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Policy Forum

Introduction: Environmental scares – the Club of Rome debate revisited

On 20 December 1997 *The Economist* published the article that forms the focus of this policy forum. It is reprinted below. While the article falls outside the range of papers normally considered in policy fora in this journal it appeared in a publication that is widely read by policy-makers and their immediate advisors, and argues a very particular and quite widely held view as to the how environmental issues should be perceived. Its tone and argument are neatly summarized by the headline statement: ‘forecasters of scarcity and doom are not only invariably wrong, they think that being wrong proves them right’.

This forum offers reactions to *The Economist* article by a group of distinguished scientists—not only from economics (Partha Dasgupta, James Hammitt, Allen Kneese, Bengt Kriström, Karl-Gustav Löfgren, Karl-Göran Mäler, Wallace Oates, Paul Portney, Kerry Smith) but also from ecology (John Krebs and Simon Levin) and climatology (Bert Bolin). The original article was clearly designed to provoke. It adopts an inflammatory style including, for example, a cartoon depicting ecologists as crazed Cassandras in Planet Doom. But it also raises serious questions about the appropriate responses to scientific information on the environmental effects of economic growth and technological change; the treatment of environmental risk and uncertainty; and the role of liberalized markets (economic freedom) in environmental protection.

The contributors to this forum consider these issues. They are less concerned with mineral reserves and prices than they are with the effect of economic activity on ecological services. Their reactions differ, but four general points come through strongly. All have profound implications for both environmental science and environmental policy. Krebs, Kneese, Dasgupta and Mäler make the point that conditional scientific predictions about acid rain, the ozone layer, climate change and the like are based on models of the dynamic processes involved. These models attempt to take account of the feedback effects in what is often a very complex set of processes. But although scientists are aware that neglect of economic feedbacks is what compromised the models underpinning the resource scarcity predictions of the Club of Rome in the early 1970s, the work of integrating models of natural and social processes has barely begun. There are many structural obstacles to the sort of interdisciplinary collaboration needed to develop predictive models that include economic feedback effects, but it is unhelpful to criticize scientific models for neglecting economic feedbacks if there is no support for the collaborative research required to take such effects into account. Modelling the dynamic general equilibrium effects of many problems of environmental change is simply beyond the reach of any one discipline.

The second point is related. Portney and Oates argue that a kind of Heisenberg Principle operates in environmental predictions: that the act of studying the problem itself affects the outcome. For example, Paul Ehrlich's various predictions have frequently been the spur to a complex set of responses that involve changes not just in policy and regulatory regimes, but also in people's preferences. Levin and Smith argue a similar point. Taken with the feedbacks offered by market prices, these various responses provide a powerful explanation for the 'failure' of many environmental predictions. The information provided by the predicted environmental damage induces a response that mitigates the actual environmental damage. Indeed, turning the problem on its head, environmental predictions that do not 'fail' imply failure of social feedback mechanisms and of markets in particular. Most of the responses discuss the options open to correct for this type of failure.

A third point concerns the uncertainty of environmental predictions and the appropriate response to uncertainty. In most cases, the scientific predictions that underpin environmental scares are built on on-going programmes of research, a major aim of which is to improve the predictive power of the models concerned and to reduce the level of uncertainty associated with the model predictions. The 'life cycle' of environmental scare stories described in *The Economist* article is very similar to the sequence of reactions to any innovation—good or bad—involving initially high levels of uncertainty. Hammitt makes the point that where data and understanding of environmental problems improves over time a sequential approach to decision making is appropriate. Environmental policy can and should change as information improves.

A final point made by Dasgupta and Mäler cautions against the use of global statistics where most environmental problems are the localized consequence of the interaction of natural and social processes. There have been many local environmental disasters that matter a great deal to the people affected. The solution to local environmental problems is often a highly specific mix of scientific research, institutional change, property rights and policy reforms. To the extent that the global story detracts from the need to find local solutions to local problems, it is unhelpful.

There are few more important items on the environmental research agenda than to understand the interactions between economic and natural processes. The disdain for ecologists reflected in the article from *The Economist* is unfortunately still all too common. It is, however, worth recording that many of the most significant advances in environmental science in recent years stem from collaboration between economists and ecologists as each has learned from the other.

Charles Perrings
Editor

Environmental Scares: Plenty of gloom

Forecasters of scarcity and doom are not only invariably wrong, they think that being wrong proves them right

In 1798 Thomas Robert Malthus inaugurated a grand tradition of environmentalism with his best-selling pamphlet on population. Malthus argued with impeccable logic but distinctly peccable premises that since population tended to increase geometrically (1,2,4,8 ...) and food supply to increase arithmetically (1,2,3,4 ...), the starvation of Great Britain was inevitable and imminent. Almost everybody thought he was right. He was wrong.

In 1865 an influential book by Stanley Jevons argued with equally good logic and equally flawed premises that Britain would run out of coal in a few short years' time. In 1914, the United States Bureau of Mines predicted that American oil reserves would last ten years. In 1939 and again in 1951, the Department of the Interior said American oil would last 13 years. Wrong, wrong, wrong and wrong.

This article argues that predictions of ecological doom, including recent ones, have such a terrible track record that people should take them with pinches of salt instead of lapping them up with relish. For reasons of their own, pressure groups, journalists and fame-seekers will no doubt continue to peddle ecological catastrophes at an undiminishing speed. These people, oddly, appear to think that having been invariably wrong in the past makes them more likely to be right in the future. The rest of us might do better to recall, when warned of the next doomsday, what ever became of the last one.

Empty imaginations

In 1972 the Club of Rome published a highly influential report called 'Limits to Growth'. To many in the environmental movement, that report still stands as a beacon of sense in the foolish world of economics. But were its predictions borne out?

'Limits to Growth' said total global oil reserves amounted to 550 billion barrels. 'We could use up all of the proven reserves of oil in the entire world by the end of the next decade', said President Jimmy Carter shortly afterwards. Sure enough, between 1970 and 1990 the world used 600 billion barrels of oil. So, according to the Club of Rome reserves should have been overdrawn by 50 billion barrels by 1990. In fact, by 1990 unexploited reserves amounted to 900 billion barrels—not counting the tar shales, of which a single deposit in Alberta contains more than 550 billion barrels.

The Club of Rome made similarly wrong predictions about natural gas, silver, tin, uranium, aluminium, copper, lead and zinc. In every case, it said finite reserves of these minerals were approaching exhaustion and prices would rise steeply. In every case except tin, known reserves have actually grown since the Club's report; in some cases they have quadrupled. 'Limits to Growth' simply misunderstood the meaning of the word 'reserves'.

The Club of Rome's mistakes have not tarnished its confidence. It more recently issued to wide acclaim 'Beyond the Limits', a book that essentially said: although we were too pessimistic about the future before, we remain equally pessimistic about the future today. But environmentalists have been a little more circumspect since 1990 about predicting the exhaustion of minerals. That year, a much-feted environmentalist called Paul Ehrlich, whose words will prove an inexhaustible (though not infinite: there is a difference) reserve of misprediction for this article, sent an economist called Julian Simon a cheque for $570.07 in settlement of a wager.

Dr Ehrlich would later claim that he was 'goaded into making a bet with Simon on a matter of marginal environmental importance'. At the time, though, he said he was keen to 'accept Simon's astonishing offer before other greedy people jump in'. Dr Ehrlich chose five minerals: tungsten, nickel, copper, chrome and tin. They agreed how much of these metals $1,000 would buy in 1980, then ten years later recalculated how much that amount of metal would cost (still in 1980 dollars) and Dr Ehrlich agreed to pay the difference if the price fell, Dr Simon if the price rose. Dr Simon won easily; indeed, he would have won even if they had not adjusted the prices for inflation, and he would have won if Dr Ehrlich had chosen virtually any mineral: of 35 minerals, 33 fell in price during the 1980s. Only manganese and zinc were exceptions (see figure 1).

Dr Simon frequently offers to repeat the bet with any prominent doomsayer, but has not yet found a taker.

Others have yet to cotton on. The 1983 edition of a British GCSE school textbook said zinc reserves would last ten years and natural gas 30 years. By 1993, the author had wisely removed references to zinc (rather than explain why it had not run out), and he gave natural gas 50 years, which mocked his forecast of ten years earlier. But still not a word about price, the misleading nature of quoted 'reserves' or substitutability.

So much for minerals. The record of mispredicted food supplies is even worse. Consider two quotations from Paul Ehrlich's best-selling books in the 1970s.

> Agricultural experts state that a tripling of the food supply of the world will be necessary in the next 30 years or so, if the 6 or 7 billion people who may be alive in the year 2000 are to be adequately fed. Theoretically such an increase might be possible, but it is becoming increasingly clear that it is totally impossible in practice.

> The battle to feed humanity is over. In the 1970s the world will undergo famines—hundreds of millions of people are going to starve to death.

He was not alone. Lester Brown of the Worldwatch Institute began predicting in 1973 that population would soon outstrip food production, and he still does so every time there is a temporary increase in wheat prices. In 1994, after 21 years of being wrong, he said: 'After 40 years of record food production gains, output per person has reversed with unanticipated

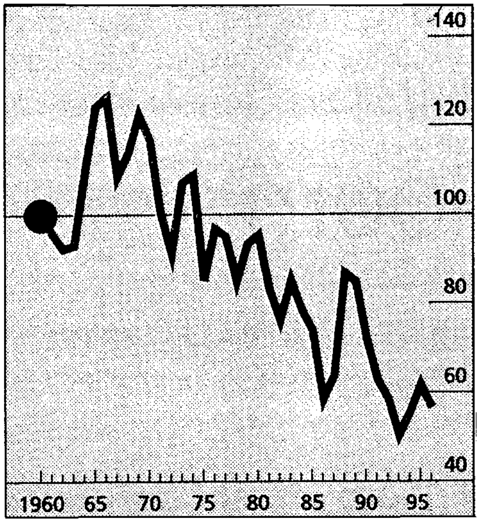

Figure 1. *Plenty of metals: metals and mineral price, real terms* 1960 = 100*

Note: Deflated by $ unit value index if G5 manufacturing exports.
Source: World Bank

abruptness'. Two bumper harvests followed and the price of wheat fell to record lows. Yet Mr Brown's pessimism remains as impregnable to facts as his views are popular with newspapers.

The facts on world food production are truly startling for those who have heard only the doomsayers' views. Since 1961, the population of the world has almost doubled, but food production has more than doubled. As a result, food production per head has risen by 20 per cent since 1961 (see figure 2). Nor is the improvement confined to rich countries. According to the Food and Agriculture Organisation, calories consumed per capita per day are 27 per cent higher in the third world than they were in 1963. Deaths from famine, starvation and malnutrition are fewer than ever before.

'Global 2000' was a report to the president of the United States written in 1980 by a committee of the great and the good. It was so influential that it caused one CNN producer to 'switch from being an objective journalist to an advocate' of environmental doom. 'Global 2000' predicted that population would increase faster than world food production, so that food prices would rise by between 35 per cent and 115 per cent by 2000. So far the world food commodity index has fallen by 50 per cent (see figure 3). With two years to go, prices may yet quintuple to prove 'Global 2000' right. Want to bet?

Perhaps the reader thinks the tone of this article a little unforgiving. These predictions may have been spectacularly wrong, but they were well-meant. But in that case, those quoted would readily admit their error, which they do not. It was not impossible to be right at the time. There were people who in 1970 predicted abundant food, who in 1975 predicted cheap

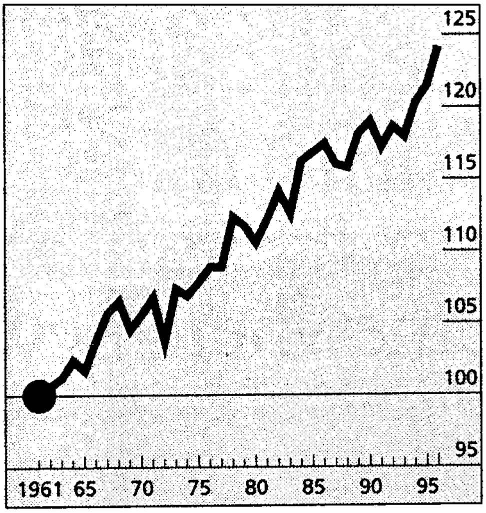

Figure 2. *Food production: per person, 1961 = 100*

Sources: FAO; World Bank.

oil, who in 1980 predicted cheaper and more abundant minerals. Today those people—among them Norman Macrae of this newspaper, Julian Simon, Aaron Wildavsky—are ignored by the press and vilified by the environmental movement. For being right, they are called 'right-wing'. The truth can be a bitter medicine to swallow.

Hot headed

Meanwhile, environmental attention switched from resources to pollution. Cancer-causing chemicals were suddenly said to be everywhere: in water, in food, in packaging. Last summer Edward Goldsmith blamed the death of his brother, Sir James, on chemicals: all cancer is caused by chemicals, he claimed, and cancer rates are rising. Not so. The rate of mortality from cancers not related to smoking for those between 35 and 69 is actually falling steadily—by 15 per cent since 1950. Organically grown broccoli and coffee are full of natural substances that are just as carcinogenic as man-made chemicals at high doses and just as safe at low doses.

In the early 1980s acid rain became the favourite cause of doom. Lurid reports appeared of widespread forest decline in Germany, where half the trees were said to be in trouble. By 1986, the United Nationals reported that 23 per cent of all trees in Europe were moderately or severely damaged by acid rain. What happened? They recovered. The biomass stock of European forests actually increased during the 1980s. The damage all but disappeared. Forests did not decline: they thrived.

A similar gap between perception and reality occurred in the United States. Greens fell over each other to declare the forests of North America acidified and dying. 'There is no evidence of a gnarl or unusual decline of forests in the United States or Canada due to acid rain', concluded a ten-

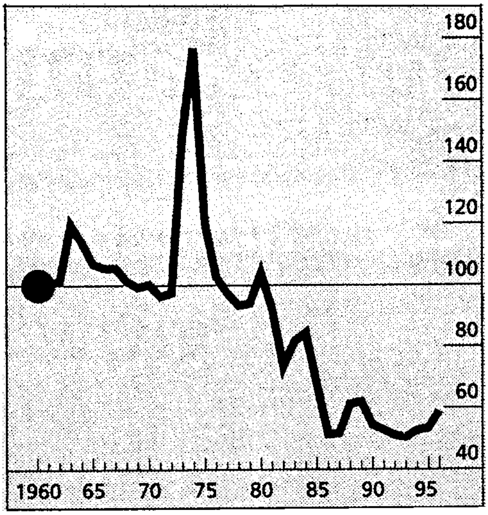

Figure 3. *Food prices: real terms*, 1960 = 100*

Note: Deflated by $ unit value index of G5 manufacturing exports.
Sources: FAO; World Bank

year, $700m official study. When asked if he had been pressured to be optimistic, one of the authors said the reverse was true. 'Yes, there were political pressures ... Acid rain had to be an environmental catastrophe. No matter what the facts revealed.'

Today the mother of all environmental scares is global warming. Here the jury is still out, though not according to President Clinton. But before you rush to join the consensus he has declared, compare two quotations. The first comes from *Newsweek* in 1975: 'Meteorologists disagree about the cause and extent of the cooling trend ... But they are *almost unanimous* in the view that the trend will rescue agricultural productivity for the rest of the century.' The second comes from Vice-President Al Gore in 1992: 'Scientists concluded—*almost unanimously*—that global warming is real and the time to act is now.' (The italics are ours.)

There are ample other causes for alarmism for the dedicated pessimist as the century's end nears. The extinction of elephants, the threat of mad-cow disease, outbreaks of the Ebola virus, and chemicals that mimic sex hormones are all fashionable. These come in a different category from the scares cited above. The trend in each is undoubtedly not benign, but it is exaggerated.

In 1984 the United Nations asserted that the desert was swallowing 21m hectares of land every year. That claim has been comprehensively demolished. There has been and is no net advance of the desert at all. In 1992 Mr Gore asserted that 20 per cent of the Amazon had been deforested and that deforestation continued at the rate of 80m hectares a year. The true figures are now agreed to be 9 per cent and 21m hectares a year gross at its peak in the 1980s, falling to about 10m hectare a year now.

Just one environmental scare in the past 30 years bears out the most alarmist predictions made at the time: the effect of DDT (a pesticide) on birds of prey, otters and some other predatory animals. Every other environmental scare has been either wrong or badly exaggerated. Will you believe the next one?

Environmental scare stories now follow such a predictable line that we can chart their course. Year 1 is the year of the scientist, who discovers some potential threat. Year 2 is the year of the journalist, who oversimplifies and exaggerates it. Only now, in year 3, do the environmentalists join the bandwagon (almost no green scare has been started by greens). They polarise the issue. Either you agree that the world is about to come to an end and are fired by righteous indignation, or you are a paid lackey of big business.

Year 4 is the year of the bureaucrat. A conference is mooted, keeping public officials well supplied with club-class tickets and limelight. This diverts the argument from science to regulation. A totemic 'target' is the key feature: 30 per cent reductions in sulphur emissions; stabilisation of greenhouse gases at 1990 levels; 140,000 ritually slaughtered healthy British cows.

Year 5 is the time to pick a villain and gang up on him. It is usually America (global warming) or Britain (acid rain), but Russia (CFCS and ozone) or Brazil (deforestation) have had their day. Year 6 is the time for the sceptic who says the scare is exaggerated. This drives greens into paroxysms of pious rage. 'How dare you give space to fringe views?' cry these once-fringe people to newspaper editors. But by now the scientist who first gave the warning is often embarrassingly to be found among the sceptics. Roger Revelle, nickname 'Dr Greenhouse', who fired Al Gore with global warming evangelism, wrote just before his death in 1991: 'The scientific basis for greenhouse warming is too uncertain to justify drastic action at this time.'

Year 7 is the year of the quiet climbdown. Without fanfare, the official consensus estimate of the size of the problem is shrunk. Thus, when nobody was looking, the population 'explosion' became an asymptotic rise to a maximum of just 15 billion; this was then downgraded to 12 billion, then less than 10 billion. That means population will never double again. Greenhouse warming was originally going to be 'uncontrolled'. Then it was going to be 2.5–4 degrees (according to the United Nations). In two years, elephants went from imminent danger of extinction to badly in need of contraception (the facts did not change, the reporting did).

Doom kills

Is it not a good thing to exaggerate the potential ecological problems the world faces rather than underplay them? Not necessarily. A new book edited by Melissa Leach and Robin Mearns at the University of Sussex ('The Lie of the Land', published by James Currey/Heinemann) documents just how damaging the myth of deforestation and population pressure has been in parts of the Sahel. Westerners have forced inappropriate measures on puzzled local inhabitants in order to meet activists' preconceived notions of environmental change. The myth that oil and gas will imminently run out, together with the worries about the greenhouse effect, is responsible for the despoliation of wild landscapes in Wales and Denmark by ugly, subsidised and therefore ultimately job-destroying wind farms. School textbooks are counsels of despair and guilt (see 'Environmental Education', published by the Institute of Economic Affairs), which offer no hope of winning the war against famine, disease and pollution, thereby inducing fatalism rather than determination.

Above all, the exaggeration of the population explosion leads to a form of misanthropy that comes dangerously close to fascism. The aforementioned Dr Ehrlich is an unashamed believer in the need for coerced family planning. His fellow eco-guru, Garrett Hardin, has said that 'freedom to breed is intolerable'. If you think population is 'out of control' you might be tempted to agree to such drastic curtailments of liberty. But if you know that the graph is flattening, you might take a more tolerant view of your fellow human beings.

You can be in favour of the environment without being a pessimist. There ought to be room in the environmental movement for those who think that technology and economic freedom will make the world cleaner and will also take the pressure off endangered species. But at the moment such optimists are distinctly unwelcome among environmentalists. Dr Ehrlich likes to call economic growth the creed of the cancer cell. He is not alone. Sir Crispin Tickell calls economics 'not so much dismal as half-witted'.

Environmentalists are quick to accuse their opponents in business of having vested interests. But their own incomes, their advancement, their fame and their very existence can depend on supporting the most alarming versions of every environmental scare. 'The whole aim of practical politics', said H.K. Mencken, 'is to keep the populace alarmed—and hence clamorous to be led to safety—by menacing it with an endless series of hobgoblins, all of them imaginary'. Mencken's forecast, at least, appears to have been correct.

Environmental scares, science and media

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The article 'Environmental Scares' in *The Economist*, 20 December last year is a typical story created by a journalist on the basis of a personal selection of 'facts'. These sometimes come from scientific journals but perhaps more often from other non-scientific sources without checks on their reliability. They are selected to make the story engaging and convincing. Conflicts of views are used to put drama into the story, being built with a specific purpose in mind. Such articles are not trustworthy and people are misinformed.

I will limit myself to comments on this particular article regarding global environmental issues, particularly acid rain, the threat to the ozone layer, loss of biodiversity and global climate change. These are all key issues and deserve careful scientific evaluation.

Acid rains were discovered in Sweden in the late 1960s and the Swedish Government presented the issue to the UN conference on the human environment in Stockholm in 1972.[1] The scientific report was factual and clearly brought home the limited knowledge at the time. The issue was discussed intensely in the press and by the Swedish parliament. The debate, however, soon became polarized. Representatives of industry and the conservative party considered the threat to fresh waters and fish and forest productivity due to acid rains as exaggerated.

Already at that time some preventive measures were taken by Scandinavian countries, but above all the Stockholm conference made scientists in other parts of the world aware of the issue. Research was initiated in the United States. In the early 1980s forest decline in Germany brought renewed interest to the issue. Agreements were reached between most European countries to reduce sulphur emissions substantially. The UK resisted this initiative, but set aside five million pounds for joint research in Norway, Sweden and the UK. In North America a political battle was fought, Canada blaming the US for damage to its forests.

Today the UK has joined the other European countries in their efforts to get to grips with the issue and rather stringent limitations of emissions have also been agreed in North America.

Yes, forests are recovering, but would this have been the case without preventive measures having been taken? Not likely so. The increase of

[1] Sweden's case study for the United Nations conference on the human environment. 96 pp.

biomass stock in Europe is largely due to larger areas nowadays being covered by forests and to improved forest management practices. Fortunately we do not know how serious the damage due to acid rains might have been without effective counter measures.

Today the issue of acid rains is high on the agenda in south-east Asia and China. The lessons learned in Europe and experiences gained have been evaluated and are used in this new battle for a healthy environment. Of course our understanding of the issue has improved greatly during the years that have gone by since the UN conference in 1972 and we know now that sulphur emissions are not the only cause of damage, but the original idea was basically correct. Why are these facts not included in the article in *The Economist*?

Also, why does *The Economist* not bring up the global environmental issue of **the decline of the stratospheric ozone layer**, which made headlines already in the middle of the 1970s and by now has been at least partly successfully resolved? The presence of CFC gases in the atmosphere was discovered by J. Lovelock in the late 1960s and the recognition of their crucial role in the atmosphere a few years later rendered the three atmospheric chemists, Paul Crutzen, Mario Molina and Sherwood Rowland, the Nobel Prize in chemistry in 1995. Once again, industrial representatives and the conservative press continued to express their doubts about the seriousness of the issue (and there are still some that reject the idea). A battle between them and the scientists/environmentalists in the United States in the latter part of the 1970s led to the legislation of some preventive measures. The use of CFC gases as propellant in spray-cans was banned in the US, which was followed by similar measures being taken in a few European countries.

Ten years later, in 1986, the ‘ozone hole’ over the Antarctica was discovered. Much more stringent measures were now quickly agreed upon by a number of developed countries. Today there is in reality a ban on using CFC gases, although some developing countries have not accepted the UN Convention for the Protection of the Stratosphere. There is therefore a risk that production is moved to these countries. A key problem is also that these gases are very long-lived in the atmosphere and their concentrations in the atmosphere are therefore still rising, although more slowly than before. The ozone layer has recently also declined somewhat in the north polar regions. Hopefully this will stop when concentrations of the CFC gases stabilize early next century, but enhanced concentrations of these gases will prevail for a long time.

On the whole, the rescue of the ozone layer around the earth has been successful, but the risks of damage are not over yet. We hopefully have learned the lesson that the global environment responds slowly to human interference and serious changes may be on the way for quite some time without being discovered. Careful scientific assessments are therefore important. Efforts at mitigation may thereby be begun early and costly crash programmes avoided later. Is this not as interesting a ‘story’ to tell the readers of *The Economist* in the present context? The early scientific explanations were in principle correct.

Yes, the risk of a **global warming** is perhaps the most serious environmental threat as far as can be judged at present. It also has the characteristic feature that the effects of the emissions are partly hidden due to the great inertia of the climate system. But the scientific assessments do not tell scare stories. Anyone concerned about this issue should consult the Assessment Reports prepared by the Intergovernmental Panel on Climate Change (IPCC), the latest of which appeared about two years ago.[2] You will not find an alarmist presentation, but carefully worded conclusions on the basis of present knowledge. The uncertainties are also described.

The IPCC pronounced that 'evidence suggests that there is a discernible human influence on the global climate'. We are, however, not yet able to determine very well the sensitivity of the climate system to human interference. Doubling of carbon dioxide concentrations in the atmosphere is expected to lead to an increase of the global mean temperature by 1.5 to 4.5 degrees C, a rather wide range of uncertainty. As of today, the increase in greenhouse gas concentration in the atmosphere is equivalent to a 50 per cet increase of carbon dioxide, but perhaps less than half of the long-term effects of such an increase have as yet been realized.

By and large the international scientific community stands behind this and other IPCC conclusions, but interest groups in society battle about the issue, vividly supported by the media. Environmental groups exaggerate what we as yet do know, while countries as well as industries dependant on the use of fossil fuels (and supported by some few scientists) try to discredit the IPCC process and conclusions. Because of the complexity of the issue there are also a number of misunderstandings. The article in *The Economist* propagates some of these further, although it admits that 'here the jury is still out'.

Newsweek (in 1975) wrote that 'meteorologists disagree about the cause and extent of the cooling trend ... but they are almost unanimous in the view that the trend will reduce agricultural productivity for the rest of the century'. The fact is, however, that there was little support for such a statement in the scientific literature. A scientific conference on climate change took place in 1974 in Stockholm with participation by many of the leading climatologists.[3] A most important study of the warming expected because of enhanced greenhouse gas concentrations in the atmosphere was presented on this occasion by Manabe and colleagues. It should be noted that their estimates of the sensitivity of the climate system to greenhouse gas emissions, remains almost the same today. The scientists never drew the conclusion that the warming was going to be 'uncontrolled' as stated by *The Economist* (whatever that expression means) and the range, quoted for the expected increase of the global mean temperature over the next century

[2] IPCC, 1996, *Climate Change* 1995.

a) *The Science of Climate Change*, Cambridge University Press, 572 pp.

b) *Impacts, Adaptation and Mitigation of Climate Change*, Cambridge University Press, 897 pp.

[3] Joint Organising Committee, ICSU, WMO, 1975, The Physical Basis of Climate and Climate Modelling. Study Conference in Stockholm, 29 July–10 August, 1974. GARP Publication Series No. 16, WMO, Geneva, 265 pp.

that shows a change of the expected warming, refers to projections based on different assumptions about future emissions.

A few short comments on the 'facts' presented on **biological diversity and deforestation** is also in place. It is unanimously agreed that the rate of disappearance of species now is very much greater than at any time during millions of years. This is of course fundamentally very worrying. Ecosystem complexity, versatility and resilience, important ecological attributes that have developed during geological times, are now being lost rapidly. Protection against such a development must necessarily be given high priority because the disappearance of species is irreversible. The negotiations about principles for the exploitation of the ecosystems in the world must be conducted in the perspective of this being indeed a long-term issue.

It is important for the public and politicians to pay attention to the role of the media in the emergence of major environmental issues. The traditional journalistic approach is to take an impartial position and present different views on the subject. There are of course no objections in principle to such an approach. The scientific process is, however, built on confronting different views on the subject matter in order to reach a deeper understanding, and in that context issues on which there are agreement are easily forgotten. Media, however, seize on the opportunity to describe and exaggerate these conflicting views and polarize the issue. Journalists are often not able to penetrate the scientific debate and, in particular, may not be able to distinguish between well-founded views by key scientists in the field and superficial ideas put forward by non-specialists or sometimes even lay-men. A scientific debate is conducted in the media, but often about issues that have been resolved in the scientific literature. This situation can also be exploited by stakeholders with special interests. There are many examples of this kind, i.e. a discussion in the press in scientific terms that in reality is political. The situation becomes particularly troublesome when dealing with phenomena such as weather, climate, storms, floods, etc. that human individuals know about and feel that they themselves are able to judge, which is not necessarily the case.

The article in *The Economist* is misleading for the reasons given above. There are of course efforts made by the media to present matters carefully, and it is important to realize that a journalist works in a different social context than a scientist. This is, however, not an excuse for being careless about facts and for acting politically while pretending objectivity.

Analysis, facts, and prediction*

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1 Analysis versus prediction

Popular writings on the environment and natural resources to a large extent make predictions. In order to do that, the authors rely on cross-sectional and time-series statistics. In contrast, ecologists and economists in their professional work engage in analysis by trying to identify those underlying processes that characterize the social and natural world. To do so, they try to uncover individual and group behaviour, be they the behaviour of cells, organisms, humans, atmospheric particulates, water bodies, or indeed of whatever it is that happens to be the object of study. Empirical testing of both the underlying hypotheses and their implications forms an essential part of the latter exercise.

The two sets of exercises can be far apart. If analysis devoid of empirical support is of only temporary interest, predictions without an accompanying analysis can be misleading, sometimes deeply so. And they can be so because, without analysis one would not know which 'facts' ought to be unearthed for air, nor what kinds of predictions one may legitimately make. *The Economist*'s article, 'Environmental Scares: Plenty of gloom', gets its facts right, but badly misleads.

Modern environmental and resource economics is over three decades old. The subject has matured to the point where the best writings on it display a common understanding not only of intent, but also of what constitutes adequate execution. It does not shun predictions, but insists that predictions be based on models that capture underlying processes. What is disheartening about the piece in *The Economist* is the author's implicit dismissal of the

* This note has been prepared for inclusion in a Symposium, being organised in *Environment and Development Economics*, on the article, 'Environmental Scares: plenty of gloom', published in *The Economist***,** December 20, 1997. We have benefited from discussions with Kenneth Arrow, Crawford Holling, Charles Perrings, Paul Portney, V. Kerry Smith, and the co-authors of Daily *et al.* (1998), from which we have borrowed some of the remarks made below.

need for analysis. Time-series statistics are quoted, but the author does not ask if the data selected are appropriate for meeting the concerns that professional ecologists and economists frequently express about population growth, increased material production, and environmental security.

2 Current versus future well-being

Thus, for example, the author rightly observes that while world population has nearly doubled since 1961, cereal production has more than doubled, and that since 1980 the world food commodity price has fallen by 50 per cent. In short, globally speaking, humanity today eats better than before. The author could have added that, speaking globally again, such indicators of human well-being as gross output per head, the infant survival rate, life expectancy at birth, and literacy, have all displayed an upward trend since the early 1960s. Indeed, much of the complacency development economists have displayed in recent years about global food availability can be traced to these recorded improvements.

The problem with this particular complacency is that such indicators as the above of the standard of living pertain to commodity production and use, not to the natural-resource base upon which all production depends. These indicators cannot say if, for example, increases in gross national product (GNP) per head are not being realized by means of a depletion of natural capital; nor, in particular, can they tell if increases in agricultural production are not being achieved by a 'mining' of soil, lowering of water tables and impairment of other ecosystem services. As is well known, such impairment can easily go unrecorded, because the use of ecosystem services all too often involves transactions that are not mediated by an effective 'price system'. So, for example, if, when drawing water from an aquifer, individual farmers were to ignore the effect of their extraction on others' future extraction costs brought about by a lowering of the water table, the social cost of agricultural production would exceed the farmers' private costs. Even though each farmer would, typically, impose only a small additional cost on others, the sum of the costs imposed by each on all could well be substantial. This means that it is possible for the real costs of agricultural production to exceed the market prices of agricultural produce. It is even possible for market prices to decline over time while the real cost of production is rising (see accompanying figure, where a hypothetical case is shown). We may conclude that market prices of agricultural produce do not have the welfare connotation *The Economist* attributes to them. This mistake is a symptom of a more general malaise: by concentrating on current-welfare measures, such as GNP and life expectancy at birth, journalists, political leaders and, frequently, even economists, bypass the links that exist between population growth, increased material output, and the state of the natural-resource base.

The author of the piece in *The Economist* could, of course, retort that he (or she) was merely responding to those among 'doomsters' whose predictions have consistently been proven to be wrong. But refuting past predictions by an appeal to time series does not make the underlying ecological and socio-economic processes disappear. It is these processes that need to be understood.

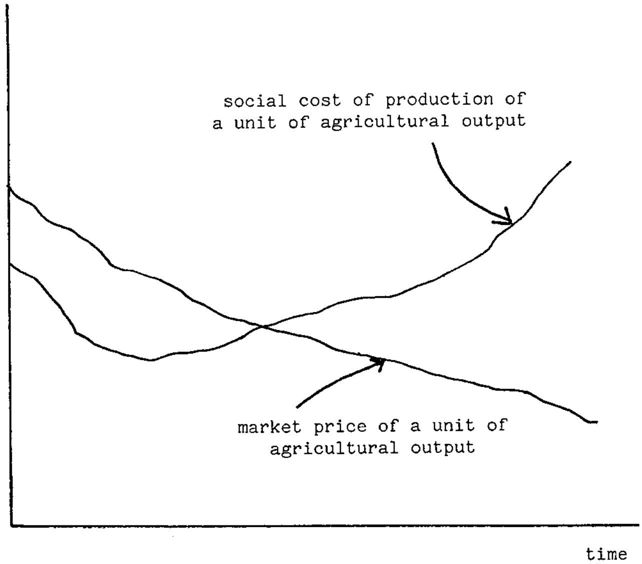

Figure 1.

3 Local versus global constraints

Ecologists' findings suggest that a near 50 per cent increase in world population, allied to a doubling of gross world product per head, by year 2030, would create substantial additional 'stresses' in both local and global ecosystems.[1] For example, global 'demand' for food could easily double over the period 1990–2030, with two-and-a-half to three-fold increases in the poorest countries. Of particular concern are Asia and Africa where, over the next fifty years, plant-derived food-energy requirements are expected to increase by a factor of 2.3 and 5, respectively, with a more-than-sevenfold increase expected in some countries (Pinstrup-Andersen, 1994; Crosson and Anderson, 1995; FAO, 1996). And these figures do not include the inevitable increases in the demand for non-food commodities that would accompany increases in GNP.

The prospects for a suitable response to such increases in the scale of the human enterprise depend on our ability to manage constraints on the supplies of production inputs and on the environmental consequences of the use of these inputs. These constraints are not present uniformly across the globe. Moreover, local problems of production and distribution can be difficult to counter even when global supplies are adequate, because the purchasing power of the poor is weak. To ask merely whether global production of goods and services can be increased to meet future demands in a sustainable way misses much of the question. For example, food scarcity manifests itself locally, so efforts to alleviate it must be tailored to local cir-

[1] See. for example, Vitousek *et al.* (1986) and the Symposium on the scale of human activity in *Science*, 20 July 1997.

cumstances. To do otherwise is akin to doctoring a sick person on the basis of global health statistics.

Correct diagnosis of the problems that lie at the population–consumption–environment nexus is usually a local matter, even though appropriate treatment may require regional and global support. For example, soil erosion may not currently be a serious threat to global agricultural capacity, but at local levels in various parts of the world it presents major problems to the people affected. Similarly, decisions concerning fertility, education, child care, food, work, health care, and the use of the local natural resource base are in large measure reached and implemented within households, who face constraints that are shaped in part by national and international policy. The influence of household decisions are felt through local interactions (e.g., intra-village and village–town trades), and then, 'upward' globally. Recent work has identified a variety of circumstances that are shaped by positive feedback mechanisms, driving poverty, hunger, fertility, resource degradation, and civic disconnection at the local level, even while national (and not merely global) income is rising.[2] This suggest that if we are to obtain reliable projections of global economic prospects, we need to adopt local, contemporary perspectives.

4 Non-linear processes, biodiversity and substitution possibilities

A major achievement of modern economics has been to show that there are many virtues in a competitive market mechanism (with a *complete* set of markets) in economies where the transformation of goods and services into further goods and services is governed by linear processes.[3] But when one talks of 'stress' and 'positive feedback mechanisms', as we have done in the previous section, one refers to systems characterized by *non-linear* processes, and so to the possible bifurcations they are subject to. It is as well to emphasize that such processes can govern both global and local systems. Even if a given global ecosystem were not to show signs of stress, local ones could, and often do, display such signs. There are also extant records of local ecosystems having collapsed in the past.

We will observe presently that the assumption of linearity in economic transformation possibilities is related to the idea that for every commodity that can be transacted there are close substitutes lying waiting. The latter assumption, if true, would imply that even as constraints increasingly make their presence felt on any one resource base, humanity could move to other resource bases. The enormous additions to the sources of industrial energy (successively human power, animal, water and wind power, timber, coal, oil and natural gas and, most recently, nuclear) that have been realized are a prime historical illustration of this possibility.

The assumption of linearity continues to be reasonable in many spheres of activity, but it becomes sorely stretched when applied to those that encroach ecosystems on a large scale. The services provided by an

[2] See Dasgupta and Mäler (1991), Dasgupta (1993, 1995, 1998), and Cleaver and Schreiber (1994).

[3] By a linear process we mean one where changes over time in a system are governed by a set of 'almost' linear differential equations.

ecosystem are dependent on the composition of biota and the abiotic processes at work. Here it is important to distinguish between the resource base that comprises an ecosystem (its structure) and the services the ecosystem provides (its functions).[4] Degradation of the resource base (e.g., destruction of populations) not only affects the volume and quality of those services; it also challenges an ecosystem's 'resilience', which is the capacity of the system to absorb disturbances without undergoing fundamental changes in its functional characteristics.[5] If a system loses its resilience, it can flip to a wholly new state when subjected to even a small perturbation (see, e.g., Wilson, 1992, Holling *et al*., 1995; Walker, 1995). One way to interpret an ecosystem's loss of resilience is to view it as having moved to a new stability domain.[6] Sudden changes in the character of shallow lakes (e.g., from clear to eutrophied water), owing to increases in the input of nutrients, provide one class of examples (Scheffer, 1997; Carpenter, Ludwig, and Brock, 1998); the transformation of grasslands into shrublands, consequent upon non-adaptive cattle-management practices, provides another (Perrings and Walker, 1995).[7]

Closely related is the concept of 'biodiversity'. Even ten years ago it was a popular belief that the utilitarian value of biodiversity is to be located solely in the potential uses of genetic material (e.g., for pharmaceutical purposes). Preservation of biodiversity was seen as a way of holding a diverse portfolio of assets with uncertain payoffs. Today it is being increasingly appreciated that biodiversity, *appropriately conceived*, is associated positively with a system's resilience and with its 'productivity' (as measured by the flow of energy and the internal cycling of nutrients).[8] In short, ecosystems must harbour biodiversity if they are to *be* productive. This has the important corollary that, to invoke the idea of substitutability among natural resources in commodity production in order to play down the utilitarian importance of biodiversity, as people frequently do, is a wrong intellectual move.

5 Institutional failure and ecosystem destruction

Non-linearities (more precisely, non-convexities) in ecological processes make their presence particularly felt when the systems in question are under stress. Modern economic analysis has shown why the market mechanism could be expected not to function well in such circumstances. But there is an additional set of reasons (illustrated in our earlier example of farmers drawing water from an aquifer) why markets cannot be relied upon to generate correct signals of resource scarcity: the nature of the

[4] Daily (1997) contains a useful collection of essays on the character of these services.

[5] So, in concentrating on functional (as opposed to structural) characteristics, we are taking an entirely utilitarian view of ecosystems.

[6] 'Ecological threshold' is an informal term often used in this context to denote bifurcations.

[7] Recovery can be costly, in some cases impossible. In short, such flips can in many cases be regarded as irreversible. The mathematics of 'relaxation phenomena' offers a formal account of what the intuitive notion of irreversibility amounts to.

[8] Tilman (1997) has a fine account of what is currently known of the links.

situation surrounding ecosystem services can keep certain crucial markets from *existing*. Thus, for example, vast numbers of ecosystem services are freely available, even though they are scarce goods.[9] As the relevant markets are absent, we should not expect the market mechanism to generate those signals that would alert us to impending shifts in the stability regimes of ecosystems. Human populations have on occasions been unable to prevent suffering from unexpected flips in their local ecosystems because of this.

Ecosystem degradation can occur not only because of market failure, it can occur also because of bad government policies (e.g., because of wrong tax policies).[10] We may put the matter more generally: an underlying cause of environmental degradation is *institutional failure*. Indeed, the various types of institutional failure pull in different directions and are together not unrelated to an intellectual tension between the concerns people share about such matters as mean global warming and acid rains, which sweep across regions, nations, and continents; and about those matters (such as, for example, the decline in firewood or water sources) that are specific to the needs and concerns of the poor in as small a group as a village community. Environmental problems present themselves differently to different people. Some people identify them with wrong sorts of economic growth. Then there are others who view them through the spectacle of poverty. Each of these visions is correct. There is no single environmental problem; rather, there is a large collection of them, some global, many local.

Over the past many years now, environmental and resource economists have responded to this fact by identifying desirable institutional reforms in a case-by-case manner. Alterations to prevailing structures of property rights, the imposition of environmental and resource taxes, regulations, local-community control, and various other devices that change individual and group incentives have been much discussed. Contrary to what is frequently suggested in popular writings on environment matters, the tools of modern economics are *not* restricted to the study of linear systems. Many of the lessons drawn have been put into use, most especially in western industrial countries.

Unhappily, far less work has been done on the economics of scientific research on a wide variety of ecosystems. There is a reason for this. Because economic systems often do not generate signals that would alert the public of growing resource scarcity, it can be a very difficult matter for those who suffer from the economic consequences of the scarcity to get an environmental problem placed on the agenda of public discourse. In poor countries, for example, there are strong links between household poverty,

9 The literature on this and the associated question of appropriate property rights is huge. See, for example, Mäler (1974), Baumol and Oates (1975), and Dasgupta (1982). Such natural resources as minerals and ores do not, on the whole, suffer from these problems, although the activity of converting them into usable products (e.g. mining and smelting) can. Thus, the markets for ores and minerals *in situ* do not suffer from the kinds of failure we are alluding to in the text.

10 Binswanger (1991) has argued that government policies in Brazil regarding agricultural income and land ownership have in the past provided incentives for deforestation in the Amazon basin.

local environmental deterioration, and a weak political voice (see, e.g, Dasgupta, 1997). As in many other aspects of life, the political economy of the matter, and in particular governance, is at the heart of many environmental problems. By cheerfully ignoring the lessons drawn by environmental and resource economists, the author of ‘Environmental Scares’ avoids all such issues. If environmentalists in their popular writings have frequently erred by warning us exclusively of future, global shortages, the author of ‘Environmental Scares’ errs by neglecting to observe that people in many parts of the world suffer from local environmental stresses even now, and that something can be done about it. This is why the article misleads.

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Environmental false alarms and policy implications

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Forecasts of potential environmental catastrophe have a long and celebrated tradition. From Thomas Malthus's eighteenth century prediction that population would outrun food supply to the elaborate analysis of the future scarcity of economically important natural resources by the Club of Rome, many of these forecasts have in common the happy circumstance that the advertised catastrophe has not (yet) occurred (Anon., 1997). What implication for current action should we then derive from the failure of so many of these predictions?

To begin, it is worth noting that not all of the proffered dangers have proved illusory. A notable exception is the 1974 prediction by Molina and Rowland that continued growth in the release of chlorofluorocarbons (CFCs) into the atmosphere would lead to substantial depletion of stratospheric ozone, which would in turn allow greater penetration of ultraviolet radiation to the Earth's surface, potentially harming humans and wildlife. Denounced by some as speculative, the claim was proven correct by subsequent atmospheric monitoring and the 1985 discovery of the Antarctic 'ozone hole'. Recognizing the probability of substantial harm, most of the nations of the world have agreed to eliminate production of CFCs and related compounds, with production halting in most of the industrialized countries by 1996. Similarly, claims that widespread use of DDT would be harmful to birds and that use of tetraethyl lead in gasoline would harm human health proved correct.

Inaccuracies in past assessments of environmental threats and response options suggest we could learn from retrospective analysis of these assessments. To date, there have been few careful comparisons between the realized and the forecast effects—benefits or costs—of environmental threats and policies enacted in response. Such comparisons are methodologically difficult, because the consequences of counterfactual policies cannot be observed, but in many cases it should be possible to make some evaluation of the accuracy of prospective estimates.

Despite limited evidence, the notion that costs of prospective environmental control measures are often overestimated appears to have become widely accepted. In the US, the price of the tradable SO_2 emission permits introduced under the 1990 Clean Air Act amendments has ranged between about \$65 and \$95 per ton, far below the *ex ante* estimates of \$300 to \$600 per ton (Ellerman and Montero, 1996). Cook (1996) and Hoerner (1995) assert that costs of regulating CFCs have been smaller than forecast, due to unanticipated technological innovation, use of a tradable-permit system, and proactive government action in reducing barriers to innovation. Goodstein and Hodges (1997) claim that the costs of proposed environmental regulations have been substantially overestimated in several other cases as well, including asbestos, benzene, coke ovens, cotton dust, strip mining, and vinyl chloride. An extreme form of the cost-overestimate argument is the 'Porter hypothesis' which asserts that environmental regulation generally triggers innovation sufficient to more than offset compliance costs, which implies that any positive cost estimate is too high.[1]

One of the virtues of using market mechanisms for environmental regulation is that information about compliance costs is much more readily available than under command and control regulations. In the US, the Montreal Protocol restrictions on CFCs were implemented by granting tradable production permits to manufacturers and importers. The market price of CFCs, including the permit price, provides an estimate of the marginal social cost of controlling CFC consumption. Consumers who can reduce use at lower cost should purchase smaller quantities of CFCs and profit by the difference between the market price and their marginal control costs; consumers for whom control costs are larger than the market price should continue to consume CFCs. As CFC consumption declined in response to limits on the number of permits issued, the total market price increased, tracing out the marginal cost of control.[2] Comparison of this

[1] See Porter (1991) and Porter and van der Linde (1995). The hypothesis is disputed by Jaffe *et al.* (1995) and Palmer *et al.* (1995).

[2] Strictly, the observed marginal cost represents not an equilibrium but a transient marginal-cost curve influenced by technological development and investment in control measures, which depend on expectations about future conditions.

revealed marginal control-cost function to prospective estimates gives a somewhat mixed result: estimates published a year and a half before the Montreal Protocol was signed (Camm *et al.*, 1986) substantially overestimated control costs for two important CFCs (11 and 12) but accurately estimated costs for the third (CFC-113). In contrast, US Environmental Protection Agency estimates accompanying the rule implementing CFC controls, published nine months after the Protocol was signed (EPA, 1988), coincide fairly closely with the realized marginal costs; if anything, the government estimates appear to have been too low (Hammitt, 1997).

Whether we learn much from past assessments or not, forecasts of future conditions will often be subject to large uncertainties—if we know anything about the future, it is that it is uncertain. What are the implications of this uncertainty for environmental policy making?

Uncertainty about the consequences of releasing a substance to the environment does not prejudice the appropriate policy response. In particular, uncertainty does not imply that we should refrain from limiting releases, as environmental skeptics often appear to believe, nor that we should prohibit any release, as a literal interpretation of the precautionary principle might suggest. Instead, we should carefully weigh the consequences of alternative emission policies, taking account of uncertainty about fundamental scientific and economic factors and the probabilities that alternative hypotheses will prove correct.

In many cases, a sequential decision-making perspective will be appropriate. We will learn more over time, and we should plan to revise our policies in the light of new information. Again, the CFC example is useful. Soon after the danger was perceived, market reactions and government regulation in a few countries led to significant decreases in CFC emissions. As continuing investigation of the science confirmed the basic premise, international interest grew, leading first to agreement to coordinate research (the 1985 Vienna Convention) followed by agreement to restrict CFC production (the 1987 Montreal Protocol) and eventually to nearly eliminate these compounds from commerce (the 1990 London and 1992 Copenhagen Amendments). In other cases, subsequent information will suggest the threat to be less serious than initially perceived and control measures may be relaxed.

From a sequential perspective, the aim of the Framework Convention on Climate Change—'stabilization of greenhouse-gas concentrations ... at a level that would prevent dangerous anthropogenic interference with the climate system'—appears misguided. Because climate depends on the stock of greenhouse gases (GHGs) in the atmosphere rather than their annual emission rate, constraining GHG concentrations appears to be a reasonable objective. An appropriate stabilization level cannot yet be determined, however, because of uncertainties about the relationships among GHG emisssions, climate change, impacts on environmental, economic, and social systems, and how such impacts are to be valued. Moreover, the value of defining optimal emission paths to reach alternative stabilization levels is limited by the certainty that today's policies will be altered in response to new information.

To examine the implications of this sequential perspective for climate policy, consider a simple, two-period model. The first period represents the next several decades during which our knowledge of climate change is highly uncertain; by the second period, these uncertainties are assumed to be substantially resolved. Assume only two possibilities exist: (a) anthropogenic global climate change is real and has serious adverse consequences, and (b) climate change is non-existent and/or benign. The probability π summarizes our current belief that possibility (a) is correct. Policy for the first period must be chosen under uncertainty, but the truth will become known before policy for the second period must be chosen.

Without controls, GHG emissions in each period are B_1 and B_2, respectively. Let x_1 and x_2 represent abatement levels (i.e., emission reductions) in the two periods. The present value of abatement costs equals $K_1(x_1) + \delta K_2(x_2)$, where marginal abatement costs in each period are positive and increasing in emission reductions. The discount factor δ accounts for the opportunity cost of diverting economic resources from other activities. The above-background atmospheric concentration in each period is represented as $C_1(x_1) = (B_1 - x_1)$ and $C_2(x_1, x_2) = \rho(B_1 - x_1) + (B_2 - x_2)$, where ρ is the fraction of first-period emissions remaining in the atmosphere in the second period. Finally, the damages in each period are assumed to be an increasing convex function of contemporaneous[3] GHG concentrations $D_t(C_t)$.

The optimal first-period abatement level can be determined by differentiating the present value sum of expected damages and abatement costs with respect to x_1 and setting the result equal to zero; this yields:

$$\mathrm{K}_1{}'(x_1) + \pi\left[-D_1{}'(C_1) - \delta\rho D_2{}'(C_2) + \delta\left\{\mathrm{K}_2{}'(x_2) - D_2{}'(C2)\right\}\frac{dx^*_2}{dx_1}\right] = 0$$

where dx_2^*/dx_1 equals the change in the optimal second-period abatement (if climate change is a real hazard) as a function of the chosen first-period abatement level.

If second-period abatement is set optimally, the marginal benefits of second-period abatement equal the marginal costs, and so $\{K_2{}'(x_2) - D'(C_2)\}$ equals zero. The optimality condition simplifies to

$$K_1{}'(x_1) = \pi\left[D_1{}'(C_1) + \delta\rho D_2{}'(C_2)\right].$$

In words, the marginal cost of greater abatement in the first period equals the probability that climate change will yield adverse consequences times the marginal damages of greater GHG concentrations. The benefits (i.e., reduced damages) of first-period abatement accrue in both periods. In the second period, they are discounted (by δ) to account for the delay and (by ρ) for the partial effect of first-period abatement on second-period concentrations. If the expected marginal damages are large, because the probability and/or magnitude of possible harms are large, then stringent first-period abatement will be appropriate. Conversely, if the expected marginal damages are small, only modest abatement is appropriate in the first period.

[3] Lags between changes in atmospheric concentrations, climate, and impacts are neglected for simplicity.

Note that the marginal cost of optimal first-period abatement is positive even though the existence and harm from climate change are uncertain. The optimal marginal abatement cost in the first period is zero only if the expected marginal benefits of first-period abatement are zero. If the possibility of harmful climate change is acknowledged, the expected benefits of abatement are positive unless the probability and magnitude of possible benefits from climate change are sufficient to offset the probability and magnitude of possible harms. The optimal marginal cost of first-period abatement may be small, however, if the expected near-term damages from climate change are small and the long-term benefits of near-term abatement are also small (because they are heavily discounted, because near-term abatement is an inefficient way to reduce future damages, or for other reasons).[4]

The complexities of environmental issues and their interaction with economic and social systems suggest that forecasting the future will always be difficult and that we should expect many alarms to prove false. But some of them will prove to be true, and sensible responses to warnings will balance the risks of over-reacting to false alarms against the dangers of under-reacting to true threats.

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[4] The optimal near-term abatement may also be small or zero if climate change is expected to yield benefits in the near term and harms in the future.

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No time for complacency

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Economists have studied natural resources from the earliest days of the profession and for good reason. Resources are seen as the basis for national prosperity, power, and wealth. For example, the ability to harness energy resources in new ways is recognized as perhaps the major factor underlying the industrial revolution. Even more fundamental, food supplies depend on forests, fisheries, and agricultural land.

It is no wonder then that there have been, at times, a number of economists, and others, who have feared the dire effects of possible resource shortages as economic development proceeds.

In years prior to the Second World War, such concerns in America were associated with names like Muir, Olmstead, Leopold, Osborne, and Powell, among others. But these men were by no means of one mind concerning the nature of resource problems. 'Conservationists' opposed 'utilitarians', for example.

The Second World War is mentioned here because its aftermath saw a peak for natural resource concerns, especially the possibility that scarcity of basic natural resource commodities would limit or halt economic growth. This concern resulted from the fact that little in the way of resource exploration and development had occurred during the war and it was unclear whether the observed drop in resource reserves represented a real increase in scarcity or merely the lack of exploration and development effort.

This concern caused the Ford Foundation to establish and fund Resources for the Future as a successor to the so-called Paley Commission. RFF's early mission was to examine the entire resource scarcity issue. I have been an employee of RFF since its earliest years.

But, as most economists know, an effort to understand the foundations of the scarcity versus growth problem in an economic framework far predates both the much newer concern resulting from the war and that of the conservation utilitarians some of whose names are listed above.

Thomas Malthus could be viewed as the first natural resource economist, even though he is most widely known for his work on population. In 1798, he published his *Essay on Population,* a clear and forceful version of the seminal idea of diminishing returns to increased effort in the presence of a scarce resource. The scarce resource, in his view, was the stock of agricultural land, which he took to be absolutely limited. (David Ricardo later built a theory of scarcity on the assumption that land was not absolutely limited but progressively declined in quality as more of it was exploited.)

Harold Barnett and Chandler Morse (1963) succinctly state the basic Malthusian proposition:

> Malthus' famous *Essay on Population* may be credited with having widely propagated the belief that natural resource scarcity impairs economic growth. His doctrine is based on presumed natural law. That natural resources are limited and population multiplies continuously, subject to a biological restriction, are taken as nature-given facts. In the absence of social preventive checks, population increases to the limits of subsistence. The limits of nature constitute scarcity. The dynamic tendency of population to press continually to the borders of subsistence is the driving force. The incompatibility of a finite amount of agricultural land with provision of subsistence to a continually increasing population entails an eventual decline in output per capita and cessation of growth. This is the economic scarcity effect.

The idea of diminishing returns to effort expended upon the land became generally accepted in economics. The concept was accepted for generations as intuitively obvious. Perhaps the most famous English economist of the late nineteenth and early twentieth century, Alfred Marshall (1890 [1920]) wrote:

> our law [of diminishing returns] states that sooner or later (it being always assumed that there is meanwhile no change in the arts of cultivation) a point will be reached after which all further doses will obtain a less proportionate return than the preceding doses. (p. 153)

But by the middle of the twentieth century, it became clear that a great deal of growth in fact had occurred in the developed world without an apparent diminishing return to effort. Part of this growth was simple expansion as new geographic regions were occupied and developed and labor and capital were applied to them. But it also was apparent that the 'arts of cultivation' or, more generally, technological progress in man's ability to find and exploit resources had much to do with it. In 1963, Barnett and Morse's *Scarcity and Growth* was published by Resources for the Future as one part of its examination of the scarcity issue, to much less notice than it merited. In this now class work, the authors explored the importance of technological change and resource substitution in combating resource scarcity. They also reported an empirical test to determine whether real resources costs had risen over the long term, which would indicate scarcity in an economic sense. Their methods and data need not detain us here, but the authors concluded:

> Our empirical test has not supported the hypothesis—let us call it the "strong hypothesis—that economic scarcity of natural resources, as measured by the trend of real cost of extractive output, will increase over time in a growing economy. Observing the extractive output in the United States from 1870 to 1957, we have found that the trend in the unit cost of extractive goods as a whole has been down—not up. (p. 199)

A later extension of the time series confirms the conclusion (Barnett, 1979, p. 175), as does more anecdotal evidence as reported in *The Economist* article.

Thus, one main theme in resource economics involves the question of whether resources are becoming more scarce. Almost two centuries ago, Malthus and others thought such increasing scarcity to be imminent and obvious. But so far, in an economic sense (rising real cost of resources), this scarcity is not apparent. Whether one believes it will become so in the future depends heavily on whether one views the world through the eyes of a technological optimist or a technological pessimist. But in the long run, even technological optimists must contemplate profound changes in the way natural resources are used.

In this regard, economic growth can be of two distinct kinds. First, an economic system can, in principle, expand like a balloon without technological or structural change. It simply gets bigger, as capital and labor inputs increase proportionally. This kind of quasi-static growth can lead to increased final consumption per capita while maintaining its equilibrium, but only by producing more of everything, in fixed ratios. (This is possible only if there are no economics or diseconomies of scale, which is an unrealistic but common economic assumption.) Also, there has to be a non-scarce input, 'nature', in order for this process to continue indefinitely. (Most existing growth models contemplate this kind of growth.)

The second kind of economic growth adds evolutionary changes in structure. These changes are driven by innovations—new products, new processes—that result not only in quantitative increases in per capital consumption, but also in qualitative changes in the mix of goods and services generated by the economy. In general, this kind of growth involves increased complexity and organization.

Quasi-static growth of the first kind can be modeled theoretically as an optimal control problem with aggregate consumption (or welfare) as the objective function. The control variable is the rate of saving diverted from immediate consumption to replace depreciated capital and add new capital to support a higher level of future consumption. The rate of growth in this simple model is directly proportional to the rate of savings, which, in turn, depends on the assumed depreciation rate and an assumed temporal discount rate to compare present and future benefits. Note that assumptions about the operation of the market play almost no role in this type of growth model.

It is noteworthy (and unfortunate) that most economic development programs in the Third World for at least two decades following the Second World War were based on the generalized type-one models; this approach assumed a primary role for aggregate capital investment and depended on central planners to maintain balance between the capital needs of various sectors. The relatively poor performance of most centrally planned economic development programs is probably due in part to their focus on investment per se, to the neglect of structural adjustments and innovation in production and embodiment of knowledge and incentives to put them to productive use.

Dynamic growth of the second, evolutionary, kind is less dependent on savings and/or capital investment. It cannot occur, however, without capital investment because new production technologies, in particular, are largely embodied in capital equipment. Technological innovation drives this kind of dynamic growth. There is ample evidence that technological progress is not an autonomous (self-organizing) process, as often assumed in economic growth models (when it has been included at all). On the contrary, knowledge and inventions are purposefully created by individuals and institutions in response to incentives and signals generated within and propagated by the larger socioeconomic system.

An actual example of the importance of knowledge and intelligence, in the information theory sense, in economic development may be illuminating. This is the so-called German economic miracle following the Second World War. In less than a decade, the German economy recovered fully from a condition so severe that many doubted it could ever again compete in the world economy. This recovery was made possible by knowledge and intelligence, in the information theory sense, embodied in human skills, organizations, and infrastructure and a powerful incentive to use them. Far greater amounts of capital became available to other countries—such as Iran—with far different results. This illustrates that financial capital and raw labor (the focus of most neo-classical economic models) are feeble engines of development compared with embodied knowledge and skills.

It is clear that technological progress is based mainly on an expanding knowledge base embodied in structures, including man. Several themes following from the prior discussion can now be summarized in terms of their implications for economic growth. First, because the economy is a dissipative structure, it depends on continuous energy (essergy) and material flows from (and back to) the environment. Such links are precluded by closed neoclassical general equilibrium models. Second, the energy and physical materials inputs to the economy have shifted, over the past two centuries, from mainly renewable sources to mainly non-renewable sources. Third, dynamic economic growth is driven by technological change (generated, in turn, by economic forces or deliberate government policy) that also results in continuous structural change in the economic system. It follows, incidentally, that a long-term survival path must sooner or later reverse the historical shift away from renewable resources. This will be feasible only if human technological capabilities rise to levels much higher than current ones. But, since technological capability is endogenous, it will continue to increase only if the pace of deliberate investment in research and development is continued or even increased. In short, the role of knowledge-generating activity in retarding the global entropic increase seems to be growing in importance.

Thus, issues raised about economic development, population growth, resource use, and environmental protection involve exceedingly complex and interrelated matters. Efforts to model and project these processes have yielded little if any insight into the forces actually involved. To achieve rigor it has been necessary to abstract from what are probably the central factors at work.

Discussion of these concerns often proceeds under the terminological umbrella of 'sustainable development', a concept that spans a range of moral and economic considerations. The general concerns it envelops are continued improvements in the well-being of people in developed countries, improvement in the well-being of people in developing countries, and protection and maintenance of a safe and attractive environment.

These goals cannot be achieved without a better understanding of the natural world than we now possess and a much greater ability to put that understanding into practical use through technology. Thus we have no choice but to make technology serve human interest better than ever before. In this context the conventional distinctions among natural resources, the environment, and human resources blur. Indeed, the central focus becomes human knowledge, skills, and innovative and adventurous behavior, all of which are beyond our present ability to measure and assess, despite their clear importance. What we do know is that education is a prerequisite for most of them. Surely the needed understanding goes way beyond that embodied in the simple models devised by economists so far.

The Economist article has done a service by informing or reminding readers that impacts of economic growth on natural resources can, and in many cases have been, cancelled by technological innovations. But the article has also done a disservice by simplifying, one is tempted to say, trivializing, the process and especially the challenges it faces in the future. We must deal with problems ever larger in both space and time, e.g. nuclear waste management, potential climate change, and the implications of globalization for technological, economic, and political processes as they bear on natural resource problems. There are areas that research and policy making have hardly touched upon, including the interrelation of human and natural resource problems and opportunities, related problems of the distribution of income and economic welfare on a national and global scale, how to develop and harness incentives and signals generated within and propagated by the larger socioeconomic system. These things are hard to research (as attested to the low status traditionally accorded 'institutional' economics within our profession). But complacency will get us nowhere.

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Predicting the environment: time series versus process based models

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The 20 December 1997 issue of *The Economist* carried an article entitled '*Environmental Scares*', with the headline '*Forecasters of scarcity and doom are not only inevitably wrong, they think that being wrong proves them right.*' Strong stuff! The article develops the thesis, now familiar as the 'greenlash' argument of Julian Simon, Wilfred Beckerman, and others, that all past predictions of environmental catastrophe from Malthus to Al Gore via the Club of Rome have been dramatically wrong. Therefore, the article suggests 'people should treat them with pinches of salt instead of lapping them up with relish'.

On superficial first inspection, the argument is seductive: the availability of key resources such as minerals and good supply, have steadily increased with increasing global population size (see figure 1). This would appear to refute the Malthusian prediction that increasing population would take us beyond the carrying capacity of the Earth towards inevitable starvation and resource depletion.

This interpretation of the evidence is, however, deeply flawed. Graphs such as figure 1 are purely descriptive: they show correlations (often between two variables, ignoring a large number of potential confounding factors) and not underlying process and therefore causation. An analysis of the processes underlying figure 1 would show that a combination of

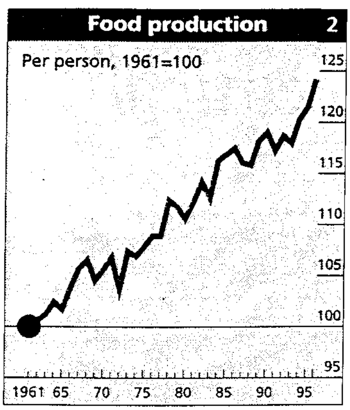

Figure 1. *Change in per capita global food production 1961 to 1995 (From* The Economist *20 December 1997)*

factors have been involved in increasing world food production (the green revolution). These include genetic improvement of crops and livestock, increased inputs of chemical fertilisers and pesticides, enhanced irrigation and increased area of land under cultivation. Simple extrapolation of past descriptive trends is not likely to be the basis of sound prediction of the future, whereas a model, or series of models, based on the underlying processes holds out more promise. In the case of food supply it is quite probable that such a model would show that past gains (in effect an increase in global carrying capacity) have been made at a price which cannot be paid at an increasing level into the future. Similar points could be made for all the other resource depletion/pollution/environmental degradation examples described in *The Economist* article.

Partha Dasgupta,[1] discussing the interconnections between population growth, poverty, and the local environmental resource base, argues for the replacement of description by an analytical approach in which '*none of these three factors [are] . . . the prior cause of the other . . . each . . . influencing the others and in turn being influenced by them*'. This line of thinking is in tune with one of the key changes in scientific analysis of the behaviour of the earth system in recent years. There has been the shift from *description* of changes (e.g. loss of biodiveristy, changes in temperature, sea level, availability of water resources) to *predictive* models based on an understanding of underlying processes, and with a recognition of the complex feedbacks and non-linearities that interconnect these processes. This, for example, is why confidence in prediction of future climate is greater now than it was 20 years ago. Prediction of our future climate is not simply based on an extrapolation of past trends (figure 2), but on models containing mathematical representations of the details of the physical, chemical, and biological processes that influence the climate. The accuracy of climate predictions is improving because our understanding of these processes is getting better, not because we have longer runs of data from which to extrapolate into the future. This sea-change in the sciences of the environment does not yet appear to have filtered through to *The Economist*.

[1] Dasgupta, P. (1995) 'The population problem: theory and evidence', *Journal of Economic Literature* **33**(4): 1879–1902.

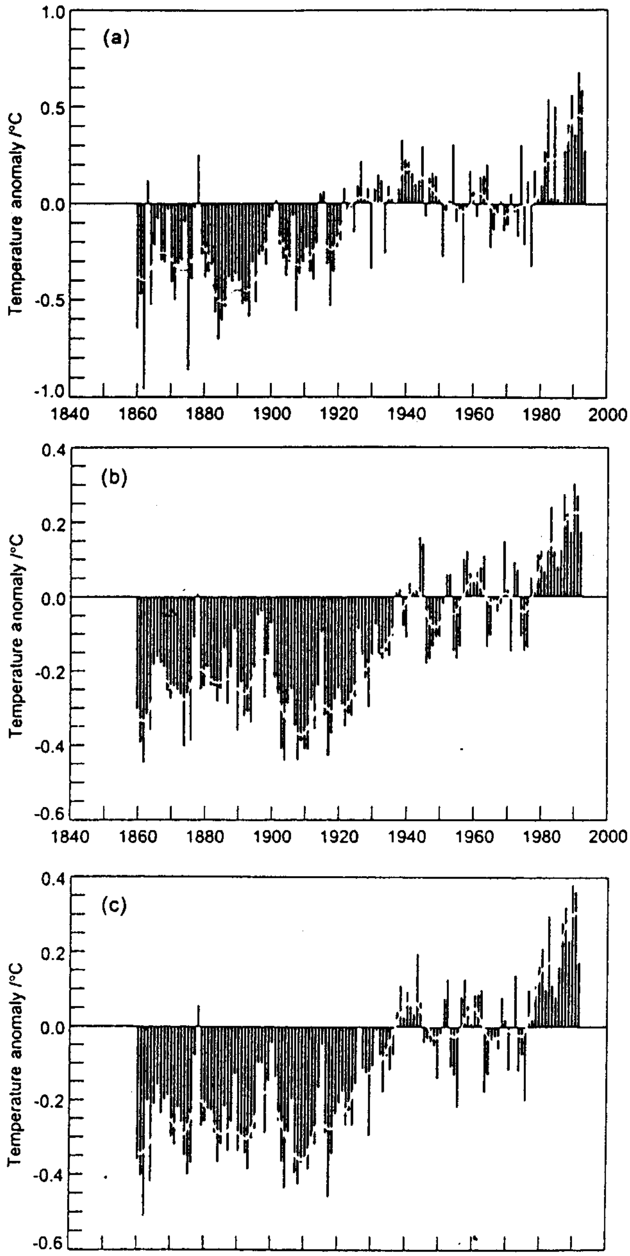

Figure 2. *Changes in global average temperature from 1860 to 1992 relative to the period 1951 to 1980. (a) over land (b) for the sea-surface (c) land and sea temperatures combined. (From Houghton. J. 1994. Global Warming. The complete briefing. Oxford, Lion Publishing plc.)*

For whom the market tolls: one-armed economists and 'Plenty of gloomsters'

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When contemplating the basic message of the piece under discussion here, the observation made by Viscount Bolingbroke in his 'Reflections upon Exile' immediately comes to mind: 'Truth lies within a certain compass, but error is immense'. And so it is with forecasts, whether they relate to an idea that all people could be Voltaires, given universal education,[1] or the world market for computers, or the weather forecast for tomorrow. Forecasts are frequently wrong, either being too optimistic, or perhaps more common, being a little too pessimistic.

There is a common theme among those who have recently contributed with gloomy predictions; their gazing into the crystal ball has generally been made with a lot of heart, a lot of brain, but also with a lack of economic theoretical foundation. Frequently, economists have been quick to point out this fact. Wilfred Beckerman's and Bill Nordhaus's critiques of the Club of Rome doomsday scenario are typical examples. They pointed out that key economic incentives were neglected, which combined with human ingenuity very likely would counteract the mechanics of the *ad hoc* dynamic computer model of the world, presented by the Club of Rome. While the 'doomsters' have been demonstrably wrong in many of their predictions, there are also examples where 'forecasts' of the ability of the ecosystem to provide for sustained human well-being have proved wrong. Perhaps the mysterious fate of Easter Island is a case in point. The inhabitants, living in apparent affluence, managed to destroy most of their resource base, turning their prosperous island into a barren, largely deserted, and lasting reminder of how humans can affect ecosystems.

It must be confessed, however, that most of the nineteenth century 'gloom' came from English economists. Thomas Malthus, David Ricardo, and Stanley Jevons are prominent examples of people from the economic profession who made long-term forecasts which were completely wrong.

[1] This example is one out of many discussed in Feynman, P. (1955), *The Value of Science* Public address, 1955 meeting of the National Academy of Sciences, reprinted in *What Do you Care what People Think*? *Further Adventures of a Curious Character*, Bantam Books, London, 1988.

In the stationary state wages would have reached a minimum acceptable level and net investment would have ceased because of low profit. The key mechanism in this is Malthus's population theory, which essentially boils down to population growing faster than the ability to provide food. This premise turned out to be wrong, and the stationary state has been postponed indefinitely by a stream of highly productive investments.

Having learnt our lesson from the failures of nineteenth century growth 'disaster' theory, we have today endogenous growth theory which promises us permanent growth, due to constant returns to capital. It is just a theory, but it has not yet been 'refuted', and it certainly colors our way of thinking.

But what exactly have we learnt? If we look at the forecasting errors exemplified in the 'Plenty of gloom' paper and those made by the great English economists, we find that the real failure is the systematic underestimation of what private economic incentives combined with human ingenuity can accomplish. The Club of Rome worried about the future supply of natural resources, so did Stanley Jevons and much later Paul Ehrlich. Jevons even collected paper in his basement to prepare for the coming shortage of coal. David Ricardo and Thomas Malthus were worried about food supply.

All the mentioned problem commodities are today produced by private enterprise. They are sold in well-functioning markets, which signals scarcity by rising prices, inducing high returns to fresh supplies or new inventions which create substitution possibilities. In other words, it is hard to beat the market, and any crash due to lack of supply or new technological possibilities will be soft. We might not even feel it.

On the contrary, there are, however, no reliable markets today that can create incentives to avoid global warming or similar transboundary environmental problems, such as a thinner and thinner ozone layer. These are very genuine externalities, i.e., there are few, if any, market incentives to avoid them. On the other hand, we have a well-developed physical theory for how the ozone layer deteriorates and/or recovers, and the same can be said about the acid rain problem. This means that we can pretty well measure and forecast the consequences of our actions on the ozone layer, and there are reasons to believe that mankind, even if only boundedly rational, can avoid a future catastrophe in terms of an ozone hole. As for global warming, we do not really know whether there is a real problem or not, and, if there is, how and where things will go wrong. Hence, our best bet for a real environmental scare would be the Greenhouse effect. While we argue about whether there is a real danger or not, it may already be over us.

If it is a real danger, what are our best chances to avoid it? Given that we agree that it is irreversible (if not, where is the problem?), we know from works of Kenneth Arrow and Anthony Fisher that there is a quasi-option value, i.e., there is a value from being conservative with CO emissions, conditional on new information becoming available in the future. This component is at least an argument on balance of 'acting now', albeit a little subtle to non-economists. If this is not enough, let us remind our readers that there is a kind of a selection bias involved in detecting 'doomsday'. You will not read about the man who detected doomsday in *The Economist*.

While there are still economists who deny the importance of ecological systems for the economic system, they are easier to count these days. Economists and ecologists increasingly work together in order to better understand what the key problems are and what effective solutions might look like. The research agenda is not to look for impending disasters or catastrophes lurking around the corner. Rather, natural scientists help identify what services ecosystems supply, and characterize the workings of the ecosystem in closer detail. Economists ponder the costs and benefits of alternative actions. In short, the focus is on production and demand functions. For example, there is widespread acceptance among ecologists that we need to shed some light on the willingness to pay for environmental quality in order to be able to make reasoned choices. Similarly, economists are not hostile towards the idea of properly specifying a production function. Consequently, while the doomsayers may have been mistaken, their predictions seemingly play little or no role in the dynamics of current research. Whether they play a significant role in policy making is altogether another issue.

Whatever the truth may be, our chances of finding it are presumably increased by serious research efforts but lessened by our possible ignorance of accepted theories in fields other than our own. Indeed, a key weakness of the Club of Rome model was its ignorance of market forces. The very optimistic forecasts by Simon and Kahn might someday end up on *The Economist*'s front page as icons of failed forecasts, even though their predictions to some extent rely on the arguably unlimited and most important factor of all—human ingenuity.

There is evidently something in the nature of human beings that forces us to be fascinated by gloomy predictions, regardless of whether such prophecies are based on accepted theory and empirical methods. A safe prediction we can make is that there will be 'more of the same'. Hopefully, those glimpses into the future will be subjected to careful scrutiny before they enter into media hype and the political process. The immense errors of the past might conceivably be reduced in this way. Perhaps what is most important about a forecast is that we can learn from its error. Not so much by indulging into *ex post* cynicism, but by probing ways of improving our theories and empirical methods.

Anticipating environmental disasters

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In a particularly snide attempt to discredit all those who would warn of impending environmental crises, *The Economist* (December 20, 1997: 21–23) has repeatedly overgeneralized in order to score points. By lumping together all environmentalists, all environmental problems, and all environmental regions, the article purports to show that the only thing wrong with the environment is environmentalists, who uniformly cry wolf to justify their existence.

All is not well, however. Temperatures are rising, the ozone hole is bigger than ever before, and new epidemics of disease ravage a continually increasing populace. World population is higher now than at any time in history, and the populations of developing nations continue to grow. Indeed, it is true that developed nations have stabilized their populations. To suggest, however, that this is evidence that those who worried about unchecked growth were guilty of poor science misses the point of scientific prediction. The goal of prognostication is not simply to depress everyone, but rather to serve as a clarion call to action. Concern about population growth has led to advances in birth control and other measures that have helped check the trend. The greatest reward for one predicting catastrophe is to stimulate the implementation of measures that invalidate the predictions. In this regard, few have had more positive influence than Paul Ehrlich, *The Economist's* favorite whipping boy. The challenge is to be a bit ahead of the wave, foreseeing the imminent crises that can be addressed, in the hope of stimulating the search for solutions.

Food supply is a case in point. *The Economist* smugly states, without citation of specifics, that 'deaths from famine, starvation and malnutrition are fewer than ever before'. Indeed, world agriculture has made remarkable strides in increasing yields, though there is disturbing evidence that yields have stopped rising and will not keep up with the expanding world population. This conclusion emerges from the analysis of the same Food and Agriculture Organization data that *The Economist* cites, and in a study jointly supported by the World Resources Institute, two United Nations Programmes, and The World Bank (1998). Even more troubling, according to the same study, is the fact that '800 million of the world's people—200 million of them children—suffer from chronic undernutrition'. These data simply support the point made eloquently by the distinguished economist, Partha Dasgupta, that the use of macroaverages to hide inequities of distribution is a dangerous and misleading practice. The Food and Agriculture Organization of the United Nations fortunately does not derive the same peace of mind from its data that *The Economist* does, and organized in 1996 a World Food Summit to attack the insidious problem of malnourishment. The ideal outcome will be that, again, attention to addressing the roots of an environmental problem will prove false the dire predictions that stimulated action.

One of the greatest threats to the human population comes from new and emerging diseases, and the crisis engendered by the rise in antibiotic resistance. AIDS is a global nightmare that is unfortunately fulfilling the worst predictions made for it; but it is only one of many that we shall see. Concern for such matters has led to the search for new vaccines, new antibiotics, and new practices for managing diseases. No one can doubt that these are urgently needed. If the result is that many of these threats prove less than predicted, that clearly is not evidence that those predictions were nonsense; rather, it is testimony to the value of having alerted the public to emergent threats. Similarly, attention to the health and other consequences of an expanding ozone hole led to restrictions upon the release of chlorofluorocarbons into the atmosphere. It is too soon to know how successful these measures will be in ameliorating the situation; but surely we will be better off than we would have been otherwise. Without the discoveries by Sherwood Rowland and Mario Molina, and by Susan Solomon, identifying the problem and linking cause and effect, no action would have been taken.

The Economist bases much of its argument upon the declining prices of resources. The prices of resources, however, do not always provide a reliable indicator of scarcity, unless externalities and property rights have been properly assigned. That is rarely the case with the harvesting of natural resources, or with other activities that lead to pollution. Garrett Hardin, that visionary that *The Economist* dismisses as Paul Ehrlich's 'fellow eco-guru', made us aware of the Tragedy of the Commons, pointing out that individual behaviors in exploiting common resources will not in general operate for the greater good. The Nobel Laureate economist, Kenneth Arrow, has written in his Foreword to the book, *Rights to Nature* (Hanna *et al*., 1996), that 'There is abundant evidence that the private property system is frequently not working as it is supposed to.' For free-access goods, he argues, overutilization is a danger because property rights have not been correctly assigned. Fisheries, for example, are treated as a free good, and consequently world fisheries are in serious decline. Market forces are not working there, as well as in a variety of other cases of the exploitation of natural resources and the pollution of air and water.

This frames the central environmental challenge facing ordinary citizens and readers of *The Economist* alike—managing a global commons. It is pure folly to argue that we are not confronted with serious environmental threats, and ones whose solution will involve the good will and joint efforts of environmentalists, corporations, governments and scientists. Traditional economic analysis, in the words of Arrow, 'is not rich enough to encompass the actual links observed in the use of natural living systems as resources'. Attention to these issues has motivated people of good will from diverse disciplines to endeavor to find appropriate schemes of natural resource accounting, and it would be far better for *The Economist* to lend its support to such efforts than to play the ostrich.

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On environmental gloom and doom

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No one can fault *The Economist* for being boring, and the tempest stirred up by its recent and provocative article, ‘Environmental Scares: Plenty of Gloom’ (20 December, 1997), certainly bears this out. If forced to choose camps between those delighted by the piece and those outraged, we are frankly more comfortable in the former. Indeed, the piece makes a point too seldom heard in environmental debates these days, but well worth remembering: the world has not yet gone to hell in a handbasket and may not ever. At the same time, the article simplifies and omits much more than it should, and in ways that are important to understand.

We begin this short response by explaining why we think environmental ‘Chicken Littles’ have missed the mark so often and then turn to the unhappy consequences of paying them too much heed. But we close by arguing that *The Economist* is mistaken in contending that we should pay these pessimists no further attention—we cannot simply assume that somehow all will be well.

Why the sky hasn’t fallen—at least yet

There are a number of reasons why the doomsday predictions have been, as *The Economist* says, ‘invariably wrong’. One is a simple misunderstanding of how market systems work in the face of growing scarcity of exhaustible resources including fuel and other mineral resources. With well-defined property rights and organized markets, the invisible hand works to conserve such resources. As their supplies dwindle relative to demand, their prices rise. And this sets in motion powerful incentives to economize on their use: to find substitutes, to recycle or rehabilitate spent resources, and finally to discover new and less-expensive ways to extract and/or produce them.

One very basic way in which such resources in finite physical supply are 'stretched' is through the development and use of new technologies. David Simpson, for example, in a forthcoming volume from Resources for the Future, looks at technological changes that have resulted in *reduced* real prices over time for four natural resources: oil and gas, coal, copper, and timber. This has been most dramatic in the case of oil and gas. Three- and even four-dimensional seismic techniques, coupled with high-speed computing, have greatly improved our ability to locate petroleum reserves, while slant drilling and off-shore extraction from deep-water platforms have made possible the recovery of reserves heretofore considered uneconomical to pursue (Bohi, forthcoming). This is just one of countless examples of induced technical change in the natural resource sector that have rendered foolish the dire warnings of the Club of Rome crowd.

Not all resources and environmental 'goods', however, benefit from such market protection. And here things get more complicated. Yet even for these resources, such as airsheds and water systems which are typically common-property resources, the forecasts of environmental catastrophe have failed to materialize. This is the result in part of the evolution of a variety of institutions for their management. Elinor Ostrom and her colleagues (1990) have documented and analysed the wide-ranging techniques that societies have developed through the ages, some quite ingenious and fascinating, to regulate access to common property resources such as grazing lands, fisheries, and undergound aquifers. More recently, the Montreal Protocol limits emissions of chlorofluorocarbons and other depleters of stratospheric ozone, a successful effort on an international scale to address a global common property problem. This is not to say that we have resolved all such common property problems—obviously we have not, and we shall return to this shortly. The point here is simply that even where property rights are ill defined, societies have shown no small capacity to organize the way they do things to mitigate the ill effects.

The danger in running scared

Why be concerned about prophecies of environmental doom? Observers make predictions all the time about economic recessions, the collapse of civil society, and the proverbial 'end of the world'. Why should we care?

The trouble is that sometimes people listen to them and, without the wherewithall to distinguish between real and fictitious problems, act on what they hear. To take but one example, it was not long ago that environmental advocates, and some regulators too, spread the cry that asbestos in schools posed a terrible threat to our children. As a result, a number of inner-city school systems in the US, including New York, spent huge sums of money and delayed the opening of schools in order to remove asbestos insulation. As many experts said at the time and as is the conventional wisdom today, in most cases this insulation posed virtually no risk to students at all. In fact, many of the children that spent extra weeks playing in unsafe neighborhoods were forced to bear much greater risks than they would have faced in school. In addition, much-needed funds were siphoned away from underfunded schools. The harm in false prophecy is clear.

There is another reason why Cassandras must be watched carefully.

Suppose that the public is so besieged by claims about, say, carcinogenicity, that people simply throw up their hands in despair: if everything causes cancer, why bother? Such confusion and frustration makes it much harder to draw attention to problems that are serious but which can be addressed with preventive or ameliorative measures. If we hear 'wolf' cried too often, we may stop listening—and get eaten.

Giving chicken littles their due

Implicit in this last point is an important message: sometimes part of the sky is falling (or being thinned out by harmful substances)! What *The Economist* failed to acknowledge is the role that the prophets of doom played in inducing the very actions that made their predictions wrong. There is something akin to the Heisenberg Principle here: the very act of observing, commenting, and especially forecasting the course of social events is likely to affect the outcome. The principal reason that concentrations of air pollutants have fallen in virtually every metropolitan area in the US over the last 25 years was the enactment of federal air pollution controls in 1970. These controls were prompted in large measure by the dire warnings of environmentalists (and some economists we might note) who foresaw the likely effects of unchecked industrial growth. Nearly every western industrialized democracy has had such an experience with air quality management. Similar warnings and responses have reversed the deterioration of many streams, rivers, lakes, and estuaries and have awakened us to the folly of the careless disposal of hazardous wastes.

A bit more on common property problems and all that

In its sweeping indictment of forecasts of environmental doom (with which we largely agree), *The Economist* leaves the unfortunate impression that all is, and will be, well with the environment. This is, of course, far from the truth. In spite of much ingenuity and many success stories, there remain numerous serious environmental challenges. Certain common property problems continue to bedevil contemporary society: free access to the world's fisheries and rain forests, for example, has put these resources under tremendous pressure. We are likewise concerned with the loss of biodiversity and the obstacles to taking appropriate measures to hedge against climate change (which is *much* harder, incidentally, than dealing with stratospheric ozone depletion). As Partha Dasgupta (1997) and others stress, there exist real problems in providing global food supplies in the context of a growing world population; existing institutions, especially in the developing world, seem incapable of protecting the essential resource base.

This leaves us with a troubling dilemma. On the one hand, the prophets of doom are typically highly misleading—and often in costly ways. Yet, at the same time, their cries have sometimes helped to mobilize public policy in useful ways. It often seems that our political systems can respond to nothing less than a *perceived* crisis. This is every bit as true, incidentally, for public policy regarding social security, homelessness, drugs, or immigration as it is for the environment. Until a 'crisis' has been proclaimed, no one pays much attention—no legislator anyway. We would do well to think more about how our legislative institutions can be made to respond to less startling, but more realistic, concerns. In the meantime, we must lend an ear to the various pronouncements of environmental doom, but be prepared to take them with a shaker or two of salt (which, incidentally, is no longer believed by some to be harmful to you!).

At any rate, no matter how one reads *The Economist*, there are surely no grounds for concluding that we can simply forget about existing environmental threats. The real challenge is to respond to them sensibly: to focus our attention on real (not imagined) problems, to give them their proper priority, and through careful analysis to find effective ways to resolve them. Fortunately, much of this kind of work has been going on for some time now and continues unabated.

Some final thoughts on forecasts

When it comes to predictions concerning the future, we do not have a lot to say; the history of forecasts should be enough to make anyone hesistant. But it seems reasonable to expect the world a century from now to have experienced some population growth—although it is quite possible (if one believes some current forecasts) that the world's population will stabilize at not much more than twice its present size of 5.7 billion. In addition, the continuation of technological progress should surely result in substantial increases in the material standard of living of the 'average' global citizen. But beyond this, we find it impossible even to begin to imagine what the world will look like a century hence. Indeed, how could anyone in 1898 have envisioned the world of 1998!

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Do environmental scares provide information?

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Few human institutions can hold a candle to the market. Even when the textbook conditions defining an ideal market are not satisfied, markets serve remarkably well in signaling the needs and availability of *private* commodities. Lest economists feel too sanguine about the virtues of markets, one should also acknowledge that markets do not always get it right. Indeed, as the scale of human activity continues to grow, with increases in population and in per capita consumption (that accompany rising incomes), there is little doubt that increased pressure is placed on the global resource base. However, pressure alone does not imply disaster in the short or even the long term. Nonetheless, complacent confidence is not warranted. To understand why we need to consider how well markets signal pressures on the resource base.

After at least two hundred years of periodic attention it seems remarkable how little is known about the quantitative significance of the widespread distortions and failures in the markets for the natural and environmental resources comprising the resource base. Under these circumstances, we cannot rely on prices to signal scarcity and to identify opportunities for the 'nimble' to respond.[1] The shortfalls extend from public intervention subsidizing resource extraction or promoting the worst open access use of natural and environmental resources to a complete failure to 'price' some of these resources. But all of this is recognized at a conceptual level (by environmental economists at least) and has been clearly described by Dasgupta (1990, 1996) among others. This forum is motivated by the complete absence of recognition given to these qualifications in *The Economist*'s recent 'bashing' of what was labeled forecasts of scarcity and doom. It is hard to incorporate such qualifications to observed market outcomes in specific terms because we do not have sufficient

[1] This characterization is taken from the first major study produced by Resources for the Future (RFF) addressing the materials problem that motivated its formation. In their book, Barnett and Morse (1963) argued that technology was the renewing resources observing that: 'the resource problem is one of continual accommodation and adjustment to an ever-changing economic resource quality spectrum. The physical properties of the natural resource base impose a series of initial constraints on the growth and progress of mankind, but the resource spectrum undergoes kaleidoscopic change through time. Continual enlargement of the scope of substitutability—the result of man's technological ingenuity and organizational wisdom—offers those who are nimble a multitude of opportunities for escape' (244).

information to compute their overall consequences. Thus, one is left saying there are 'concerns' and little else.

George Will's recent *Washington Post* (22 March, 1998) column echoes a similar tone to that of *The Economist*, suggesting more generally that this moment of relative abundance is not a golden accident but rather 'has been produced by scientific creativity that is largely the fruit of freedom in industrialized countries'. One can acknowledge the contributions of freedom and the market activities that flourish in these circumstances. History also provides stories of past 'great' civilizations that disappeared from causes we do not today understand.[2] Indeed, the very freedom that promotes market exchanges also stimulates a wide range of other informational signals. The challenge that confronts today's policymakers is one requiring integration of the diverse signals available in ways that promote *informed choices.*

We do know that the market overlooks important non-market effects. However, a response to *The Economist*'s commentary itemizing the required empirical 'wish list' to make a more prudent judgment is unlikely to change anyone's mind. It also cannot do justice to the reasoned conceptual arguments for concern that were ignored by *The Economist*'s blanket indictment of 'environmental scares'. Instead in what follows, I will consider a different issue that, to my knowledge, has not been addressed—have environmental scares, in and of themselves, created some incentives for change? In what follows I will suggest the answer is yes, but, that the responses are likely to be *too slow*, and may well be smaller as the volume of instantaneous information available competes for the limited attention span of today's decision makers. Thus, it is too *risky* to rely upon popular warnings as the exclusive signal for scarcity of the globe's environmental resources.

When environmental scares are interpreted in these terms, we are directed to consider the characteristics of these 'warnings' that caused constructive responses. The remainder of this discussion is divided into two short sections. The first discusses how environmental information has changed private and public behavior. The second describes alternatives to 'scare' tactics in an information congested world.

1. Non-market signaling

Markets comprise a small fraction of the types of interaction people have. Most behavioral exchanges convey information that, in turn, leads to dif-

[2] At a recent RFF conference an exchange focused on concerns about if the adequacy of the resource base is worth summarizing. The optimist in the debate suggested the compounding effect of geometric technological progress is daunting in its effects. The pessimist reminded the conference that analysts predicting the state of well-being today from the vantage of the high point of the Roman Empire would, on these grounds, have concluded everyone alive would be billionaires (see Portney and Weyant (1998)). More generally, past episodes of human civilization have experienced interruptions, declines, and even disappearances (e.g., the Cliff Dwellers of the American Southwest and advanced Indian civilizations of Central and South American are some examples) that are difficult to explain.

ferent choices. A substantial portion of Nobel Laureate Gary Becker's (1993) research has systematically opened today's economists' eyes to the first point. A large volume of empirical research is documenting the second. People respond to news that conveys positive and negative messages—whether it is an 'event study' using financial markets,[3] public warnings about chemical risks,[4] or simply the first announcement of the Toxic Release Inventory—choices are affected by information provided outside market transactions.[5]

A strong case can also be made for episodes of public concern and debate leading to long-term change. These are less easy to document empirically but they are also potentially more pervasive in their impacts. Consider two examples. In 1952, the President's Materials Policy Commission asked about whether the US had the material means 'to sustain its civilization'. Their report changed the focus of the materials debate at the time from physical to economic measures. The Commission Report recommended (and its chairman, William S. Paley, helped to facilitate) the establishment of Resources for the Future (RFF). Most observers would agree that RFF's work over nearly a half century has changed the landscape for public policy toward environmental resources. Where did the ideas for the US environmental legislation (and the associated statutes in other developed and developing nations) of the seventies come from? I would not try to contend they were exclusively (or even primarily) from RFF. However, I am confident that without RFF we would have seen a *very* different physical and policy environment!

More recently, the Brundtland report (the World Commission on Environmental and Development, *Our Common Future*, 1987) transformed the international rules-of-the-game for development agencies and lending institutions. The results can be seen in a number of venues, as the international community responds to these concerns with everything from international agreements, such as the FAO Code of Conduct on The Distribution and Use of Pesticides (1989), the Convention on Biological Diversity (1992), and the Montreal Protocol on Ozone Depleting Substances (adopted in the same years as the Brundtland report) to the new 1992 organizational rules for the operations of the Global Environment Fund.[6] Trade patterns, the level and composition of development, and the protection of the world's environmental resources are beginning to change as a result of these international responses to global concerns.

The Economist's editors argue that because the worst cases described in

[3] Schwert (1981) offers an early example of an event study.

[4] Examples of cases where news of the potential for chemical risk affected individual behavior are common in the literature with early studies of mercury contamination affected pheasant hunting (Shulstad and Stoevener (1978)) or kepon and fishing (Swartz and Strand (1981)) to recent findings for radon (Desvousges *et al.* (1992) and Smith (1997)) or Alar and apples (see Van Ravenswaay and Hoehn (1990)).

[5] Hamilton's (1995, 1996) analysis demonstrates the impact on both financial market discussions and subsequent behavior.

[6] See Keohane (1996) for a discussion of the changes in GEF governance rules.

past ‘scares’ did not materialize the warnings were unnecessary. However, we cannot overlook the fact that the outcomes we have observed over the twentieth century are *in part* a result of the warnings they suggest we should ignore!

2. Getting noticed

Scare tactics offer one strategy for getting noticed in an information congested environment. The challenge faced by today’s policy community in evaluating any warnings, including those dealing with environmental problems, is to recognize the cases providing information that warrants a response. This will be more difficult as it becomes easier for anyone to contribute to the public discourse. The Internet and other aspects of the computer revolution make it easier to add to what is increasingly an open access information pool. This is a cost of the freedoms George Will endorses. To be sure, it is one we should happily endure. However, it is important to also acknowledge the need for mechanisms to sort through what is presented and identify the informational signals worth considering. Institutions, national and international in their scope, detached from the whims of government offer one approach, but *not* the only one. Informed and careful journalism is another. Simple summaries such as that of *The Economist* do not help in that process. The record on the sustainability of current paths of growth and environmental change is not as clear cut as their treatment implies. Changes are warranted and the real issue is the extent of change that is prudent for efficient stewardship.

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