Internal and External Sources of Environmental Impacts:

A Comparative Analysis of the EU with Other Nation Groupings

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Abstract

We systematically analyze the driving forces behind a diversity of national environmental impacts (the "ecological footprint," and the emissions of ozone depleting substances, carbon dioxide, and methane), with an eye toward determining whether the patterns in European Union (EU) nations are characteristically different from other nations. We use the STIRPAT model, a stochastic version of the IPAT model, as our analytic tool. STIRPAT allows for a more precise specification of the relationship between driving forces and impacts than other widely used modeling techniques. We find that national environmental impacts of all types are proportional to population size, indicating that population is a major driving force of environmental change. We find that per capita GDP monotonically increases all types of impacts examined, except the emission of ozone depleting substances, where emissions begin to drop as per capita GDP moves beyond approximately US$ 13,000. Overall, the results regarding affluence suggest that development is likely to further exacerbate, rather than alleviate, environmental problems. We also find that EU nations differ from other nations in methane emissions and in ecological footprints (specifically the arable land component of the footprint). EU nations have lower methane emissions and higher footprints than other nations, controlling for other factors. These results suggest that EU nations externalize their environmental impacts, by importing resources.

Introduction

The cumulative evidence from our ongoing research program has demonstrated that population and affluence (per capita GDP) are the primary determinants of a wide variety of national environmental impacts (Dietz and Rosa 1997; Rosa, York, and Dietz 2001,2002; York, Rosa, and Dietz 2001a,b,c, 2002). We have tested the robustness of this basic finding by introducing a variety of other factors theoretically predicted to shape environmental impacts. In general we have found that for some impacts climate, urbanization and age structure of the population have an effect, but for all impacts we have examined, other factors, such as state environmentalism, political rights, civil liberties, and development of the service economy have no effect (Rosa, York, Dietz 2001; York, Rosa, and Dietz 2001b,c). Even where other factors have some effect population and affluence are key to explaining impacts; they alone explain the vast majority of cross-national variance in all types of impacts we have examined.

Here we refine our approach to look for effects that are specific to nations in the European Union (EU). We re-run analyses from our previous work (Rosa, York, and Dietz 2002), to assess whether EU nations conform to the general pattern of other nations with particular attention to the effects of population and affluence on impacts. Furthermore, we consider the relationship between internal impacts (those generated within national borders) and external impacts (those generated beyond national borders, but for national consumption).

Analysis

Global environmental change, the conceptual rubric that comprises the wide variety of ecological threats of current concern (land and ocean transformations, alterations in biogeochemical cycles including the widespread dispersal of persistent pollutants, and biotic changes including deforestation and species losses or invasions), is generally agreed to consist of two complementary domains: cumulative effects (effects that are local in domain but so widely replicated that in sum they have global consequences – e.g. deforestation) and systemic effects (effects that occur on large spatial scales or alter the function of large systems – e.g., ozone depletion, climate change) (Talbot 1989; Turner et al. 1991).

We use as indicators of systemic environmental impacts emissions of carbon dioxide (CO_2), methane (CH_4), and ozone depleting substances (ODS), due to their effects on atmospheric systems (Houghton et al. 2001; Vitousek et al. 1997).[†] We use as an indictor of cumulative effects a measure rapidly growing in scientific acceptance, the “ecological footprint” (EF).[‡]

[†] CO_2 is measured in thousands of metric tons of emissions from fossil fuel combustion and industrial processes, including cement manufacturing. CH_4 is measured in thousands of metric tons of emissions from solid waste, coal mining, oil and gas production, wet rice agriculture, and livestock. ODS includes chlorofluorocarbons (CFCs), halons, other fully halogenated CFCs, carbon tetrachloride, methyl chloroform, HCFCs, and methyl bromide and is measured in metric tons of ozone depleting potential. CO_2 data are for 1996 from WRI (2000). CH_4 data are for 1991 from WRI (1996). ODS data are from Prescott-Allen (2001). The year for ODS varies between cases, although for the vast majority of nations it is between 1996 and 1998. In a few cases the data are for earlier years. The ODS data represent consumption, except for in a few cases where production is used as a proxy for consumption. To control for any confounding effects in the ODS analysis we include a dummy coded control variable indicating whether the measure is for production or consumption.

[‡] For a complete description of the methodology used to calculate the EF, see Wackernagel et al. 1999. The EF is calculated using a trade balance approach to estimate national consumption. Data used in this analysis are from Wackernagel et al. (2000). Despite its broad acceptance as a composite impact measure, the EF is not without criticism (See, for example, *Ecological Economics* 32:341-394, 2000). Nevertheless, the EF is especially apt for the types of analyses presented here because it is one of

The EF is the most widely accepted of an emerging suite of measures that attempt to place diverse environmental impacts into a common metric. It is based upon the idea that land is fundamental to the three functional benefits provided to humans by the environment: space, products and services, and a sink for wastes. Productive land is, therefore, a realistic proxy for the natural capital and services provided by the environment. The EF of a nation is calculated by "adding up the areas (adjusted for their biological productivity) that are necessary to provide us with… the ecological services we consume" (Wackernagel et al. 1999). The EF represents the amount of biologically productive space at world average productivity, measured in hectares (ha), that it would take to support the resource consumption of a given nation.[§] The EF, therefore, allows comparison across types of impacts by converting all impacts into a common metric (land area). Different components make up the total EF. The forest, grazing land, arable land, and fishing ground EFs are the amount of land or water area that would be required to produce, respectively, the forest products, grazing animal products, crops, and seafood a nation consumes. The built-up area EF is the amount of developed land within a nation. We examine separately the five component EF land demands – forests, arable land, grazing land, fishing ground, and built-up area – and the combination of these components, the total EF.

Our assessment is framed by the well-known I=PAT formulation—called the Third Law of Human Ecology by one ecologist (Hardin 1993) and the redoubtable triad by another ecologist (Myers 1997)—where total environmental impacts (I) are a multiplicative function of population (P), per capita consumption or affluence (A), and impact per unit of consumption or technology (T).[¶] As an accounting equation, the I=PAT formula does not lend itself to straightforward hypothesis testing and it assumes *a priori* that the effects of P, A and T on I are strictly proportional.

To address these limitations we have reformulated the I=PAT formula into stochastic form, calling it STIRPAT (<u>ST</u>ochastic estimation of <u>I</u>mpacts by <u>R</u>egression on <u>P</u>opulation, <u>A</u>ffluence, and <u>T</u>echnology).[**] The STIRPAT formula, a modified version of the I=PAT formula, is:

$I_i = aP_i^bA_i^cT_i^de_i$

Whereas the original I=PAT formula assumes proportionality, that $a=b=c=d=e_i=1$, the STIRPAT model treats these as parameters to be estimated. For ease of estimation all variables are converted to natural logarithms, and T is included in the error term since appropriate direct measures of technology (which represents impact per unit of consumption) are lacking and any specific indicator is highly disputed. Additionally, we include the square of the log of per capita GDP (centered before squaring by subtracting the logarithmic mean to avoid problems with

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the few tools that provide an integrated resource accounting, because it is consistent with thermodynamic principles, and because it reveals the impacts to natural capital from human activity.

[§] The component EF measures include a weighting system to take into account the fact that different types of land vary in productivity. The EF for each type of land is scaled to its productivity relative to the worldwide average productivity of all land (including water). For example, arable land is more productive than other types of land, therefore, an amount of consumption requiring one hectare of arable land would have an EF larger than one hectare, reflecting the productivity of arable land relative to the average productivity of all land on Earth. Built-up land is treated as arable land.

[¶] Details of the formula and its history can be found in Chertow (2001) and Dietz and Rosa (1994).

[**] This model has previously been applied to the analysis of national CO_2 emissions (Dietz and Rosa 1997). Population and affluence were found to explain most of the cross-national variation. The model was originally developed by Dietz and Rosa (1994), but, due to its stochastic reformulation, it was later given the name STIRPAT (Rosa and Dietz 1998).

collinearity) to allow for an assessment of a non-monotonic relationship between affluence and impact.[††] We further add a dummy coded variable (1-0) indicating whether a nation is a member of the EU, to assess whether there is an "EU effect" on impacts.[♦♦] These modifications yield the following model where the parameters a, b, c, d, f, and e are to be estimated:

$$\ln(I) = a + b(\ln(P)) + c(\ln(A)) + d(\ln(A))^2 + f(EU) + e$$

The constant "a" scales the model, "b," "c," "d," and "f" are the exponents of the independent variables and "e" is the error term.

For the driving force variables we use the population (P) of nations and the per capita GDP (converted to purchasing power parity) of nations as our indicator of affluence (A).[‡‡] The sample size varies slightly between analyses due to data availability, but in all cases the sample includes nations that contain the vast majority (at least 95%) of both the world's population and its economic output.

Table 1 here

The findings from the regression models for each analysis are presented in table 1.[§§] If the quadratic of per capita GDP was not significant at the .05 alpha level, we only present results from the log-linear model where the quadratic is excluded from the analysis. Furthermore, we only present models including the EU variable if it was significant at the .05 level. The coefficient for population can be interpreted as the percentage change in impact from a one-percent change in population — similar to an elasticity measure in economics. The coefficient for affluence can be interpreted in the same manner when the quadratic is not included in the model. The antilog of the coefficient for the EU variable is the impact multiplier for EU nations relative to other nations.

The population coefficient in all models is positive and significantly different from 0, but is never significantly different from 1.0, indicating that population consistently has a proportional effect on **all nine types of impacts** examined. This suggests that continued population growth will exacerbate both cumulative and systemic impacts.

The affluence effect is, likewise, significant in all models, but the relationship varies with type of impact. Affluence has a positive monotonic effect within the range of observations on seven of the nine impacts examined; forest EF and ODS emissions are the exceptions. ODS emissions increase with affluence until a maximum of US$13,000 per capita is reached, after which emissions decline. When starting at very low affluence levels the forest EF declines with economic growth until the minimum of US$2,400 per capita is reached, after which impact rises rapidly. For CO_2 emissions and for the total EF the quadratic of affluence is significant, indicating that the relationship is not linear in log form. However, both impacts monotonically increase within the range of

[††] In this and related analyses we have explored the use of terms that are non-linear in the log of population but find that population has a directly proportional effect, so the linear in log term suffices to model its effects.

[♦♦] We include all EU nations except Luxembourg, for which sufficient data are not available. The fourteen EU nations in the sample are Austria, Belgium, Denmark, Finland, Germany, Greece, Spain, France, Ireland, Italy, Netherlands, Portugal, Sweden, and the United Kingdom.

[‡‡] We use data matching the year of the dependent variable where available and substitute data for other years, or interpolate (e.g., average 1995 and 1997 values), where necessary. Data are from (Wackernagel et al. 2000; WRI 1996, 1998, 2000).

[§§] We have also estimated models using least absolute values regression and a robust regression based on Huber weighting followed by Biweighting and have estimated standard errors based on the Huber/White robust method. None of these alternative statistical methods yields results substantively different from those reported here.

observations (for CO_2 emissions the projected maximum occurs at US$34,800, for the total EF the quadratic coefficient is positive indicating impact continually escalates with economic growth).

Our findings for the most part embarrass a theoretical expectation from neo-classical economics, called the "environmental Kuznets curve," after economist Simon Kuznets (1955), that predicts an inverted U-shaped relationship between environmental impacts and national income.[¶¶] With the exception of the supportive results for ODS emissions (but where a $13,000 per capita GDP is well beyond the foreseeable reach of the majority of nations), our findings contradict that prediction for global impacts.

For three impacts there is an "EU effect." EU nations have 48% lower CH_4 emissions than other nations (the antilog of -.65 is .52, indicating EU nations an impact that is 52% of non-EU nations – i.e., 48% less) controlling for population and affluence. However, EU nations have a 39% higher total EF and a 40% higher arable land EF relative to other nations. This finding has important implications for assessing sustainability. The EF, which is based on consumption, suggests that the EU has greater environmental impacts than other nations. Whereas, a production based indicator, CH_4 emissions, suggests the EU does better than other nations. These results suggests that EU nations may in part curb environmental problems by externalizing them – i.e., importing resources so that impacts occur elsewhere. This finding points to the importance of what Ehrlich and Holdren (1971) call the "Netherlands Fallacy" – the flawed assumption that impacts are geographically conterminous with the populations that generate them. This finding, coupled with the failure to find an EKC for most impacts, strongly challenges claims that developed nations in general and EU nations in particular are further along the road to sustainability than other nations.

Together population and affluence, accounting for between 60% and 95% of cross-national variance, clearly appear to be important drivers of environmental impacts. Lacking consistent definitions and widely available measures, our analysis does not estimate the effects of cross-national variation in institutions, culture, political economy, technological stock or other factors that are plausible mediators of the effects of population and affluence. However, as noted above, we have run models including indicators of some of these factors and found then to have only minor effects or no effects whatever. Future explorations of these factors may further increase our understanding of anthropogenic drivers and of the possibilities for reducing environmental impact.

Conclusion

Our results suggest that population and affluence are key determinants of national environmental impacts. Both factors typically increase impacts monotonically, with few exceptions. European Union nations in general do not differ dramatically from the overall pattern, although they tend to have somewhat higher ecological footprints and lower methane emissions relative to other nations, controlling for population and affluence. The specific features of the EU that may account for these differences remain to be explored. Overall, our findings suggest that economies cannot grow their way out of ecological problems, nor is "Europeanization" likely to lead to

[¶¶] The theory behind the environmental Kuznets curve (EKC) and major empirical findings are summarized in Nordström and Vaughan (1999) and Stern (1998). Empirical tests of the EKC often use a model simpler than STIRPAT, where the effects of population are typically assumed to be strictly proportional. The literature suggests that the EKC is more likely found for local impacts than for the types of global impacts we examine here.

sustainability. Serious efforts to achieve sustainability must focus on the key drivers of impacts: population and affluence.

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Table 1. OLS regression results for ecological impact indicators regressed on population, per capita GDP, the quadratic of per capita GDP (the quadratic of affluence was centered before squaring), and European Union status (1-0). All variables except EU status are in log form.. If the quadratic of affluence or EU status were not significant at the .05 alpha level, then results are presented for a model with only the significant variables included. The "Max/Min" column shows the per capita GDP (US$) turning point for impact if the relationship is non-monotonic and indicates whether the turning point is a maximum or a minimum. The two-tailed significance tests are for the null hypothesis that the coefficient equals zero. *** p<.001, ** p<.01, * p<.05 (two-tailed test)

Impacts	**Population**	**Affluence**	**Affluence^2**	**EU** [% diff.]	**Constant**	**Max/Min**	**R^2**	**N**
Systemic								
ODS[a]	1.07*** (0.08)	0.67*** (0.11)	-0.31** (0.10)		-17.18*** (1.73)	$13,000 Maximum	0.73	131
CO_2	1.02*** (0.05)	1.48*** (0.07)	-0.33*** (0.07)		-18.63*** (1.03)	$34,800[b] Maximum	0.85	146
CH_4	1.04*** (0.05)	0.40*** (0.08)		-0.65* [-48%] (0.28)	-6.81*** (0.81)		0.76	147
Cumulative								
Total EF	0.99*** (0.02)	0.37*** (0.03)		0.33** [+39%] (0.11)	-2.50*** (0.41)		0.95	142
Forest EF	0.99*** (0.07)	0.26** (0.09)	0.30*** (0.09)		-3.86** (1.42)	$2,400 Minimum	0.60	142
Grazing EF	0.94*** (0.04)	0.64*** (0.06)			-5.51*** (0.85)		0.81	142
Arable land EF	1.04*** (0.02)	0.31*** (0.04)		0.34** [+40%] (0.13)	-3.77*** (0.50)		0.94	142
Fishing Ground EF	1.00*** (0.09)	1.18*** (0.11)			-13.85*** (1.73)		0.63	142

Built-up area EF	1.02*** (0.07)	1.33*** (0.09)			-14.60*** (1.33)		0.77	142

[a] A binary (0-1) control variable was included in this model to control for whether the ODS measure was for production (1) or consumption (0). The coefficient for this variable is 1.33**. The removal of this variable from the model does not substantively alter our results.

[b] This maximum occurs beyond the range of observations and is, therefore, a projection.