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TOWARDS AN ENVIRONMENTAL MACROECONOMICS*

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Abstract:

Other than some incipient efforts at including environmental costs in national accounts there are no points of contact between traditional macroeconomics and the environment. This condition is explained in terms of Schumpeter's notion of pre-analytic visions: The economy as isolated flow of exchange value versus the economy as open subsystem of the finite ecosystem. From the second pre-analytic vision the first analytical questions that occur are: how big is the economic subsystem relative to the total ecosystem, and how big should it be? This is the macroeconomic question of optimal scale and needs to be clearly distinguished from the microeconomic question of optimal allocation.

I. Introduction

Environmental economics, as it is taught in universities and practiced in government agencies and development banks, is overwhelmingly microeconomics. The theoretical focus is on prices, and the big issue is how to internalize external environmental costs so as to arrive at prices that reflect full social marginal opportunity costs. Once prices are right the environmental problem is "solved" –there is no macroeconomic dimension. Cost/benefit analysis in its various permutations is the major tool for estimating full-cost prices, so in practice as well as theory we remain within the domain of microeconomics. There are, of course, very good reasons for environmental economics to be

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closely tied to microeconomics, and it is not my intention to argue against that connection. Rather I want to ask if there is not a neglected connection between the environment and macroeconomics.

A search through the indexes of three leading textbooks[1] in macroeconomics reveals no entries under any of the following subjects: *environment; natural resources; pollution; depletion.* One of the three does have an entry under "resources", but the discussion refers only to labor and capital, which, along with efficiency, are listed as the causes of growth in GNP –natural resources are not mentioned. Evidently GNP growth is thought to be independent of natural resources. Is it really the case, as prominent textbook writers seem to think, that macroeconomics has nothing to do with the environment? What historically has impeded the development of an environmental macroeconomics? If there is no such thing as environmental macroeconomics, should there be? Do parts of it already exist? What needs to be added? What policy implications are visible?

The reason that environmental macroeconomics is an empty box lies in what Thomas Kuhn calls a "paradigm", and what Joseph Schumpeter more descriptively calles a "preanalytic vision"[2]. As Schumpeter emphasized, analysis has to start somewhere –there has to be something to analyze. That something is given by a preanalytic cognitive act that Schumpeter called "vision". One might say that vision is what the "right brain" supplies to the "left brain" for analysis. Whatever is omitted from the preanalytic vision cannot be recaptured by subsequent analysis. Schumpeter is worth quoting at length on this point:

"In practice we all start our own research from the work of our predecessors, that is, we hardly ever start from scratch. Bur suppose we did start from scratch, what are the steps we should have to take? Obviously, in order to be able to posit to ourselves any problems at all, we should first have to visualize a distinct set of coherent phenomena as a worthwhile object of our analytic effort. In other words, analytic effort is of necessity preceded by a preanalytic cognitive act that supplies the raw material for the analytic effort. In this book, this preanalytic cognitive act will be called Vision. It is interesting to note that vision of this kind not only must precede historically the emergence of analytic effort in any field, but also may re-enter the history of every established science each time somebody teaches us to see things in a light of which the source is not to be found in the facts, methods, and results of the pre-existing state of the science".

The vision of modern economics in general, and especially of macroeconomics, is the familiar circular flow diagram. The macroeconomy is seen as an isolated system (i.e. no exchanges of matter or energy with its environment) in which exchange value circulates between firms and households in a closed loop. What is "flowing in a circle" is variously referred to as production or consumption, but these have physical dimensions, and the circular flow does not refer to materials recycling, which in any case could not be a completely closed loop, and of course would require energy which cannot be recycled at all. What is truly flowing in a circle can only be abstract exchange value –exchange value abstracted from the physical dimensions of the goods and factors that are exchanged. Since an isolated system of abstract exchange value flowing in a circle has no dependence on an environment, there can be no problem of natural resource depletion, nor environmental pollution, nor any dependence of the macroeconomy on natural services, or indeed on anything at all outside itself (Daly, 1985, pp. 279-297).

Since analysis cannot supply what the preanalytic vision omits, it is only to be expected that macroeconomics texts would be silent on environment, natural resources, depletion and pollution. It is as if the preanalytic vision that biologists had of animals recognized only the circulatory system, and abstracted completely from the digestive tract. A biology textbook's index would then contain no entry under "asimilation" or "liver". The dependence of the animal on its environment would not be evident. It would appear as a perpetual motion machine.

Things are no better when we turn to the advanced chapters at the end of most macroeconomics texts, where the topic is growth theory. True to the preanalytic vision the aggregate production is written as $Y = f(K, L)$, i.e. ouput is a function of capital and labor stocks. Resource flows (R) do not even enter! Neither is any waste output flow noted. And if occassionally R is stuck in the function along with K and L it makes little difference since the production function is almost always a multiplicative form, such as Cobb-Douglas, in which R can approach zero with Y constant if only we increase K or L in a compensatory fashion. Resources are seen as "necessary" for production, but the amount required can be as little as one likes!

What is needed is not ever more refined analysis of a faulty vision, but a new vision. This does not mean that everything built on old the vision will necessarily have to be scrapped –but fundamental changes are likely when the preanalytic vision is altered. The necessary change in vision is to picture the macroeconomy as an open subsystem of the finite natural ecosystem (environment), and not as an isolated circular flow of abstract exchange value, unconstrained by mass balance, entropy and finitude. The circular flow of exchange value is a useful abstraction for some purposes. It highlights issues of aggregate demand, unemployment and inflation that were of interest to Keynes in his analysis of the Great Depression. But it casts an impenetrable shadow on all physical relationships between the macroeconomy and the environment. For Keynes this shadow was not very important, but for us it is. Just as, for Keynes, Say's Law and the impossibility of a general glut cast an impenetrable shadow over the problem of the Great Depression, so now the very Keynesian categories that were revolutionary in their time are obstructing the analysis of the major problem of our time –namely, what is the proper scale of the macroeconomy relative to the ecosystem?

Once the macroeconomy is viewed as an open subsystem, rather than an isolated system, then the issue of its relation to its parent system (the environment) cannot be avoided. And the most obvious questions is how big should the subsystem be relative to the overall system?

II. The Macro-Macro Economics of Optimal Scale

Just as the micro unit of the economy (firm or household) operates as part of a larger system (the aggregate or macroeconomy), so the aggregate economy is likewise a part of a larger system, the natural ecosystem. The macroeconomy is an open subsystem of the ecosystem and is totally dependent upon it, both as a source for inputs of low-entropy matter-energy and as a sink for outputs of high-entropy matter-energy. The physical exchanges crossing the boundary between system and sybsystem constitute the subject matter of environmental macroeconomics, or "macro-macro economics". These flows are considered in terms of their scale or total volume relative to the ecosystem, not in terms of the price of one component of the total flow relative to another. Just as standard macroeconomics focuses on the volume of transactions rather than the relative prices of different items traded, so environmental macroeconomics focuses on the volume of exchanges that cross the boundary between system and subsystem, rather than the pricing and allocation of each part of the total flow within the human economy or even within the nonhuman part of the ecosystem.

The term "scale" is shorthand for "the physical scale or size of the human presence in the ecosystem, as measured by population times per capita resource use". Optimal *allocation* of a given scale of resource flow within the economy is one thing (a microeconomic problem). Optimal *scale* of the whole economy relative to the ecosystem is an entirely different problem (a macro-macro problem). The micro allocation problem is analogous to allocating optimally a given amount of weight in a boat. But once the best relative location of weight has been determined, there is still the question of the absolute amount of weight the boat should carry, even when optimally allocated. This absolute optimal scale of load is recognized in the maritime institution of the Plimsoll line. When the watermark hits the Plimsoll line the boat is full, is has reached its safe *carrying capacity*. Of course if the weight is badly allocated the water line will touch the Plimsoll mark sooner. But eventually as the absolute load is increased the watermark will reach the Plimsoll line even for a boat whose load is optimally allocated. Optimally loaded boats will still sink under too much weight –even though they may sink optimally! It should be clear that optimal allocation and optimal scale are quite distinct problems. The major task of environmental macroeconomics is to design an economic institution analogous to be Plimsoll mark –to keep the weight, the absolute scale, of the economy from sinking our biospheric ark.

The market of course functions only within the economic subsystem, where it does only one thing: it solves the allocation problem by providing the necessary information and incentive. It does that one thing very well. What it does not do is to solve the problem of optimal scale or of optimal distribution. The market's inability to solve the problem of just distribution is widely recognized, but its similar inability to solve the problem of optimal or even sustainable scale is not as widely appreciated[3].

An example of the confusion that can result from the nonrecognition of the independence of the scale issue from the question of allocation is provided by the following dilemma[4]. Which puts more pressure on the environment, a high or a low discount rate? The usual answer is that a high discount rate is worse for the environment because it speeds the rate of depletion of nonrenewable resources and shortens the turnover and fallow periods in the exploitation of renewables. It shifts the allocation of capital and labor towards projects that exploit natural resources more intensively. But it restricts the total number of projects undertaken. A low discount rate will permit more projects to be undertaken even while encouraging less intensive resource use for each project. The allocation effect of a high discount rate is to increase throughput, but the scale effect is to lower throughput. Which effect is stronger is hard to say, although one suspects that over the long run the scale effect will dominate. The resolution to the dilemma is to recognize that two independent policy goals require two independent policy instruments –we cannot serve both optimal scale and optimal allocation with the single policy instrument of the discount rate (Tinbergen, 1952). The discount rate should be allowed to solve the allocation problem, within the confines of a solution to the scale problem provided by a presently nonexistent policy instrument that we may for now call an "economic Plimsoll line" that limits the scale of the throughput.

Economists have recognized the independence of the goals of efficient allocation and just distribution and are in general agreement that it is better to let prices serve efficiency, and to serve equity with income redistribution policies. Proper scale is a third independent policy goal and requires a third policy instrument. This latter point has not yet been accepted by economists, but its logic is parallel to the logic underlying the separation of allocation and distribution. In pricing factors of production and distributing profits the market does of course influence the distribution of income. Providing incentive requires

some ability to alter the distribution of income in the interest of efficiency. The point is that the market's criterion for distributing income is to incentivate efficient allocation, not to attain justice. And in any case historical conditions of property ownership are major determinants of income distribution and have little to do with either efficiency or justice. These two values can conflict, and the market does not automatically resolve this conflict. The point to be added is that there are not just two, but three, values in conflict: allocation (efficiency), distribution (justice), and scale (sustainability).

Microeconomics has not discovered in the price system any built-in tendency to grow only up to the scale of aggregate resource use that is optimal (or even merely sustainable) in its demands on the biosphere. *Optimal scale, like distributive justice, full employment, or price level stability, is a macroeconomic goal.* And it is a goal that is likely to conflict with the other macroeconomic goals. The traditional solution to unemployment is growth in production, which means a larger scale. Frequently the solution to inflation is also thought to be growth in real output, and a larger scale. And most of all the issue of distributive justice is "finessed" by the claim that aggregate growth will do more for the poor than redistributive measures. Macroeconomic goals tend to conflict, and certainly optimal scale conflicts with any goal that requires further growth, once the optimum has been reached.

III. How Big is the Economy?

In the past it has not been customary to consider the macroeconomy as a subsystem of a larger ecosystem. As long as the human economy was infinitesimal relative to the natural world, then sources and sinks could be considered infinite, and therefore not scarce, and if not scarce then safely abstracted from by economics. There was no need to consider the larger system since it imposed no scarcities. This was a reasonable view at one time, but no longer. As Kenneth Boulding says, when something grows it gets bigger! The economy has gotten bigger, the ecosystem has not. How big has the economy become relative to the ecosystem?

Probably the best index of the scale of the human economy as a part of the biosphere is the percentage of human appropriation of the total world product of photosynthesis. Net primary production (NPP) is the amount of solar energy captured in photosynthesis by primary producers, less the energy used in their own growth and reproduction. NPP is thus the basic food resource for everything on earth not capable of photosynthesis. Vitousek *et al.* (1986)[5] calculate that 25% of potential global (terrestrial and aquatic) NPP is now appropriated by human beings. If only terrestrial NPP is considered the fraction rises to 40%. Taking the 25% figure for the entire world it is apparent that two more doublings of the human scale will give 100%. Since this would mean zero energy left for all nonhuman and nondomesticated species, and since humans cannot survive without the services of ecosystems, which are made up to other species, it is clear that two more doublings of the human scale an ecological impossibility, although arithmetically possible. Furthermore the terrestrial figure of 40% is probably more relevant since we are unlikely to increase our take from the oceans very much. Total appropriation of the terrestrial NPP is only a bit over one doubling time in the future. Perhaps it is theoretically possible to increase the earths's total photosynthetic capacity somewhat, but the actual trend of past economic growth is decidedly in the opposite direction.

Assuming a constant level of per capita resource consumption the doubling time of the human scale would be equal to the doubling time of population, which is on the order of 40 years. Of course economic growth currently aims to increase the average per capita resource consumption and consequently to reduce the doubling time of the scale of the human presence below that implicit in the demographic rate of growth. The greenhouse effect, ozone layer depletion, and acid rain all constitute evidence that we have already gone beyond a prudent Plimsoll line for the scale of the macroeconomy.

IV. Cowboy, Spaceman, or Bull in the China Shop?

If one starts from the vision of the economic process as an open subsystem of a closed finite total system, then the question of how big the subsystem should be relative to the total system is hard to avoid. How then have we managed to avoid it? In two ways: first by viewing the economic subsystem as infinitesimally small relative to the total system, so that scale becomes irrelevant because negligible; second, by viewing the economy as coextensive with the total system –if the economy includes everything then the issue of scale relative to a total system simply does not arise. These polar extremes correspond to Boulding's colorful distinction between the "cowboy economy" an the "spaceman economy". The cowboy of the infinite plains lives off of a linear throughput from source to sink, with no need to recycle anything. The spaceman in a small capsule lives off of tight material cycles and immediate feedbacks, all under total control subservient to his needs. For the cowboy scale is negligible, for the spaceman scale is total –there is no material environment relative to which scale must be determined; there is no ecosystem, only economy. In each of these polar cases the only problem is allocation –scale is irrelevant.

It is only in the middle ground between the cowboy and the spaceman that the issue of scale does not get conflated with allocation. But the middle ground happens to be where we are. Between the cowboy and the spaceman economies is a whole range of larger and smaller "bull-in-the-china-shop economies" where scale is a major concern. We are not cowboys because the existing scale of the economy is far from negligible compared to the environment. But neither are we spacemen, because most of the matter-energy transformation of the ecosystem are not subject to human control either by prices or by central planning. In a finite system subject to the conservation of mass, the more that is brought under our economic control, the less remains under the spontaneous control of nature. As our exactions from and insertions back into the ecosystem increase in scale, the qualitative change induced in the ecosystem must also increase, for two reasons. The first is the first law of thermodynamics (conservation of matter-energy). The taking out and putting back of equal quantities of matter-energy must disrupt the ecosystem even if the quality of matter-energy remained unchanged. The second reason is the second law of thermodynamics which guarantees that the matter-energy exacted is qualitatively different from the matter-energy inserted. Low-entropy raw material are taken out, high-entropy wastes are returned. This qualitative degradation of the matter-energy throughput, along with the purely quantitative dislocation of the same, induces changes in the ecosystem which to us are surprising and novel, because our information and control system (prices) assumes nonscarcity (nondisruptablity) of environmental source and sink functions. Economic calculation is about to be overwhelmed by novel, uncertain, and surprising feedbacks from an ecosystem that is excessively stressed by having to support too large an economic subsystem (Perrings, 1987).

How big should the subsystem be relative to the total ecosystem? Certainly this, the question of optimal scale, is the big question for environmental macroeconomics. But since it is such a difficult question, and since we cannot go back to the cowboy economy, we have acquired a tendency to want to jump all the way to the spaceman economy and take total control of the spaceship earth. The September 1989 special issue of *Scientific American* entitled "Managing Planet Earth" is representative of this thrust. But, as Environmentalist David Orr points out, God, Gaia, or Evolution was doing a nice job of managing the earth until the scale of the human population, economy and technology got out of control. Planetary management implies that it is the planet is at fault, not human numbers, greed, arrogance, ignorance, stupidity, and evil. We need to manage ourselves more than the planet, and our self-management should be, in Orr's word, "more akin to child-proofing a day-care center than to piloting spaceship earth". The way to child-proof a room is to build the optimal scale playpen within which the child is both free and protected from the excesses of its own freedom. It can enjoy the light and warmth provided by electrical circuits beyond its ken, without running the risk of shorting out those circuits, and itself as well, by experimenting with the "planetary management technique" of teething on a lamp cord.

Our manifest inability to centrally plan economies should inspire more humility among the planetary managers who would centrally plan the ecosystem. Humility should argue for the strategy of minimizing the need for planetary management by keeping the human scale sufficiently low so as not to disrupt the automatic functioning of our life support systems thereby forcing them into the domain of human management. Those who want to take advantage of the "invisible hand" of self-managing ecosystems have to recognize that the invisible hand of the market, while wonderful for allocation, is unable to set limits to the scale the macroeconomy. Our limited managerial capacities should be devoted to institutionalizing an economic Plimsoll line that limits the macroeconomy to a scale such that the invisible hand can function in both domains to the maximum extent. It is ironic that many free marketeers, by opposing any limit to the scale of the market economy (and therefore to the increase in externalities), are making more and more inevitable the very central planning that they oppose. Even worse is their celebration of the increase in GNP that results as formerly free goods become scarce and receive a price. For allocation it is necessary that newly scarce goods not continue to have a zero price –no one disputes that. The issue is that, for all we know, we might have been better off to remain at the smaller scale at which the newly scarce goods were free, and their proper allocative price was still zero. The increase in measured national income and wealth resulting as formerly free goods are turned into scarce goods is more and index of cost than of benefit, as was recognized by the classical economist Lauderdale back in 1819[6].

V. A Glittering Anomaly

Optimal scale of a single activity is not a strange concept to economists. Indeed microeconomics is about little else. An activity is identified, be it producing shoes or consuming ice cream. A cost function and a benefit function for the activity in question are defined. Good reasons are given for believing that marginal costs increase and marginal benefits decline as the scale of the activity grows. The message of microeconomics is to expand the scale of the activity in question up to the point where marginal costs equal marginal benefits, a condition which defines the optimal scale. All of microeconomics is an extended variation on this theme.

When we move to macroeconomics, however, we never again hear about optimal scale. There is apparently no optimal scale for the macro economy. There are no cost and benefit functions defined for growth in scale of the economy as a whole. It just doesn't matter how many people there are, or how much they each consume, as long as the proportions and relative prices are right! Buf if every micro activity has an optimal scale then why does not the aggregate of all micro activities have an optimal scale? If I am told in reply that the reason is that the constraint on any one activity is the fixity of all the others and that when all economic activities increase proportionally the restraints cancel out, then I will invite the economist to increase the scale of the carbon cycle and the hydrologic cycle in proportion to the growth of industry and agriculture. I will admit that if the ecosystem can grow indefinitely then so can the aggregate economy. But, until the surface of the earth begins to grow at a rate equal to the rate of interest, one should not take this answer too seriously.

The total absence in macroeconomics of the most basic concept of microeconomics is a glittering anomaly, and it is not resolved by appeals to the fallacy of composition. What is true of a part is not necessarily true for the whole, but it can be and usually is unless there is some aggregate identity or self-cancelling feedback at work. (As in the classic examples of all spectators standing on tiptoe to get a better view and each cancelling out the better view of the other; or in the observation that while any single country's exports can be greater than its imports, nevertheless the aggregate of all exports cannot be different than the aggregate of all imports). But what analogous feedback or identity is there that allows every economic activity to have an optimal scale while the aggregate economy remains indifferent to scale? The indifference to scale of the macroeconomy is due to the preanalytic vision of the economy as an isolated system– a view the inappropriateness of which has already been discussed.

As an economy grows it increases in scale. Scale has a maximum limit defined either by the regenerative or absorptive capacity of the ecosystem, whichever is less. However, the maximum scale is not likely to be the optimal scale. Two concepts of optimal scale can be distinguished, both formalisms at this stage, but important for clarity.

(1) *The anthropocentric optimum.* The rule is to expand scale, i.e., grow, to the point a which the marginal benefit to human beings of additional manmade physical capital is just equal to the marginal cost to human beings of sacrificed natural capital. All nonhuman species and their habitats are valued only instrumentally according to their capacity to satisfy human wants. Their intrinsic value (capacity to enjoy their own lives) is assumed to be zero.

(2) *The biocentric optimum.* Other species and their habitats are preserved beyond the point necessary to avoid ecological collapse or cumulative decline, and beyond the point of maximum instrumental convenience, out of a recognition that other species have intrinsic value independent of their instrumental value to human beings. The biocentric optimal scale of the human niche would therefore be smaller than the anthropocentric optimum.

The definition of sustainable development does not specify which concept of optimum scale to use. It is consistent whith any scale that is not above the maximum. Sustainability is probably the characteristics of optimal scale on which there is most consensus. It is a necessary, but not sufficient condition for optimal scale.

VI. Steps Already Taken in Environmental Macroeconomics

What has macroeconomics contributed to environmental economics so far? As we have seen the textbooks make no claim to any contribution whatsoever, but that is too modest. National Income Accounting is a part of macroeconomics, and there has been an effort to correct our income accounts for consumption of natural capital and for counting environmental clean up costs as final consumption rather than intermediate

costs of production of the commodity whose production gave rise to those costs (Hueting, 1980; Leipert, 1986; Repetto *et al.*, 1987; Ahmad *et al.*, 1989). Although traditional national income accountants have not exactly been in the forefront of this effort, and may even be said to be dragging their feet, the conservatively motivated and impeccably orthodox attempt to gain a closer approximation of true Hicksian income (maximum available for consumption without consuming capital stock) will surely make this effort an important foundation of environmental macroeconomics.

Inter-industry or input-output analysis is also a useful tool of environmental analysis, although it is hard to classify it as either micro or macro. But because of its close relation to national accounts let us call it macro and credit it as an existing part of environmental macroeconomics. Certainly is has been important in elucidating total (direct and indirect) requirements of material and especially energy that must be extracted from the environment ir order to increase any component of the economy's final bill of goods by some given amount.

VII. Carrying Capacity as a Tool of Environmental Macroeconomics.

Many resist the application of the concept of carrying capacity to human beings. Certaintly the concept is easier to apply to animals than to humans. For animals carrying capacity can be considered almost entirely in terms of population. This is because per capita resource consumption for animals is both constant over time (animals do not experience economic development), and constant across individual members of the species (animals do not have rich and poor social classes). The latter is not to say that animals are egalitarian. Clearly there exist dominance hierarchies and territoriality. But these inequalities are mainly related to reproduction, not to large differences in per capita consumption. Also for animals technology is a genetic constant, while for humans it is a cultural variable. For human beings we cannot speak of carrying capacity in terms of population alone, but must specify some average level of per capita consumption ("standard of living"), and some degree of inequality in the distribution of individual consumption levels around that average, and some given level or range of technology. A great deal of human and nonhuman suffering could be avoided by employing the carrying capacity concept in environmental macroeconomics. The case of Paraguay provides an example.

Paraguay's greatest environmental advantage has been its small population (some 3 million in 1982, and close to 4 million today). At the current 2.5% annual rate of population growth (doubling time of 28 years or roughly one generation) this advantage is rapidly disappearing. Furthermore this environmental advantage has historically been considered an economic disadvantage. Demographic pressures are exacerbated by the fact that all public lands available for colonization have been distributed. In the future land cannot be made available to some citizens without taking it away from others. Also fractioning of landholdings into uneconomic minifundia is driven by population growth and the practice of equal inheritance.

There is very little concern about population growth. Traditionally the goal has been to increase the population by bringing in colonists to settle the land. After the disastrous war of the Triple Alliance Paraguay was left in 1875 with only something like 220,000 people. It is quite understandable that pronatalist views should be overwhelmingly dominant. Some prominent leaders have conjectured that Paraguay could support 20 million people with no difficulty. Yet a FAO 1979 study[7] concluded that "the agricultural frontier has already exceeded the limits of desirable development in most of the Eastern Region", and that continued expansion would be profoundly destructive of the ecosystem.

At the time (1979) that the FAO study said limits had been reached Paraguay's population was 3 million. Thus their implicit estimate of carrying capacity was around 3 million, neglecting the Chaco. The prominent leaders' estimate of 20 million is larger by almost a factor of seven. It is quite important to narrow this range of difference as a precondition for any sensible economic planning and policy. A few back of the envelope calculations can be very useful.

How many people could be supported by the ecosystem of the Chaco, if it were as densly populated as the Oriente? Multiplying the population density of the Oriente times the area of the Chaco (18.6 persons/km^2 times 247,000 km) gives 4,594,200 people. Viewed in this way, 5 million is an absurdly high overestimate, because it assumes that the carrying capacity of the Chaco is equal to that of the Oriente. There are good reasons for the fact that 98% of all Paraguayans live in the Oriente and only 2% in the Chaco.

A better estimate of carrying capacity for the Chaco can be gotten by taking the most successful colony in the region, the Mennonites, calculate their population density, and then generalize that to the whole region. There are (in 1987) 6,650 Mennonites living on 420,000 hectares, giving a density of 6,650/420,000 - .0158 persons/ha. To get persons per km^2 we multiply by 100, the number of hectares in one km^2, giving, 1.58 persons/km^2. That density times the total area of 247,000 km^2 gives 390,260 or roughly 400,000 persons, not even half a million. The two estimates differ by an order of magnitude and it is extremely important to plan on the basis of the more realistic number.

It is obvious that the second is more realistic. But it is very crude and more information is needed. The Mennonites themselves have unused land and think that they could double their number on their existing land (which at their 2% population growth rate they will do in 35 years). So perhaps our estimate should be 800,000. On the other hand our calculation assumes that the Mennonites have average Chaco land when in fact it is better than average by virtue of the fact that they got there first. The calculation also assumes that other settler could do as well as the Mennonites which is doubtful for several reasons. First, the Mennonites brought with them the peasant traditions of Europe, which are absent among Paraguayan colonos. They also had a strong community of mutual aid and support, as well as help from European and American Mennonites. That community cohesion cannot be assumed for new colonists. And we must remember that it took the Mennonites 60 years of hard work and sacrifice to reach their present level. All things considered it would be difficult to match their productivity, and consequently even the 400,000 may well be an overestimate for Chaco carrying capacity, especially if ranching rather than agriculture is the best use of much of the non-Mennonite area, as seems likely. Water, rather than soil quality, is the limiting factor, so naturally one thinks of large irrigation projects. The Mennonites are extremely skeptical of irrigation in the Chaco and are convinced that it would ruin the soil by salinization (raising the level of existing salt closer to the surface). Drip irrigation and minimum tillage methods seem promising to them.

Even these very crude calculations are enough to allows us to dismiss the 20 million estimate as whimsy and the 5 million estimate as highly unrealistic within the time frame of one generation. On the basis of technologies and investment capacities likely to be available to Paraguay over the next 28 years any estimate of Chaco carrying capacity over half a million faces a heavy burden of proof. Since population is projected to increase by about 4 million over this period it is clear that there is a strong likelihood of over-

shooting the carrying capacity of the Chaco. Optimistic speculations about undreamed of technologies a century from now may prove true, but would not change the impasse posed by the next doubling in the next 28 years.

A country such as Paraguay that is unwilling to countenance population policy must plan for roughly one more doubling of the population (to 8 million) over the next generation. The very low population density of the Chaco makes it the "obvious" place to put the 4 million new people. Land conflicts in the Oriente are already becoming violent. The stage is set for a large, expensive settlement program of the type witnessed in the Brazilian Amazon. The likelihood of failure due to ecological reasons is very high. The ecosystems of the Chaco and the Amazon are very different, but the common feature is the political unwillingness to respect the ecological reasons for the historically low population density. Politically the colonization of the Chaco will be seen as the way to: minimize already serious land conflict in the Oriente; postpone dealing with population control; and maintain temporarily the mirage of progress and optimism, as well as offer a great national project to galvanize public support. Against such political advantages realistic estimate of carrying capacity over the next generation may not be very persuasive. But such a study is a precondition for any realistic plan. It is an elementary but very important contribution of environmental macroeconomics. Nothing is more uneconomic than to waste resources in the pursuit of an impossible goal.

VIII. Policy Implications of Environmental Macroeconomics

Optimal scale is not well defined at present, but one characteristic at least is know –the optimal scale must be sustainable. Our attention then naturally becomes focused on how to limit scale to a sustainable level, thereby giving the sustainable development discussion a bit more of a theoretical foundation than it has had to date. From there we can being to investigate operational principles of sustainability, of environmental macroeconomics, such as those summarized below.

(1) The main principle is to limit the human scale (thoughput) to a level which, if not optimal, is at least within carrying capacity and therefore sustainable. Once carrying capacity has been reached the simultaneous choice of a population level and an average "standard of living" (level of per capita resource consumption) becomes necessary. Sustainable development must deal with sufficiency as well as efficiency, and cannot avoid limiting scale. An optimal scale (in the anthropocentric sense) would be one at which the long run marginal costs of expansion are equal to the long run marginal benefits of expansion. Until we develop operational measures of cost and benefit of scale expansion the idea of an optimum scale remains a theoretical formalism, but a very important one. The following principles aim at translating this general macro level constraint to micro level rules.

(2) Technological progress for sustainable development should be efficiency-increasing rather than throughput-increasing. Limiting the scale of resource throughput (raising resource prices) would induce this technological shift. A high tax on energy would go a long way in this direction. Both technological optimists and pessimits should agree on a policy of high resource prices: the pessimists in order to limit the growth of throughput and the related environmental stress; the optimists in order to incentivate the very resource-efficiente technologies in which they have so much faith.

(3) Renewable resources, in both their source and sink functions, should be exploited on a profit-maximizing sustained yield basis and in general not driven to extinction

(regardless of the dictates of present value maximization), since they will become ever more important as nonrenewables run out. Specifically this means that:

a) Harvesting rates should not exceed regeneration rates; and
b) Waste emissions should not exceed the renewable assimilative capacity of the environment.

(4) Nonrenewable resources should be exploited, but at a rate equal to the creation of renewable substitutes. Receipts from the exploitation of a nonrenewable resource should be divided into an income component and a capital component. The division is made in such that by the end of the life expectancy of the nonrenewable a new renewable asset will have been built up by the annual investment of the capital component. The annual sustainable yield from that renewable asset must be equal to the income component of the nonrenewable that was being consumed annually from the beginning. El Serafy[8] has shown how this separation of capital from income can be calculated in the context of national income accounting. But the principles are quite general and are applicable to the project level as well. The capital component will be larger the shorter is the life expectancy of the nonrenewable and the lower is the rate of growth of the renewable asset. Nonrenewable investments should be paired with renewable investments and their sustainable joint rate of return should be calculated on the basis of their income component only, since that is what is perpetually available for consumption in each future year. If a renewable resource is to be partially divested, then the same pairing rule should apply to it as for a nonrenewable resource. Thus the mix of renewable resources would not be static, but there would be a compensating renewable investment for every divestment.

Perhaps there are other principles of sustainable development as well, and certainly those listed above need to be refined, clarified, and made more consistent between the micro and macro levels. But these four are both an operational starting point and a sufficient political challenge to the present order. Will the nations seeking sustainable development be able to operationalize a concept from which such "radical" principles follow so logically? Or will they, rather than face up to the scale limits (population control and/or per capita consumption limits) required in order to live on income, revert to the cornucopian myth of unlimited growth, rechristened as "sustainable growth"? It is easier to invent bad oxymorons than to develop the environmental macroeconomics of sustainability.

Will environmental macroeconomics be able to shift the primary attention of standard macroeconomics away from "full-employment without inflation via an ever-growing GNP and ever-tighter planetary management", towards defining the optimal scale of the macroeconomy –from the spaceman economy towards the playpen economy? Can we draw a "Plimsoll line" at which quantitative growth must cease and give way to qualitative development as the dynamic path of human betterment? Can macroeconomics serve sustainable development rather than unsustainable growth?

Notes:

1 Dornbusch and Fischer (1987), Hall and Taylor (1988), and Barro (1987).
2 See Schumpeter (1954), p. 41.
3 This can be illustrated in terms of the familiar microeconomic tool of the Edgeworth box. Moving to the contract curve is an improvement in efficiency of *allocation*. Moving along the contract curve is a change in *distribution* which may be deemed just or unjust on ethical grounds. The *scale* is represented by the dimensions of the box, which are taken as given. Consequently

the issue of optimal scale of the box itself escapes the limits of the analytical tool. A microeconomic tool cannot be expected to answer a macroeconomic question. But so far macroeconomics has not answered the question either –indeed has not even asked it. The tacit answer to the implicit question seems to be that a bigger Edgeworth box is always better than a smaller one!
4 See for example Pearce *et al.* (1989), p. 135.
5 See Vitousek *et al.* (1986), pp. 368-373. The definition of human appropriation underlying the figures quoted includes direct use by human beings (food, fuel, fiber, timber), plus the reduction from the potential due to degradation of ecosystems caused by humans. The latter reflects deforestation, desertification, paving over, and human conversion to less productive systems (such as agriculture).
6 See Lauderdale (1819) and also Foy (1989), pp. 3-10.
7 PNUD/FAO/SFN (1979), p. 13.
8 See El Serafy (1989), pp. 10-18.

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