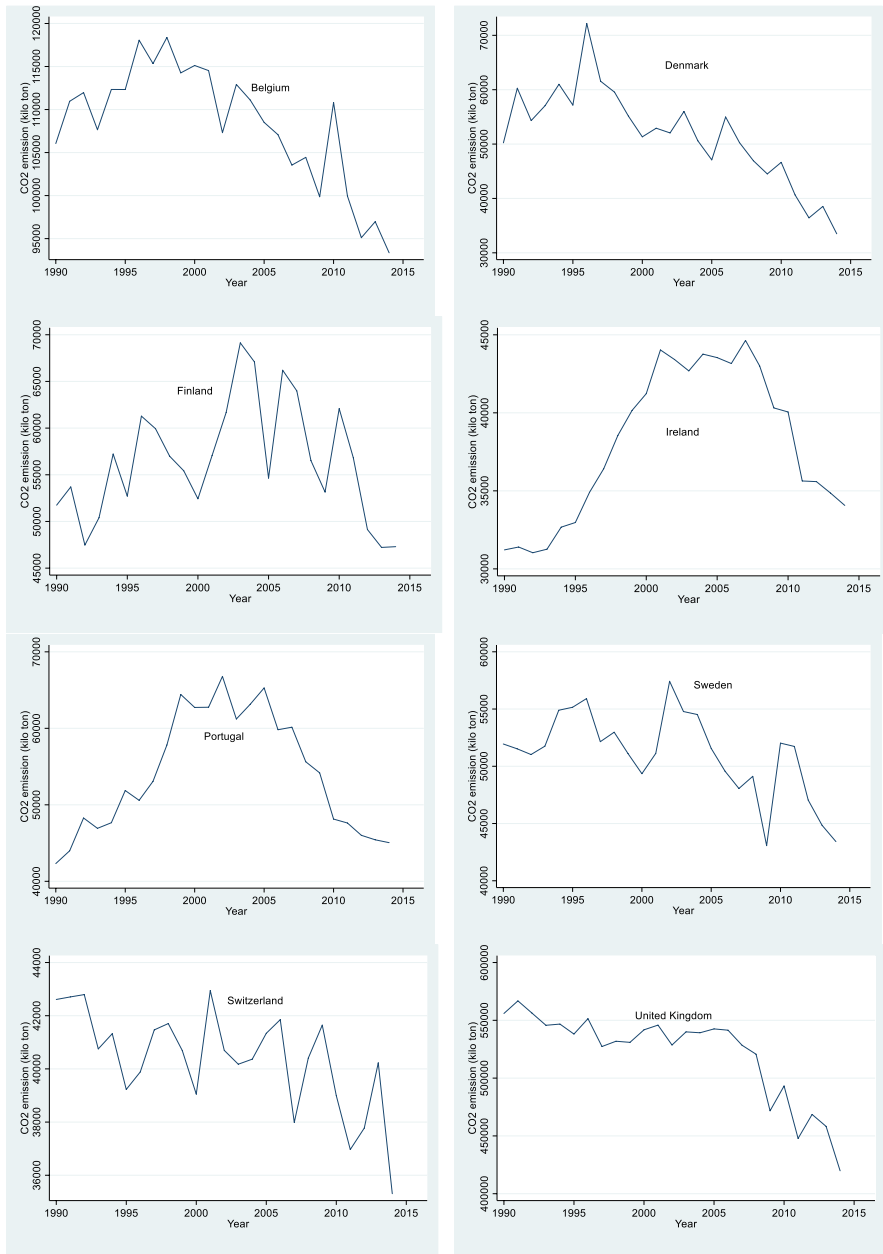
Fig. 1 Sample countries which signed onto the Kyoto Protocol: CO_2 emissions before and after 2000

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