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Can natural factors explain any cross-country differences in carbon dioxide emissions?

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This articles examines what role natural factors play in explaining cross-country differences in carbon dioxide emissions. Natural factors mean here differences in the climatic conditions, the availability of renewable and fossil fuel resources and the transportation requirements of countries. While income remains the main variable, regression results show that natural factors contribute significantly to an explanation of cross-country differences in carbon dioxide emissions. Furthermore, drastic differences in natural conditions can lead to substantial differences in predicted emission requirements for individual countries at approximately the same level of income.

Short title: Natural factors and carbon dioxide emissions

Key words: temperature, renewable and fossil resources, transportation

1. Introduction

Many studies have examined the empirical relationship between carbon dioxide (CO_2) emissions and income, as traditionally measured by gross national product (GNP) or gross domestic product (GDP). These studies differ in the functional form as well as in the independent variables employed to explain cross-country differences in CO_2 emissions. For example, while the early pioneering studies such as Grossman and Krueger (1995), Shafik (1994) and Holtz-Eakin and Selden (1995) concentrated on income as the explaining variable and used standard estimation techniques, later studies have taken into account additional explanatory factors such as, for example, income inequality (Ravallion, Heil and Jalan 2000) or have employed more complex econometric estimation techniques (see, for example, Schmalensee, Stoker and Judson 1998; Galeotti and Lanza 1999).

What has been somewhat neglected so far is the question to what extent natural factors can explain any cross-country differences in CO_2 emissions. Natural factors mean here differences in the climatic conditions, the availability of renewable and fossil energy resources and the transportation requirements that could explain such cross-country differences even after controlling for the effect of income. Theoretically, we would expect cold countries to have greater heating requirements and hot countries to have greater cooling requirements, all other things equal. We would expect big countries with higher transportation requirements to have higher emissions than small countries. Similarly, we would expect countries that have access to domestic renewable energy resources to have lower emissions than countries that lack such resources. Finally, countries without major fossil fuel reserves should have lower CO_2 emissions than countries that are rich in such reserves. This is for two reasons: First, because of the emissions generated in the extraction and possibly – for example, in the case of oil – processing of such resources. Second, and probably more importantly, because countries that have lacked historically major domestic fossil fuel reserves have had strong incentives to develop in a less fossil fuel intensive way in order to cut down on energy import costs. The classical example for this is fossil fuel poor Japan.

This short article tries to examine these issues. Apart from a better positive understanding of what determines cross-country differences in CO_2 emissions, this study is also motivated by the role natural factors have played in normative discussions on an internationally just distribution of CO_2 emission rights (see, more generally, also Neumayer 2000). For example, Grubb et al. (1992, p. 314) examine, without endorsing, "reasonable emissions" as one criterion for an internationally just allocation rule. They define a 'reasonable level of emissions for each country' as the 'level that would support a consistent, modest standard of living, *given the national climatic and other conditions* [emphasis added]. Permits would be granted for emissions at this level, but not for those "luxury" emissions in excess of this amount'. The Intergovernmental Panel on Climate Change (IPCC 1995, p. 104) contemplates a similar allocation rule under the heading "basic needs". Such a rule would allow countries 'the right to emit the minimum levels of greenhouse gases needed to meet the basic needs of their citizens (…). It would perhaps be close to the allocation of emission permits according to population, although basic needs could vary from country to country *depending on climate and other matters* [emphasis added]'. As a final example, consider the attempt by Benestad (1994) to construct a formula for just allocation of CO_2 emission rights according to energy needs, including such things as a country's heating and cooling requirements, transportation needs as well as renewable energy sources potential. Since this study examines the relative importance of a number of natural factors explaining cross-country differences in CO_2 emissions, it can also shed some light on the relevance of normative allocation rules that refer to such natural factors.

2. Methodology and data

Variants of the following basic model were estimated:[1]

$$E_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 (Y_{it})^2 + \beta_3 L_i + \beta_4 H_i + \beta_5 A_i + \beta_6 R_i + \beta_7 F_i + \beta_8 T_t + e_{it}$$

E are logged CO_2 emissions per capita, *Y* is logged income per capita, *L* is the lowest average minimum temperature, *H* is the highest average maximum temperature, *A* is the log of the percentage of total land area impacted by human activities, *R* is the percentage of renewable energy sources of total energy use, *F* is the log of combined oil and gas reserves, *T* is a time trend and *e* is a stochastic error term.

The data consisted of a panel covering 1960-1988. The latter date was chosen in order to avoid biases introduced by either awakening policy responses to combat global warming or by the collapse of the Communist system and the drastic falls in CO_2 emission in these countries. Emission and income data were available for 148 countries with a total of 3673 observations. However, the poor availability of data on renewable and fossil energy resources meant that the estimations could use only 106 countries with 2647 observations. Data are missing mainly for very small countries, but also for a few poor developing countries particularly in Sub-Saharan Africa. Note that not all countries have observations over the whole time period.

A fixed effects model could not be estimated as all of the explanatory variables apart from income do not vary over time and would have therefore been dropped. A random effects model avoids this problem, but a Hausman specification test rejected it. Variations of equation (1) were therefore estimated via ordinary least squares (OLS). It is unlikely that more complex estimation techniques would lead to drastically different results. Since Cook-Weisberg tests rejected the hypothesis of constant variance, heteroscedasticity robust standard errors were used throughout.

Per capita CO_2 emissions from fossil fuel burning and cement manufacturing, the dependent variable, is based on the data set used by Shafik (1994). Where necessary, it has been extended using data in Marland, Boden and Andres (2000). Income is measured as real per capita GDP in purchasing power parity taken from the Penn World Table 5.6 (an earlier version of which is described in Summers and Heston 1991). As a proxy for heating requirements a country's lowest average minimum temperature was taken from Harding (1998). Similarly, a country's highest average maximum temperature was taken from the same source as a proxy for cooling requirements. For most country's this source states the climatic conditions in the capital city. For the bigger countries and the ones attractive to tourists, temperatures are given for several cities. In these cases, the simple average was taken. As an alternative proxy for heating requirements, the average number of frost days in winter months as listed in Masters and McMillan (2000) could have been taken as well. However, the absolute value of the Pearson correlation coefficient between a country's lowest average minimum temperature and its average number of frost days is very high (.88). This together with the fact that minimum temperatures were available for more countries made it the preferred choice.

Big countries have higher transportation requirements as goods and people are typically moved over longer distances. However, it would be misleading to simply take a country's total land area as a proxy for its transportation requirements. This is because often huge parts of big countries are sparsely inhabited, if at all. CIESIN (2001) provides data on the percentage of total land area impacted by human beings, that is either urbanized (as indicated by lights at night) or used for agriculture. This provides a good proxy to the share of total land area inhabited by human beings, the idea being that people live in urban areas or where agriculture takes place. The proxy for a country's transportation requirements is then the share of total land area impacted by human activities (data for land area taken from World Bank 2000).[2]

Renewable resource use was measured in per cent of total energy consumption from all sources in 1997, taken from WRI (2000). Ideally, it would have been desirable to employ panel data for the sample period. Unfortunately, such data are unavailable so that the 1997 data, the only ones available, were simply taken for the whole period 1960-1989. While this leads to biased estimates, nothing can be done about it. Renewable resources encompass hydroelectric, geothermal, solar and wind resources as well as “fuel and waste”, which comprise biomass and animal products, gas/liquids from biomass, industrial waste, and municipal waste. Fuel and waste renewable energy sources in the form of biomass are much used by poor developing countries. While “fuel and waste” partly create CO_2 (and other greenhouse gas) emissions, they are usually not included in CO_2 emission data, which derive exclusively from estimates of fossil fuel burning and cement manufacturing. In as much as fuel and waste substitute for fossil fuels, which would have otherwise been used, their consumption should lead to lower CO_2 emissions thus measured. In this respect, they do not differ from other substitute renewable energy sources that entail few CO_2 emissions, such as hydroelectricity. It is therefore correct to include them for the purposes of explaining cross-country CO_2 emissions here.

Fossil fuel reserves were measured as the log of British Thermal Units (BTUs) per capita proven crude oil and natural gas reserves in 1993, taken from Gallup and Sachs (1999), with WRI (1996) as the original source. As with the renewable resource variable, it would have been desirable to use panel data from the period 1960 to 1988, but such data are not readily available.

3. Results

Table 1 shows the results of OLS estimation, starting with a model that includes only income as explanatory variables. This model is augmented by each of the additional explanatory variables in isolation. Finally, the full model is estimated, excluding the *H* variable for reasons explained further below.

< Insert table 1 here >

Regression 1 reproduces the typical Environmental Kuznets Curve (EKC) result. CO_2 emissions per capita rise first with higher GDP per capita, but at a decreasing rate, until a threshold is reached after which emissions fall. Note that in accordance with earlier studies (for example, Shafik 1994) the turning point, while theoretically existent, is way beyond the relevant range of GDP per capita so that throughout the sample per capita CO_2 emissions are predicted to increase with higher income levels.

Regression 2 adds *L* to the explanatory variables. It has the expected sign and is highly statistically significant. The lower is the lowest average minimum temperatures the higher are CO_2 emissions per capita. Regression 3 adds *H* instead. Unexpectedly, the estimated coefficient is significantly negative indicating that the higher is the highest average maximum temperatures the lower are CO_2 emissions per capita. Regressions 4 to 6 add *A*, *R* and *F* respectively. All estimates have the expected signs and are strongly significant. A larger land area impacted by human activities leads to higher CO_2 emissions per capita. A higher share of renewable energy sources and lower per capita reserves of oil and gas lead to lower CO_2 emissions per capita.

The estimated coefficient for *H* presents a puzzle. Hotter countries are estimated to have lower instead of higher emissions. How can this be explained? Probably the reason for this counter-intuitive result is a combination of hotter countries being poorer on average than less hot countries and the demand for cooling being a luxury good. That the hot countries close to the equator on average have lower GDP per capita than countries in more temperate climate zones is a well documented fact (see, for example, Gallup and Sachs 1999; Masters and McMillan 2000). Table 2 lists the partial Pearson correlation coefficients of the variables used, which confirms this result. It can be seen that logged GDP per capita is highly negatively correlated to the lowest average minimum temperature (-.52) and to the highest average maximum temperature (-.41), indicating that colder and less hot countries have higher incomes. Furthermore, whereas heating represents a necessity good in cold climates with consumers having few alternatives if they do not want to freeze to death, cooling is likely to be a luxury good in hot climates. Those who can afford will have air conditioning and other cooling devices, those who cannot will not. Supportive of this hypothesis is the fact that the sign of the coefficient of *H* changes to positive in regression 3 if the sample is restricted to observations with a GDP per capita greater than US$5000 (results not reported). The small relevance of adding the maximum average temperature as an explanatory variable can also be appreciated by the fact that R^2 rises only from .7657 to .7738 after *H* becomes included in the estimated equation.

<Insert Table 2 here>

Because of the unexpected sign of the *H* variable in the full sample, regression 6 in table 1 estimates the full model excluding *H*. As can be seen, all variables keep their expected signs and remain statistically significant. Also, coefficients and their significance do not change dramatically in comparing regression 6 with the other five regressions. This might be interpreted to mean that multicollinearity, which could be a problem looking at the partial correlation coefficients in table 2, is actually not so much of a problem.

How relevant are natural factors in explaining cross-country differences in emissions? The results in table 1 suggest that they are of relevance, but limited so. There are two ways to see this. First, note that the improvement in R^2 due to including the natural factor variables is relatively small: It rises from .7657 to .8349, that is by about 9 per cent. Second, to allow comparison of the estimated coefficients, which are held in different units, the last column in table 1 reports standardised coefficients. These indicate by how many standard deviations the explained variable changes for a one standard deviation increase in one of the explanatory variables. It can be seen that the standardised coefficients for the income variables are much higher than the ones for the natural factor variables. In other words, income is a much more potent predictor of cross-country differences in emissions than natural factors are. Income is the main explanatory variable to which natural factors merely add some explanatory power.

Belsley, Kuh and Welsch (1980) suggest excluding observations as outliers that have both high residuals and a high leverage. Applying their criterion together with their suggested cutoff point would exclude another 188 observations.[3] Table 3 repeats the estimation of the pure income and the full model using the restricted sample. It can be seen that the estimated coefficients in regressions 7 and 8 do not change dramatically in comparison to regressions 1 and 6. Only *F* becomes insignificant, which sheds some doubt on whether cross-country differences in fossil fuel reserves have any impact on differences in emissions. Importantly, the major result that income is the main explanatory variable of cross-country differences in CO_2 emissions remains valid if the outliers are excluded.

<Insert Table 3 here>

4. Implications and concluding observations

Can natural factors explain any cross-country differences in CO_2 emissions? Yes, they can, but only to some limited extent. A country's income level is and remains the main explanatory variable. Countries with, for example, colder climates or a lower availability of renewable resources can claim that they have higher fossil fuel requirements than comparable countries with warmer climates or higher availability of renewable resources. However, given that an international allocation of emission rights will have to deal with the fact that countries have hugely different income levels and that countries at different income levels have hugely different emissions per capita, natural factors are bound to play a minor role only.

This does not mean that for individual countries natural factors cannot play an important role in determining their CO_2 emissions. The cold, big, fossil fuel rich, but renewable resource poor Soviet Union had of course higher emission requirements than warm, comparatively small, fossil fuel poor, but renewable resource rich Ethiopia, for example. To see the impact of natural factors, assume for a moment that both countries were at the same income level, say, the sample mean in 1997, which is US$5233. The Soviet Union would then have predicted per capita CO_2 emissions of 2.97 metric tons, whereas Ethiopia would have .53 metric tons per capita emissions. The Soviet Union emissions would therefore be almost six times higher than Ethiopia's emissions. This dramatic difference would entirely be due to differences in natural factors. Countries with drastically disadvantageous natural conditions will therefore demand higher emission rights than countries at roughly the same income levels and rightly so if one thinks that natural factors should impact upon a just allocation of such rights.

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NOTES

[1] Inclusion of logged income in cubic form was tried as well. However, it was left out because its inclusion rendered all income variables insignificant in some estimations due to strong multicollinearity.

[2] A country's total length of road network, both paved and unpaved (taken from International Road Federation 2000), failed as an alternative proxy variable because of strong positive correlation with GDP per capita: rich countries tend to have more roads, but there is no reason why richer countries should have higher natural transport requirements.

[3] The criterion is to exclude an observation if its so-called DFITS is greater than twice the square root of (k/n), where k is the number of independent variables and n the number of observations. DFITS is defined as the square root of ($h_i/(1-h_i)$), where h_i is an observation's leverage, multiplied by its studentized residual.

Table 1. Regression results, full sample.

Regression	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Stand. coeff.**
Constant	-11.19	-20.50	-13.63	-14.44	-15.17	-15.17	-22.28	
	(2.65)	(5.55)	(3.24)	(3.79)	(3.75)	(3.75)	(6.54)	
Y (lnGDP)	2.47	2.72	2.52	1.36	2.85	2.85	2.01	1.20
	(8.74)	(10.60)	(7.78)	(4.64)	(10.57)	(10.57)	(8.13)	
Y^2	-.06	-.09	-.07	-.01	-.07	-.09	-.06	-.53
	(3.65)	(5.88)	(3.94)	(.51)	(4.15)	(5.31)	(3.74)	
L (mintemp)		-.04					-.03	-.16
		(16.56)					(11.83)	
H (maxtemp)			-.02					
			(8.11)					
R (renewable)				-.01			-.01	-.19
				(16.10)			(13.04)	
F (lnfossil)					.03		.01	.04
					(9.06)		(3.80)	
A (lnarea)						.11	.06	.06
						(10.40)	(6.48)	
T (time trend)	-.003	.002	-.001	.002	-.002	-.002	.004	.02
	(1.41)	(1.25)	(.59)	(1.07)	(1.14)	(1.11)	(2.80)	
N	2647	2647	2647	2647	2647	2647	2647	
R^2	.7657	.8083	.7738	.8083	.7762	.7862	.8349	

Dependent variable is E ($lnCO_2$); OLS estimation 1960-1988 panel; absolute t-values in parentheses; heteroscedasticity-robust standard errors

Table 2. Pearson correlation coefficients.

	E ($lnCO_2$)	Y	L	H	R	F
Y (lnGDP)	.88					
L (mintemp)	-.62	-.52				
H (maxtemp)	-.42	-.41	.48			
R (renewable)	-.68	-.59	.50	.20		
F (lnfossil)	.28	.23	-.15	.12	-.24	
A (lnarea)	.10	-.02	-.26	-.06	-.04	.36

Table 3. Regression results, restricted sample excluding outliers.

Regression	**7**	**8**	**Standardised coefficients**
Constant	-12.59	-22.37	
	(3.77)	(8.86)	
Y (lnGDP)	2.20	1.39	.87
	(10.38)	(7.81)	
Y^2	-.05	-.02	-.20
	(3.55)	(1.83)	
L (mintemp)		-.02	-.14
		(17.38)	
R (renewable)		-.01	-.01
		(20.85)	
F (lnfossil)		.00	.00
		(.31)	
A (lnarea)		.09	.09
		(12.86)	
T (time trend)	-.001	.006	.03
	(.91)	(4.92)	
N	2459	2459	
R^2	.8350	.9021	

Dependent variable is E ($lnCO_2$); OLS estimation 1960-1988 panel; absolute t-values in parentheses; heteroscedasticity-robust standard errors