An econometric analysis of ecological footprint determinants: implications for sustainability

Mariano Torras and
Sviatoslav A. Moskalev*

Department of Accounting, Finance and Economics,
School of Business,
Adelphi University,
Garden City, NY 11501, USA
E-mail: torrasm@adelphi.edu
E-mail: moskalev@adelphi.edu
*Corresponding author

James K. Hazy and
Allan S. Ashley

Department of Management, Marketing and Decision Sciences,
School of Business,
Adelphi University,
Garden City, NY 11501, USA
E-mail: hazy@adelphi.edu
E-mail: ashley@adelphi.edu

Abstract: Most research on the impact of income and other socioeconomic variables on the environment focuses on specific local environmental effects and not on the broader sustainability picture. We seek to fill the apparent gap in the literature, exploring whether and the extent to which income, economic openness, income inequality and the distribution of power influence sustainability. We employ ecological footprint data and from it derive a sustainability indicator, the ecological deficit. Using econometric analysis, we test the effects of our explanatory variables on the ecological deficit. While we find that economic openness appears to run counter to the goal of sustainability, the results for the other variables are more ambiguous and inconclusive.

Keywords: ecological footprint; ecological deficit; sustainability; environmental effects; biocapacity.

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Biographical notes: Mariano Torras is an Associate Professor of Economics at Adelphi University. His research and teaching are in the areas of development, ecological and institutional economics. He specialises on economic and social measurement and is particularly interested in how ecological and social change bears on the general question of well-being and progress. He is a Visiting

Fellow at the Institute for Latino Studies at Notre Dame University and Research Scholar at the Political Economy Research Institute in Amherst, MA. He is also the recipient of the 2004 Maestro Jesús Silva Hérzog Award from UNAM in Mexico City.

Sviatoslav A. Moskalev is an Assistant Professor of Finance at Adelphi University. He joined Adelphi University in 2005 after receiving his PhD in Finance from the Terry College of Business at the University of Georgia in Athens, GA. His research interests are in the areas of international corporate finance with emphasis on foreign direct investment, cross-border mergers and acquisitions and cross-border joint ventures and law. While at Adelphi, he has been teaching courses in corporate and international finance, microeconomics and international business.

James K. Hazy is an Associate Professor of Management at the Adelphi University School of Business in Garden City, NY. He has published over 20 articles and book chapters and is a Coeditor of the recent book: *Complex Systems Leadership Theory: New Perspectives from Complexity Science on Social and Organizational Effectiveness*. He obtained his Doctoral degree in Human Resource Development from the George Washington University and his MBA in Finance from the Wharton School of the University of Pennsylvania. Before joining Adelphi University, he was a Senior Executive with the multinational firms AT&T and Ernst & Young.

Allan S. Ashley is a Professor of Management and Decision Sciences and a Chair of the Department of Management, Marketing and Decision Sciences at Adelphi University School of Business in Garden City, NY. He has published articles in the areas of decision sciences, operations, total quality management and ethics. He has also published two books in the area of mathematics for managers and total quality management. He received his PhD in Operations Research and Management from Polytechnic Institute of Brooklyn (n/k/a Polytechnic Institute of New York University).

1 Introduction

General concern over the state of our natural environment has grown significantly over the past three decades. No doubt as a consequence, environmental matters have increased in importance in economics research. One of the more frequent topics addressed in the literature is the environmental Kuznets curve (EKC) hypothesis (see e.g. Bagliani et al., 2008; Dinda, 2004; Grossman and Krueger, 1995; Selden and Song, 1994; Spangenberg, 2001), which posits a relationship between a country's income and its environmental quality. While there have been numerous criticisms of the hypothesis, the one that is, important to the present study is the claim that EKC oversimplifies environmental problems by placing too much emphasis on income as an explanatory variable.

We are interested in factors other than income that influence environmental outcomes, but we also go beyond the EKC's almost exclusive focus on environmental damage. While the policy implication of the EKC is that growth may be the solution to environmental problems, much of the sustainable development literature suggests that continued growth is itself not necessarily sustainable (Daly, 2009; Wilson et al., 2007).

Therefore, instead of considering different classes of local environmental damage in this paper, we explore possible factors that determine whether a country is on a sustainable course.

Of the numerous indicators of sustainability that have been introduced over the past 25 years, we focus in this paper on the ecological footprint[1] because of the availability of international panel data suitable for the econometric analysis that we conduct. We also use the data to compute ecological deficits for individual countries to be used as the sustainability indicator in our analysis. Our paper is an attempt to explain ecological footprints and ecological deficits. We go beyond the seemingly obvious link with income, testing also for the effects of economic openness, income inequality and power distribution. Given how little that is, understood about ecological footprints and ecological deficits, we have no strong *a priori* beliefs about the nature of these effects. We therefore consider our study to be more in the nature of an exploratory analysis.

2 Sustainability and the ecological footprint

One might argue that discourse over the past 25 years on the question of sustainable development has produced more heat than light. There is still no widely-accepted interpretation of what the term means. Ideas run the gamut from GDP growth that is, sustainable to substantial reductions in global resource use and simpler living. Extensive surveys of the literature and evaluation of the controversies around sustainable development include Lélé (1991), Pezzoli (1997) and Wilson et al. (2007). While these and other authors find sustainable development to be ambiguous if not oxymoronic, it is our view that much of the controversy originates in what exactly 'development' means. Unlike growth, which is a quantitative concept, development implies a qualitative improvement, which may be subject to myriad subjective interpretations.

Sustainability, in contrast, seems somewhat easier to define, and is what we emphasise in this paper. Most would agree that the term implies inter-generational equity of some form, and very few would argue that, so defined, sustainability is not desirable to some degree. Given the relatively rapid global environmental changes, we have experienced over the last two decades (Millennium Ecosystem Assessment, 2003), it is our contention that sustainability can no longer be taken for granted and that, to the extent that we value the well-being of future generations, we must work to reverse some of the more troubling environmental trends.

Martinez-Alier (1995) distinguished the term *ecological distribution* to describe the degree to which certain types of environmental damage create winners and losers, and distinguishes among three types: social, spatial and temporal ecological distribution. By social ecological distribution, he refers to the distribution of environmental damage within a local, regional or national population. This is related to conflicts over environmental discrimination and environmental justice (see e.g. Lambert and Boerner, 1997; Ong and Blumenberg, 1993; Vasquez, 1993).

Spatial ecological distribution expresses how environmental damage is distributed across – rather than within – specific populations, such as where ecologically-unequal trade relations in which poor countries degrade their environments in order to remain 'economically-competitive' (i.e. produce at a low-market price). Through this 'leakage effect' (see e.g. Gan and McCarl, 2007; Nogueira Ramos, 2007; Peters and Hertwich, 2006), rich countries can at least partially avoid the environmental impact of their consumption by importing natural resources and exporting wastes.

Finally, temporal ecological distribution refers to the (social or spatial) distribution of environmental damage across different generations. Of the three types, this is the one that has received the most attention in the literature, because of its connection to the problem of achieving sustainability (see e.g. Repetto et al., 1989; Solórzano et al., 1991). Temporal ecological distribution addresses inequality across generations, such as when a country directly or indirectly consumes more raw material resources than produced by the natural environment (either within or outside its own borders), thus reducing its size to the detriment of future generations.

Recent work on ecological footprints has provided some useful indicators of sustainability, or temporal ecological distribution. In the simplest terms, a country's ecological footprint is its per capita resource consumption, measured in area units (global hectares to be precise) meant to reflect the implied land area required to support it. The indicator provides insight into the extent to which a county's economy is sustainable when compared with the available productive land per capita (termed 'biocapacity' in the ecological footprint literature).[2] The basic idea is that if the land requirement exceeds the availability, it is indicative – though by no means incontrovertible evidence – that the country is not on a sustainable course; when the opposite holds, it is.

In the former case, we can say that the country has an *ecological deficit*, in the latter, an *ecological surplus*. In contrast to the traditional accounting equivalents, however, there is no duality between ecological deficits and surpluses. If there were, the world as a whole would be in 'ecological balance', implying that the global footprint exactly matches available biocapacity. This can only be if the present generation uses all material flows available to it, no more, no less. Data from the *Living Planet Report*, an internationally collaborative effort (WWF, ZSL and GFN, 2005), show that the global ecological footprint exceeds the total world biocapacity. As of 2005, the global ecological footprint was estimated to be 17.5 billion global hectares (gha), or 2.7 gha per person. In comparison, biocapacity was only 13.6 billion gha, or 2.1 gha per capita.[3]

Research on the ecological footprint therefore appears to support the argument that total global consumption of resources is presently unsustainable. While it is a compelling argument, we do not pursue it any further here. Instead, we seek to gain a greater understanding of sustainability in general by investigating some of the economic or social factors that might be related to ecological footprints and ecological deficits. To be more specific, we will test the extent to which per capita income, economic openness, income inequality and the distribution of power determine a country's ecological footprint and ecological deficit. We now turn to these questions.

3 Economic and social determinants of environmental quality

Probably the most well-known expression of the relationship between income and environmental quality is the EKC hypothesis. It depicts a quadratic functional form, where environmental conditions worsen with income increases early in a country's development, after which, beyond a certain income level, environmental quality improves as income continues to increase (e.g. Bagliani et al., 2008; Dinda, 2004; Grossman and Krueger, 1995; Selden and Song, 1994; Spangenberg, 2001). Yet as has been demonstrated by Ekins (1997), Fischer-Kowalski and Amann (2001) and Shafik (1994) (among others), the quadratic functional form implied by the EKC at best applies to only a subset of environmental variables, such as local atmospheric pollution and in some cases, water pollution. For a variety of other variables, the latter author finds monotonic changes. Some indicators (e.g. deforestation rates, access to sanitation or safe water) improve with income while others – CO_2 emissions or municipal waste per capita – worsen.

There has been less work to date on the relationship between economic openness (as measured by the sum of a country's exports and imports as a percentage of GDP) and the environment. Some researchers have, however, found that tropical deforestation and increased emissions of carbon dioxide are examples of troubling environmental trends related to greater economic openness due to increased export prices of agricultural and forest products (see e.g. Capistrano, 1994; Managi, 2004).

We know that severely indebted lesser developed countries (LDCs) often engage in economic activity that is, harmful to their natural environments – such as deforestation or ecologically-degrading monocrop agriculture – in hopes of gaining adequate export revenue with which to finance their external debts (Andersson et al., 1995; Kox, 1997; Muradian and Martinez-Alier, 2001). While it is fair to say that more severely indebted countries probably degrade their environments to a more significant degree, it is not always the case that more economically 'open' economies have larger external debts. Yet LDCs have for the most part been losing ground in relative terms (see e.g. Haynes and Husan, 2000; Homer-Dixon, 1995; Pritchett, 1997; Slaughter, 1998) as a consequence of unfavourable trade relations that overwhelmingly emphasise primary products, the production of which often puts undue strain on their natural resource base. We might therefore conclude that LDCs that are more economically open (in terms of greater trade volumes) are more likely to degrade their environments. The phenomenon is related to the 'leakage effect' described earlier (Mayer et al., 2006; van den Bergh and Verbruggen, 1999).

Others have emphasised cross-country distributional inequity as a determinant of environmental degradation. For example, Torras and Boyce (1998) and Magnani (2000) test for the separate effect of income distribution in some EKC regression equations, finding that equality in the distribution of income explains environmental outcomes at least as well as, and in some cases better than, per capita income. Martinez-Alier (1995) argues that income distribution influences environmental outcomes from both the demand and the supply side. On the demand side, he distinguishes between environmental 'amenities' (e.g. pristine wilderness areas) and environmental 'necessities' (e.g. potable water) arguing that since income elasticity is higher for the former, income redistribution would influence the demand for each of these categories of environmental goods. Since supply of environmental goods is determined by the cost of providing them, income redistribution will also alter their supply since, as Martinez-Alier (see also 1993) puts it, 'the poor sell cheap'. In other words, the fact that environmental goods are not traded in any market makes the poor undervalue them relative to other commodities more than rich people.

Boyce (1994) was the first to take the inequality-environment link a step further by positing that the distribution of power in society influences environmental outcomes. He advanced the 'power-weighted social decision rule' (PWSDR), which weights individual net benefits by the power accruing to each individual, to remind us of an inescapable fact so often overlooked in standard economics approaches: some individuals have significantly greater influence on social or environmental outcomes than others.

The PWSDR predicts inefficiently low levels of pollution in the event that those with greater power are net losers from environmentally degrading economic activity, and inefficiently high levels if they are largely net gainers. Since, as he argues (on this point, see also Khan, 1997; Martinez-Alier, 1995; Torras, 2001), the latter is more plausible, the PWSDR predicts that reduced power equality will, *ceteris paribus*, lead to a lower quality natural environment. Boyce et al. (1999) find empirical support for the hypothesis in their study of the 50 US states, and Torras (2006) uses an international dataset to find further confirmation.

In this paper, we test for the environmental impacts of per capita income, economic openness, income inequality and power distribution. Unlike earlier studies, however, we use the ecological footprint and ecological deficit as dependent variables instead of some specified measure of environmental quality like particulate emissions. The main reason for this is that ecological footprints, because they indirectly measure resource use, are more relevant to the question of sustainability than are measures of environmental quality such as pollution or emissions levels.

4 Methodology and data

Per capita income, openness, income distribution and power equality are the principal regressors in our model. Based on the studies discussed earlier, we believe that environmental sustainability should conform to the following functional form:

$$\mathrm{E} = f(Y, X, G, B, D) \tag{1}$$

where E represents environmental sustainability with a higher value signifying a 'greater degree' of sustainability. We use Y to represent per capita income, X to represent the degree of economic openness and G for the Gini coefficient. Finally, π stands for power equality (higher value signifying greater equality) and D is a vector of dummy variables to distinguish between rich and poor country effects. Since ours is, as noted earlier, an exploratory study, we have no strong *a priori* assumptions about the signs of the partial derivatives E_Y, E_X, E_G and E_π.

The equations to be estimated are as follows:

$$\mathrm{EF} = \alpha_1 + \beta_{11}\mathrm{Y} + \beta_{21}\mathrm{X} + \beta_{31}\mathrm{G} + \beta_{41}\pi + \beta_{51}\mathrm{D} + \mathrm{e}_1 \tag{1a}$$

and

$$\mathrm{ED} = \alpha_2 + \beta_{12}\mathrm{Y} + \beta_{22}\mathrm{X} + \beta_{32}\mathrm{G} + \beta_{42}\pi + \beta_{52}\mathrm{D} + \mathrm{e}_2 \tag{1b}$$

where EF and ED stand for ecological footprint and ecological deficit.

We obtained the ecological footprint data from the Global Footprint Network.[4] Figures include country biocapacities and footprints of consumption and production for the period 1961 to 2001. The consumption-based ecological footprint is the biocapacity claimed by the consumption activity of a given country, whether or not this activity makes claims on domestic or foreign resource inputs (in terms of gha's). The latter case is what is sometimes referred to in the literature as 'appropriated carrying capacity'. In contrast, the ecological footprint of production is the total domestic biocapacity claimed by production within a country's borders irrespective of whether the resulting goods and services are consumed domestically or internationally. Since we are interested in direct sustainability implications to particular countries, i.e. spatial ecological distribution does not interest us here, we use the production-based footprint and use it also to calculate the ecological deficit.[5]

Measuring power, to say nothing of its distribution, is a difficult task because the concept itself is somewhat elusive. It can, for example refer to the relative economic influence that one possesses as a consequence of inequality in the distribution of assets. Alternatively, it can stand for the skills or capabilities that one possesses that may generate more life opportunities to enjoy. As a third possibility, power might capture political influence. Individuals or groups, in other words, have greater power if they are able to make their demand (e.g. improvements in health infrastructure or environmental quality) effective through the political process.

The second and third are exceedingly difficult to quantify, and the first is more or less the same as income distribution. We might, however, obtain a reasonable quantitative estimate by considering other variables related to power. We use five in the present study: political rights and civil liberties, literacy rate, higher education density, internet user density and percentage of female representation in government.[6] We assume that poor performance in political rights or civil liberties indicates less power equality with the opposite holding, where rights and liberties are more widespread. Since power is to some degree related to information access, in turn related to education, we use literacy rates and higher education density (college degrees or equivalent per 10,000 inhabitants) as additional proxies. We employ both variables because of the different connotations; literacy is a means of access to general written information but is no substitute for higher level formal education. We assume that higher literacy rates and greater higher education densities reflect greater power equality.

We additionally include density of internet access because a literate and educated population may still be disempowered if the technology required to access the myriad sources of information is in short supply. Again, we assume that a higher density of internet access suggests greater equality in the distribution of power. Finally, we represent higher levels of power equality with a higher percentage of female representation in government, since the figure at least shows the extent to which certain positions of power are available to one-half of a given country's population.

We employ principal components analysis to reduce existing international data for the five variables in question to a factor that serves as the key ingredient in a country's index of power equality. In addition to facilitating inter-country comparisons, derivation of such an index is sensible given the likely multi-collinearity among the individual components. As we can see from the correlation matrix (Table 1), each of the constituents of power equality is significantly correlated with all others. Were we to test for the individual effect of each variable on environmental or health outcomes, low *t*-ratios would be likely, yet they may be misleading. We therefore obviate the problem by condensing the five variables into a representative index.

Power equality figures for individual countries are reported in Table 2. Note certain geographical patterns; the Nordic European countries occupy five of the top seven places signifying greatest power equality, while the bottom 19 are, with only three exceptions, Saharan or sub-Saharan African nations. While on the whole, there are few major surprises, some peculiarities should be noted. It is mildly surprising, for example that South Korea should result more equal in terms of power distribution than Italy, France or Greece; 8, 10 and 21 places ahead of them, respectively. It is a greater surprise that power equality in Uzbekistan appears greater than in countries such as India and Tunisia. There is also no obvious reason for why Armenia should have such a low ranking (105th of 180 countries), not much better than Zimbabwe or China and far lower than other countries in its geographical vicinity, such as Georgia (53rd) and Azerbaijan (84th).

Table 1 Correlations among power equality codeterminants

	Political rights and civil liberties	*Literacy rate*	*Higher education density*	*Internet density*	*Females as % of government*
Political rights and civil liberties	–				
Literacy rate	0.461**	–			
Higher education density	0.551**	0.682**	–		
Internet density	0.460**	0.405**	0.602**	–	
Females as % of government	0.345**	0.360**	0.382**	0.556**	–

**Significant at the 1% level of confidence.

Table 2 Index of power distribution for individual countries

Sweden	10	Latvia	5.1	Philippines	3.9
Finland	9.4	Bahamas	5.1	Namibia	3.8
Iceland	9.2	Grenada	5.1	Suriname	3.8
Canada	8.8	Lithuania	5	Trinidad and Tobago	3.8
Norway	8.7	Czech Republic	4.9	Peru	3.7
Australia	8.1	Greece	4.8	Bosnia	3.7
Denmark	8.1	Barbados	4.8	Kazakhstan	3.7
USA	8	Poland	4.7	Jamaica	3.6
New Zealand	7.9	Malta	4.7	Antigua and Barbuda	3.6
The Netherlands	7.1	Bulgaria	4.7	Cape Verde	3.6
Austria	6.9	Panama	4.6	St. Vincent and Grndns	3.6
UK	6.4	Chile	4.5	Fiji	3.5
Belgium	6.3	Croatia	4.5	Macedonia	3.5
Switzerland	6.3	Hungary	4.4	Mongolia	3.5
Germany	6.3	Dominica	4.3	St. Lucia	3.4
Spain	6.2	Seychelles	4.3	Samoa	3.4
South Korea	6.2	Belize	4.3	Colombia	3.4
Estonia	6	Ecuador	4.2	Belarus	3.4
Ireland	6	Guyana	4.2	Cuba	3.3
Portugal	5.7	Cyprus	4.1	Azerbaijan	3.3
Israel	5.6	Georgia	4.1	Botswana	3.2
Japan	5.6	Ukraine	4.1	Mauritius	3.2
Luxembourg	5.6	St. Kitts and Nevis	4.1	Thailand	3.2
Argentina	5.5	Dominican Republic	4.1	Lebanon	3.1

Table 2 Index of power distribution for individual countries (continued)

Italy	5.3	Turkmenistan	4	Brazil	3.1
Slovenia	5.3	Mexico	4	Uzbekistan	3.1
France	5.3	Venezuela	3.9	São Tome e Principe	3.1
Singapore	5.3	Bolivia	3.9	Turkey	3
Costa Rica	5.3	Romania	3.9	North Korea	3
Slovakia	5.1	Russia	3.9	Serbia	3
Uruguay	5.1	Moldova	3.9	Jordan	3
South Africa	5.1	El Salvador	3.9	Tajikistan	3
Vietnam	3	Liberia	2.3	Senegal	1.4
Tonga	2.9	Ghana	2.3	Central African Republic	1.4
Qatar	2.9	Myanmar	2.2	Nepal	1.4
Indonesia	2.8	Republic of Congo	2.2	Morocco	1.4
Solomon Islands	2.8	Iran	2.2	Cameroon	1.4
Malaysia	2.8	Zambia	2.2	Eritrea	1.4
Bahrain	2.8	Uganda	2.2	Equatorial Guinea	1.4
Maldives	2.8	Madagascar	2.1	Cambodia	1.3
Armenia	2.8	Lesotho	2.1	Bhutan	1.3
Honduras	2.8	Saudi Arabia	2.1	Congo, Democratic Rep.	1.3
Nicaragua	2.8	Syria	2.1	Cote d'Ivoire	1.3
Paraguay	2.7	Oman	2	Togo	1.2
Kuwait	2.7	Papua New Guinea	1.9	Angola	1.2
Brunei	2.6	Malawi	1.9	Sudan	1.1
Sri Lanka	2.6	Gabon	1.9	Pakistan	1.1
Vanuatu	2.6	Guinea-Bissau	1.8	Sierra Leone	1.1
Zimbabwe	2.6	Laos	1.8	Djibouti	1.1
China	2.6	Swaziland	1.8	Somalia	1
Libya	2.6	Algeria	1.7	Afghanistan	0.9
Tanzania	2.5	Nigeria	1.7	Guinea	0.8
Kyrgyz Republic	2.5	Egypt	1.7	Burkina Faso	0.8
Albania	2.5	Iraq	1.7	Mauritania	0.8
Rwanda	2.4	Mali	1.7	Burundi	0.8
Guatemala	2.3	Haiti	1.6	Yemen	0.7
UAE	2.3	Kenya	1.6	Ethiopia	0.6
Tunisia	2.3	Comoros	1.6	Chad	0.5
Mozambique	2.3	Bangladesh	1.6	Gambia	0.3
India	2.3	Benin	1.5	Niger	0

It should not be surprising that rich countries tend to be clustered near the top of the power equality rankings and the poorest countries mostly at the bottom. Countries with higher incomes in general perform better on each of the individual variables, since greater national income often leads to a more developed 'information infrastructure' (improved communication, etc.), which presumably bears favourably on the distribution of power. Yet as we can see from Figure 1, the link between the two variables is far from perfect. Luxembourg (abbreviated 'lxb' in the diagram), the country with the highest per capita income in the set, performs only modestly in power equality, and five middle eastern countries with per capita incomes greater than $10,000 – Kuwait (KWT), Qatar (QTR), United Arab Emirates (UAE), Bahrain (BHR) and Saudi Arabia (SDA) – have relatively low-power equality. In contrast, countries such as Costa Rica (CRC), Estonia (EST), New Zealand (NZL) and Slovakia (SVK) enjoy high-power equality relative to their per capita income levels.

Finally, we obtained population data from the World Development Indicators (WDI) compiled by the World Bank in order to convert our footprint and deficit figures to per capita basis. We matched our ecological time series data with figures of GDP per capita, economic openness and Gini coefficient, which we also obtained from WDI. Our GDP per capita figures are in constant 1995 US dollars and in our regressions we use their one-year lag (i.e. GDP_{t-1}). We defined economic openness as the sum of a country's exports and imports as a percentage of GDP. To minimise the effect of the outliers, we linearised all our dependent and independent variables by taking their natural logarithm.[7] We controlled for heteroskedasticity using Huber (1967) and White (1980) corrections. In Table 3, we present the correlation coefficient matrix of the variables as they appear in the regressions.

Figure 1 Relationship between power equality and per capita GDP

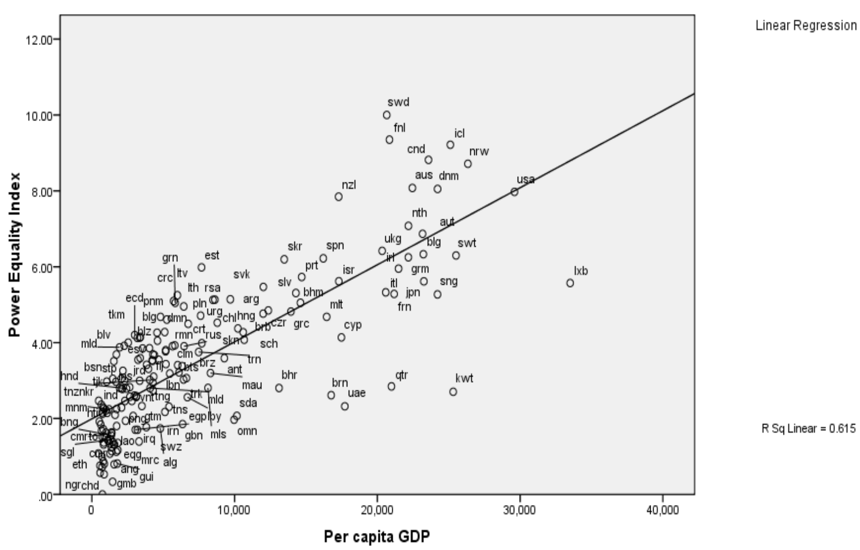

Table 3 Correlation coefficient matrix

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
Ecological footprint, per capita (1)	1				
Ecological deficit, per capita (2)	0.9156	1			
GDP per capita (3)	0.3411	0.4611	1		
Openness (4)	0.6806	0.6772	0.3234	1	
Gini coefficient (5)	–0.2128	–0.3668	–0.3051	–0.0606	1
Power equality (6)	0.4547	0.5673	0.6303	0.314	–0.2857

5 Results

Table 4 presents the results of the linear regressions with ecological footprint as the dependent variable. In the first estimation, we consider only the effect of GDP per capita and economic openness, finding that only the latter is statistically significant. The positive sign of the coefficient suggests that countries that are more economically open will have larger ecological footprints. The result is not obvious, but it is also not anomalous as it is reasonable that countries more engaged in trade supply more markets and therefore call upon more resources. Adding the income inequality and power distribution variables (estimation 2) does not change the significance of the openness variable but does cause GDP to become statistically significant. Surprisingly, however, the sign is negative, suggesting that countries with a higher GDP per capita have lower per capita ecological footprints. The result appears, at first glance, not to be intuitive.

The coefficient signs for the two new variables are statistically significant, and both imply that greater equality (of income or power) produces larger footprints. While it appears to contradict earlier studies on the link between inequality and environmental damage, it is not obvious that the same logic applies to the case of sustainability. Moreover, the ecological footprint (in contrast to the ecological deficit) is more an indicator of the volume of resource use than of sustainability *per se*.

In next estimation, we add a dummy variable that takes on a value of 1 if the country is a developing country and 0 otherwise.[8] The only effect on the previous equation is to render statistically insignificant the coefficient for power equality. The coefficient for the LDC dummy is statistically significant, however, suggesting that poor countries tend to have smaller ecological footprints than rich ones (as is reasonable). Finally, for the fourth estimation, we include four interaction terms which are the product of the LDC dummy and the respective independent variables to see if we observe any difference in the relationships between rich and poor countries.

GDP and openness remain statistically significant and with the same sign. The other two variables (Gini and power equality) trade places: now the Gini coefficient is statistically insignificant whereas power equality is again significant and positive, suggesting that societies with a more equal power distribution utilise more resources per capita. Note that with the interaction terms included, the coefficient for the LDC dummy becomes positive, suggesting that LDCs have larger ecological footprints than rich countries. Yet this is not the end of the story since the power equality interaction coefficient is statistically significant and negative (the interaction with GDP is also significant, but only at the 5% level of confidence). This suggests that LDCs with power inequality may have sizable ecological footprints, even when compared to rich countries, while LDCs that are more politically equal tend to have relatively small ones.

Results of the regressions where ecological deficit is the dependent variable are found in Table 5. Keep in mind, in interpreting the coefficients, that ecological deficits are negative numbers and surpluses are positive. We find, again looking first at the equation that considers only GDP and openness, that only GDP is statistically significant. The positive sign implies that richer countries are on the whole less likely than LDCs to be in ecological deficit. Conceptually, the relationship seems somewhat ambiguous, since it is not obvious to us that rich countries on the whole practice more sustainable economics than poorer ones.

In the second estimation, we once again add the two variables related to inequality. GDP remains statistically significant (and with the same sign) while openness becomes significant as well, albeit only at the 5% level of confidence. The negative sign of its coefficient suggests that more open economies are less likely to be sustainable (i.e. more likely to have an ecological deficit), a result that seems reasonable, especially in the case of LDCs. Gini is statistically insignificant, but power equality is significant with a positive sign. This suggests that more equal societies have economies that are more sustainable, a result that appears reasonable if we consider the earlier work on inequality and environmental quality.

We see no noteworthy changes to the second estimation when we add the LDC dummy: the same variables are statistically significant, and with the same signs. The coefficient for the LDC dummy is also significant and positive suggesting that LDCs on the whole are more sustainable than developed countries. It is the opposite of what would appear to be suggested by the positive sign for the GDP coefficient. However, the final estimation appears to eliminate the inconsistency. When we add the interaction terms, the results change noticeably.

Table 4 Determinants of ecological footprint (per capita)

	Estimation 1	*Estimation 2*	*Estimation 3*	*Estimation 4*
Intercept	–21.23**	–18.37**	–17.51**	–26.66**
GDP per capita	0.01	–0.02**	–0.04**	–0.11**
Openness	1.42**	1.59**	1.71**	1.87**
Gini coefficient		–0.95**	–0.76**	0.04
Power equality		0.57**	0.10	3.36**
LDC dummy			–1.73**	6.38**
GDP interaction				0.08*
Openness interaction				–0.24
Gini interaction				–0.44
Power equality interaction				–3.44**
Adjusted R^2	0.45	0.53	0.59	0.62
N	2,321	2,043	2,043	2,043

*Statistically significant at 5% level of confidence.

**Statistically significant at 1% level of confidence.

Table 5 Determinants of ecological deficit (per capita)

	Estimation 1	*Estimation 2*	*Estimation 3*	*Estimation 4*
Intercept	–6.71**	–17.66*	–21.72*	135.99**
GDP per capita	0.53**	0.53**	0.61**	1.07**
Openness	–0.92	–1.35*	–1.89**	–0.54
Gini coefficient		3.41	2.51	–12.84**
Power equality		2.80**	5.03**	–53.31**
LDC dummy			8.18**	–125.9**
GDP interaction				–0.49
Openness interaction				–1.63
Gini interaction				9.19**
Power equality interaction				61.65**
Adjusted R^2	0.38	0.37	0.38	0.49
N	2,321	2,043	2,043	2,043

*Statistically significant at 5% level of confidence.

**Statistically significant at 1% level of confidence.

First, economic openness becomes statistically insignificant. The openness interaction term is also insignificant, so our results imply that, when other factors are considered, economic openness has no bearing on sustainability (independent of whether the country is rich or poor). Secondly, Gini coefficient becomes significant (with negative coefficient) while power equality – also significant – changes its sign from positive to negative. Before explaining it, we should also note that both of the respective interaction terms are statistically significant and positive. Based on the Gini coefficient, greater inequality implies greater ecological deficits hence unsustainable economies; among developing countries, however, greater inequality implies sustainability. For the power equality variable, the opposite is observed in each case. We will explore the implications further in what follows. Finally, the coefficient for the LDC dummy also changes sign from positive to negative implying that developing economies are on the whole less sustainable than rich ones. The result is now consistent with the positive sign for the GDP coefficient.

6 Discussion

Theoretically, we would expect the relationship between GDP and ecological footprint to be positive, since richer countries tend to consume more resources. This is indeed the case, but *only* looking at the correlation coefficient of the two variables (see Table 3). Otherwise, in any multivariate regression estimation, the sign for GDP becomes negative. We interpret the result as follows. While richer countries may have larger ecological footprints *ceteris paribus*, there are in fact several other factors that influence the size of a country's footprint – all of which, recalling Table 3, are correlated with GDP to a significant degree. When controlling for these variables, the negative coefficient for GDP only pertains to the portion of the effect of GDP that does not overlap or correlate with the other variables. While it is far from obvious that its sign should be negative, it is difficult to judge given the collinearity among the variables on the regression line. Meanwhile, the coefficient for the GDP interaction term is positive suggesting that LDCs with higher incomes have larger ecological footprints.

The relationship between economic openness and ecological footprint is positive for all the estimations. The result appears reasonable since, by producing for more markets, countries that are well integrated into the global economy are likely to require more resource inputs. In the case of inequality, however, the story is a bit more ambiguous. There is no consensus on whether inequality promotes or detracts from efficiency, so it is even less clear whether it would contribute to larger or smaller ecological footprints. While we did not hypothesise any relationship, the results indicate that countries that are more unequal (either in income or power distribution) have smaller ecological footprints. The opposite appears to be true for developing countries, however, judging from the sign of the power equality interaction coefficient.

We had no pre-conceptions regarding the effects of our independent variables on the ecological deficit. Theoretically, neither the statement that rich countries tend to have more sustainable economies than poor ones, nor its' opposite, appears obvious. Yet our results support the argument that richer countries are more sustainable. Not only is the GDP coefficient consistently positive with ecological footprint, but also the LDC dummy coefficient is negative in the final estimation that includes all the variables. This suggests that, *ceteris paribus*, developing countries are less likely to have sustainable economies. While we would not consider this as a conclusive result, we believe it is certainly suggestive and – given the policy importance of this relationship – calls for further research into the matter.

We find, moreover, that countries with more open economies are more likely to have ecological deficits hence be on an unsustainable course. Yet the result is tenuous, as the statistical significance of the coefficient disappears when the dummy and the interaction terms are added to the regression line. The fact that openness appears to detract from sustainability but only under some specifications suggests that the relationship needs to be further studied. Finally, results for the relationship between inequality and ecological deficit are strongly statistically significant. Unfortunately, they are also inconsistent. According to the Gini coefficient of income inequality, greater inequality implies less sustainable economies overall, but more sustainable economies in the LDC group. In contrast, if we base our interpretation on the power equality measure, we arrive at the precise opposite conclusion: greater inequality makes economies overall more sustainable, but LDC economies less so. Given the strong statistical significance for both variables, further investigation into the relationship between inequality and sustainability appears warranted. It should consider alternative measures of inequality, different specifications of the model or both.

7 Conclusion

We should reiterate that ours has for the most part been an exploratory study, and that our conclusions are therefore tentative in nature. We nevertheless believe that our findings are a preliminary step towards better understanding the factors that influence whether – as well as the degree to which – a country's economy is sustainable.

Our finding that higher GDPs are associated with smaller ecological footprints, while seemingly counterintuitive, makes sense when considered in light of the leakage effect. To the extent that rich countries are able to consume goods and services that command resources from countries other than their own – as occurs under a spatial maldistribution regime where the environmental impacts of consumption in rich countries is suffered by poor countries – it is not unreasonable that on a per capita basis footprints in rich countries might tend to be smaller. We do not believe, however, that the phenomenon sufficiently explains the anomalous relationship. More than likely, it is also due to the effects of intervening variables with which GDP is collinear.

Our observation that higher GDPs are associated with less likelihood of an ecological deficit might be explained by the sectoral shifts that most national economies undergo as they grow progressively wealthy. Without exception, the world's rich countries have economies that are majority service (tertiary sector), which is generally presumed on average to be less environmentally intensive that manufacturing. Perhaps as a consequence, rich countries are on the whole found to be more sustainable.

Our least ambiguous and most intuitive results appear to be for the coefficients for economic openness. We find, first, that greater economic openness results in larger ecological footprints, which is reasonable if we assume that countries that supply more markets will call upon a greater volume of resources for production. We also observe that countries that are more open tend to have an inferior ecological balance (larger deficits); although here more research is needed since the result is highly dependent on the specification used.

Our results are least conclusive when we consider the effects of inequality. Here, we find that the more unequal a country, the lower its ecological footprint tends to be. The coefficients for the measures of income and power inequality are not statistically significant across the board, but none of the instances of statistical significance for either variable contradicts the finding. The relationship is reversed, however, in the case of LDCs – i.e. greater inequality produces larger ecological footprints. It is not clear to us whether we should have expected such outcomes. If inequality is conducive to efficiency, hence more rapid growth, we might expect it to produce larger footprints. But we would likely see the opposite if in fact inequality runs counter to the goal of efficiency. Since a clear consensus on the question is lacking, we cannot be certain of the proper interpretation of the results.

Finally, our regression results for the effect of inequality on ecological deficits appear contradictory. The conclusion depends on which inequality variable we consider – income or power. If anything, we might have expected more equal countries, because they tend to be wealthier, to have a greater environmental impact overall because the majority of the population – even the working class – consume significant amounts, potentially translating to greater ecological deficits. But it is not clear from the results, despite the fact that we find strong statistical significance for both variables and their corresponding interaction terms. We believe that this curious result calls for further research into the relationship between these variables.

Another promising area for future research is the link between resource use and environmental damage on the one hand, and sustainability on the other. Although the conceptual difference between environmental 'sources' and 'sinks' is clear enough, it is not as obvious how they impact on the question of sustainability. As an indicator of sustainability, the ecological deficit can be a useful tool. Finally, we believe that much more remains to be discovered regarding the relationship between inequality and sustainability. While a fair amount of research has been conducted on inequality and the environment, it has mostly concerned the environmental damage part of the picture. A more complete investigation would ideally utilise the ecological deficit concept in order to illuminate on the relationship between inequality – either social or spatial – and sustainability.

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Notes

[1] The ecological footprint methodology was introduced by Rees and Wackernagel (2004).

[2] See, e.g. Bagliani et al. (2008) and Ferguson (2002).

[3] According to this report, a global hectare represents a hectare with 'world-average' ability to produce resources and absorb wastes. For details on how ecological footprint and biocapacity figures are computed, see the latest report (WWF, ZSL and GFN, 2005).

[4] Available at: www.FootprintNetwork.org.

[5] It turns out that the differences in the econometric results using the consumption-based as opposed to the production-based footprints are negligible.

[6] This differs slightly from Torras (2006) in that he also included the Gini coefficient. We consider power distribution and income distribution separately.

[7] Taking logs in the case of the ecological accounts proved impossible in cases where a country was in ecological deficit. What we did in such cases is multiply by negative one, take the log and again multiply by negative one.

[8] Most countries take 1. We defined a developing country as any i.e. *not* the USA, Canada, Japan, Australia, New Zealand or/and Western European country.