Renewable Energy Production and Environmental Policy Stringency

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Motivation cont.

- In the free market economy, renewable energy production may not be thrive due its cost disadvantage relative to fossil fuel substitutes. Individual cost of using renewable energy is higher than the social cost where the social benefit of using renewable energy is higher than the individual benefit. As renewable energy production posses several properties of merit good, Governments particularly in OECD countries undertake several policies to promote renewable energy production.

- OECD countries have also placed topmost priority for promoting low carbon technology and eliminating fossil fuel subsidies by 2025 (OECD, 2011).For example, OECD countries underwent colossal investment in renewable technologies, exert substantial influence in administering renewable energy strategies, and focused on the synchronization of the member countries to continue sustainable development issues (OECD, 2011).

- Many OECD countries also strive to reduce the dependency on imported crude oil from mostly OPEC countries.

Motivation

- There is a scarcity of literature assessing empirical insights about the impact of stringency of environmental policies (OECD, 2016; Johnstone et al., 2010).

- The impact of government or pro-market policies where one to one country-specific empirical comparison or qualitative discussion has been provided for OECD countries (Polzin et al., 2015; Toke and Lauber 2007, Morthorst, 2000, Kozluk and Zipperer 2014; Malzi et al., 2020; Kozluk and Timiliotis 2016; Sauvage, 2014).

- Another stream of literature assessing the connection between policies and renewable energy deployment is qualitative and theoretical (Gan et al., 2007; Harmelink et al., 2006; Wang, 2006).

Motivation cont.

- A few of them studied this nexus for the US (Carley, 2009; Menz and Vachon, 2006), and European countries only (Marques et al., 2010); therefore, the results are not applicable for countries of other regions.
- Literature relevant to heterogeneous samples studies the nexus between renewable energy policies and technological innovation (Johnstone et al., 2010) & technological change and renewable energy capacity (Popp et al., 2011).
- Our data set has a more extended time dimension (1990-2016) and a larger number of sample countries (24) compared to these studies.
- Given several markets and non-market-based policies in place, it is plausible to investigate their efficacy in fostering renewable energy production in OECD member countries.

Contribution

- We provide an first empirical assessment between EPS and REP, concluding that more stringent environmental policies are associated with a higher level of REP in OECD countries. Our finding is comprehensive as EPS provides a composite measure of policy stringency, including both market and non-market approaches, encompasses a maximum number of cross country and time dimension, presents reasonable stability concerning changes, weighting and aggregation.

- Given strong financial integration, joint initiatives, foreign collaborations for the growth of environmental technologies, and the implementation of common environmental policies, commonness in renewable energy sources creates a common correlation effect which necessitates CS-ARDL as the most appropriate econometric method.

Contribution, cont.

- The substitution effect is stronger, as confirmed by the inverse relation between country specific proven oil reserve and REP. The existence and discovery of proven oil reserve pose a substantial threat to the energy security of the overlapping generations for oil-importing OECD countries.

- The robustness checks have been done by taking alternative proxies for EPS. We have applied both environmental technology, government expenditure for environmental protection (supply-side incentives) and environmental taxes (demand-side incentives) to complement the analysis. The results of the robustness checks do comply with the findings of the main analysis.

- Several policy implications arise from the results for OECD countries. The relevance of this finding is more pronounced for the policy-making for the sample countries due to the commitment of OECD countries to comply with the renewable energy promotion agenda.

Methods, Variables and Data

We follow a sequential order to select the best approach to simulate our models.

- we detect whether our respective variables have cross-sectional dependence or not.
- Given presence of cross-sectional dependence (CD), we apply the second generation panel unit-root approach.
- Presence of CD and non-stationarity properties of our variables indicate the usage of the Cross Sectional Auto Regressive Distributed Lag (CS-ARDL) approach.
- Before applying CS-ARDL, we detect optimum lag order by utilizing panel VAR framework and conduct a homogeneity test ($\beta_i = \beta\ or \beta_i = \beta_i$) for both short run and long run slope parameters.

Description of the Variables

Variable	Definition	Source
Renewable Energy Production (REP)	Renewable Energy Production has been defined as a share of total energy production.	IEA, 2020
Environmental Policy Stringency (EPS)	Environmental Policy Stringency is a country-specific index ranging from least stringent (0) to the highest degree of stringency (6) based on the explicit or implicit punitive actions taken to handle environmentally harmful behaviour. The index provides a comparable measure of environmental policy stringency across OECD countries, including both the market and non-market approaches to environmental policies.	OECD, 2017
Country Specific Proven Oil Reserve (POR_C)	Country specific Proven Oil Reserve is measured in crude oil, including lease condensate reserves in billion barrels.	IEA, 2020
Oil Price (OP)	Oil price is the annual data for crude oil, which is the WTI spot price FOB measured in dollars per barrel.	IEA , 2020
Log of GDP per Capita (LGDPC)	Log of GDP Per Capita constant 2015 is the log of gross domestic product (GDP) constant prices, 2015 measured in US dollar millions.	OECD , 2017
Financial Development (FD)	Financial Development Index abridges the development of financial markets and institutions according to their size and liquidity, the potential of the individual and companies to access financial services, the efficiency of the financial institutions measured in terms of providing financial services at a cheaper cost together with overall activity of the capital markets.	IMF , 2020
Environmental Related Technology (ENT)	Environmental Related Technology is defined as an index measured with total patents involved with the foreign collaboration in the development of environmental-related technologies, inventions per unit of Govt R&D, inventions per capita for general environmental management, climate change mitigation and environmental-related technologies.	OECD , 2017
Environmental Taxes (ENTX)	ENTX indicates the Environmental Taxes the country has been implementing or not. A dummy variable has been considered where 1 indicates implementation of environmental taxes and 0 otherwise. The data is the annual pollution taxes measured in millions (EURO).	OECD , 2017
Environmental expenditure (ENEX)	Environmental protection expenditure has been explained as a percentage of total Govt expenditure.	OECD ,2017

Special features of **EPS** indicator

- It includes air and climate policies on upstream sectors like energy, transport where environmental pollution has been a serious concern across OECD countries over time.
- The index provides a measure of environmental policy stringency across OECD countries, including both the market and non-market approaches to environmental policies. This indicator has particularly emphasized policies related to electricity production, generation and distribution subject to the availability of data.
- It covers the highest number of cross country and time dimension compared to other direct policy measures and presents reasonable stability concerning changes, weighting and aggregation (OECD, 2016).
- The rationale for the selection of the energy sector is due to the primary contribution of the electricity sector to the emissions of GHG gases in OECD countries. The relevance of this indicator is more profound in assessing the impact of environmental policies on REP due to the global nature of climate externalities in a cross country setting.

The Cross sectional Auto regressive Distributed Lag (CS-ARDL) Model

- CS-ARDL model is an advanced version of pooled mean group estimation method developed by Pesaran et al. (1999). It provides long-run ,short term parameters along with error correction coefficients .
- CS-ARDL method provides unbiased estimators in the presence of potential endogeneity, serial correlation, potential dynamic heterogeneity, and common correlation biased problem.
- Most effective in the presence of both observed and unobserved common factors and can address the cross sectional dependence (CD) both in the short run and long run (Chudik et al., 2016). This approach addresses the bias that may occur due to the unobserved common factors by considering residual spatial dependence.

The Cross sectional Auto regressive Distributed Lag (CS-ARDL) Model, cont.

- The baseline regression equation for the empirical model is as follows:

- $\Delta REP_{it} = \mu_i + \varphi_i\big(REP_{it-1} - \beta_i X_{it-1} - \phi_{1i}\overline{REP}_{t-1} - \phi_{2i}\bar{X}_{t-1}\big) + \sum_{j=1}^{p-1}\lambda_{ij}\,\Delta REP_{it-j} + \sum_{j=0}^{q-1}\zeta_{ij}\,\Delta X_{it-j} + \eta_{1i}\Delta\overline{REP}_t + \eta_{2i}\Delta\bar{X}_t + \varepsilon_{it})$…………………………………………..(2)

where ΔREP_{it} is the dependent variable, X_{it} denotes the independent variables in the long run, REP_{t-1} is the mean of the dependent variable in the long run, $\bar{X}_{t-1}$ is the mean of the independent variables in the long run, ΔREP_{it-j} is the dependent variable in the short run, ΔX_{it-j} is the independent variables in the short run, ΔREP_t is the mean of the dependent variable in the short run, $\Delta\bar{X}_t$ is the mean of the independent variable in the short run, ε_{ij} is the error term. Further, we define i as the cross-sectional dimension, λ_{ij} as the short-run coefficient of the dependent variable, ζ_{ij} as the short-run coefficient of the independent variables, $\eta_{1i}\eta_{2i}$ as the means of the dependent and independent variables in the short run.

Table 2: Cross-Sectional Dependence (CD) Test, Pesaran (2004)

	Over time Horizon		Short Run (1st Differenced)		Long Run (One Year Lag)	
Variables	CD	abs (Corr)	CD	abs (Corr)	CD	abs (Corr)
REP	48.58***	0.740	12.50***	0.223	46.75***	0.729
EPS	75.06***	0.871	15.50***	0.254	73.54***	0.868
LGDPC	78.21***	0.907	84.71***	1.000	84.71***	1.000
FD	68.18***	0.791	24.81***	0.309	67.32***	0.795
ENT	43.41***	0.520	15.45***	0.245	43.42***	0.529
ENTX	10.80***	0.406	20.55***	0.509	13.18***	0.469
EXEP	4.45***	0.454				

Table 2 presents the results of cross-sectional dependence test of Pesaran CADF (2004) for 24 OECD countries during 1990-2016.No CD is hypothesized under the null hypothesis. The second column represents CD statistics, and average correlations among the cross-sections over the horizon, in the short run and in the long run respectively. The CD test statistic for EXEP is more profound after 2010 due to the increment in execution of the environmental policies among the OECD countries during these years. The symbol *** measures 1% significance.

Table 3: Order of Integration, Pesaran Panel Unit root test (2007)

Variables	CADF (Level)	CADF (1st Difference)
REP	0.049	-11.831***
EPS	-3.570***	-9.515***
LGDPC	-1.300	-4.767***
FD	-2.788	-9.549***
ENT	-4.872	-13.536***
ENTX	N/A	N/A
EXEP	-0.544	-5.827***

The second and third column of Table 3 report the results for panel unit root test of Pesaran (2007) for 24 OECD countries during 1990-2016. The second and third column of the table represents the CADF (Z (t bar) statistics for the level and 1st difference forms of the variable respectively. The total no of lags for computing the CADF (Z (t bar)) statistics for the level and the first difference forms of the variables is three (3) for each variable. As dummy variable has been constructed for environmental taxes the CADF test is not applicable (N/A) for this variable. The symbol *** measures 1% significance.

Table 4: Panel VAR model and Slope heterogeneity Tests

Lags	CD	J p-value	Short Run (1st Differenced)			Long Run (One Year Lag)		
1	0.9999996	0.0114*		Delta	p-value		Delta	p-value
2	0.9999993	0.216		-1.297	0.195		-0.469	0.639
3	0.9999984	0.995	adj	-2.495	0.013*	adj	-0.756	0.450
4	0.9998443	0.986						

The first three columns of table show the Panel VAR model estimates where the second & third column indicate the overall coefficient of determination by Hansen's J statistic (1982) and corresponding p value, for a series of panel vector autoregression of order 1 up to max no of lags which is similar to maximum likelihood estimation method. The fourth and fifth column show the short run and long run estimates of slope heterogeneity test. The adjusted Delta value is significant implies rejection of the H_0: slope coefficients are homogenous in the short run. Both the Delta values show acceptance of H_0 in the long run. The symbol * measures 10% significance.

Table 5: Renewable Energy Production and Environmental Policy Stringency (EPS)

	CD in SR	CD in LR	CD in SR & LR
Variables	M1	M2	M3
Error Correction	-0.0450**	-0.1587***	-0.1781***
	(0.01)	(0.03)	(0.04)
Long Run Estimates			
EPS_{t-1}	2.1289***	0.6319**	0.5223***
	(0.49)	(0.31)	(0.15)
POR_C_{t-1}	-0.0552*	-0.2693*	-0.0223**
	0.0291	(0.18)	(0.009)
OP_{t-1}	0.1661***	0.0508***	0.0186***
	(0.03)	(0.009)	(0.005)
$LGDPC_{t-1}$	0.8127	-2.8243**	-1.2109**
	(2.46)	(1.18)	(0.57)
FD_{t-1}	-8.7927*	3.5780	-2.0098*
	(3.66)	(2.28)	(1.63)
Short Run Estimates			
ΔEPS	0.2124	0.0689	0.1532
	(0.14)	(0.15)	(0.18)
ΔPOR_C	0.4366	2.9786	1.9030
	(2.05)	(1.98)	(1.17)
ΔOP	-0.0001	0.0032	-0.002
	(0.003)	(0.002)	(0.003)
$\Delta LGDPC$	0.2246	-0.6164	3.0873
	(3.42)	(2.71)	(3.28)
ΔFD	-1.2000	0.0113	-2.5830
	(1.44)	(1.29)	(1.87)
Constant	0.0477*	4.5300***	2.1571***
	(0.30)	(0.96)	(0.73)
Countries	24	24	24
Observations	623.000	623.000	623.000

Renewable Energy Production and Environmental Policy Stringency (EPS) Nexus

- More stringent environmental policies play a conducive role in fostering REP in OECD countries.
- More stringent environmental policies expedites the productivity growth of technologically advanced firms and reduces the productivity growth of least productive firms. The technologically advanced firms experience an expansion in their productive capacity due to the development of pro-environmental technologies.
- Our finding is similar to the findings of existing literature, where strict enforcement of environmental laws and regulations accelerates REP by creating incentives for the development of environmentally friendly technologies (Albrizio et al ., 2014; Sauvage, 2014).
- The impact of EPS on REP is more prominent due to its emphasis on climate and air policies in principal upstream sectors, including energy, transport which are reasonable proxies for polluters across OECD countries (OECD, 2016).

Renewable Energy Production and Environmental Policy Stringency (EPS) Nexus Cont.

- The country-specific proven oil reserve (POR_C) shares an inverse relationship with REP after controlling for CD in SR, LR and both in LR & SR.
- An increment in OP has a positive association with REP in SR, LR and both in the SR and LR for OECD countries. An oil price increase will make REP relatively cheaper because of the prevalence of substitution motive and speculative trader behaviour. Our inferences resemble with the findings of the existing literature (Reboredo et al., 2017; Reboredo 2015; Kumar et al., 2012; Broadstock et al., 2012).
- LGDPC has a negative impact on REP in the LR and in the SR and LR for OECD countries which implies dependence of richer countries on the usage of fossil fuel in a large extent. Our finding is in harmony with the findings of the existing literature (Dogan et al., 2020).

Renewable Energy Production and Environmental Policy Stringency (EPS) Nexus Cont.

- Financial development (FD) shares a negative relationship with REP for SR and for SR and LR for OECD economies which implies positive connection between FD and non-renewable energy usage. Financial resources directed to the private sector mostly invest in non-environmentally friendly projects in OECD countries so do not provide incentives for renewable manufacturers' growth and do not encourage development in renewable energy technologies. A similar finding has been confirmed for the European countries, a subset of OECD countries where FD has a positive relation with pollution or non-renewable energy consumption (Al-Mulali et al., 2015).

- The error correction coefficients are negative and significant under all three specifications, which confirm a long-run relationship between REP and EPS through an adjustment in the economic process.

- The short-run coefficients of the variables are not significant, therefore REP does not respond to the changes in EPS, OP, LGDPC, FD, POR_C in the short run.

Robustness Checks

Robustness checks are done through alternative specifications of the model by replacing EPS with

- Environmental technology (ENT),
- Environmental Taxes (ENTX) and
- Environmental protection expenditure as a percentage of total Govt expenditure (ENEX).

Table 6: Renewable Energy Production and Environmental Friendly Technology (ENT)

	CD in SR	CD in LR	CD in SR & LR
Variables	M4	M5	M6
Error Correction	-0.0289*	-0.0658***	-0.0339**
	(0.010)	(0.010)	(0.010)
Long Run Estimates			
ENT_{t-1}	0.7695***	0.7050***	0.8120***
	(0.270)	(0.240)	(0.260)
POR_C_{t-1}	-1.3444**	-1.3008	-1.5343**
	(0.650)	(0.860)	(0.810)
OP_{t-1}	0.2817***	0.2165***	0.2268***
	(0.050)	(0.040)	(0.050)
$LGDPC_{t-1}$	3.1020	-13.1578*	-9.9945**
	(3.01)	(6.50)	(4.95)
FD_{t-1}	-14.8143*	-9.4036	-38.1035***
	(5.930)	(10.570)	(11.521)
Short Run Estimates			
ΔENT	-0.0282	-0.0181	-0.0266
	(0.04)	(0.03)	(0.04)
ΔPOR_C	1.7634	1.9301	1.8328
	(3.22)	(2.24)	(3.22)
ΔOP	0.0015	0.004	0.001
	(0.003)	(0.002)	(0.003)
$\Delta LGDPC$	1.7292	2.2047	2.8164
	(3.71)	(2.55)	(3.78)
ΔFD	-1.6604	-1.1658	-2.2821
	(1.43)	(1.44)	(1.47)
Constant	-0.8681	-14.3746***	-2.8665
	(0.380)	(2.800)	(1.460)
Countries	24	24	24
Observations	624.000	624.000	624.000

Robustness Checks Cont.

- The long run error correction terms for all these models are significant.
- The long run parameters of ENT has a positive impact on REP after controlling for CD in SR , LR and in the SR and LR which is in line with our main findings.
- The adoption of stringent environmental policies provides incentives for the growth of pro-environmental technologies that increase REP in OECD countries. An increment in the total number of patents associated with foreign collaboration in the development of pro-environmental technologies is another crucial factor for boosting REP.
- POR_C, FD, OP, LGDPC share relation with REP similar to the main findings after controlling for CD in SR & in SR & LR.
- Therefore, any environmental policy in the form of supply-side incentives for promotion of REP is successful in the OECD countries.

Table 7: Renewable Energy Production and Environmental Taxes (ENTX) Nexus under different time horizons

	CD in SR	CD in LR	CD in SR & LR
Variables	M7	M8	M9
Error Correction	-0.0541**	-0.1662***	-0.2054***
	(0.02)	(0.04)	(0.05)
Long Run Estimates			
$ENTX_{t-1}$	3.1401***	0.7225***	0.2637***
	(0.75)	(0.26)	(0.12)
POR_C_{t-1}	-3.3545***	-0.2556***	-0.3021***
	(0.72)	(0.07)	(0.07)
OP_{t-1}	0.1188***	0.0299***	0.0130***
	(0.01)	(0.005)	(0.002)
$LGDPC_{t-1}$	8.4072**	-3.629***	-1.5619***
	(3.59)	(0.94)	(0.53)
FD_{t-1}	-11.9827***	-2.8308**	-2.3089***
	(4.12)	(1.61)	(1.14)
Short Run Estimates			
$\Delta ENTX$	0.1358	0.2772	0.1024
	(0.22)	(0.22)	(0.22)
ΔPOR_C	0.3851	-0.5346*	1.1088
	(2.38)	(1.28)	(1.48)
ΔOP	-0.0007	0.0017*	-0.0032
	(0.003)	(0.002)	(0.004)
$\Delta LGDPC$	2.2975	-1.3655*	1.7883
	(3.83)	(2.65)	(3.27)
ΔFD	-0.9806	0.0303	-0.8409
	(1.40)	(1.21)	(1.29)
Constant	-3.7017**	-2.6080***	-11.5155***
	(1.64)	(0.97)	(3.27)
Countries	24	24	24
Observations	624.0000	624.0000	624.0000

Renewable Energy Production and environmental taxes (ENTX) Nexus under different time horizons

- Twenty one OECD countries are included in the analysis during 2008- 2016 depending on the availability of the data.
- Literature has provided shreds of evidence in favour of using Environmental taxes (ENTX) to test for robustness checks for EPS (Hills and Michalena, 2017; Lalemand and Albrecht, 2014).
- The error correction terms are significant. POR_C, FD, OP, LGDPC share relation with REP similar to the main findings after controlling for CD in SR & in SR & LR.
- The long-run coefficients of ENTX for all models are significant at 1 percent. Thus, the execution of ENTX in the energy and transport sector is the demand side incentives to reduce the consumption of non-renewable energy in the energy and transport sector thereby increase renewable energy production for OECD countries during the sample period.
- POR_C ,OP, LGDPC, FD share relationship with REP in line with the main analysis. The short-run coefficients of these variables under consideration are not significant.

Renewable Energy Production and Expenditure on Environmental Protection (EXEP) Nexus under different time horizons

	CD in SR	CD in LR	CD in SR & LR
Variables	M10	M11	M12
Error Correction	-0.2091***	-0.2092***	-0.2558***
	(0.04)	(0.05)	(0.05)
Long Run Estimates			
$EXEP_{t-1}$	1.1768	1.2388**	0.7946***
	(0.97)	(0.53)	(0.21)
POR_C_{t-1}	0.0856**	-0.4398***	-0.4282***
	(0.03)	(0.07)	(0.08)
OP_{t-1}	0.0570***	0.0648***	0.0199***
	(0.009)	(0.01)	(0.007)
$LGDPC_{t-1}$	-3.8170	-4.8820**	-3.4235***
	(3.45)	(2.22)	(0.98)
FD_{t-1}	-2.6067	15.1712***	-0.8243
	(4.24)	(4.56)	(2.57)
Short Run Estimates			
$\Delta EXEP$	0.7581	0.9755	1.2205
	(2.15)	(0.88)	(1.05)
ΔPOR_C	10.3671	-3.3074	0.8087
	(14.91)	(4.00)	(1.51)
ΔOP	-0.0057	0.0045	-0.0031
	(0.004)	(0.003)	(0.005)
$\Delta LGDPC$	6.7356	1.9410	2.5966
	(7.73)	(4.71)	(5.48)
ΔFD	-6.7427	-1.0171	-5.4407
	(4.64)	(1.87)	(1.86)
Constant	11.5506***	11.3993***	8.2379***
	(2.51)	(3.06)	(2.07)
Countries	20	20	20
Observations	400	420	420

Renewable Energy Production and Expenditure on Environmental Protection (EXEP) Nexus under different time horizons

- Nineteen OECD countries are included in the analysis during 1995-2016 depending on the availability of the data.

- The long run coefficients for EXEP are significant at 5 percent, 1 percent level after controlling for CD in LR and SR & LR respectively. Therefore, an increment in EXEP leads to an increment in REP for OECD countries after controlling for CD among the OECD countries.

- POR_C, FD, OP, LGDPC share relation with REP similar to the main findings after controlling for CD in SR & in SR & LR.

- The long run error correction terms are significant for all models .
- The short-run coefficients of these variables under consideration are not significant.

Policy implications

- *First*, appropriate policies, including both the market and non-market approaches for bringing change in the relative price between renewable and non-renewable energy is encouraged.

- *Second*, expenditure on R&D, environmental taxes, expenditure on environmental protection can be useful tools to augment REP and help maintain energy security to comply with the SDG goal. These policies can also be corrective to ensure the relative price in favour of renewable energy in the presence of exogenous factors, including country-specific proven oil reserve and changes in the international oil prices.

- *Third*, Financial incentives provided by the private sectors will find it profitable to guide the resources towards renewable energy sector if the correct policy is in place.

- *Fourth*, More foreign collaboration to promote pro-environmental patents should be encouraged.

Appendix:
List of Countries included in the sample

Australia	Italy
Austria	Japan
Belgium	Netherlands
Canada	Norway
Czech Republic	Poland
Denmark	Portugal
Finland	Spain
France	Sweden
Germany	Switzerland
Greece	Turkey
Hungary	United Kingdom
Ireland	United States