Theme 2: Human-Environmental Systems as Complex Adaptive Systems

Title: The Complex Big Picture of Sustainability

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The Complex Big Picture of Sustainability

Abstract. The earth, its ecosystems and human civilization are not just complex, they are also complicated. There is a danger of being blinded by this complication, of losing track of the forest because it has so many trees. Current research in sustainability often suffers from the problem of placing too much focus on details even when basic aspects are not qualitatively understood. This is particularly true when it comes to problems of risk and uncertainty. It is essential to keep sight of the big picture. In this white paper I provide several examples and try to argue that the NSF program needs to keep its focus at a high level, funding basic problems whose solutions are essential.

The need for a synthetic approach. Problems of sustainability are inherently interdisciplinary and complex. Sustainability involves an understanding of the geology of the earth and its natural resources, its ecosystems, and its human systems, including technology, economics, politics, psychology and anthropology. All of these are becoming increasingly strongly interacting as the population grows, the standard of living increases, and the world becomes ever more globalized. It is ineffective to address one of these areas without taking into account the others.

Because these systems are all so complicated, even when taken on their own, in the quest for realism there is a temptation to plunge into ever greater levels of detail. Sometimes this is needed and appropriate. But if there are lingering problems at a high level this can be a complete waste of time. In England there is a website that offers predictions of the climate in 2080 at the geographical level of individual postal codes. This is of course absurd, and one wonders how it was ever funded.

Risk and uncertainty in climate models. Climate models tend to focus on single number predictions, such as the expected global temperature change at a given target date. There should be much more emphasis on making predictions of risk and emphasizing uncertainty. We know little or nothing about distributions. Are the distributions of expected temperatures or sea level rise heavy tailed? (It would be surprising if they weren't). How heavy are the tails? These questions are essential in understanding the likely outcomes. While expected sea level rise on might be 1 - 4 feet, if there is a very heavy tail, there might be a 1% probability that it will be 20 feet. This makes an enormous difference in interpretation, and it also makes an enormous difference in mitigation planning.

This point should be emphasized at the highest level. Rather than saying "we know that global warming is going to occur", we should say "with high probability there will be a substantial and rapid climate change driven by human activity". The second statement is much harder to argue with.

Better statistical testing. While climate models are becoming ever more sophisticated, there is a danger that they are also becoming ever more overfit, and therefore less useful for prediction. Climate models are validated by matching against historical time series. The problem is that, when the model fails to fit the data, it is then modified and then tested again on the same data to see whether the match has improved. This process is repeated until the predictions (about the past) match the historical data.

This procedure invariably leads to overfitting. With high likelihood it results in models that match history well but predict the future poorly. It is essential to educate climate modelers about this problem in statistics and to enforce more discipline in testing and validating models. For example, a better procedure is to withhold data during model development and test predictions only when a model is believed to be well-specified. In fact, typically one wants to divide the data into at least three different sets, making out of sample tests on the second set sparingly, and on the third set extremely sparingly. The NSF should form collaborations with statisticians, who should educate climate modelers, develop better protocols, and push to integrate them into IPPC reporting.

Economic mitigation models. Current attempts to model the economic consequences of climate change are often packed with detail, even though the basic assumptions used to produce the results are untested and the answers may off by orders of magnitude, or even have the wrong sign. I discuss some of the problems below:

Discounting. Climate mitigation models must make assumptions about discounting in order to translate possible damages or benefits in the far future into net present value. This is universally done using exponential discounting. However, real interest rates or real economic growth rates fluctuate, which means that the correct method of discounting is not exponential. This is not just a small matter -- as recently demonstrated, it can change the results by orders of magnitude. Until this problem is addressed more carefully, economic mitigation models are almost pointless. While Stern may be closer to the truth than Nordhaus, neither of them are right.

Assumptions about technological progress. To make intelligent policy decisions we need the capacity to make sensible forecasts about technological progress. For example, to develop low greenhouse gas emitting energy sources, the private and public sectors need to make investment decisions. How much should we invest in solar, wind, nuclear, carbon sequestration, and biofuels, or completely new possibilities? Within each of these basic areas which technologies should we support? How much investment is needed, and what are the payoffs likely to be? When will they supplant fossil fuels under different scenarios of carbon taxes? Current models make primitive, ungrounded assumptions that fail to take uncertainties into account. They assume a fixed palette of technologies. To see the danger of this, just imagine going through the same exercise in 1910: Solar and nuclear would not even be on the table. We need better generic models of technological change, whose forecasting errors are well understood.

How much does investment stimulate the economy? Mitigation models tend to simply add up expenditures without any understanding of how investment might stimulate growth. This point can be illustrated by asking the following question: Apart from the

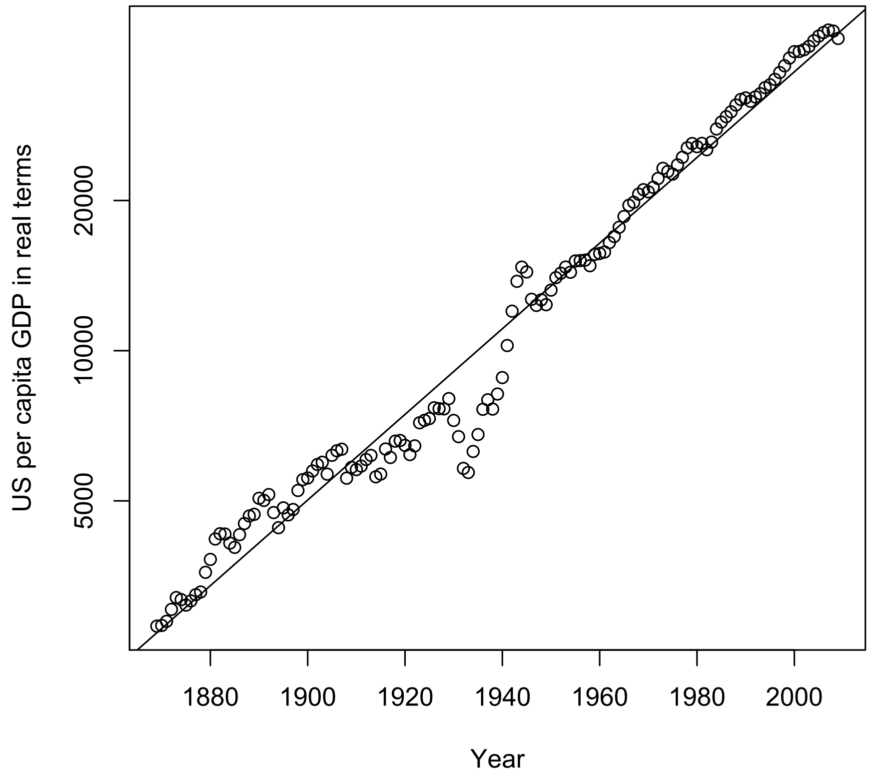

Figure 1. GDP of the US from 1869 - 2009 in 2005 dollars, on semi-log scale. The solid line is a least squares fit. Note that during the war the GDP returned to the trend it was on before the depression began.

horrible costs in terms of human life, what were the economic costs to the United States of World War II? To address the question, consider the GDP growth of the US over a span of 130 years, as illustrated in Figure 1. After the huge drawdown during the depression, during the war GDP not only returned to exponential growth, but furthermore returned to the same trend line it was on before the depression. Thus what was the economic cost of the war? One could easily argue it was less than zero. This is certainly not the conclusion a “war mitigation model” would come to using current methods, which simply count the costs of the expenditures.

Utility. Essentially all models in neoclassical economics are based on assumptions about maximizing utility, where utility is typically measured as a function of consumption. This has a very poor empirical basis. There is a substantial psychological literature on measuring happiness through methods such as surveys of subjective well-being, reports by peers, or physiological measures such as facial expression. Such studies give a very different appraisal of what makes people happy. For people whose basic needs are met, the absolute level of economic well-being registers fifth or sixth on a scale, just behind social networks and environment. Psychologists provide us with a detailed understanding of subjective well being -- economists should use it in modeling the costs and benefits of economic policies.

These are just a few examples of a few issues that are fundamentally wrong with economic mitigation models. Until such issues are addressed it is pointless to continue adding ever more detail to models that are fundamentally flawed.

Sustainable increase of GDP. Is it possible to continue increasing GDP at an exponential rate while lowering environmental impacts? The naive answer would seem to be no. However, this depends on what kind of benefits we get from GDP. Elegant, low weight, low enegy consumption technologies, or low impact service industries can potentially fuel a continued expansion of GDP while lowering overall environmental impact.

Engineering social change. Most experts in sustainability agree that the fundamental impediments to sustainability are social rather than technological. How can we educate the public so that they properly understand the issues, and understand the sacrifices that will need to be made and the benefits that will accrue from a transition to a sustainable world? What social and governmental structures are needed to effect the changes that need to be made?

Summary. It is essential to keep the big picture in sight in the attempt to understand complex systems. Paradoxically, understanding complex systems often requires simple models -- complication all too often obscures deep and fundamental problems. Any NSF effort on sustainability should try to maintain a proper focus on addressing the biggest problems without getting lost in the forest of details.