Environmentally Efficient Well-Being: Rethinking Sustainability as the Relationship between Human Well-being and Environmental Impacts

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Abstract

The question of how to measure sustainability remains vexing. We approach the problem by noting that most theories of environmental impact assume that exploitation of the environment provides benefits to human well-being. However, this assumption has not been subject to much empirical discipline. We propose a model of Efficient Well-Being (EWEB) inspired by the Stochastic Frontier Production Models commonly used in economics. EWEB assesses a nation-state's efficiency in enhancing human well-being through the use of economic, natural and human resources. This approach shifts attention from the elusive question of whether a nation is sustainable to the more tractable question of how efficient a nation is in producing human well-being. We model human well-being as a function of physical, natural and human capital. In a preliminary test of this approach here we operationalize human well-being as life expectancy, flows of physical capital as gross domestic product per capita, flows of natural capital as the ecological footprint, and human capital as education. Using data from 135 nations, we find that controlling for physical and human capital, exploitation of the environment has no net effect on well-being. This suggests that improvements in well-being may be attainable without adverse effects on the environment. We also find that many nations could substantially improve their efficiency in using human and natural resources to generate well-being.

Keywords: *sustainability, human well-being, ecological footprint, Stochastic Frontier Production models*

Introduction

How might we measure sustainability? At least since the International Union for the Conservation of Nature issued its World Conservation Strategy (International Union for the Conservation of Nature 1980), the idea of sustainable development—balancing human well-being with impacts on the biophysical environment—has been a popular goal.[2] However, the meaning of sustainable development remains uncertain, despite an overwhelming number of efforts to define it.[3] There are broadly accepted definitions, such as the idea of a triple bottom line used in discussions of sustainability and business (Elkington 1999) or the concepts of "strong" and "weak" sustainability that emerge in economic analyses (Daly and Cobb 1989). But there is as yet no broad consensus on measures that would allow us to assess the sustainability of a nation.[4] The question of how to measure sustainability is of great policy importance because answering it will allow us to assess the efficacy of alternative strategies for achieving sustainability. It is of great theoretical importance, too, because answering it will engage some of the most fundamental questions in human ecology.

In this paper we first briefly consider the two common approaches to assessing sustainability of nation-states. We then suggest a third approach that is a strong complement to both. We offer a simple and precise model to examine how efficient nations are at producing human well-being. This reconceptualization of sustainability is somewhat different than either the triple bottom line or the emphasis on future generations that dominates discussions grounded in economics. We use our proposed approach to estimate the efficiency of nation-states in producing human well-being. We show that nations differ substantially in their ability to produce well-being and that, net of affluence, generating environmental stress does not enhance well-being.

Assessing Sustainability

Parris and Kates (2003, 559) warned that the state of sustainability measurement is troubled. As they put it: "We conclude that there are no indicator sets that are universally accepted, backed by compelling theory, rigorous data collection and analysis and influential in policy." This is not surprising given that sustainability means so many things to so many people. Most efforts to operationalize sustainable development focus on *developing* human well-being while *sustaining* the biosphere. Hence, as noted by Parris and Kates (2003), measures of sustainable development must take account of what is to be sustained and what is to be developed. We will adopt that focus as well.

Before describing our proposed approach to assessing sustainability, it is useful to consider the two major traditions of sustainability measurement. We offer criticisms of these perspectives to indicate how the approach we propose might complement rather than displace them. Each approach has substantial merit as well as substantial limitations. Progress will come most rapidly if we pursue multiple paths to assessing sustainability and work toward a triangulation of them.

One sustainability assessment tradition assays all available indicators to select those that are plausibly related to sustainability. This is the path followed, for example, by the World Conservation Union in its "Well-being Assessment" (Prescott-Allen 2001) and by the World Economic Forum in its "Environmental Sustainability Index"[5] (World Economic Forum 2002). The suite of indicators is then combined into multiple scales that are aggregated into an overall index that is interpreted as the measure of sustainability.[6] For example, the Environmental Systems component of the 2002 Environmental Sustainability Index includes measures of air quality (comprising measures of urban SO_2 concentration, urban NO_2 concentration, and urban total suspended particulate concentration), water quantity, water quality, biodiversity and amount of land impacted by human activity. These efforts to develop aggregate measures are of great value in assembling and assessing available data. But there are several problems with the approach (York in press; Parris and Kates 2003). First, as a careful analysis of missing data in the Environmental Sustainability Index 2002 report documents, the overall ESI and especially the Environmental Systems component is based on measures for which there is a great deal of missing data (Abayomi et al. 2002). This requires imputation procedures that are not transparent and that may not be representative of the broad array of nations for which data are not available. Data sets are most complete among the most affluent countries since they typically have well-developed statistical reporting systems. Imputations for less-developed nations may be problematic. Second, the extensive use of variables that are available only for recent years means that it will never be possible to extend the data set backward in time and, therefore, to assess the unfolding of process. If the goal of a sustainability measure is to help monitor and plan for the future, that is not an issue. But for comparative and causal analysis, it is an important liability. Third, the measures combined into the aggregate scales and ultimately the sustainability index are typically collected for other purposes, and for many of them there is not an international consensus on how to collect and tabulate data. As a result, such indices are vulnerable to changes in how the direct measures are defined and collected by the organizations that develop them. Of course this is true for all secondary data. But the more component measures included, the more likely that changes in components will destroy comparability over time.[7] Fourth, as Parris and Kates (2003) have noted, these measures are intended to include more or less all "good" and "bad" attributes for which measurements are available, but in doing so they combine causes and effects (York in press). For example, a measure might include both the level of environmental degradation and the policies and institutions in effect to protect the environment. This papers over the pivotal issue of how policies and institutions influence the state of the environment. Fifth, because so many components are aggregated, the final measure of sustainability is cryptic and hard to interpret (York in press). It is quite a number of computational steps away from what has been measured directly and thus its meaning is not intuitive. In particular, while the research teams compiling data sets reach normative consensus on what to include as a "good" or "bad" attribute, it is not clear that the consensus on what to include and how to interpret it would extend beyond the team.[8]

The other major conceptualization of sustainability measurement is "green accounting" where adjustments for externalities are made to national measures of economic activity, such as gross domestic product (GDP) or savings rates, to reflect environmental and social concerns not captured in the traditional measures (Hecht 2005; U.S. National Research Council 1999). The literature in this area is quite dynamic, but two approaches seem to dominate. One, the Genuine Progress Indicator, adjusts gross domestic product to add in various "goods" not captured in gdp, such as the value of non-market labor, and to subtract out various uncaptured "bads," such as inequality and the costs of environmental degradation, crime and congestion (Talberth et al. 2007).[9] The other adjusts estimates of wealth or savings (i.e. changes in wealth) to take account of natural capital (natural resources and the state of the environment) and human capital (World Bank 2006). A major advantage and a major disadvantage of these measures is that they are firmly rooted in economic theory. It is an advantage because the formidable toolkit of macro and welfare economics can be brought to bear in advancing these analyses. It is a disadvantage because, to some considerable degree, the toolkit anchors them in a line of reasoning that equates income and wealth with utility and utility with well-being. While this is a popular conceptual framework for sustainability analysis, it is by no means flawless or the only approach. The other major limitation of adjusted national accounts as a measure of sustainability is that the data requirements for calculating estimates are substantial so they may not be available for many nations and time periods.

How does the Environment affect Human Societies?

A growing body of research examines the anthropogenic drivers of environmental change, including the papers in this special section of *Human Ecology Review*.[10] This body of research illuminates a great imbalance between the conceptual frameworks that organize international discussions of sustainability and the portfolio of empirical work currently available to discipline those discussions. A variety of conceptual frameworks emphasize *both* the effects of humans on the environment (Human activities→Environment) *and* the effects of the environment on humans (Environment→Human Activities) (Alcalmo et al. 2003; Liu et al. 2007a; Liu et al. 2007b). While steady progress is being made in developing and testing theories of how human actions drive environmental change, very little work has been done on how environmental change affects the social world.[11]

This is rather surprising since both core theory and major international assessment efforts suggest that human impact on the environment is not driven by ignorance or carelessness but by the advantages derived from exploiting the environment. The idea is very old and very new. It is old in the unforgettable dictum—"Knowledge is Power"—uttered in 1597 by Francis Bacon, where he was referring to human power over nature for the betterment of the human condition. It is new in such examples as the Millennium Assessment of Ecosystems and Human Well-being (MEA) which had as a major goal "to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being" (Reid et al. 2005, v). The goal reflects a longstanding concern in discussions of sustainability: how does human well-being relate to ecosystems?

One of the MEA's major conclusions is "The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the Millennium Development Goals" (Reid et al. 2005, 1). However, as the MEA also notes, "The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of degradation of many ecosystem services, increased risk of nonlinear changes, and the exacerbation of poverty for some groups of people" (Reid et al. 2005, 1). These findings suggest that we have, indeed, purchased some well-being at the cost of environmental degradation. However, we may be reaching a phase transition (tipping point in the popular vernacular) beyond which the returns in human well-being from environmental degradation will decline sharply.

The sociological literature also has acknowledged instrumental reasons to degrade the environment. This idea is at the heart of Schnaiberg's "treadmill of production" (Schnaiberg 1980). The politics that drive extraction of raw materials from the environment and the dumping of wastes into the environment are grounded in the quest for minimizing costs of production to maximize profits. Schnaiberg, neo-Marxists (Foster 1994, 1999, 2000) and neo-classical economists are in agreement on this point, though they view the political dynamics of environmental use much differently.

Combining these arguments with the question "How might we measure sustainability?" suggests that it might be fruitful to investigate how nations differ in the amount of well-being they create for each unit of environmental stress they produce. That is, it may be appropriate to move from looking just at environmental "bads" to looking at what "goods" nations manage to produce from stressing the environment. That is our core task here; to estimate the "environmental efficiency in producing human well-being" or just "efficient well-being" or EWEB. This is our approach to measuring sustainability. Sustainability is conceptualized as the efficiency with which human well-being is produced from the use of resources, including the environment. Higher efficiency implies greater sustainability. Next we will discuss how we can quantify this approach to yield numeric estimates of EWEB for nations or other social units.

The EWEB approach allows a search for the nations that are most and least efficient at producing well-being, focusing sharply on the relationship between environmental inputs and human well-being outputs. This is a more precise concern than sustainability per se, but we believe it may be a useful complement to the broader conceptualizations that have generated substantial literature but little consensus and relatively little empirical analysis of what contributes to sustainability. Like all approaches, the one we use here has its limitations. For example, a nation that is very efficient at generating well-being may still use resources in excess of what ecosystems can support in the long run, and thus the nation may not be ultimately sustainable. Additionally, in focusing on human well-being, EWEB does not address the important ethical consideration of the intrinsic value of other species. Thus, in referring to EWEB as a measure of sustainability, we acknowledge that it is only so in a limited sense and should not be used to indicate the state of the natural environment or as the singular focus of efforts to address environmental problems. The particular virtue of our approach is that it assesses the degree to which humans benefit from environmental exploitation, potentially highlighting social structural changes that can be made that will improve human well-being without increasing our impact on the environment.

In this strategy we are following in the footsteps of Mazur and Rosa (Krebill-Prather and Rosa 1995; Mazur and Rosa 1974; Rosa 1997). They examined the link between energy consumption and lifestyle and between carbon emissions and well-being and demonstrated that energy consumption had "decoupled" from human quality of life or well-being and that carbon emissions were decoupled from well-being for many nations. This approach embeds the question of how stressing the environment contributes to human well-being into a more general question of what factors overall contribute to well-being, a theme that is tacit in most work in political economy.

A Simple Model

In 1994, in this journal, we reviewed the diverse assertions about the human sources or anthropogenic drivers of environmental change and argued they had not been much disciplined with empirical work (Dietz and Rosa 1994). We offered a simple model, subsequently labeled STIRPAT,[12] which would allow progress in systematic hypothesis testing about the anthropogenic drivers of environmental change. This approach consciously followed one of Richard Levin's (1966) three strategies for model development: it is both *general* and *precise* though as a result it may lack *realism* in some applications. Our rationale for following this strategy is that it is always possible to elaborate a general and precise model to make it more realistic. At the same time, models that emphasize generality and precision allow for rigorous testing of hypotheses, an advantage not always possible if either of these attributes is sacrificed to the interests of realism. Indeed, a great deal can be learned by examining exactly what is needed to make a general and precise model more realistic for application in a particular context.

We have adopted the precision and generality strategy here. The problem of understanding cross-national variation in efficiency of well-being immediately brings to mind the sophisticated suite of methods developed by economists to examine efficiency in production. Among these, Stochastic Frontier Production Models (SFPMs) are especially apt, for they provide a powerful machinery for modeling variation of efficiency in producing the most economic output from the least inputs (Aigner et al. 1977; Kuhmbhakar and Knox 2003). The standard formulation for such a model is:

1) $O_i=f(\mathbf{X}_i)*E_i$

where E_i is the efficiency of a nation in producing output, O_i, and $\mathbf{X}_i$ is the vector of inputs.

We can modify this formulation to assess the environmental efficiency in producing well-being. We could represent the well-being of a nation i as:

2) $W_i=f(\mathbf{X}_i)*E.$

In this formulation W_i, is well-being and E_i is the EWEB, or the Efficiency of Well-Being measure, E_i, is thus our surrogate for the sustainability of a nation, on the assumption that nations that are more efficient in producing well-being are more sustainable than those that are not. E_i is assumed to have an upper bound of 1, so that nations are compared to a hypothetical most efficient nation. The larger the value of E the more efficient the nation is at producing well-being from economic activity and use of the environment. Finally, we would assume that there is a stochastic term representing random shocks, measurement error in W, etc. so, adding the stochastic term D, the model becomes:

3) $W_i= f(\mathbf{X}_i)*E_i*D_i$

What are the candidate components of **X**? Answering this question is a central concern in the approach to sustainability we are proposing. In this initial foray into empirical analysis, we offer a simple specification that, while defensible, will certainly warrant elaboration in subsequent work. Macro-economic theory assumes that social welfare is a function of three forms of capital: manufactured (physical) capital, human capital and natural capital.[13] Thus, it seems reasonable to consider well-being as a function of affluence, human capital and natural capital. If we represent physical, natural and human capital by A (for affluence), I (for environmental stressors)[14] and H (for human capital) then the model becomes:

4) $W_i = f(A_i, I_i, H_i) * E_i * D_i$

If we assume that the production function is linear in the logs[15] we have:

5) $\ln(W_i) = B_0 + B_1 * \ln(A_i) + B_2 * \ln(I_i) + B_3 * \ln(H_i) - \ln(E_i) + \ln(D_i)$

B_0 is a constant that scales the model. We constrain $\ln(E_i)$ to be strictly negative or zero to allow $0<E\leq 1$. There is a substantial literature in econometrics on how to estimate this function with the appropriate constraint on $\ln(E_i)$. The most common approach, which we will use here, is the half-normal distribution where values are restricted to one side of the normal distribution.

Using the Model

What are reasonable measures for A, I, H and W? The standard measure of affluence, A_i, is gross domestic product per capita (GDPPC). This seems appropriate, for while GDPPC is a measure of national income it has its origins in the full economic activities in an economy, and so is a measure of the processes that produce all the goods and services (Hecht 2005).[16] Note that in this simple formulation we are not taking account of distributional issues, but we acknowledge that they are certain to be of great importance to well-being.[17]

The problem of a measure for I_i is more challenging. Measures that rely on a single environmental stressor, such as emissions of greenhouse gases, are limited for our purposes. They ignore tradeoffs and, therefore potentially underestimate environmental costs. For example, a nation might reduce greenhouse gas emissions by increased reliance on nuclear power, but nuclear power has its own environmental consequences. To address this challenge we use the ecological footprint (EF) as our measure of environmental stressors. The EF is calculated by taking basic forms of consumption—crops, meat, seafood, wood, fiber, energy, and living space—and converting them, at world average productivity, into six types of biologically productive land and sea space—crop land, forest land, grazing land, water area, land for infrastructure and land needed to absorb CO_2 emissions.[18] Not without criticism, the EF is, nevertheless, the most comprehensive and most widely adopted overall measure of threats to environmental sustainability. Among its strengths is the capture of tradeoffs, for example, between consumption of fish and consumption of meat or between the use of fuel wood and fossil fuels (Wackernagel et al. 2002). Its major limitation is that it does not account for stressors with local impacts such as pollution emissions (except for CO_2). However, cross-national data on local impacts are so meager that at present they cannot be included in the footprint.

Human capital, H_i, is even more difficult to assess, in part because it is more difficult to conceptualize and in part because comparable measures across nations are difficult to obtain. Nevertheless, there is general agreement that human capital implies the acquisition of knowledge and skills that permit an individual greater efficacy in navigating through life. For this initial effort, we will use the U.N. education index, which combines adult literacy and school enrollment (United Nations Development Programme 2001).[19] This measure, of course, does not take into account informal and traditional forms of education, and, therefore, is not without its limits.

There are many candidate measures of human well-being, W_i, but no universally accepted one. In this initial exploration of our approach we will restrict our attention to life expectancy at birth. Life expectancy has a number of advantages as a measure of well-being. It is well-measured in most countries. It is widely accepted as a measure of a societal "good." For example, it is one of the three components of the U.N. Human Development Index (United Nations Development Programme 2001).[20] Once adjusted for the effects of ill-health or disability, life expectancy becomes either "healthy life expectancy" or "disability adjusted life expectancy" each of which is widely accepted in the public health community as a key measure of desirable outcomes from policy.[21,22]

Life expectancy also captures some aspects of equity. Poverty and inequality tend to increase infant and child mortality more than adult mortality, and infant and child mortality weigh more heavily than adult mortality in the calculation of life expectancy (because more potential years of life are lost by an early death than by a later one). For all these reasons, life expectancy seems a reasonable starting point in our exploration of well-being.[23]

Some Initial Results

We assembled cross-sectional data on these four variables for 1999 to provide an initial test of our approach. Data on life expectancy and the education index are from the United Nations (United Nations Development Programme 2001). Data for the ecological footprint are from the Living Planet Report (World Wide Fund for Nature 2002). GDP per capita in 1999 U.S. dollars at parity purchasing power is from the World Bank Data online site.[24] We used both a standard OLS regression model and a SFPM using a half-normal distribution for estimating the efficiency parameter.[25] Reported significance levels are based on maximum likelihood estimates, which are equivalent to ordinary least squares for the simple regression models. Robust estimates of standard errors via

Table 1. Production Models of Human Well-Being

	OLS Regression	Half normal stochastic frontier production model
A (Affluence)	0.088***	0.064***
I (Impacts)	-0.007	-0.022
H (Human Capital)	0.243***	0.235***
Intercept	3.502***	3.836***
R^2	0.696	—
N	135	135

*** p<0.001

Jackknife procedures yielded substantively identical results except that the significance level for A in the SFPM dropped from p<0.001 to p<0.05. The Variance Inflation Factors (VIFs) for A, I and H were 5.57, 4.77 and 2.10 respectively, all within an acceptable range.[26] Niger has the highest leverage in the data set, but removing it does not change substantive conclusions.

Table 1 displays the results of estimating a standard OLS regression in log-log form, where no special structure is imposed on the residuals and the SFPM using a half-normal distribution for estimating the efficiency parameter. The results for both approaches (OLS and SFPM) are quite consistent. Affluence has a significant positive effect, as does human capital. However, we find no evidence that adversely stressing the environment improves human well-being, net of affluence and human capital. The per capita ecological footprint has a negative effect but is not statistically significant via any method of estimation we have used. This suggests that, in the tradition of Mazur and Rosa (Mazur and Rosa 1974), the direct link between human well-being and exploitation of the environment is decoupled. However, we stress that this is a direct effect. Although impacts in and of themselves do not improve well-being once affluence is taken into account, it is important to recognize that to the extent impacts are linked to affluence they may have an indirect effect on well-being.[27] We return to this point below.

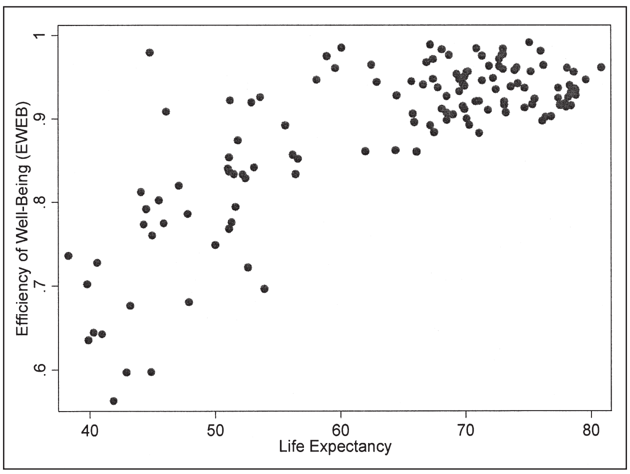

Figure 1. Life Expectancy versus Efficiency of Well-Being (EWEB)

The E_i in Equation (3) is the efficiency in production of well-being, our measure of sustainability. A likelihood ratio test rejects the hypothesis that the log of the efficiency parameters are simultaneously zero (p<0.001); thus there is evidence of some inefficiencies across nations implying variation in sustainability. Figure 1 displays the efficiency multipliers for the nations in our sample plotted against life expectancy. Virtually all the cases with life expectancy under 60 years and EWEB less than 0.9 are in sub-Saharan Africa. It appears that many, but by no means all, African nations are relatively inefficient in their production of well-being. This suggests that the problems with improving well-being in Africa will require not only raising the levels of education and alleviating poverty, but also changing the factors that underpin this lack of efficiency. It also points to the importance of expanding on this analysis to better understand those factors. We also note that a number of moderate and low-income nations—such as Jamaica, Morocco, Yemen, Syria, Nicaragua, and Egypt—do quite well in generating well-being from their modest levels of affluence and human capital. These findings raise two key questions: Why are these nations relatively efficient in translating their inputs of affluence and human capital into well-being? Will those efficiencies hold as affluence and human capital increase? An answer to both questions is crucial to developing broad strategies and policies for improving well-being without serious ecological deterioration. Of course, at this incipient stage of this line of research these results are illustrative and the details may change as this approach is explored further. We conclude by considering the logical next steps in such explorations.

Conclusions and Directions for Further Work

We have pursued several goals in this paper. The first, and most general, is to point out that the effect of the exploitation of the physical environment on human societies deserves much more extensive theorizing and empirical examination. The second is to suggest that looking at the relationship between stresses visited on the environment and human well-being is one way to frame an examination of these links. Third, this approach provides a complement to existing methods of assessing sustainability. Finally, we have offered a first line of empirical results and we recognize that these results must be viewed as very preliminary. We have used a very simple Stochastic Frontier Production Model (SFPM) for human well-being. That model certainly warrants elaboration based on further theorizing and analyses.

We have examined only one measure of human well-being (life expectancy), albeit one we consider quite defensible. Furthermore, we have looked at only a cross-section of nations. This precludes us from examining the dynamics, including cross-lagged and other effects, between the environment and society.

The results from this analysis need to be considered in the context of other findings from the STIRPAT research program and from other research to more fully understand their implications. First, one of the most consistent findings from previous STIRPAT research is that affluence, as measured by GDPPC, is closely linked to environmental impacts (York et al. 2003; York et al. 2002; Rosa et al. 2004). Here and in other analyses we have found a decoupling of environmental stressors and well-being, but only once the effects of affluence are controlled (Dietz et al. 2007). We should not lose sight of the fact that growth in affluence, at least as measured by GDPPC, typically comes at a high environmental cost. Second, it also appears likely that improvements in well-being from growing affluence are best characterized by a relationship of diminishing returns; i.e., growth in affluence for very low-income countries can substantially improve well-being, but this benefit rapidly diminishes so that for affluent countries, further economic growth does little to improve human well-being (Di Tella and MacCulloch 2006).[28] Perhaps an explicit focus on improving human well-being directly, rather than indirectly via expanding wealth, may serve to both limit human impacts on the environment and improve the human condition. However, further analyses are necessary to delineate such an approach.

Despite the empirical limits in our analysis, we believe this has been a useful exercise. Like the original STIRPAT formulation, it awaits elaboration and challenge. Nevertheless, like STIRPAT, it provides a framework for examining how societies make use of the biophysical environment. It allows testing of specific conjectures about how social structure, political economy, culture and other factors influence sustainability. This is a move from thoughtful, well-meaning, but perhaps overly general and operationally challenging approaches to sustainability, to a more specific formulation—measuring the efficiency with which well-being is obtained from use of nature's capital and services.

The approach, we can note, is quite flexible. It can be used with data for virtually any scale: for individuals, for households or for any geopolitical unit up to the global economy as long as data are available. The data requirements, while not trivial, are less taxing than those of many other measures of sustainability. And the approach is amendable to systematic quantitative comparisons of different conceptualizations of human well-being, environmental stressors and other key variables. It also encourages investigation into why nations (or other units of analysis) vary in their efficiency in producing well-being. And in doing so, it connects work on sustainability with other literatures that address human well-being.

Instead of asking how "sustainable" various social systems and practices are, we ask how efficient are they in producing human well-being, privileging the idea of ecological efficiency over the more contested concept of sustainability. This approach allows conjectures to be disciplined with data, provides quantitative assessment of the performance of nations and promises operational guidance for informed decision-making about best practices for sustainability. We believe that the process of elaborating and testing models of the environmental efficiency in producing human well-being will provide useful information for the transition towards sustainability.

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Endnotes

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2. The Brandt (Independent Commission on International Development Issues 1980) and Bruntland reports (World Commission on Environment and Development 1987) were influential in making these ideas accessible to the international development community.
3. Pearce and Walrath (no date accessed June 17, 2007) found over 200 definitions of the term.
4. In this paper we focus on the nation-state as a unit of analysis. Some approaches to sustainability, such as the triple bottom line, can be applied to any organization or geopolitical unit, while others, such as those related to weak and strong sustainability, are well-defined only for nations or geopolitical units. The measure we propose can be developed for any unit of analysis from the individual to the globe.
5. In recent years, the team that produced the Environmental Sustainability Index has focused on an Environmental Performance Index (Esty et al. 2008) that has evolved from a major component of the Sustainability Index. While some of the concerns we raise also apply to the Environmental Performance Index, we emphasize that this is a rapidly evolving effort that hones its approach over time so concerns with earlier versions may not apply to emerging instantiations of this index.
6. The final step of the Well-being Index produces a ratio of human well-being to environmental well-being, an approach somewhat similar to what we propose. It is limitations in the construction of the

two measures that are eventually compared that is the subject of our concerns here.

7. Of course, with a large enough number of component measures, changes in definition or methods for a few often will have only limited influence on the aggregate measure.
8. Many goals for human well-being have been developed by international consensus. These might be used as normative underpinnings for understanding what is meant by sustainability (U.S. National Research Council 1999). There are far fewer explicit international consensus standards for the environment.
9. In the original formulation (Daly and Cobb 1989), it was called the "Index of Sustainable Economic Welfare."
10. See Dietz et al. (in press) for a review of theory, conceptual issues and findings in this literature.
11. Some scholars addressing the *longue durée* are exceptions (Moran 2006; Lenski 2005; Diamond 1999, 2005; Bloch 1966; Braudel 1980) as is the literature on vulnerability to environmental change, which for several decades has wrestled with the best way to incorporate environmental influences into social theory (McLaughlin and Dietz 2007; Kasperson et al. in preparation). However, the *longue durée* tradition emphasizes how the environment constrains and shapes societal evolution, while the vulnerability tradition typically focuses on untoward events (floods, droughts, famines, etc.). We are applying a much different lens, as we hope will be clear below.
12. Available at www.stirpat.org.
13. For example, Arrow et al. (2004) performed an extensive analysis of the problem of optimal and sustainable consumption by assuming that welfare is a function of these three forms of capital. It would make sense to expand our treatment to include social capital (Das-Gupta 1999), but it is not easy to identify adequate measures of social capital for empirical analysis so we will defer that extension for later work.
14. For the most part, human activities intended to enhance human well-being generate stresses on the environment, what are often called "drivers." Ecosystems respond to these stressors in complex and dynamic ways, and the resulting changes are the impacts. To adequately address the issue of impacts requires data on and models of the responses, not just the stressors, so for initial applications, we will focus on stressors. However, we use the term "I" because it is conventional to discuss "environmental impacts" even when the more proper term is "stressors."
15. In STIRPAT applications we have used base e, natural logarithms, and base 10 logarithms depending upon the objectives of the analysis. There is a longstanding tradition in econometrics of using natural logarithms on modeling stochastic frontier production functions, so we follow that tradition and here use natural logs. As with STIRPAT we begin with a form that is linear in the logs, but can easily expand to examine functional forms that are non-linear in the logs when that seems theoretically appropriate.
16. As noted in our discussion of sustainability indicators, an intellectual path parallel to the one we are walking estimates three measures of capital stocks—manufactured capital, human capital and natural capital—and aggregates them into "genuine investment" or "genuine savings" as a sustainability indicator (Arrow et al. 2004; The World Bank 2006). Mulder et al. (2005) have used individual level data to explore the contributions of built, human, social and natural capital to quality of life.
17. Most measures of affluence, such as gross domestic product per capita, are population averages that do not take account of income or wealth distribution or other aspects of privilege versus marginality. This is also true for most other measures we use, such as those discussed below for human capital and for environmental stressors—they, too, are population averages. Further analysis of efficient well-being will have to attend to distributional issues for at least two reasons. First, in the presence of substantial inequality, large segments of the population may not benefit from the inputs to well-being. Second, inequality itself may be a source of stress and social dysfunction that adversely impacts well-being and the environment (Mikkelson et al. 2007). In this preliminary analysis we do not incorporate distributional effects but we acknowledge their importance. We thank a reviewer for reminding us of the importance of distributional issues.
18. Energy generated from nuclear power is given the same footprint as if it were generated by the typical fossil fuel power plant. This is done because there is no single clear way to estimate the land impacts of nuclear power, particularly risks associated with contamination of the environment from storage of radioactive wastes and the potential for meltdowns.
19. The education index is a weighted average of the adult literacy rate (given 2/3 weight) and the school enrollment ratio (given 1/3 weight) scaled to range from 0-1.
20. The other two are the education index and a standardized version of GDPPC. We are treating education and affluence as causes of well-being rather than as well-being per se, so in a sense we are decomposing the Human Development Index to elucidate its causal structure while also taking account of the effects of environmental impact in generating well-being.
21. Available at http://www.who.int/healthinfo/boddaly/en/index.html
22. A major alternative is the "life satisfaction" approach where the measure of well-being is the national average of survey responses to questions on individual happiness, well-being or life satisfaction (Kahneman et al. 1999). In an approach parallel to ours, Welsch (2007) has estimated national average happiness as a function of gross domestic product per capita, air pollution and scientists and engineers per capita. While the life satisfaction approach is appealing, data limitations reduce sample sizes for such analyses to around 50. Ultimately, multiple measures of well-being deserve exploration.
23. In this discussion we do not address the issue of stocks versus flows. GDP per capita and the ecological footprint can be considered annual flows, the education index is a weighted average of a stock (literacy) and a non-annual flow (enrollment rates) while life expectancy is largely a stock. However, the critical issues are these: which variables are subject to substantial short term changes and which move more slowly, and which causal effects are instantaneous when viewed from an annual perspective and which unfold more slowly (York et al. 2002). We expect that this will be an important issue for future work. Since we restrict our analysis here to cross-sectional data, we believe it best to address these issues in a subsequent paper deploying panel data.
24. Available at devdata.worldbank.org/dataonline/SMRresult.asp; accessed June 14, 2004.
25. Models were estimated with Intercooled Stata 9.2.
26. There is no established standard for VIFs. Hamilton (1992, 134) sug-

gests values above 5 (a tolerance of .20, the reciprocal of 5) or 10 (a tolerance of .10) may be a problem. Similarly, Chatterjee et al. (2000, 240) suggest that a VIF above 10 (which corresponds to a tolerance below .10) is a problem and Greene (2000, 258) suggests a VIF above 20 is a problem (which corresponds to a tolerance of below .05).

27. This argument parallels one offered by Welsch (2007), who treats pollution as a "quasi-input" to income and as a direct input to happiness. While not significant, the negative coefficient for "I" in our estimates is consistent with his result that, controlling for affluence, local pollution decreased average national happiness. The ecological footprint assigns impacts to the country where consumption takes place. With international trade, the stress on the environment generated by consumption may take place in a different country than the consumption itself. This may be one reason that we find the decoupling of environmental stress and well-being.
28. Graphing life expectancy against affluence suggests that the largest gains in well-being occur before a gross domestic product per capita of $10,000 is reached. Including a quadratic term in the log of gross domestic product per capita in our model and solving for the maximum indicates that a value of gross domestic product per capita of about $42,000 would maximize life expectancy, with declines expected above that value.

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