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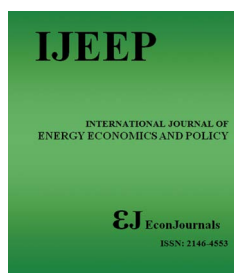
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A Growth Curve Model for CO₂ Emissions in G19 Countries

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ABSTRACT

CO₂ emissions per capita (Emc) and CO₂ emissions intensity (Emint) are among the main metrics used to report emissions in environmental studies. The main aim of this note is to compare the evolution of Emc and Emint in the G19 countries. Comparing their varying trends is useful in benchmark analysis. Indeed, in our study of the G19 countries, we offer evidence that such metrics show different trends for the same group of countries both at the sample and the individual level. Using a growth curve modeling approach, we find that Emint has been decreasing in the G19 countries while Emc has been increasing, but at a slower pace. Further, countries with high initial Emint have achieved the greatest reduction in the period analyzed, whereas there is no evidence of such a change in the case of countries with high initial Emc. We also find that a country's area affects its Emint growth, but not its Emc. Used together, Emint and Emc offer better insights into environmental performance as measured through these metrics.

Keywords: Emissions Intensity, Emissions per Capita, Growth Curve Model, G19, CO₂ Reduction

JEL Classifications: C15, Q53, Q56

1. INTRODUCTION

The reduction of future CO₂ emissions at a global level is one of the main goals of mitigating climate change effects. In most emissions studies, the two main metrics used are emissions per capita (Emc) and emissions intensity (Emint). The former represents the total country CO₂ emissions per capita (in metric ton of CO₂). The latter represents emissions intensity defined as the ratio of total CO₂ emissions to the GDP of the country. (In this note, the Emint is reported in kg of CO₂ per constant 2010 \$US.) Understanding their variation in time is important for policy analysis and design.

Most research is focused on per capita emissions (Brännlund et al., 2015) and equal per capita allocation criteria is widely referenced. As such, there is a vast number of studies on per capita CO₂ emissions evolution. One area of focus has been the concept of the convergence of Emc ratios among different countries. However, the results of this research stream are mixed. Among the studies that point to a convergence are: Sun et al. (2016), on the 10 largest economies;

Solarin (2014), on 39 African countries; and Li and Lin (2013) on 110 countries. In contrast, studies confirming a divergence include Yavuz and Yilanci (2013), on G7 countries; Yamazaki et al. (2014), on 34 OECD countries; and Herreras (2013), on 162 countries.

Yet, the analysis of the convergence of CO₂ Emint has received little attention among economists (Zhao et al., 2015), although Emint as a metric for allocation of emissions mitigation has been advocated in different studies such as Rowlands (1997) and Winkler et al. (2002). It has also been used to assess convergence at a regional level such as in province comparisons in China (Zhao et al., 2015) and at the industrial level in Sweden (Brännlund et al., 2015).

The main aim of this note is to compare the evolution of Emc and Emint in G19 countries. The G19 countries are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, and United States.

A growth curve modeling approach is used to study the evolution of Emc and Emint during the 1960-2015 period for these countries. Emc and Emint data for the countries are retrieved from World Bank's World Development Indicators (2016). One of the neglected aspects of extant studies on emissions is the direct effect of a country's area on its emissions evolution. To assess this, we also condition the growth rates of emissions on the corresponding country areas.

2. DATA AND MODELING

The growth curve model is a multilevel approach applied to assessing longitudinal data. A general quadratic two level model for variable Y (Emc or Emint) would be:

$$Y_{ij} = \beta_{0j} + \beta_{1j} \times \text{year}_t + \beta_{2j} \times \text{year}_t^2 + e_{ij} \quad (1)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \times X_j + u_{0j} \quad (2)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} \times X_j + u_{1j} \quad (3)$$

Equation 1 is the first level of the model; it represents the within-subject model, which shows individual j's response in year t. The within-subject model represents the variability of variable Y for individuals in a sample. Equations 2 and 3 are the second level of the model; they represent the between-subject part of the model, which examines the differences between individuals.

In equation 2, using the terminology of growth curve modeling, the initial outcome (intercept) is decomposed into two parts: the overall average outcome γ_{00} and the individual specific effect (through γ_{01}). The random error u_{0j} is a representation of individual uniqueness and the variable X_j is an explanatory subject-specific variable (more variables could be used if needed) not varying with time.

Similarly, the slope β_{1j} in equation 3 is decomposed into an overall rate of change and a subject-specific part. It is not necessary that the explanatory variable X_j is the same in both equations 2 and 3. The error term e_{ij} in the model is assumed to be normally distributed with zero mean and variance σ^2 . u_{0j} and u_{1j} represent how individual j's initial level (intercept) and rate of change (slope) deviate, respectively, from the average intercept and average slope. It assumes that u_{0j} and u_{1j} have a bivariate normal distribution: $N(0, \Omega)$. The variance and covariance matrix Ω can be represented as:

$$\Omega = \begin{pmatrix} \sigma_{u0}^2 & \sigma_{u01}^2 \\ \sigma_{u01}^2 & \sigma_{u1}^2 \end{pmatrix} \quad (4)$$

where σ_{u0}^2 and σ_{u1}^2 are variances of the random intercept and slope coefficients and σ_{u01}^2 is the covariance between the intercept and the slope. u_{0j} and u_{1j} are assumed not to correlate with e_{ij} .

The coefficient of the quadratic term is assumed to be a fixed effect, although it can be modeled as a random effect as in equations 2 and 3. This choice is for convenience, as the linear term coefficient would suffice to study the evolution of the rate of change.

The main outcomes of the model are the five fixed effects (γ_{00} , γ_{01} , γ_{10} , γ_{11} , β_{2j}) and the four random effects (σ^2 , σ_{u1}^2 , σ_{u0}^2 , σ_{u01}^2). An important issue in growth modeling is the centering of the time measure. Indeed, the interpretation of the intercept estimate is important since it enters into the random part of the model. Centering the time data on the average value of the time variable is a central method used in this regard. Then, the intercept would be easily interpreted as the value of the variable in year = zero.

3. RESULTS AND DISCUSSION

For both Emc and Emint, we run two models. In the base model (M1), the slope of the linear term is considered a fixed coefficient (equation 3 is not considered) and the randomness is assumed only at the intercept level without considering any explanatory variable (X_j). The base model will be used to assess the improvement that occurs by considering a random effect on the rate of change of the variables Emc and Emint and the use of an explanatory variable on the slope equation (the country area, in our case). The second model (M2) considers the full representation (equations 1-3) along with an explanatory variable, which is the country area (area). The variable "area" is calculated as the area of the country divided by the area of Russia to avoid large values. The use of the variable "area" helps show whether the size of the country explains some of the variations in the Emc and the Emint variables. If M2 is better than M1 in terms of model fit, then the variance in the error term e_{ij} would be reduced. The main insights from the results are as follows.

Table 1 shows the covariance matrix parameter estimates and Table 2 shows the fixed effect estimates for both models M1 and M2 and for both variables Emint and Emc.

3.1. G19 Countries Do Differ in Their Rates of Change in Emissions

Table 1 shows that the introduction of randomness in the slope in M2 reduces the residual variance σ^2 significantly for both Emint (from 0.11 to 0.0242) and Emc (from 2.86 to 1.1373). This shows that much of the unexplained variance in the within-subject model (equation 1) can be attributed to the between-subject part (equations 2-3), which supports the use of the multilevel approach in this analysis. In M2, and for both variables Emint and Emc, σ_{u1}^2 and σ_{u0}^2 are statistically significant, indicating that the G19 countries do differ in their initial emissions levels (intercept) but, more important, their emissions' rates of change (slope) are significantly different (σ_{u0}^2 is also statistically significant in the base model M1).

3.2. Emint is Decreasing and Emc is Increasing At a Slower Pace

The base model M1 (Table 2) shows that, on average, Emint has been decreasing in the G19 countries; the rate of change is $(-0.0067 - 2 \times 0.00014 \times \text{year})$, which is negative in the $(-27.5 - 27.5)$ period (data centered on the mean of the years). In contrast, Emc has been increasing; the rate of change is $(0.06 - 0.002 \times \text{year})$, which is positive in the $(-27.5 - 27.5)$ period. However, there is evidence (P-value of the coefficient -0.002 is < 0.0001) that this increase is slowing. M2 shows similar results (Table 2).

Table 1: Covariance matrix estimates (P-values in parentheses)

	Emint				Emc			
	σ^2_{u0}	σ^2_{u01}	σ^2_{u1}	σ^2	σ^2_{u0}	σ^2_{u01}	σ^2_{u1}	σ^2
M2	0.40 (0.0018)	-0.008 (0.013)	0.0003 (0.0019)	0.0242 (<0.0001)	26.98 (0.0018)	0.028 (0.80)	0.0078 (0.0021)	1.1373 (<0.0001)
M1	0.48 (0.0014)	NA	NA	0.11 (<0.0001)	28.127 (0.0014)	NA	NA	2.86 (<0.0001)

Table 2: Coefficients estimates (P-values in parentheses)

	Emint					Emc				
	γ_{00}	γ_{01}	γ_{10}	γ_{11}	β_{2j}	γ_{00}	γ_{01}	γ_{10}	γ_{11}	β_{2j}
M2	0.44 (0.038)	1.40 (0.018)	0.0026 (0.63)	-0.04 (0.008)	-0.0001 (<0.0001)	6.51 (0.0008)	6.22 (0.17)	0.057 (0.053)	0.014 (0.86)	-0.002 (<0.0001)
M1	0.75 (0.0002)	NA	-0.0067 (<0.0001)	NA	-0.00014 (0.0062)	7.96 (<0.0001)	NA	0.06 (<0.0001)	NA	-0.002 (<0.0001)

3.3. The Reduction Rate of Emint is Higher in Countries That Began with High Emint: This is Not the Case for Emc

The covariance estimate for Emint (Table 1) is negative and statistically significant ($\sigma^2_{u01} = -0.008$, $P = 0.013$), indicating that countries that started in the period with high initial Emint tended to have lower slopes. As such, countries that started with higher Emint have achieved greater reduction in their energy intensity over time. In view of the almost one-to-one relation between energy use and CO₂ emissions, one possible explanation for this finding is that the potential for energy efficiency and diversification is higher in less energy intensive economies. Another potential explanation is a change in the energy mix to less polluting sources. For Emc, the covariance σ^2_{u01} is not significant, indicating that the initial level of Emc and its change during the study period are not strongly correlated.

3.4. Countries with More Area have Higher Emint and more Reduction Over Time; This is Not the Case for Emc

Model M2 shows that the variable “area” has significant effects on Emint growth; the main effect ($\gamma_{01} = 1.4$, $P = 0.018$) and the interaction term ($\gamma_{11} = -0.04$, $P = 0.008$) are significant. The main effect ($\gamma_{01} = 1.4$) shows that countries with more area have higher energy intensity. There are several reasons that support this finding. For example, economies with larger areas would emit more emissions since they would need more transportation for products and services, which would require greater energy use and, consequently, generate more emissions. Similarly, larger areas require extensive transmission networks with more power losses and corresponding emissions. The interaction term coefficient ($\gamma_{11} = -0.04$) shows that with time, countries with larger areas tend to reduce their Emint more than smaller countries. The effects of the variable area are not significant in the case of Emc.

3.5. Emint and Emc Country Deviations

As shown in Table 1, for both Emint and Emc, the slope variance, σ^2_{u1} , is significant, indicating that the G19 countries do differ in their rates of change in emissions. Table 3 shows the deviation for each country with respect to the overall slope γ_{10} . A negative deviation indicates more improvement compared to the sample: more reduction in Emint since Emint is decreasing in the sample or a smaller increase in Emc since Emc is increasing in the

Table 3: Country deviations from the overall mean slope (coefficient of the “year” variable)

	Emint	Emc
ARG	0	0
AUS	0.01382	0.09499
BRA	0.01894	0
CAN	0.01552	0
CHN	-0.0565	0
FRA	0	-0.1113
GBR	-0.0143	-0.133
GER	0	-0.0848
IDN	0	0
IND	0.00927	0
ITA	0	0
JPN	0	0
KOR	0	0.1711
MEX	0	0
RUS	0	0
SA	0	0
KSA	0.01516	0.1966
TUR	0	0
USA	0	-0.0736

sample. Non-significant values are reported equal to zero for convenience.

For Emint, China appears to have achieved the highest reduction compared to the average slope, while Brazil has a greater upward deviation. For Emc, Saudi Arabia followed by Korea, have the highest deviations above the average slope, while Great Britain, followed by France and then Germany, has the highest deviation below the average slope. China has no significant deviation from the average slope.

4. CONCLUSION

Emc and Emint are among the main metrics used to report emissions levels. Comparing their varying trends is useful in benchmark analysis. Indeed, in our study of the G19 countries, we offer evidence that such metrics show different trends for the same group of countries both at the sample and the individual level. There is statistical evidence that Emint has been decreasing in the G19 countries and that this reduction is higher in advanced economies among the G19. There is also evidence that while Emc has been decreasing, emissions growth is decelerating.

Therefore, used together Emint and Emc offer better insight into environmental performance measured through these metrics. Indeed, the effort to mitigate climate change through agreements on emissions targets and the allocation of reduction targets among countries is a sensitive issue. Thus, designing some “fair” allocation mechanisms requires more understanding of the evolution of emissions using different metrics along with the main drivers of emissions. In this note, we show that certain variables, like the area of a country, have an impact on emissions. From this standpoint, neglecting the area of the country in any allocation mechanism is likely to have a negative effect on that country. From a methodological perspective, growth curve modeling, which is multilevel modeling, applied to longitudinal data can be helpful in defining the general trend (in time) of the variable under study at the group level; equally important, it shows the deviations of the elements of the sample with respect to the general trend, which is useful in benchmarking analysis. Using such a framework, it appears, for example, that India has higher upward deviation from the average slope in terms of Emint, while its Emc is in line with the average of the group. In contrast, China has achieved the highest reduction in terms of Emint compared to the average of the group, while its Emc has not deviated from the general trend of the G19 countries.

These findings offer several important policy and management implications. The individual deviation from the group mean urges these “poor performers” to investigate the causes of this divergence. The divergence between countries could imply that there is room for cooperative opportunities to reduce CO₂ emissions even further. Such cooperation could take the form of emissions trading and commercial trade to collectively benefit

from those countries that have better capabilities to produce lower energy intensity.

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