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Commentary

Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science

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ABSTRACT

The ecological footprint is a measure of the resources necessary to produce the goods that an individual or population consumes. It is also used as a measure of sustainability, though evidence suggests that it falls short. The assumptions behind footprint calculations have been extensively criticized; I present here further evidence that it fails to satisfy simple economic principles because the basic assumptions are contradicted by both theory and historical data. Specifically, I argue that the footprint arbitrarily assumes both zero greenhouse gas emissions, which may not be ex ante optimal, and national boundaries, which makes extrapolating from the average ecological footprint problematic. The footprint also cannot take into account intensive production, and so comparisons to biocapacity are erroneous. Using only the assumptions of the footprint then, one could argue that the Earth can sustain greatly increased production, though there are important limitations that the footprint cannot address, such as land degradation. Finally, the lack of correlation between land degradation and the ecological footprint obscures the effects of a larger sustainability problem. Better measures of sustainability would address these issues directly.

1. Introduction

The ecological footprint was introduced by Wackernagel and Rees (1996) as a simple measure of the sustainability of a population's consumption. The footprint converts all consumption into the land used in production, along with the theoretical land needed to sequester the greenhouse gases produced. While it does a commendable job of condensing a complex array of consumption down into a single, intuitive number, too often it is used in arguments about the sustainability of past, current and future consumption that is not only bad economics, it is contradicted by historical data.

In a recent paper, Moran et al. (2008) use the ecological footprint to analyze the relationship between development and environmental impact. They find a striking trend between an increase in development and an increase in a nations footprint. Assuming a minimum level of development and a minimally sustainable footprint, they claim only one country, Cuba, can be considered on a positive track. The authors argue that their analysis shows that "minimum conditions for sustainable development can be measured", that they have evidence that high income countries have not moved their consumption to the "ecological limits" of the world, and that nations are moving away from sustainable development. These conclusions, and similar conclusions from other researchers, though are due to the strong assumptions behind the ecological footprint, which has many problems as a measure of sustainability.

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There exist a number of criticisms of the ecological footprint[2]. I will expand in this paper on the excellent criticisms of van den Bergh and Verbruggen (1999), hereafter referred to as B&V, using further examples and historical data. I am not aware of much discussion regarding the appropriateness of the ecological footprint in recent years, though the popularity of the footprint in sustainability arguments necessitates a continued critical assessment of it[3]. In order to ground the discussion, I do not attempt here a comprehensive critique of the ecological footprint, but motivate much of the discussion through the paper by Moran et al., whose work well illustrates the problems of using the footprint to make sustainability arguments.

One immediate problem with the ecological footprint noted by B&V is that it is dominated by energy as over 50% of the footprint of most high and middle income nations is due to the amount of land necessary to sequester greenhouse gases. In additional to the number of comments by B&V on this issue, it is important to note that, while a major reduction in greenhouse gas production is needed, it is not at all clear from an environmental, let alone economic, standpoint that all greenhouse gases mankind produces need to sequestered or eliminated. This is an especially important point given that, according to the Global Footprint Network database used by Moran et al., mankind is consuming 25% more resources than the biocapactiy of the Earth. If for instance only 50% of current greenhouse gas production is determined ex ante beyond the sustainable capacity of the Earth, then mankind is currently within the limits of sustainability as defined by the footprint.

The remainder of this paper is organized as follows. The next section discusses how a footprint can misspecify the current sustainability of a system by arbitrarily determining boundaries, which is especially problematic for cross-country comparisons. Section 3 explores the role of technology in calculating the footprint and how this can also lead to misleading comparisons. I argue that the footprint cannot take into account intensive production, and so comparisons to biocapacity are erroneous. I also explore historical data on crop yields which show a focus on intensive farming by producers and alone suggests, perhaps misleadingly, that much larger production could be sustainable. In Section 4, I compare the dataset used by Moran et al. with other sustainability indicators and find that the footprint is not well correlated with land degradation, which has larger implications to sustainability than the footprint alone. Looking at land usage alone then can lead to a misestimate of the sustainability of a system. Section 5 is the conclusion where I argue that the best solution to the issues raised here is to abandon composite indicators and instead look directly at the two issues most important for sustainability.

[2] See for example a special forum in Ecological Economics on the ecological footprint, which includes excellent critiques by Ayres (2000), Herendeen (2000), van Kooten and Bulte (2000) and Moffatt (2000), as well as others.

[3] A short list of recent work using the footprint, including some of those discussed here, includes Moran et al. (2008), Rees (2008), Stoglehner (2003), Wackernagel et al. (1999), van Vuuren and Smeets (2000) and Bicknell et al. (1998).

2. Sustainability of current consumption

As already critiqued by B&V and Gordon and Richardson (1998), there is a serious problem with the comparison of the current ecological footprint with the actual physical area of a region or city. An extreme example is Rees (2008), who presents a calculation of the city of Vancouver, Canada, which he argues requires 174 times as much land to sustain it as is currently contained within the city. While it may be informative to understand what it takes to sustain a city, it should not come as a surprise to anyone that the ecological footprint of a city is significantly larger than the city boundaries. This fact comes from one of the most basic tenets of economics, where products will be produced according to comparative advantage. People live in cities, even large sprawling ones, in large part because they are more efficient than rural living[4].

Likewise, van Vuuren and Smeets (2000) look at the footprints of Benin, Bhutan, Costa Rica and the Netherlands. They find that consumption in the Netherlands requires more than twice the land contained within the Netherlands, while the other countries studied show much lower rates. This result should again not be surprising as people in the Netherlands not only have more money, but the country has very little overall land for its population and so a significantly higher population density. Similar to a city then, the boundary defined as the nation is arbitrary. Attempts to better measure a regions footprint through input/output measures and trade[5] cannot solve this problem as there is still an arbitrary boundary that must be used.

While almost all national measures could face a similar argument regarding the use of boundaries, from an environmental perspective historical and administrative boundaries are especially irrelevant. Rather than measuring sustainability of a given area, the footprint of a region or nation in fact measures inequality of resources. For instance, the difference in the per capita footprint of Canada and Benin is due to the difference of per capita consumption, which is due to the difference in per capita income between the two nations. But within Canada we would also see similar large differences, and studying different areas of Vancouver would likewise produce different results.

Cross-country comparisons of the ecological footprint then rely on boundaries that are arbitrary, and thus potentially meaningless. This criticism is of course possible for any definition that relies on national boundaries, though it poses an especially important problem for the issue of relative biocapacity, where average consumption within a nation is multiplied by world population and then compared to the capacity of the Earth. For example, Moran et al. use data on consumption that suggests that if everyone on the planet were to live in the same manner as the average American, it would

[4] For a detailed analysis of the relationship between agglomeration and externalities, see Grazi, van den Bergh and Rietveld (2007).

[5] See for example Wiedmann et al. (2006), Wiedmann et al. (2007), Lenzen Pade and Munksgaard (2004), Turner et al. (2007) and Peters (2007).

have required 3 Earths in 1975 and 5 Earths in 2003 to sustain this consumption. Multiplying by the average footprint though misses the variance within a nation and so makes a strong assumption about which consumption level to generalize upon. As I discuss in the next section, it also makes a strong assumption about the total biocapacity of the Earth.

3. The role of technology in sustainability

In the calculation of an ecological footprint, the technology level that is assumed for producing a given product is either a world average of technologies, called the global hectare, or more recently through the input/output literature, a calculated mixture based on trade data of imported and local technologies. Because globalization has increased the interrelatedness of production it is important to not just use a local economies production level, but to measure production at the source.

While this makes for an interesting thought experiment, as discussed by B&V and Kitzes et al. (2007), and well recognized by users of the ecological footprint, technology change makes the footprint useless for understanding the effect of future growth in consumption. For instance, while individuals in the developing world are increasing their consumption very rapidly and could one day reach the consumption levels of the developed world, the ecological footprint cannot answer what this increased consumption will look like as it can only describe production growth without technological progress. This though suggests that the ecological footprint is useless for not just future predictions, but also presents a logical flaw in the comparison of a consumption level and the biocapacity of the Earth. Biocapacity comparisons, such as the argument that it would take 5 Earths to sustain consumption if everyone consumed like Americans, assume that the average consumption of an area extends to the entire world population, with all production at the current technology level. Yet it is well known that this kind of calculation is meaningless and partial. Before such a growth, much technological progress would have occurred.

To explore the issue of intensive versus extensive production growth and what this means for biocapacity further, I discuss below a simple model of production growth and review some historical data on the elements of the ecological footprint.

3.1. *Intensive vs. extensive production*

Looking over almost any time period in the last 100 years, world consumption has increased dramatically. This increase did not happen over night but happened slowly, due in part to changing preferences, but also to changes in incomes (the ability to demand certain products) and, most importantly, changes in technology (the ability to produce and deliver certain products).

Imagine there are only 2 countries in the world, A and B, each producing a number of different products. Assume country B is rich and very efficient at producing food and produces enough food for themselves and some for export. Country A is poor and relatively inefficient at producing food and so imports some food from country B. Also assume that all markets are in equilibrium so that supply of food equals demand. Now, let the people of country A acquire more wealth, perhaps through the other products they produce. As they are wealthier, they will likely either demand more food, or better quality food. In either case, demand has increased and so the price of food has increased. If the price of food increases sufficiently and business movement in the food production market is free, there will naturally be an increased search to produce more food.

This increased search will come in two forms: extensive and intensive. The extensive approach has producers look for more land to produce food, which is the assumption used to calculate relative biocapacity. Alternatively, the intensive approach has producers increase production technology to increase the yield of food, and thus not increase total land used. For instance, producers in country B could invest in R&D to increase their own yields. Conversely, producers in country A, seeking increased rents, could invest in moving better technology to country A to increase their yield efficiency. Eventually a new equilibrium will be reached where the average person consumes more food, while the total amount of land used is unknown.

While the ecological footprint cannot address intensive production growth, it does offer a useful tool for understanding extensive growth. This then raises the question of whether intensive or extensive investment has been the main force of production growth. Data on agriculture yields suggests an answer to this question.

3.2. *Historical data*

Cropland represents approximately 25% of the total world ecological footprint (Global Footprint Network, 2008), and so is very important for measures of sustainability. Figs. 1 to 3 show, by region from 1961 to 2006, the production, yield and land area used for all cereals respectively[6]. Total world production has been increasing at an average rate of 2.17% yearly, with yield rates increasing at 2.06% yearly. Thus, the total world land area dedicated to all cereal production has only increased on average by 0.09% each year. Clearly, from 1961 to 2006, the world market of cereal producers has focused most of their efforts to increase production intensively. In all regions except Europe and Africa, the yield of cereals has more than doubled in the last 45 years.

The importance of technology in production growth has been well discussed by researchers since Adam Smith. It is of course likely that there is a limit to crop yields[7]. For instance, some regions may not be able to match other regions in yield, even with the best technology. In 2006, American production levels were 40% higher than the world average, and 36% higher

[6] Data is from FAO (2008). Similar results are obtained for each individual cereal product as well as wheat products and so are omitted.

[7] Two excellent discussions of the limits of technology for increasing production include the problem of scale discussed by Daly (1996) and population growth discussed by Ehrlich and Holdren (1971).

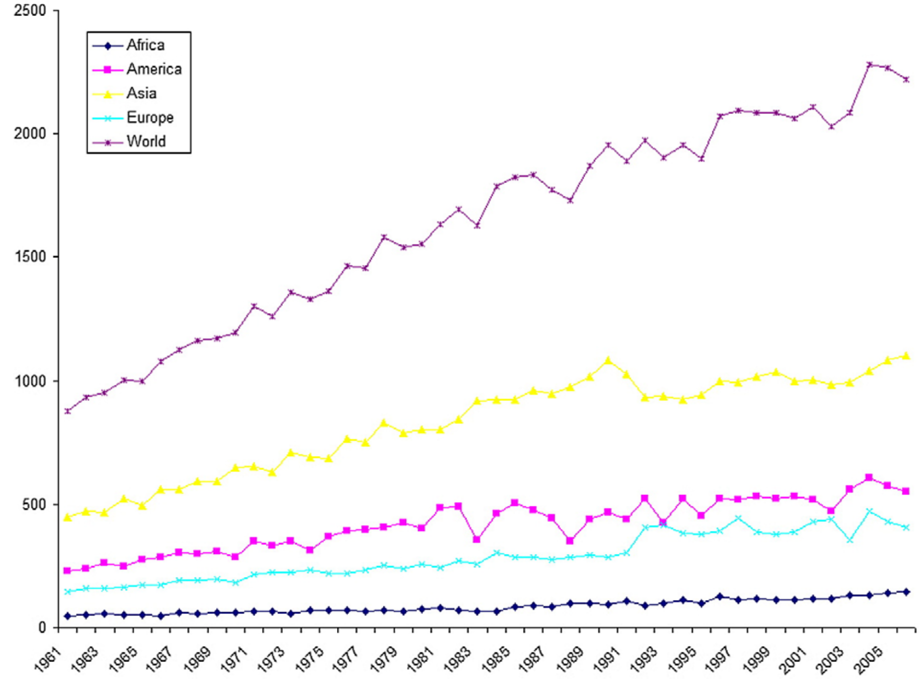

Fig. 1 – Total cereal production in millions of hectares by region.

than Europe. Until 1992 though Europe had historically higher yields than America which America only reached in 2004. Also, while world average yield is much lower than America, it has reached historical 1989 American levels, suggesting world yields are about 18 years behind American. If current trends continue, or if Europe were to return to its historically high yields, the world average yield could one day reach the 2006 American yield, and then potentially move even higher. This could mean that, rather than needing five Earths to sustain consumption if everyone consumed like Americans, one Earth may be enough.

The other major categories of the ecological footprint include built-up land, natural resources, wood, animal production and greenhouse gas offsetting. Most of these though are not likely to increase much beyond their current levels, due to the inherent value of intensive investment. For instance, land

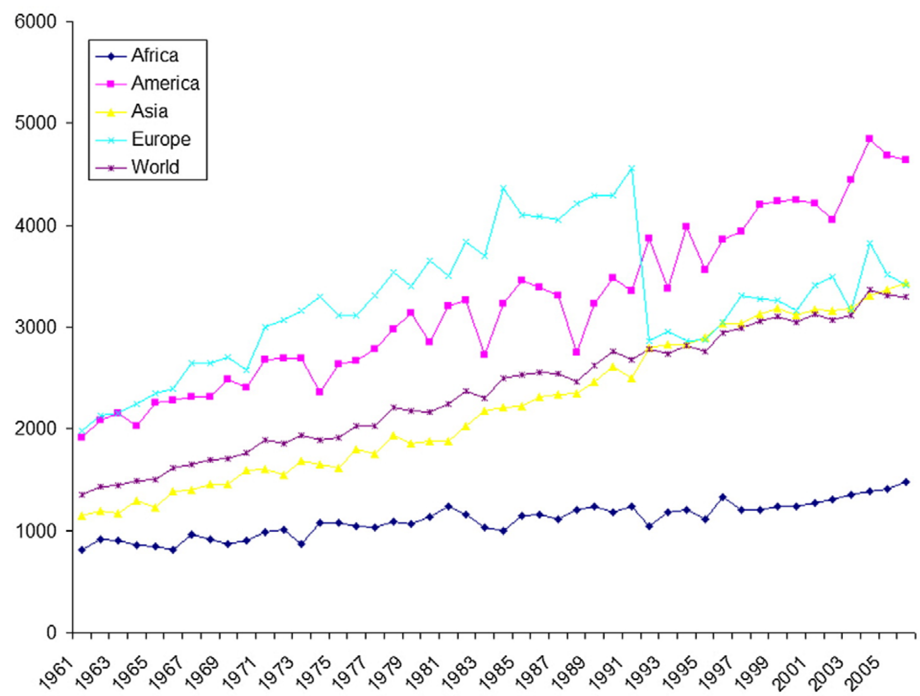

Fig. 2 – Total cereal yield in kilograms per hectare by region.

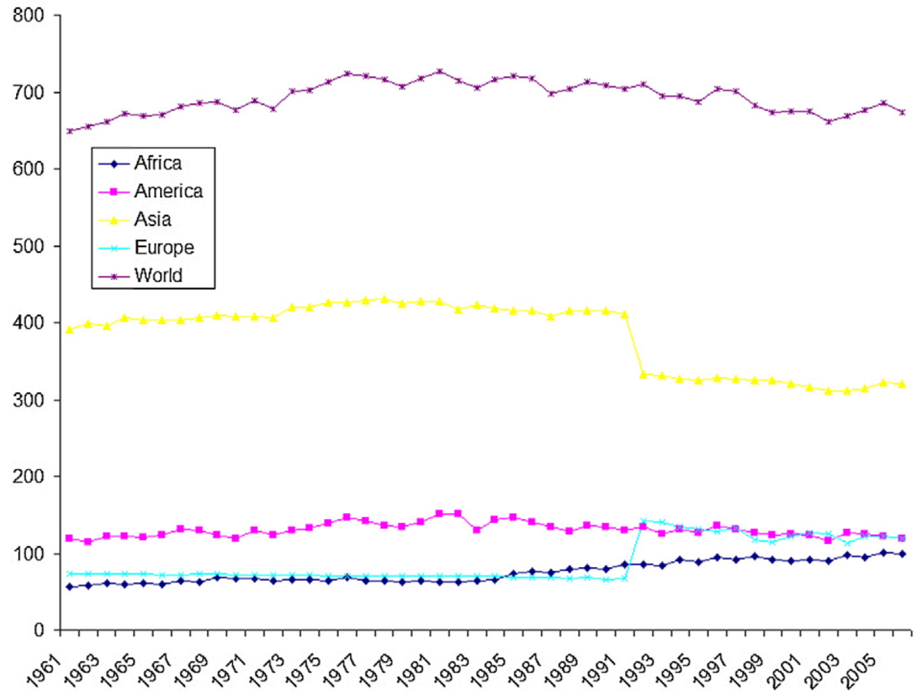

Fig. 3 – Total land area for all cereal in millions of hectares by region.

taken over by cities, as mentioned above, is a relatively efficient use of land for people. A person that moves to the city takes up less land for living that a person on a farm. Additionally, the marginal increase in land usage for housing an additional person living in a city is smaller than the average of the people in that city, meaning that calculating the average land usage for housing a person is misleading for future land needs. Finally, the increased popularity of confined animal feeding operations (CAFOs) decreases the land needed for grazing and raising animals and so from a footprint standpoint it represents a move to greater sustainability. Actual physical land needed to produce all of these goods in the future then could stay at the same level we have today, or potentially even decrease, while total consumption of products around the world increases.

Intensive production growth of course causes its own problems. For example, as discussed in Fiala (2008) and Subak (1999), CAFOs can lead to important cultural changes and contribute to topsoil loss. Intensive production in general increases waste, land depletion and land degradation. In the next section I discuss how a nation that engages in dangerous intensification could appear to be moving toward sustainability while in fact moving away from it (or vice versa).

4. Comparisons of data on sustainability

As van Kooten and Bulte (2000) discuss, the ecological footprint fails to capture one of the most important issues of sustainability, land degradation. Land that has been degraded can either no longer be used, or it is used at a severely decreased efficiency. If an area that was once producing for a given population becomes unusable, other land will need to be found to farm. Destroying land, and then needing to move from one land area to another, clearly presents an important sustainability problem for a population. On the other hand, if a population is using land inefficiently, but is doing so without destroying the land, the system could be sustainable. A large land footprint then could be more sustainable than a small one, depending on how the land is used. The ecological footprint is a static concept, and so cannot address this issue.

Table 1 presents the correlations across HDI and the ecological footprints in 2003 used by Moran et al. It also presents tonnes of carbon per capita for each country in 2004 from Carbon Dioxide Information Analysis Center (2008), which is the total CO_2 equivalent greenhouse gases per person produced in each nation, as well as wheat and cereal yields and percent of land degradation types for 2004 from FAO (2008). Land degradation is classified according to severity and is caused by agriculture, overgrazing, deforestation, industrialization and/or over

Table 1 – Correlations of variables

	HDI	Footprint	Tonnes of carbon per capita	Wheat yield	Cereal yield
HDI	1				
Footprint	0.7298	1			
Tonnes of carbon/capita	0.6711	0.8475	1		
Wheat yield	0.4218	0.4346	0.1884	1	
Cereal yield	0.1541	0.2377	0.2484	0.1866	1
Light+ degradation	0.2212	0.0489	−0.0659	0.1055	0.1071
Moderate+ degradation	0.2234	−0.1089	−0.0452	0.0474	−0.0680
Severe+ degradation	0.0875	−0.1942	−0.0791	−0.0440	−0.2912

exploitation of vegetation. I separate land degradation into three indicators, light degradation or greater, moderate or greater and severe/very severe.

As greenhouse gases are a large part of most countries footprints it is not surprising that it has a high correlation with respect to the footprint data, though the correlation is very high. The correlations with HDI, which index a countries level of development through life expectancy at birth, literacy, education enrollment and GDP, show very little difference between tonnes of carbon and ecological footprint per capita. This suggests that studies using footprint measures are capturing most of the effect from carbon. But better, more informative and policy relevant indicators are available, such as the aggregation of greenhouse gases via CO_2 equivalents.

There is though very little correlation between the different measures of degradation and HDI, ecological footprints and carbon. This has two important implications. First, the footprint is capturing almost no effect of land degradation, and when it does capture it, it does so in the opposite direction we would like. Thus, a country that would look positive with regards to an ecological footprint could in fact have a very high rate of land degradation and so is consuming its land faster and in more harmful ways than countries that are more careful with land.

Second, the lack of strong correlation between land degradation and HDI suggests that the results of Moran et al. are not robust to different specifications of sustainability. That is, more developed nations are not associated with greater land degradation. A final result of the correlation matrix is the relationship between soil erosion and crop yields. van Kooten and Bulte (2000) discuss the importance of better understanding this relationship, though they note that there is not much evidence. The correlations presented here are extremely low, except with respect to severe/very severe degradation and cereal yields. Higher cereal yields appear to be associated with lower land degradation. While this is not a causal argument, it does suggest that there may be an important relationship between these variables. Exploring this relationship more may be an interesting area of future research.

5. A way forward

While the ecological footprint offers a simple and intuitive estimate of the production inputs for a given consumption level, it fails to address the sustainability of consumption that it was originally conceived to do. In summary, the criticisms of the ecological footprint that I have highlighted here include the arbitrariness of assuming both zero greenhouse gas emissions and national boundaries, that the footprint is in fact a measure of inequality, historical evidence that intensive, rather than extensive, investment is the main driving force of production growth, though the footprint is an entirely static measure and so cannot capture this technological change, and the lack of correlation between land degradation and the ecological footprint, which obscures the effects of larger sustainability problems.

In general, but especially for research projects such as Moran et al., I believe it is more useful to look directly at sustainability measures, such as land degradation and CO_2 aggregations, rather than using a footprint that at best poorly captures these problems. For instance, it is not clear why it is useful to convert greenhouse gases to land as methane and nitrous oxide are already aggregated into CO_2 equivalent indicators of greenhouse gases. For land degradation though, the benefits of looking directly at soil erosion rates are obvious as the ecological footprint gives no information on this.

While the ecological footprint has its uses, it is important to continue the debate about using the footprint lest it obscure important problems or make erroneous arguments about the sustainability of current and future consumption patterns.

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