Exam Report

Applied Environmental and Climate Policy Evaluation

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1 Introduction

The Environmental Kuznets Curve (EKC) hypothesizes an inverted U-shaped relationship between environmental degradation and income. At low income levels, economic growth tends to increase pollution as industrialization intensifies and environmental regulation is weak. However, beyond a certain income, further growth is associated with declining environmental impact, driven by structural changes in the economy, technological innovation, and stronger environmental policies. This concept, originally inspired by Kuznets' work on income inequality, has been widely applied to various pollutants, particularly CO_2 emissions (Grossman and Krueger (1995), Dinda (2004)).

This report empirically investigates the Environmental Kuznets Curve (EKC) hypothesis using data from 40 countries over 30 years (1990-2020), analyzing the relationship between GDP and CO_2 emissions, and employing a novel indicator: the **Environmental Policy Stringency Index (SI)**. It employs a fixed effects model to control for country- and time-specific factors (respectively and altogether).

2 Data Description

Data on CO_2 emissions, GDP, population, and energy consumption was retrieved from a comprehensive World Bank dataset (CO2 and Greenhouse Gas Emissions), together with other variables that were then discarded after the pre-processing phase. This data was merged with values for the EPS, retrieved from the OECD database (OECD Data Explorer - Archive - Environmental Policy Stringency Index). The SPI index was available for 40 countries[1] from the year 1990 to 2020. The sample covers more than 95% of world's emissions during these years.

> **In-depth 1: Environmental Policy Stringency Index**
>
> The EPS Index aims to depict the cost of polluting and, in particular, to measure the extent to which it becomes costlier for a firm to undertake "bad" environmental behaviours. It reflects the implicit cost imposed on polluting activities, ranging from 0 (least stringent) to 6 (most stringent), and distinguishes between market-based instruments (e.g., carbon taxes) and non-market regulations (e.g., technology standards) - see Figure 1. The index is calculated annually and enables cross-country and temporal comparisons. Its primary strength lies in capturing upstream policy intensity in key sectors over time. However, it excludes certain policy domains—most notably, agriculture (Botta and Koźluk (2014)).

[1] Australia, Austria, Belgium, Brazil, Canada, Switzerland, Chile, China, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Indonesia, India, Ireland, Iceland, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, Netherlands, Norway, New Zealand, Poland, Portugal, Russia, Slovakia, Slovenia, Sweden, Turkey, United States, South Africa.

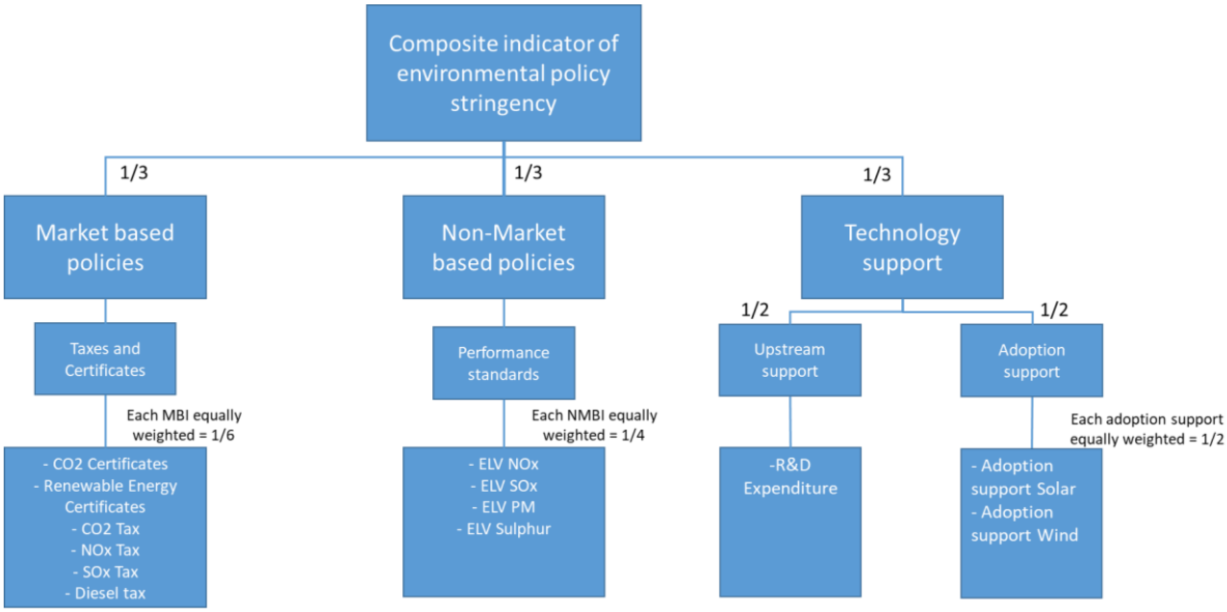

Figure 1: Aggregation structure of revised EPS Index (2021) OECD (2022)

3 Data Exploration

From the EPS time series, one can see in Figure 2 how, on average, countries have increased their environmental ambitions through the years and that from 2008 all nations in the sample have adopted some form of environmental measure.

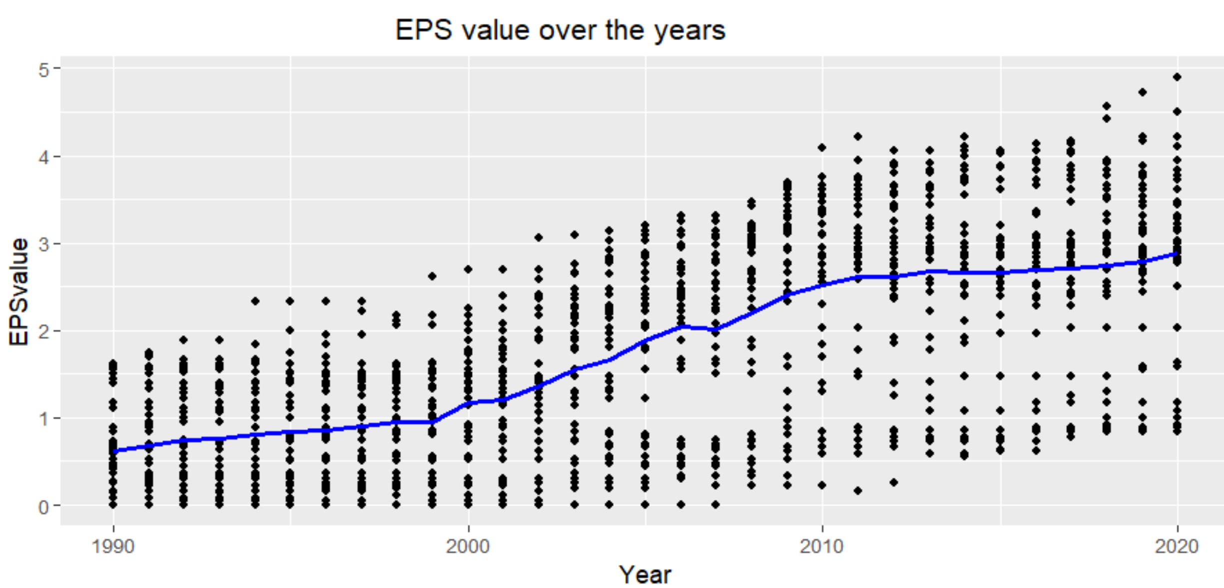

Figure 2: Trends in the stringency of environmental policies

Has this upward trend contributed to condition the level of emissions of individual countries in a significant way? A higher EPS may capture advanced policy responses in high-income countries, reinforcing the downward slope post-turning point of the Kuznet curve. From a preliminary visual exploration in Figure 3, comparing the EPS values with logged and per capita emissions shows that, while at first more stringency tends to have a mild effect, beyond a certain threshold increasing values of EPS are correlated with decreasing emissions.

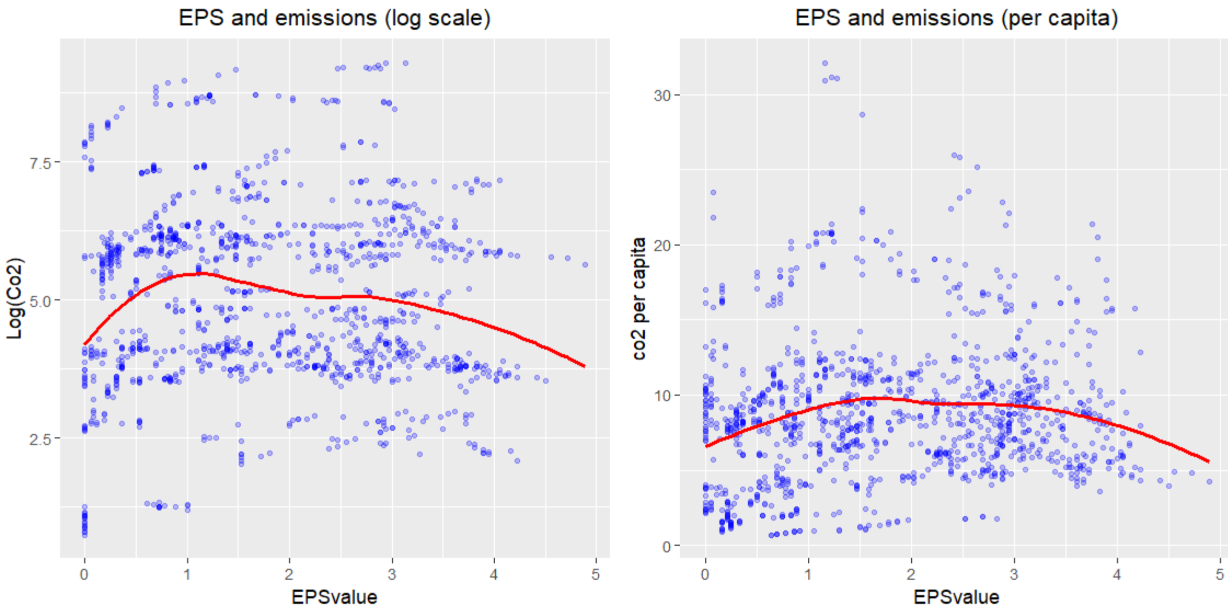

Figure 3: Relationships between EPS and emissions (logged and per capita

This pattern suggests that as countries grow more ambitious, they tend to enact those policies necessary to enable green growth trajectories. Is this inverted U-shaped pattern verified also for GDP and energy consumption? In other words, have front-runner countries grown greener and become less energy-intensive, following their increasing policy commitments?

The next scatterplots, with the *loess* lines plotted to shed more light on the apparent trajectories, show the extent to which the bell-shaped relationships are manifested, for the sample employed, also in the "classic" sense of the Kuznet curve concept. Albeit not emphatically, Figure 4 shows that countries have indeed tended to reduce their emissions, per additional unit of GDP or energy consumption, after having reached a certain level of these latter two variables. It seems, however, that this pattern emerges only for a little more than a handful of countries: Figure 4 shows that the humps see many more points to their left than to their right.

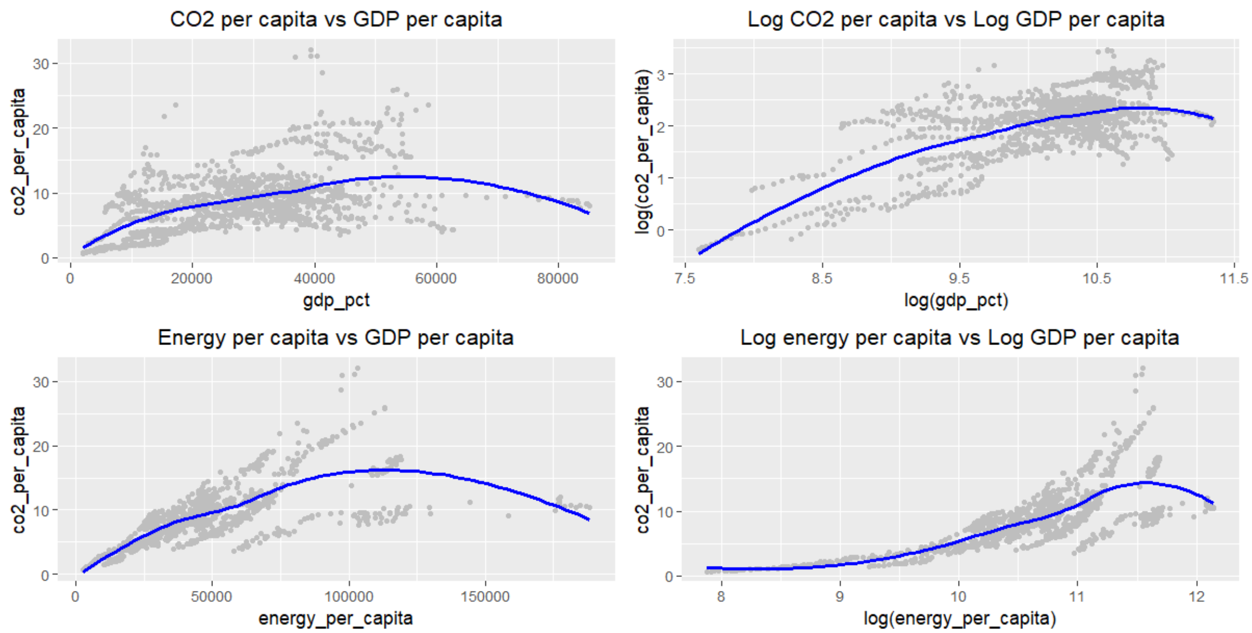

Figure 4: Inverted U-shaped Kuznet curves, scatterplots

Here below (Figure 5) is shown a box with basic descriptive statistics of the main variable used in the regressions. CO_2 and GDP vary widely between countries, as one would expect, so logged columns were created. The EPS values range from 0 to a maximum of 4.89.

Statistic	co2	EPSvalue	gdp	gdp_pct	primary_energy_consumption	energy_per_capita
Mean	5.882600e+02	1.780000e+00	1.551580e+12	2.834480e+04	2.583780e+03	4.770065e+04
Median	1.502500e+02	1.580000e+00	4.379380e+11	2.820999e+04	7.376500e+02	4.390299e+04
Standard.Deviation	1.384410e+03	1.190000e+00	2.999829e+12	1.454555e+04	5.491130e+03	2.961916e+04
Minimum	2.100000e+00	0.000000e+00	7.011078e+09	2.000720e+03	2.119000e+01	2.643110e+03
Maximum	1.090569e+04	4.890000e+00	2.415180e+13	8.513978e+04	4.149371e+04	1.882940e+05
Observations	1240	1240	1240	1240	1240	1240

Figure 5: Descriptive statistics, selected variables

Moreover, Figure 6 shows the correlations between the variables. It is noteworthy how the relationships between emissions, growth and energy consumption remain positive and strongly reflected in the data: countries, at the aggregate level, (still) tend to grow, consume more energy and emit more CO_2 in the process. Whereas the positive correlation of emissions with population is less pronounced, there seems to be no significant correlation between environmental policy stringency and emissions. Looking back at the graphs in Figure 3, this makes sense as the fitted lines display very clearly a U-shaped pattern (more pronounced than for GDP and energy consumption).

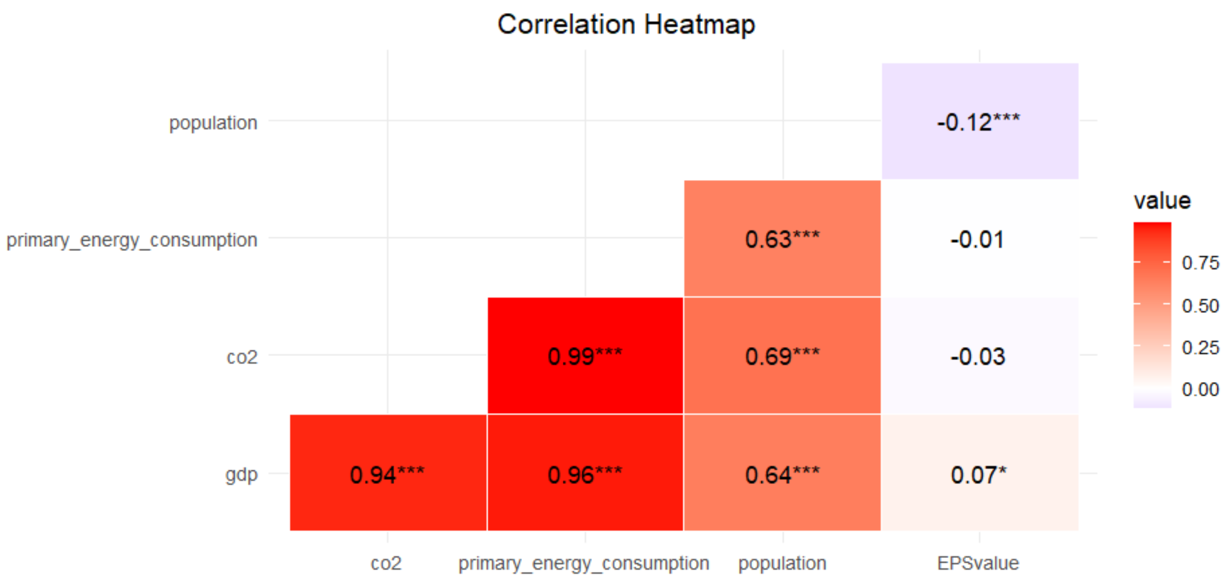

Figure 6: Correlation heatmap, selected variables

Do these correlations suggest a lag between the implementation of stringent environmental and climate policies and their purported effect of reducing emissions? In other words, does the Kuznet curve tend to manifest only a while after having committed to more sustainable ways of producing and consuming? This hypothesis is in line with the fact that phasing out CO_2 and other GHG entails a systemic transformation, where almost every production process has to be re-thought. In this context, it is likely that implementation of policies to penalise dirty processes and to support cleaner alternatives will show their effect only through time, and that the true right-hand descending side of the Kuznet curve still has to show up in the data. Yet, controlling for fixed effects, so looking at country-specific trajectories and isolating out time-related common patterns, a different picture might emerge, with certain (Western) countries already decoupling their growth from their emissions. In this case, it may be that the data do not fully support the Kuznet curve hypothesis only because there are not a lot of countries that have gotten over the hump of CO_2-driven growth, even though the few ones who did show that green growth bears his fruits.

4 Regression Analyses

4.1 Regression tables and interpretation

Regressions have been run using two different dependent variables: the *logarithm* of CO_2 emissions and CO_2 emissions *per capita*. Regressors of interest are *log GDP* and *GDP per capita*, respectively. For the log-log model, only the EPS has been included as control variable since the log of energy consumption is highly collinear with GDP (as can be seen also from Figure 6). For the per capita regressions, instead, *energy per capita* has been included as control as well.

OLS regressions are first run in their simplest form. Then, in order, country, time, and country-time fixed effects are included in the regression models (see below in the box the in-depth discussion on fixed effects). Results are presented and discussed first for aggregates (Table 1) then for per capita levels (Table 2).

Table 1: Results (Variables: aggregate)

	Dependent Variable: log Co2 Emissions			
	-Linear Reg-	-Country FE-	-Time FE-	-Both FE-
	(1)	(2)	(3)	(4)
log GDP	55.662***	32.030***	56.098***	46.006***
	(0.452)	(1.227)	(0.446)	(1.696)
log GDP (squared)	3.296***	6.787***	3.785***	6.159***
	(0.450)	(0.503)	(0.445)	(0.469)
EPS value	−0.203***	−0.135***	−0.128***	−0.074***
	(0.011)	(0.007)	(0.014)	(0.009)
Observations	1,240	1,240	1,240	1,240
R^2	0.925	0.507	0.930	0.561
Adjusted R^2	0.925	0.489	0.928	0.533

Note: *p<0.1; **p<0.05; ***p<0.01

Table 1 shows that using totals yields positive coefficients for log GDP (richer countries pollute more) and positive coefficients also for the squared term (the relationship between log GDP and log emissions is changing at an increasing rate, in other words the richer a country is the more it tends to pollute when it grows). A positive coefficient for log GDP squared indicates that there is a U-shaped relationship, the opposite of what postulated by Kuznet curve's backers. Yet this comes with some caveats. Indeed, the original Kuznet curve hypothesis is strongest for local pollutants per capita (i.e. SO_2, particulate matter, etc.), so a model specification with total levels of CO_2 as variable of interest might be skewed its EKC behaviour (Dinda (2004)). Moreover, larger countries (e.g., China and India) tends to dominate the relationship due to their sizes, and they are countries which have not surpassed that growth threshold after which an environmental policy mindset starts to phase in. Nevertheless, the conclusion from this Table, albeit not disproving the EKC hypothesis, stands as it is: measured in total emissions, richer countries still pollute more, and at an increasing rate — implying that population scaling and aggregate demand override efficiency gains[2].

It is interesting how *country fixed effects* change the numeric value of the coefficients. The 2nd and 4th columns, where country f.e. are included, display lower coefficients for the linear log GDP term and higher ones for the squared term, suggesting that *within* countries the U-shaped increasing relationship is even more pronounced.

[2]This somewhat resembles conclusions reached in the agricultural field. Under the *Irrigation Paradox*, scholars have argued that efficiency gains translate into higher demand for water for several reasons (Grafton et al. (2018)). The case could be true at the more general level: as economies reaps the environmental and economic benefits of efficiency improvements, no brake is put on total production and consumption volumes

Table 2: Results (Variables: per capita)

	Dependent Variable: Co2 Emissions per capita				
	-Linear Reg-		-Country FE-	-Time FE-	-Both FE-
	(1)	(2)	(3)	(4)	(5)
GDP per capita	109.631***	24.336***	6.563	23.305***	48.781***
	(4.752)	(6.131)	(5.219)	(6.121)	(6.622)
GDP per capita (squared)	−44.563***	−29.612***	−6.830***	−28.000***	−18.467***
	(3.774)	(3.412)	(2.255)	(3.386)	(2.428)
energy per capita		0.0001***	0.0001***	0.0001***	0.0001***
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
EPS value	−1.279***	−0.337***	−0.573***	0.190	−0.190**
	(0.114)	(0.112)	(0.065)	(0.136)	(0.077)
Observations	1,240	1,240	1,240	1,240	1,240
R^2	0.348	0.495	0.418	0.511	0.393
Adjusted R^2	0.346	0.494	0.398	0.497	0.356
Note:					*p<0.1; **p<0.05; ***p<0.01

From Table 2, where the model is framed in terms of per capita values, the curved relationship is reversed, as inverted are all the signs of the squared coefficient of GDP per capita. Given that the change in Y is given by $\beta_1 + 2\beta_2 x$, positive coefficients for GDP per capita and negative coefficients for GDP per capita squared mean that as income per person rises, CO_2 emissions per person first rise, then eventually fall - with the turning point being $-\frac{\beta_1}{2\beta_2}$. This aligns with the EKC hypothesis.

Looking at the specific model specifications, one notices that when energy per capita is included as control variable, the coefficient for GDP per capita significantly tend to decrease. This reflects the importance of the decrease in per capita energy consumption, which is usually the initial way an individual or a firm cut emissions - either through becoming more efficient in that same activity, or substituting that economic activity with another less energy-intensive. Moreover, while *time* fixed effects do not do much apart from making the EPS control lose its significance, *country* fixed effects again condition very much the results, with the variation *within* countries resulting in lower level of the squared GDP per capita coefficient - implying a less steep inverted U curve. The fixed effects also dampens the significance of the linear GDP coefficient, which in itself does not invalidate the quadratic functional form - as explained above, the correct interpretation depends on the joint contribution of both terms, not on each coefficient in isolation.

In-depth 2: The importance of Fixed Effects

Fixed effects is a method of controlling for all variables, whether they're observed or not, *as long as they stay constant within some larger category.* These categories are groups at some level of hierarchy: in different contexts, they can mean "persons", "schools", "countries", etc. **Individual fixed effects**, essentially, help to get rid of the variation *between* groups, keeping only the variation *within* groups. In terms of regressions (as straight line fits), it means that all the individuals in the data are constrained to have the *same slope* but *different intercepts.*

Conversely, **time fixed effects** enable comparisons of individuals to each other *at the same period of time*. If time was expressed in years, including time fixed effects would isolate the variation *within every year*. **Two-way fixed effect** are thus used to look at the variation *within individual as well as within year*. The crucial importance of using fixed effects stems from the fact that it enables controlling for characteristics (i.e. a country's culture) or trends (i.e. upturns and downturns, or specific macroeconomic events like the Great Recession) which are in most cases unobservable (HuntingtonKlein (2021)).

4.2 Residual analysis

The residual analysis is performed only for the last identification (dep. variable: CO_2 per capita, model: Both F.E.). Here are shown two Q-Q Plots, one (*left*) with the complete sample and the other (*right*) without Luxembourg and Estonia. This distinction is specified because, as shown in Figure 8 below, these two countries present ambiguous patterns which tend to skew the distribution of residuals. Indeed, the right side of Figure 7 displays quantiles of residuals better resembling those of a Normal distribution. Still, the S-shaped curve and its heavier-than-normal tails suggests some kind of non-normal behaviour in the data[3].

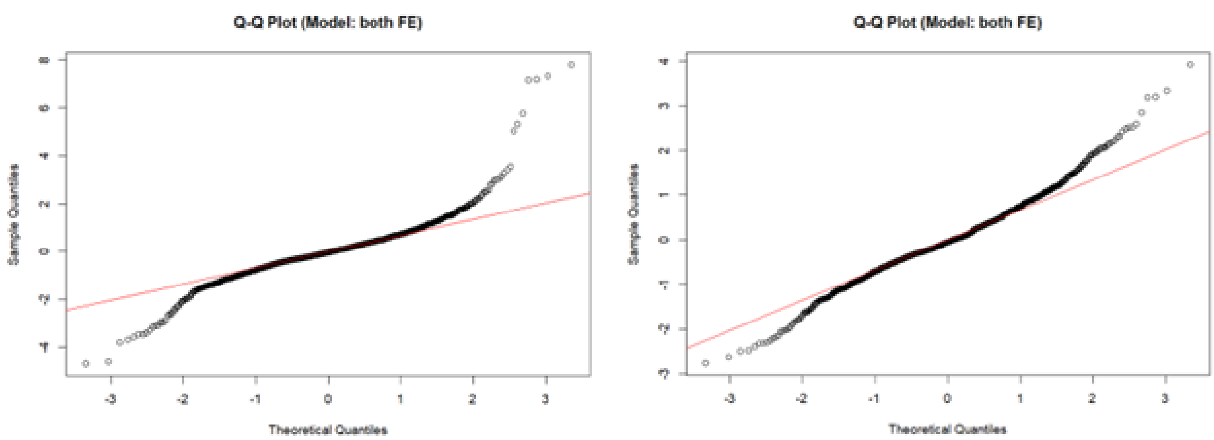

Figure 7: Normal Q-Q Plots, both Fixed Effect model, (right) without Estonia and Luxembourg

[3] Heavy tails are probably due to the presence of other outliers. The year 2020 when Covid bursted out should be controlled for by the time fixed effects. Probable culprits are other countries which have drastically change their environmental commitments when their governments have been replaced (i.e. Brazil or the US).

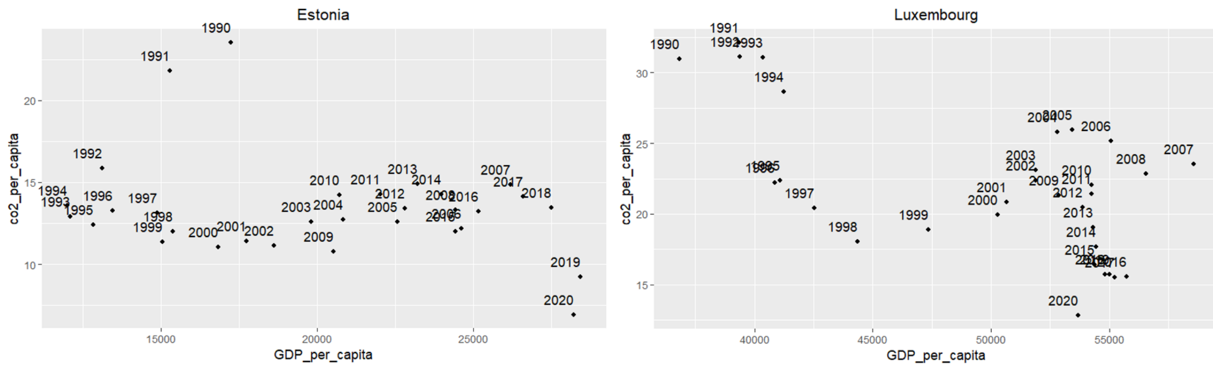

Figure 8: CO_2 and GDP per capita, selected countries

5 Discussions

The analysis conducted in this report sheds light on several aspects related to the EKC hypothesis. First, the findings tell us that emissions tend to decrease after a certain level of income has been reached only if computed at the per capita level. Using totals, this relationship is reversed, suggesting that richer countries have not embarked (at least during the time-period covered in the dataset) on a low-emission green growth pathway. Second, controlling for unobservable country characteristics tend, in both cases, to significantly condition the results, implying that more refined analyses of the Kuznet Curve hypothesis should inspect individual countries' trajectories rather than inferring from aggregates. Third, the analysis has shown the importance of the EPS parameter, found significant for almost all model specifications. It would be interesting assessing to what extent there is a lag between the implementation of stringent climate policies and subsequent falls in emissions. The EPS value calculated by the OECD is indeed comprehensive enough to support this kind of analysis; yet refinements in the calculations of the EPS, like the OEC (2025) initiative brought forward by the OECD, will continue to be welcomed in an ever-evolving world in which the scope and type of policy measures is continuously changing.

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