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Commentary

Population, development, and human natures

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Ehrlich and Ehrlich have advanced three points, of which the first two can be summarized as saying that economic development is adversely affected by population and consumption patterns through their effects on natural capital. The third point is that sociopolitical organization and ethics do evolve over time to meet new problems, though with a lag so that at any time (and perhaps especially today) they are not adequate to current problems.

The last point is an important one, with its combination of hope and apprehension. Our attitudes and behavior do evolve and sometimes quite rapidly. One can amplify the Ehrlichs' list of changes in many dimensions of social behavior. Of especial relevance here is the emergence of the conservation ethic at the beginning of the twentieth century, including at least some attempts at forest management and the revival of that attitude with the new goals of pollution control in the 1960s. In many ways, the success in CFC control and the partial commitment to abating greenhouse gas emissions, with all their limitations, are remarkable. They are not responses to widely observable challenges; they are reactions to scientific predictions of possible (not completely certain) adverse consequences in the fairly distant future. It may be undue optimism on my part, but I believe this degree of anticipatory behavior represents a new and higher level of social response.

The Ehrlichs' first two points, as joined above, are hardly disputable by themselves. Population and consumption jointly impose increasing strains on the natural environment which has supported them. Indeed, the Ehrlichs' list is far from exhaustive. Species extinction and near-extinction goes far beyond what even capable observers in the past thought possible. In Herman Melville's novel, *Moby-Dick*, the narrator at one point raises the question whether the sperm whales would be wiped out by the intense hunting; he finally dismisses the issue (not without some ambivalence) by pointing to the vast herds of bison then still extant.

The question is, as usual, the completeness of the analysis. Consider the history of economists' thinking on the implications of population and consumption pressures. After all, *eco*nomics and *eco*logy share more than a Greek root in their world perceptions; scarcity and complex interaction are key elements in both. The grim pressure of population on resources was first emphasized by T.R. Malthus (1798), precisely with a view to refuting the optimistic views of the possibility of human progress held by such thinkers as Condorcet. That real wages were stuck at a subsistence level because population would inevitably rise to absorb any temporary increase in the level of well-being was a staple of economists such as David Ricardo and John Stuart Mill (although the concept of 'subsistence' was gradually whittled down to something more like, 'socially acceptable'). These views led Thomas Carlyle to dub economics as, 'the dismal science'. It was the critics of classical economics who emphasized the flaws in the doctrines of Malthus and Ricardo, noting, for example, that British birth rates were falling even as real income was rising. Silently the economists retreated in the face of the facts, and population came to be regarded as outside the economic paradigm.

W. Stanley Jevons (1865) introduced a new element into the discussion by raising the issue of exhaustible resources. Malthus and Ricardo emphasized the scarcity of agricultural land, which set a bound on the annual flow of food (and fiber) that could be produced. Jevons was concerned with the stock of coal. He observed that the seams of coal closest to the surface were being mined out, and therefore that the cost of extracting coal was rising. He foresaw that England's industrial leadership would be eroded, since, in his judgment, it was based on cheap coal for the manufacture of steel. Carl Schurz, the United States Secretary of the Interior (and one of the few able and honest politicians of his day), calculated in his 1870 report that, at the then current rate of extraction, the known coal reserves of the United States would be exhausted in 20 years.

One could go on with further examples, such as fears of exhaustion of minerals, especially iron ore, around 1950. None of these predictions have come true, and economists have to some extent abandoned their pessimistic views. One particular argument is very interesting. The modern economic analysis of exhaustible resources stems from a 1931 paper by Harold Hotelling, who argued that the price of an exhaustible natural resource (net of extraction costs) should rise over time. Repeated studies have shown no consistent trends in the prices of minerals or oil; indeed, the only resource-based good that does show secular increase is timber for building. Agricultural prices in fact have fallen sharply relative to other goods in spite of the increased demand generated by increasing population and growing consumption per capita (including increased meat consumption, which indirectly causes an increase in grain use).

What I am suggesting is that the natural bent of economic analysis to find scarcities has been altered by the empirical evidence. It may be that we simply have not allowed enough time, that the scarcity predictions of traditional economists and ecologists will be realized. But at the very least the evidence to date is that rapid population and consumption growth has not harmed the bulk of humanity.

Indeed, this fact is a conundrum for economists. The answer increasingly given in recent years (documented initially by Jan Tinbergen, Jacob Schmookler, Moses Abramovitz, and Robert Solow) is that advanced societies at least are getting more product out of given inputs, so that growth in total consumption is not entirely at the expense of natural resources. This greater efficiency is, in turn, due in part to increased knowledge and better-designed economic institutions. I should add that these last concepts are pretty vague.

Economists are quick to add that looking at totals is inadequate. There are different types of consumption, and some use natural resources more than others. To the extent that natural resources are available at zero price or otherwise underpriced (as the air and the water as receptacles for combustion and other wastes), they will be overused. Prices, taxes, or regulations may induce a reduction in natural resource inputs for a given amount of consumption.

Let me conclude with two observations, one about the cause and one about the consequences of population growth. Why, after all, have we had this great upsurge in population over the last two centuries? It is, in good measure, because of something that we must regard as a good, namely, better health and consequent prolongation of life. The precise factor may be public health, it may be better nutrition due to increased resource availability, it may be in some part better individual health care. But whatever it is, we know that better health has caused longevities in many very poor countries today to exceed that in the most advanced countries one hundred years ago. One can hardly criticize this cause. Of course, the reaction in birth rates was delayed, but it is occurring.

Population and consumption growth do seem to have an effect in increasing the rate at which productive knowledge grows. At least this is a reasonable conjecture. The argument is that a new idea (say a method of reducing natural resource inputs, as gasoline in automobile transportation) is expensive to develop. The larger the amount of the product produced, the less will be the cost of innovation per unit. Hence, so it has been theorized ever since Adam Smith (1776), efficiency in production is easier to achieve at high levels than low ones. It must be remembered that efficiency here includes a reduction in the use of natural resources per unit output.

There is one more difficulty with achieving a sharp reduction in population. During the initial phase, the effect of reducing the birth rate and thus eventually the working population is to increase the ratio of retired to working individuals. Thus, the burden of supporting the retired, through social security or other transfers can increase sharply during the transition.

Let me be clear. The considerations adduced by the Ehrlichs are all valid. I merely want to emphasize that there are further considerations in this dialogue which all of us hope will clarify the ethics underlying the growth of population and consumption and the formation of policies for controlling them or modifying their adverse impacts.

Population, development, and human natures: a response

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In their paper 'Population, Development, and Human Natures', Paul and Anne Ehrlich discuss the 'critical challenge of the decades ahead to incorporate the lagging four-fifths of the world's still expanding population into the global economy while preserving the life-support systems that make our planet habitable'. They emphasize the second part of the challenge, that is how to ensure that, whatever development results, it will not threaten the Earth's life support systems. When thus formulated, hardly anyone will question this challenge, but the authors seem to have a more ambitious goal. The concepts of strong and weak sustainability, as described by Turner (1990) for example, allow for a choice between keeping all natural capital intact and preserving essential life-support systems, but with some substitution. The authors clearly advocate strong sustainability. Their paper alludes to five major developmental threats to the attainment of this goal: (i) population growth; (ii) excessive consumption in developed countries; (iii) technological development; (iv) lack of public consciousness about the need to curb the first two; and (v) weakness of political mechanisms to create a consensus around this need and to act accordingly.

Although less central to this paper than to some of the authors' earlier work (Ehrlich, 1968), population nevertheless occupies a prominent place in the title and the paper itself. Yet, this may be ultimately the most manageable of the threats. Of course, *ceteris paribus*, population growth aggravates various problems related to sustainability, whereas it seems to have few benefits, at least at the global level (Smil, 1993). But there is little consensus about the Earth's total carrying capacity. The 'optimum' size of 1.5–2.0 billion mentioned in the paper is the lowest estimate around. In his survey of similar numerical exercises, Cohen (1995) found a wide range of carrying capacities, reaching upward to as much as 200 billion. More importantly, much progress has been made since the days of 'The Population Bomb'. True, world population growth is still substantial: 1.33

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per cent per annum, about two thirds of the 2.04 per cent per annum prevailing in the late 1960s. However, much of this growth is now *inertial*: it results no longer from the propensity to have many children, but from the transitory circumstance of having many women of reproductive age, due to high fertility in the past. The *intrinsic* growth rate of world population, that is the rate attributable to current reproductive patterns, has fallen much more: from 2.35 per cent per annum in the late 1960s to 0.55 per cent per annum at present (Martine, Hakkert, and Guzmán, 2000). If the world fertility decline of the 1990s were repeated during this decade, intrinsic growth would reach zero by 2010 and all remaining population increase would be inertial. Of course, this is scant consolation to those who consider the planet already over-populated and who realize that at least another two million will be added before inertial growth subsides. The numbers show, however, that the population bomb, while not entirely stripped of its explosive charge, has now largely been defused.

The tendency to over-emphasize the negative aspects of change is a general feature of the paper. All development involves costs and benefits, and trade-offs have to be considered in a world with preferences that strongly differ. Although further growth of already high consumption levels is a threat to the environment, the answer is not necessarily to bring down consumption and restore the environment to its pristine state. As long as life on Earth is not threatened, most people are willing to give up some natural capital to sustain consumption. This is not necessarily a matter of ignorance, as the paper seems to suggest, but can be a deliberate choice.

The view that change (whatever it may be) is bad comes through most forcefully with respect to population issues. One may accept the general thesis that aggregate world population growth has few redeeming qualities, but what about population concentration? Population concentration has its own logic and is not a mechanical consequence of aggregate growth: some of the world's largest urban agglomerations are located in sparsely populated countries. The authors seem to argue against concentration, but the disease threats that they associate with population settlement patterns actually derive from quite disparate processes. While it is true that population concentration favors the propagation of some diseases, the hanta virus and lyme disease, which the authors mention, are actually associated with population deconcentration. The incidence of infectious hepatitis in the USA also varies inversely with population density. As for HIV/AIDS, incidence in Africa is roughly equal in urban and rural areas, whereas in India it is now increasing most rapidly in the countryside (FAO, 2000). Cities still have the best health indicators, to say nothing of the economic and environmental advantages of settling a large number of people in a limited space.

The paper's view on technological development is also surprisingly gloomy. True, the Industrial Revolution was bad news for the environment, but increased awareness of pollution and resource limitation has changed the view on technology. A leading idea in environmental policy nowadays is to *decouple* growth and the burdening of the environment (for example Weizsäcker, Lovins, and Lovins, 1997). With a fixed emission–output ratio, growth will further burden the environment but if technology can change that ratio, growth may promote reduced environmental stress. This process is not automatic, as the environmental Kuznets curve literature seems to suggest, but judicious constraints and incentives may steer it into the desired direction. In the case of the phase-out of CFKs and the reduction of SO_2 emissions, new technologies reduced the environmental burden, without compromising consumption levels. These are only examples, but they do show that not all technological development hurts the environment. In the early 1970s, the Club of Rome predicted a fast exhaustion of resources if growth were to continue unabated. Growth continued, but, due to technological development again, the availability of most resources has never been greater.

Another general feature of the paper is to blame everything on a lack of understanding and leadership. This ignores the possibility that people are informed but have different preferences than the authors. It also ignores the possibility that people share the same preferences, but current institutional arrangements do not invite them to act accordingly. Consider the example of climate change. Within the framework of the IPCC, at least at the government level, people are well informed and conscious about the possible effects of global warming. However, governments do not necessarily take strong measures to reduce the emissions of greenhouse gases. The reasons are threefold. First, a change in climate is not only negative: advantages may occur for agriculture at higher latitudes. It also proves to be very costly to reduce the emissions of greenhouse gases, and the trade-off between costs and benefits differs widely among countries. Second, when the possible effects will occur and to what extent is highly uncertain. As long as the potential damage is limited and risk aversion low, it can very well be explained that strong measures are omitted although one is well informed. Third, climate change is a global problem and requires international agreements. If benefits to other countries are ignored, any one country may opt to refrain from acting. Even if an agreement is reached, individual countries have an incentive to deviate and to have the job done by others. The challenge is to design stable international agreements, with sufficient signatories to be effective (for example, Barrett, 1994).

We agree that the current political mechanisms are too weak to handle the environmental problems of this new century. Not only at the international level, but also within countries environmental issues are weakly integrated into the regular political process. What is needed is a balanced assessment of the costs and benefits, a visualization of explicit choices, and political mechanisms to build and implement policy with a broad support. Focusing, as it does, on the downside of change, the paper lacks such an assessment. It reflects a strong view on which development path ‘should’ be followed and how to ‘guide’ society to do so, but it lacks a balance in the assessment of the pros and cons of this scenario *vis-à-vis* other possible development paths. The issues are also changing. Neither the population issue nor the resource issue are the same as 30 years ago. This requires constant adjustments of the analysis, which is another reason why this paper may not have the impact it aims for. This is unfortunate because the environmental problems are real and important and need a prominent place on the political agenda.

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The evolution of norms within institutions: comments on Paul R. Ehrlich and Anne H. Ehrlich's, 'Population, development, and human nature'

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The concerns raised by Paul and Anne Ehrlich about the effects of the growth of human population, human consumption, and technology are ones that all natural and social scientists should take seriously. Many do. After the experiences of the twentieth century, however, we need to

[1] Thanks to Laura Wisen for doing this search. In addition to these fifteen journals, this rapid search also identified many other journals with a similar focus such as *Land Economics, Land Use Policy, Society and Natural Resources*, and *Sustainable Development*.

understand the difficulty of trying to increase the level of stewardship that individuals exercise in regard to the environment and the multiple ways in which this can be done. Much of the first half of the century was spent in coping with the terrible consequences of powerful authoritarian governments and colonial empires. Many environmental policies proposed during the second half of the century tried to establish powerful central control over natural resources in the belief that the users of forests, water and fish could not extract themselves from tragic overuse. The all-too-frequent result has been that institutional diversity as well as biological diversity has been drastically reduced (Baland and Platteau, 1996; Ostrom, 1998b).

Resources that were subject to community stewardship under little-known and poorly understood, indigenous institutions, were opened up for public access (Bromley *et al*., 1992; McCay and Acheson, 1987). Forests that had been protected for centuries by locally evolved institutions and norms were harvested rapidly once local groups lost their claim to ownership and thus their incentive to manage these resources sustainably (Bromley and Chapagain, 1984; Arnold, 1998). Of course, many natural resources were not sustainably managed. Destroying the effective along with the ineffective institutions, however, set us back substantially in increasing the number of resources subject to sustainable management. While overcentralization is not the only cause of unsustainable resource use—just as population growth is also not the *only* cause of this malady—both must be taken seriously as factors leading to the overuse of natural resources. Thus, we need to take care in designing future institutions so as to reduce the likelihood of unintended consequences and particularly those that produce the opposite effect.

Before turning to a substantive discussion of the interrelationship between the evolution of norms and the design of institutions, let me first address the Ehrlichs' assertion that natural scientists have a straightforward understanding of the problem and its solution, namely 'the growth of the human population should be halted and a slow decline begun toward a sustainable population size.' They criticise social scientists as paying 'too little attention' to overpopulation, overconsumption, the evolution of culture and specific norms, and to ways of coping more effectively with these problems. Simply identifying a problem and indicating a 'simple solution' does not, however, represent a straightforward understanding. Calling entirely on national governments to move toward stricter control contributes to the trend of reducing institutional richness at all levels and centralizing power in national governments. It was, after all, a noted natural scientist, Garrett Hardin, who articulated the core dilemma potentially underlying almost all environmental problems in his well-known 1968 article in *Science*. Hardin did identify a problem existing in all open-access natural resources. Hardin was, however, unaware that many common-pool resources were already managed by long-established common-property institutions (as he grudgingly admitted 30 years later (Hardin, 1998)) and were not left open for anyone to use. By making a wholesale recommendation of government ownership or privatization as the 'only' solutions to the problems of overconsumption of natural resources, Hardin provided 'scientific' justification for substantial government takeovers of natural resources with tragic consequences for many of the poorest of the earth, and for the resources on which they depend (Bruce, 1999).

Further, the presumption that 'too little attention has been paid' by social scientists to ways of discouraging overconsumption is a strange assertion to be made in a journal, *Environment and Development Economics*, whose mission is exactly that of confronting these issues. Besides *EDE*, a rapid search of the Social Science Citation Index (SSCI) and the Science Citation Index (SCI) identified 15 other social science journals (defined as having more articles included in the SSCI than in the SCI) with the terms *environment(al)* or *ecology* in their titles which contain large numbers of citations to issues of overuse of natural resources within their covers. The Committee on the Human Dimensions of Global Change at the National Research Council of the National Academy of Sciences and the US Scientific Committee on Problems of the Environment (US SCOPE) have both actively examined the types of questions that the Ehrlichs pose (Liverman *et al.*, 1998; Dietz *et al.*, forthcoming; Burger *et al.*, 2001).

The evidence mounted by extensive social science research challenges the Ehrlichs' assertion that: 'While more scientific information would be useful in dealing with the human predicament, *more than enough is in hand to know the sorts of changes that will be necessary to establish a sustainable society*' (my emphasis). Their call for population reduction may not be consistent with creating a sustainable society. This problem is illustrated by several decades of draconian measures to reduce population growth in China without creating institutions fostering resource stewardship. Russia's fertility rate has plummeted and is now only 1.17 (from 1.89 in 1990). This dramatic fall in birthrates is leading analysts to question the capabilities of an 'aging population when there is a crucial need for young people to rejuvenate Russia's farms, re-energize industry and rebuild the economy' (Wines, 2000: 1). In all of the OECD countries, serious concerns are being voiced concerning the sustainability of social security systems as birthrates drop. Security in old age without needing to have a large family has itself been an important factor in the reduction of birthrates in these countries. Reducing population is no guarantee of establishing a sustainable society.

The Ehrlichs' do point out an important question for both natural and social scientists, How do norms evolve? The policy issue is how to achieve widespread adaptation of norms that are more consistent with sustainability than a highly self-centered focus on immediate consumption regardless of the adverse impact on others or on one's self in the future. A growing literature exists on the subtle interaction between the development of institutions and the evolution of norms. Let me provide a quick overview of some of the recent findings of the rich mix of anthropologists, human ecologists, economists, game theorists, political scientists, sociologists, and other social scientists working in this tradition.

The general theoretical structure that Hardin described in 1968 is called a social dilemma. If all participants in a social dilemma are 'rational egoists', in that they take into account only their own immediate payoffs and ignore the impact of their actions on others (and on their own long-term benefits), and if individuals act independently without the structure of rules and norms affecting access and use, Hardin's prediction of a tragedy is theoretically correct. And, in a laboratory setting where individuals are presented with a one-shot social dilemma and are not allowed to communicate with one another, behavior is more closely associated with this theoretical prediction than any other theory is able to generate. On the other hand, in a laboratory setting where individuals can communicate (and in other types of distributional games), behavior is not consistent with these predictions (for an overview see Ostrom, 1998a; Fehr and Schmidt, 1999; Ostrom and Walker, 1991). Instead of all individuals behaving in the *same* manner, multiple *types* of individuals appear to exist. In addition to rational egoists, who are always present to a greater or lesser extent, other types of individuals, who follow a strategy of conditional cooperation or reciprocity, are also present to a greater or lesser extent. Modest differences in the distribution of types of players is associated with culture. Even more important for policy is the fact that the structure of the rules changes the distribution of types of players over time (Ahn, 2001).

Recent work on an *indirect* evolutionary approach to the study of human behavior offers a rigorous theoretical approach for understanding how preferences—including those associated with social norms—evolve or adapt (Güth and Yaari, 1992; Güth, 1995). In an indirect evolutionary model, players receive objective payoffs, but make decisions based on the transformation of these material rewards into intrinsic preferences. Those who value reciprocity, fairness, and being trustworthy add a subjective change parameter to actions (of themselves or others) that are consistent or not consistent with their norms (Crawford and Ostrom, 1995). This approach allows individuals to start with a predisposition to act in a certain way—thus, they are not rational egoists who only look forward—but it also allows those preferences to adapt in a relatively short number of iterations given the objective payoffs they receive and their intrinsic preferences about those payoffs.

Only the trustworthy type survive evolutionary processes in complete information settings (Güth and Kliemt, 1998: 386). Viewed as a cultural evolutionary process, new entrants to the population are more likely to adopt the preference ordering of those who obtained higher material payoffs in the immediate past (Boyd and Richerson, 1985; Bowles, 1998). Viewed as a learning process, those who were less successful would tend to learn the values of those who had achieved higher material rewards (Börgers and Sarin, 1997). If a player's type can be made common knowledge, rational egoists would not survive. Accurate information about player's types, however, is a very strong assumption and unlikely to be met in real-world settings without institutions that generate substantial information.

If there is no information about player types for a relatively large population, preferences will evolve so that only rational egoists survive—the situation that Hardin described. However, if information about the proportion of a population that are trustworthy is known, even though no information is known about a specific player, Güth and Kliemt (1998) show that players will cooperate with others as long as the expected return of meeting trustworthy players and receiving the higher payoff exceeds the payoff obtained when no one trusts anyone. Further, if there is a noisy signal about a player's type that is at least more accurate than random, trustworthy types will survive as a substantial proportion of the population. Noisy signals may result from opportunities for face-to-face communication, from their interaction in a variety of community settings, and from the many institutional mechanisms that humans have designed to monitor each other's behavior. Field research is generally supportive of findings in the experimental lab (Gibson, McKean, and Ostrom, 2000).

Thus, encouraging norms of reciprocity for others (including future generations) is a delicate, dynamic process depending both on general cultural norms as well as the kind of institutions within which individuals relate on a daily basis (Costanza *et al*., 2001). Institutions that allocate long-term stewardship rights and responsibilities to small- to medium-sized groups who are able to devise ways of monitoring use patterns and resource conditions are more likely to lead to sustainability of many of the worlds natural resources, except those that are global in extent. Not only can such institutions change the overt incentives that individuals face in the short run, they can provide arenas in which individuals learn social norms that are more likely to lead to a sustainable society than top–down policies mandating population controls. National governments and international agreements have a major role to play in the design of effective polycentric institutions, but they are less effective when sole reliance is placed on them to solve the wide diversity of problems associated with achieving sustainable use of natural capital.

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Human natures and the resilience of social-ecological systems: a comment on the Erhlichs' paper

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Paul and Anne Ehrlich make three points in their paper: (1) development problems are intertwined with human population size, growth and consumption patterns; (2) development progress will be negatively affected by this through impacts on natural capital; and (3) the major impediment to achieving a sustainable civilization is the failure of human cultural evolution (in particular ethical development) to keep pace with the evolution of technological capability. The first two points are not new. Not everyone agrees on just how important they are, but they are widely recognized and despite some positive indicators in some parts of the world (e.g., Ausubel, 2000) many scientists would agree with the comments made in regard to these first two points.

The third point, the failure of cultural evolution to keep pace with technological evolution, flows from Paul Erhlich's new book *Human Natures*, and is one that deserves particular attention. It is appropriate to begin, however, by considering the ways in which the first two points influence the difficulties the Ehrlichs attribute to the relatively slow pace of cultural evolution.

The interaction between the consumption patterns of humans and this disparity in rates offers one reason why degradation of natural capital occurs when no-one wants it to happen. The issue of consumption is complicated by the fact that its effects no longer feed back directly and quickly to the consumers. As globalization proceeds, the gap widens. The natural capital consequences of the consumption patterns of residents in Manhattan, Manila or Mexico City are not experienced by them. The effects are felt in the regions providing the raw materials for satisfying their consumer demand—whether in their own countries or elsewhere in the world. More generally, there is an asymmetry, spatially, in the benefits and costs of consuming natural capital that leads to a lack of recognition about the problem on the part of the consumers. This leads to two kinds of externalities that are difficult to overcome. As an example of the first, in Australia today increasing salinity in the major agricultural regions is identified as the country's biggest environmental problem. It has arisen because the landowners in the upper parts of catchments have cleared perennial, deep-rooted native vegetation to enable annual cropping. This has led to rising water tables in lower parts of the catchments, bringing salt up to the surface. The beneficiaries of the clearing (the users of the natural capital) do not suffer salinity consequences and see no reason why they should forego their livelihood for the sake of others lower down. The second kind of externality is more global in scale. Natural capital consequences of agriculture and forestry in a number of developing countries are not experienced by, or even known to, the consumers in developed countries. The prices of the goods do not reflect the full costs of production, which include such things as soil erosion and biodiversity loss.

In the first kind of externality the actions of the beneficiaries, the users of natural capital, have direct, negative impacts on the natural capital of others elsewhere, greatly reducing the utility these others derive from the environment. In the second, the direct users (the managers) of the natural capital use the capital in ways and to extents dictated by consumer demand in other countries. The prices they are offered (which by and large they are obliged to accept in order to survive) do not reflect the costs of production, and their methods of natural capital use are therefore deleterious to themselves in the long term (and ultimately to the world). The emerging trend in the ecological–economics literature on recognizing and correctly valuing the full array of ecosystem services that are either used or otherwise affected in commodity production is a start in alleviating this asymmetry—but it has a long way to go.

The importance of the relationship between this consumption issue and the Ehrlichs' third point on culture is that culture evolves in response to the immediate environment of a society, and if the effects that the dominant consumers in society are having on natural capital are not experienced by them, then it is not surprising that the relevant aspects of their culture are not evolving at an appropriate speed. The Ehrlichs make a strong point about the relative speeds of technology development and ethical evolution and no doubt the speed of technology is such that it would in any case be difficult for ethical change to keep up. But the problem is made much worse by the lack of direct feedback.

Considering the change in society's attitudes to natural capital in the fifty years since Aldo Leopold (1949) made his famous plea for a land ethic, there is some reason for hope. There are now over a hundred thousand conservation NGOs around the world and they have become our global society's conscience with regard to natural resources. They reflect the front of the developing land ethic. The 'Factor fours' and 'dolphin friendly' practices that are steadily increasing may not be very effective yet, but they did not exist in Leopold's day, and they are the harbingers of change in consumer behaviour. Ethical investment is a growing business and though early forms of this were mostly about defining what not to invest in (like socially undesirable enterprises involving child labour), there are now investment companies concentrating on locating environmentally sound/sustainable investments—i.e. a positive rather than negative approach. The question is whether the rate of this change in ethics will be fast enough to avoid really serious declines in sustainability of natural capital. The Ehrlichs conclude by pinning their hopes on finding ways 'to change the natures of very many human beings—to guide cultural evolution'. While agreeing with this sentiment, there is something else that needs to be done to ensure that ethical change has a chance to proceed at a sufficiently rapid pace.

At the heart of the growth in consumerism is the notion of increased efficiency of production. The philosophy (if not the ethic) of today is optimization and maximum efficiency. While the notion of an efficient market is laudable (no externalities), in practice increasing efficiency is more often reflected in getting rid of processes and components perceived as being redundant. This is evident in the drive for fewer, bigger government services (such as education, with fewer school boards, and so forth) and in corporate amalgamations with subsequent closure of 'wasteful' or unnecessary entities, such as small bank branches in rural areas. Increasing efficiency in the globalization of business is resulting in a decreased diversity in the ways of doing and producing things. Yet in ecological systems it is just this overlapping structure of processes and functions (the apparent redundancy) that render them resilient and able to cope with external shocks (Gunderson, Holling, and Light, 1995, Levin, 1999).

The kind of ethical change the Ehrlichs are hoping for is less likely to be enhanced by a business and government philosophy focused on maximizing discounted returns through increasing efficiency of natural capital use than by a philosophy which sees greater value in maximizing resilience and building adaptive capacity. A social-ecological system that is resilient in the face of a variety of future stresses and unforeseen shocks has a greater likelihood of delivering a continued supply of services to society than one engineered to efficiently deliver a maximum, discounted flow of particular goods and services under today's conditions. The goal of maximizing production of some defined set of goods is a natural consequence of a view of the world that envisions some optimal condition or state. Once that state has been defined the task is to get there as efficiently as possible, and those in charge can bring to bear the arsenal of optimization techniques to do so. If, however, the world view is one envisioning human society as an integral, linked component of a complex adaptive system of people and natural ecosystems, defining an optimal state is less plausible. It is like asking what the optimal state of biological evolution might be—a nonsense question.

Changing the world view from one that allows for an optimal state and therefore how best to get to it, to one that sees society and ecosystems as a complex adaptive system, changes the goal of those in charge. It changes from defining a state to understanding trajectories of the system through time; and, given the enormous uncertainties in future environmental and technological conditions, it follows that it makes less sense to try to define the 'best' trajectory than to define the set of trajectories that are acceptable—a satisficing goal rather than an optimizing one. It puts more emphasis on seeking how to avoid getting locked into trajectories that we do not like (the blind alleys of biological evolution). The corollary of such a world view is the design of policies and management goals that are robust under the range of future uncertainties, rather than a policy that will deliver some particular maximum product(s).

Peoples' perceptions of how the world works, their 'mental models', are what drive their actions. It will be difficult to change the minds of those with a big investment in the optimal state/maximum efficiency model, especially if they are accustomed to high consumption patterns. But, as the weight of opinion shifts, this will inevitably happen. What will drive ethical change, therefore is change in peoples' mental models of the dynamics of the world they live in.

Returning to the Ehrlichs' concern about the race between ethical change and technological evolution, the something else we can do to help swing the race in favour of an ethical catch-up is to change peoples' perceptions of how the world works; from the fallacy of optimal states to the more realistic view of multiple possible trajectories, encompassing the notion of resilience to future shocks and how to avoid sliding into undesirable trajectories from which we may not be able to recover. Promoting a change in ethics, directly, in the face of a world view of optimal states and efficiently getting to them, is unlikely to fall on fertile ground. However, changing understanding of the dynamics of linked social-ecological systems, and the consequences of different approaches to using natural capital, will complement and enhance the ethical shift that is currently, albeit too slowly, under way.

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Genetic modification technologies in agriculture: externalities and socially optimal management rules

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Finding ways to incorporate the 'lagging four-fifths of the world's still-expanding population into the global economy while preserving the life-support systems that make our planet habitable' is, as very succinctly put by Ehrlich and Ehrlich (2001), a critical challenge of the decades to come. The fundamental problem is, of course, a multifaceted one, which needs to be approached and analyzed in various contexts. An issue of great importance in this framework is the challenge of tripling the global food production in the poorest societies, some of which have been doubling their numbers in as little as thirty years (Ehrlich and Ehrlich, 2001). Given that by 2030 an increase of two billion people relative to today's population is expected, hunger and poverty should be addressed on a global scale.

One of the most prominent ways of satisfying the demand for food resulting from an expanding world population is the use of scientific discoveries and new technologies. A big class of such new technologies is associated with the use of biotechnology in agriculture and comes under the name of genetic modification technology (GM) or genetic engineering.

GM technology was initially developed in the 1970s; one of its most prominent applications has been the development of transgenic crop plant (TC) varieties.[1] TCs such as soybean, cotton, tobacco, potato, and maze have been grown in such countries as the USA (28.7 million hectares in 1999), Canada (4 million hectares in 1999), Argentina (6.7 million hectares in 1999) (James, 1999). GM technology is regarded as a means for improving supply conditions in agriculture through various methods, including improved pest resistance, inbuilt resistance to biotic and abiotic stresses, reduction of the need to use marginalized land in agriculture, increase in the production of nutritional benefits, and reduction of the environmental impacts of intensive and extensive agriculture. For example, it has been estimated that direct benefits to growers of *Bt* corn, cotton and potatoes exceeded $100 million in 1999. *Bt* seed also has positive environmental benefits, especially for aquatic wildlife as it replaces more toxic organophosphate and pyrethroid insecticides (EPA, 2000). GM technologies are considered especially relevant to the goal of achieving food security in low-income areas of the developing world through income generation and more effective distribution of food stocks.[2]

Looking at the issue of transgenic plants in agriculture from the point of view of deciding whether or not to accept the introduction of new technologies, the issue seems to rely on the comparison of expected costs and benefits. However this comparison is by no means straightforward since the introduction of new technologies is related to a number of externalities.

One such externality relates to the development of insects resistance to *Bt* crops. As has been recognized, the existence of transgenic plants with resistance to a certain pest (like for example the *Bt* crops) may create the emergence of new resistant pests through natural selection mechanisms.[3] The emergence of new resistant pests might not only eliminate the productivity advantage of the *Bt* crops but also ultimately reduce the productivity of the whole agricultural system (*Bt* and non-*Bt* crops). Since engineered plants are crop-specific and target specific pests, the entire value of an insect protected crop may depend on the susceptibility of a single insect pest. Thus the success of *Bt* crops as a potential long-run solution to the problem of food supply depends crucially on preventing pests from adapting quickly to them.

[1] GM technology has been used to produce varieties of crop plants with resistance to insect pests or viruses, tolerance to specific herbicides, or in cases of fruits, increased shelf life. Transgenic crops contain a protein-producing gene from the soil bacterium *Bacillus thuringiensis* (*Bt*). This protein, which is engineered into the tissue of the plant, is lethal to certain target insects.

[2] See for example Interacademies (2001).

[3] See for example Birch *et al*. (1999), Hilbeck *et al*. (1998), Hurley, Babcock, and Hellmich (1997), Hurley *et al*. (1999), Mellon and Rissler (1998).

As a response to this issue, insect-resistance management (IRM) has assumed major importance to environmentalists, policy makers, agriculture producers, and consumers. The primary strategy of resistance-preventing programs consists of a high dose strategy combined with a refuge of non-*Bt* plants. This combined strategy potentially delays the development of pest resistance.[4] In practice IRM has been introduced either in the form of instructions to or mandatory obligation by the farmers to maintain a certain proportion of their land in unimproved non-*Bt* crops, in order to be allowed to use the *Bt* seed technology.[5]

The purpose of this note is to discuss the possibility of suboptimal IRM which is related to the emergence of a transgenic crop monoculture because of the deviation between market and social incentives in the process of introducing GM technologies, resulting in the eventual loss of the productivity advantage of these technologies. The main idea is that, even if agricultural producers recognize the usefulness of IRM, private profit-maximizing incentives might prevent the attainment of some socially optimal management level.

Let us consider an agricultural region occupied by 'small' profit-maximizing farmers. These farmers will tend to choose the proportion of their total area to be covered with transgenic crops, relative to conventional non-transgenic crops, by maximizing net private profits. When farms are small, each farmer, when choosing the proportion of the total area to be covered with transgenic crops, regards the effects of his/her actions on the possible emergence of new resistant pests to *Bt* crops, through natural selection mechanisms, as negligible. Since transgenic crops have a net advantage over conventional crops, the privately optimal behavior of a single farmer is to cover his/her whole area with *Bt* crops. With 'small' farmers each one takes as given the best response of the rest and the final outcome is that the whole region is planted with transgenic plants. If we regard the coexistence of *Bt* and non-*Bt* crops as a limited form of biodiversity then private profit-maximization incentives in a market consisting of 'small' agents tend to a monoculture of transgenic plants. The monoculture of transgenic plants in combination with natural selection mechanisms tends to create *directional selection*, so that pests resistant to the transgenic plants are developed. Since the whole region has been planted with transgenic plants it is the whole region that loses resistance to pests with a resulting overall productivity loss.[6]

The loss of the system's resistance to pests and the accompanying productivity loss because of the farmers' management rules stems from private profit-maximizing incentives which ignore the underlying natural selection mechanisms that govern the development of resistance to the *Bt* crops. The elimination of transgenic plants' productivity advantage because of these mechanisms seriously hampers the advantages of such crops as a means of providing a long-run solution to the food supply problem.

[4] For a critique of this approach, see Liu *et al*. (1999).
[5] For the case of Newleaf *Bt*-expressing potato, see Feldman (1997).
[6] For the modeling of this process, see Brock and Xepapadeas (2000).

The type of adverse effects discussed here is of a different type from the possible adverse effects on human health and safety,[7] since we discuss a more subtle type of externality, which is generated by profit-maximizing behavior of small agents.[8] From the point of view of economic theory this externality emerges when the natural selection mechanism describing the development of pest resistance is not taken into account in the private profit-maximization problem of deciding the relative area to plant with transgenic/conventional crops.

Introducing the natural selection mechanism into the decision-making problem creates a new conceptual framework, which can be used for the management of agricultural systems in terms of unified economic-ecological modeling. In this modeling the usual dynamic laws governing the growth of biomasses and the types of species competition need to be combined with dynamic laws describing population genetics.

In the unified economic ecological conceptual framework, the economic management of transgenic plants implies choosing the relative amount of land devoted to transgenic versus conventional crops by optimizing an economic objective function, subject to the constraints imposed by biomass growth, species competition, and population genetics. The solution results in an optimal combination of transgenic-conventional crops, which can be called the socially optimal refuge strategy.[9] The deviation between the socially optimal refuge strategy and the privately optimal one, where population genetics are ignored, determines the structure of the desired socially optimal regulation. Conventional crops are still used, in this regulatory approach, with the purpose of preventing the development of pests which are resistant to the transgenic crops, thus preserving the productivity of the system in the long run.

When a regulatory framework is introduced, a mandatory condition for a refuge strategy is a command-and-control (CAC) type of regulation, since it represents essentially an upper limit on the proportion of the area that can be planted with *Bt* crops. It is, however, well known from the theory of environmental policy, that the target obtained by CAC can be obtained relatively more cheaply by the use of market-based instruments. Thus a potentially useful area of study would be the analysis of refuge strategy policies through transferable permits to plant *Bt* crops or by directly increasing the cost of *Bt* technology using input charges, in order to reduce short-term profit margins and prevent monoculture of *Bt* crops.

Thus it seems that effective IRM regulation is crucial in maintaining the productivity advantage of *Bt* crops. On the other hand, given the divergence between the short-term private incentives discussed above, and social incentives that take into account natural selection mechanisms, the

[7] This by no means implies that the possible adverse effects on human health and safety are not a serious issue that requires constant scrutiny. This issue simply is not addressed in this note.

[8] If a single owner managed the whole region, then it would be expected that the owner would take into account the effects of his/her own actions on pest development through natural selection mechanisms.

[9] For an analytical presentation of such policies, see Brock and Xepapadeas (2000).

application of effective IRM might be impeded by informational constraints. Thus failure to effectively monitor whether the pre-specified proportion of land is planted with *Bt* crops creates a situation of moral hazard with hidden actions. Under moral hazard the proportion of land maintained for non-*Bt* (conventional) crops will fall short of what the IRM rule specifies. A strong institutional framework is therefore required in order to secure the effective application of the IRM.

Although such an institutional framework might be expected either to exist or to be relatively easily created in developed countries, this might not be the case in developing countries where a large proportion of agriculture is in the hands of small-scale farmers. The combination of small-holder farming, incentives for short-run benefits from *Bt* crops under conditions of pressure to increase food supply, and structural problems related to the creation of regulatory institutions could create situations of unregulated use of *Bt* technology. Therefore, unless *Bt* technology is introduced along with an effective regulatory framework, its potential productivity advantages might be mitigated relatively faster in cases where they are needed more and could produce the highest incremental benefits.

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