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Perceptual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective

Mathis Wackernagel [a,*], William E. Rees [b]

[a] Universidad Anáhuac de Xalapa, Priv. Antonio Chedraui Caram s/n, C.P. 91180 Xalapa, Mexico
[b] School of Community and Regional Planning, University of British Columbia, 6333 Memorial Road, Vancouver, BC V6T 1Z2, Canada

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Abstract

This paper argues that perceptual distortions and prevailing economic rationality, far from encouraging investment in natural capital, actually accelerate the depletion of natural capital stocks. Moreover, conventional monetary analyses cannot detect the problem. This paper therefore makes the case for direct biophysical measurement of relevant stocks and flows, and uses for this purpose the ecological footprint concept. To develop the argument, the paper elaborates the natural capital concept and asserts the need of investing in natural capital to compensate for net losses. It shows how the ecological footprint can be used as a biophysical measure for such capital, and applies this concept as an analytical tool for examining the barriers to investing in natural capital. It picks four issues from a rough taxonomy of barriers and discusses them from an ecological footprint perspective: it shows why marginal prices cannot reflect ecological necessities; how interregional risk pooling encourages resource liquidation; how present terms of trade undermine both local and global ecological stability; and how efficiency strategies may actually accelerate resource throughput. Affirming the necessity of biophysical approaches for exploring the sustainability implications of basic ecological and thermodynamic principles, it draws lessons for current development.

Keywords: Perceptual barrier; Structural barrier; Investment; Natural capital

1. Introduction: natural capital as appropriated carrying capacity

Let us take a closer look at this 'natural capital' (Schumacher, 1974, p. 12).

The purpose of this paper is to highlight some of the present barriers to investing in natural capital. It argues that perceptual distortions and prevailing economic rationality, far from encouraging investment in natural capital, actually accelerate the depletion of natural capital stocks. As conventional monetary analyses seem blind to natural capital depletion, the paper therefore makes the case for direct physical measurement of relevant stocks and flows, and uses for this purpose the ecological footprint concept.

However, before embarking on this task, the meaning of the 'natural capital' concept needs to be clarified. Ecological economists acknowledge that industrialized societies depend for survival not only on labor and human-made capital, but also on natural

* Corresponding author. Fax: (52-28) 142-343; e-mail: mathiswa@coacade.uv.mx

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capital. However, natural capital has not yet been developed into an operational concept, even within ecological economics. Various interpretations of natural capital have been advanced. Narrow definitions identify natural capital mainly with commercially available renewable and non-renewable resources (Barbier, 1994, p. 292). However, this paper builds on a more ecologically complete definition that would include not only all the biophysical resources and waste sinks needed to support the human economy, but also the relationship among those entities and processes that provide life support to the ecosphere (Costanza and Daly, 1992). Natural capital refers to a stock of natural assets that is capable of producing a sustainable flow. For example, a forest or a fishery is capable of producing a perpetual harvest, year after year. The forest or the fish stock is the natural capital, the sustainable harvest is natural income.

There is renewable natural capital, including self-producing stocks like biomass or other biological resources, or replenishable assets such as water, solar energy or atmospheric ozone. And there is non-renewable natural capital like fossil fuel, minerals and ores whose income can be considered sustainable if the capital losses are compensated (see below). Natural capital is the totality of these assets, and this paper uses a biophysical approach to aggregate its various forms.

In short, natural capital is not just an inventory of resources; it includes all those components of the ecosphere, and the structural relationships among them, whose organizational integrity is essential for the continuous self-production of the system itself. [1] Indeed, it is this highly evolved structural and functional integration that makes of the ecosphere the uniquely livable 'environment' it is for the very organisms it comprises (Rees, 1990, 1992a). Geoclimatic, hydrological, and ecological cycles do not simply transport and distribute nutrients and energy, but are among the self-regulatory, homeostatic mechanisms that stabilize conditions on Earth for all contemporary life-forms, including humankind.

1.1. The constant capital stocks criterion

Having formalized the concept of natural capital, ecological economists are debating various formulations of a 'constant capital stocks' condition for sustainability (Costanza and Daly, 1992; Daly, 1989; Pearce and Atkinson, 1993; Pearce et al., 1989, 1990; Pezzey, 1989; Rees, 1992a). In keeping with our emphasis on ecologically significant forms of natural capital, and given current indications of global ecological deterioration, we subscribe to the precautionary principle that each generation should inherit a stock of essential biophysical assets *alone* no less than the stock of such assets inherited by the previous generation. [2] Adequate natural capital stocks are needed to maintain sufficient ecological flows for the human economy. And, growing populations would need to translate in reducing economic inputs per capita. In fact, to secure material well-being in the future, one could even argue for the maintenance of per capita stocks (Barbier, 1994, p. 295). For more people, we would need more forests, more farm land and more wilderness areas.

This interpretation emphasizes ecological necessity, particularly the life-support functions of self-producing biophysical capital. It also reflects Daly's definition of 'strong sustainability' which recognizes that manufactured (or human-made) capital and natural capital remain non-substitutable complements in most production functions (Daly, 1989, p. 22).

We should acknowledge here that however radical the constant stocks criterion might appear, it still reflects prevailing anthropocentric and 'resourcist' values. Emphasis is on the pragmatic minimal bio-

[1] 'Organization' signifies those properties and relationships that must be present for a thing to exist. Maturana and Varela (1988, pp. 42–43) refer to the unique self-producing and self-regulating properties that define living systems as 'autopoietic organization.'

[2] The major alternative interpretation of the 'constant capital stocks' criterion argues for maintaining a constant *aggregate* stock of human-made and natural capital (see Pearce et al., 1989; Pezzey, 1989). However, this version assumes the substitutability of manufactured for natural capital. Or, one could argue that it is the natural income that should be kept constant — more efficient technology might produce the same flow on a smaller capital. However, as many ecological functions such as biodiversity, ecological stability and integrity, or atmospheric ozone for UV protection depend on stocks rather than flows, and as we may already be short of natural capital, it seems more reasonable to focus the analysis on the stocks, and use the technological improvements for living better on the same capital.

physical requirements for *humane* survival. On the other hand, the preservation of biophysical assets essential to humankind does imply the direct protection of whole ecosystems and thousands of keystone species, and thousands more will benefit indirectly from the maintenance of the same systems upon which humans are dependent. In short, the most promising hope for maintaining significant biodiversity under our prevailing value system may well be the ecologically enlightened human self-interest implicit in stronger versions of the constant natural capital stocks criterion.

Of course, should humankind shift to more ecocentric values, its own survival might be assured even more effectively. Respect for and the preservation of other species and ecosystems for their intrinsic value would automatically ensure human ecological security.

For the present, however, the next steps are to determine how best to measure constancy of natural capital, or in other words, how the various forms of natural capital can be aggregated. Pearce and colleagues identify three possible approaches to the measurement issue based on constant physical inventory, constant present valuation of stocks, and constant income flows. They finally settle on monetary measures on grounds that constant physical capital would "be appealing for renewable resources, but, clearly, has little relevance to exhaustible resources since any positive rate of use reduces the stock" (Pearce et al., 1990, p. 10).

We challenge this view. Using money values as a measure of natural capital constancy is misleading from an ecological perspective precisely because a constant (or increasing) dollar value of a resource stock can result from the physical depletion of the stock (and its functions). Similarly, a stable income may result from rising marginal prices for resource commodities as corresponding stocks decline (this of course assumes that market prices are accurate and involatile, which they are not). Thus, monetary measures can foster the illusion of constant stocks while physical inventories actually shrink. More fundamentally, prices can say nothing at all about non-market,

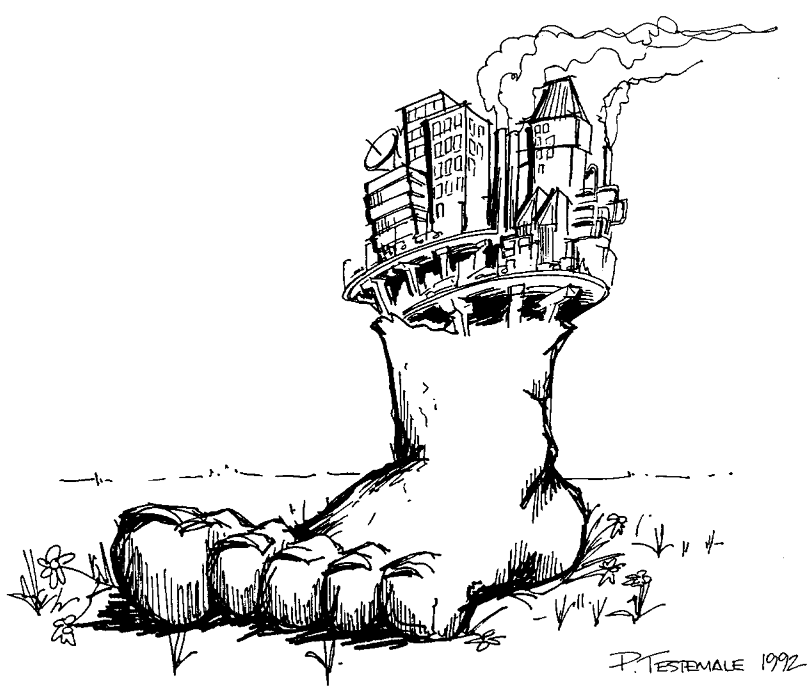

Fig. 1. The ecological footprint. The ecological footprints of individual regions are much larger than the areas they physically occupy. Since industrial economies draw on resources from all over the world, we say that they are in effect appropriating carrying capacity from elsewhere, including the global commons (Phil Testemale).

but ecologically essential, stocks and processes (e.g., the ozone layer and photosynthetic CO_2 uptake), nor about those ecosystems functions whose value to humankind is not revealed *until* they are in jeopardy or disappear (see Rees, 1992a).

We therefore submit that at least for renewable natural capital, constancy can be assessed meaningfully only in physical terms. The natural capital occupied by an economy must be understood as the physical stocks required to produce the biophysical 'goods and services' that this economy extracts from global flows (natural income) to sustain itself without compromising future production. We therefore also concur with a biophysical interpretation of the monetary proposition of El Serafy (1989) which states that non-renewable resource harvest is sustainable if the stock depletion is compensated with the build-up of equivalent financial capital. Similarly, we argue that non-renewable energy resources can only be used sustainably if, in compensation, an amount of biophysical capital with an equivalent content of available energy is being accumulated.

To summarize, an economy depends on natural capital to provide all the resource flows and waste sinks necessary to sustain a given material standard of living, while simultaneously maintaining the functional integrity and productivity of the stocks themselves. It follows that rising material standards or increasing population levels necessarily require corresponding *increases* in natural capital stocks.

Monetary approaches are blind to these biophysical realities. Therefore, Ecological Economics requires other measuring rods to assess the natural capital stocks and their change.

1.2. The ecological footprint and appropriated carrying capacity

All economies need measurable quantities of natural capital to function. Such capital is an essential factor of production. We have developed a method that represents critical natural capital requirements of a defined economy or population in terms of the corresponding ecologically productive areas. We refer to these requirements as this population's 'ecological footprint' on the Earth (Fig. 1) or its 'ap-

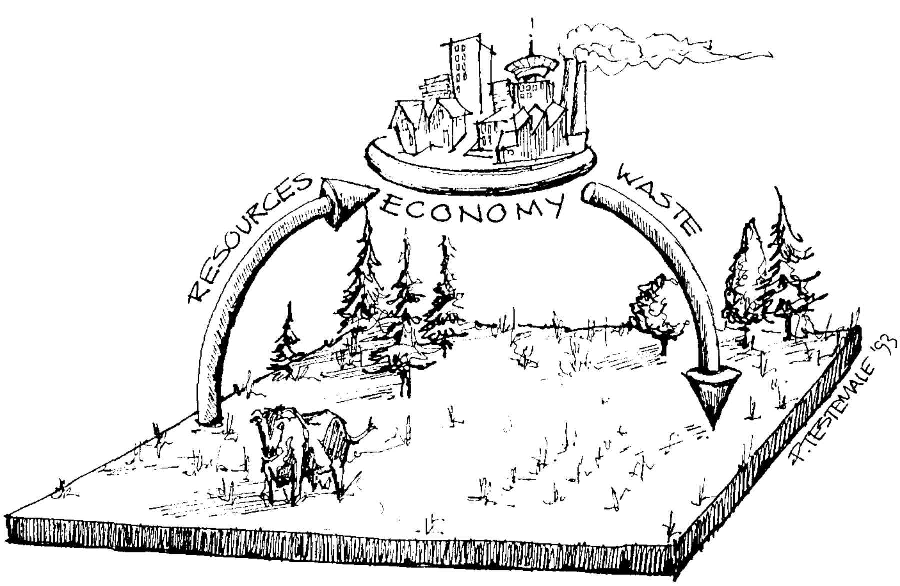

Fig. 2. Defining footprints. The ecological footprint or appropriated carrying capacity of an economy represents the ecological capacity necessary to sustain this economy. As a first approximation, ecological footprints can be defined as the aggregate area of land and water in various ecological categories that is claimed by participants in this economy to produce all the resources they consume, and to absorb all their wastes they generate on a continuous basis, using prevailing technology. The ecological footprint therefore stands as a surrogate for the 'natural capital' of the economy, while the resource and waste flows represent 'natural income' (Phil Testemale).

propriated carrying capacity'. [3] As a first approximation, the ecological footprint can be represented as the aggregate area of land and water in various ecological categories that is claimed by participants in that economy to produce all the resources they consume, and to absorb all their wastes they generate on a continuous basis, using prevailing technology (Fig. 2).

Evidently, the area of the footprint depends on the population size, material living standards, technology and ecological productivity. It also reflects the amount of human carrying capacity 'appropriated' from the global total by the given population. It is important to recognize, that ecological footprints do not overlap; the carrying capacity appropriated by one economy is not available to another.

Productive land is a good proxy for many of the resource flows and essential life support services that natural capital provides. Land area communicates the finite character of the world in readily understandable terms; the area in each ecosystem category is roughly proportional to its photosynthetic potential for low entropy biomass production; the quality of the land is an indicator of the functional integrity of related ecosystems and their potential long-term [4] production. These characteristics of real wealth are rarely reflected in the money price of land-as-commodity.

It is useful to think of the essential self-producing natural capital represented by an economy's ecological footprint as 'Hicksian natural capital.' Hicksian income is the level of consumption that can be sustained from one period to the next without reducing wealth (productive capital) (Hicks, 1946, p. 171). In the present context this corresponds to 'natural income.' For a given economy, the Hicksian natural capital would therefore be the aggregate natural capital stocks necessary to sustain this economy's ecological flows (natural income) and consumption patterns indefinitely.

Analyzing the relationship between an economy and its natural capital requirements in terms of appropriated carrying capacity reveals both the mechanisms that presently favor the liquidation of natural capital and the long-term ecological constraints on the economy. The biophysical approach also makes it possible to explore the implications of such ecological principles as von Liebig's Law of the Minimum, and the First and Second Laws of Thermodynamics, all of which are ignored by conventional analyses. (For an historical overview of this perspective, see Martinez-Alier, 1987; for more contemporary studies see Odum, 1972; Georgescu-Roegen, 1975; Cleveland et al., 1984; Peet, 1992).

Finally, estimates of the ecological footprint and appropriated carrying capacity provide clear direction for action. They indicate whether current or projected consumption levels can be sustained by available ecological productivity. By definition, the difference between the size of a region (adjusted by its ecological productivity) and the footprint of this region's population must be covered by imports of ecological surpluses or the depletion of natural capital stocks. Thereby, the ecological footprint becomes a useful yardstick for sustainability. As the ecological footprint of humanity needs to be smaller than the available carrying capacity, it becomes an absolute benchmark. It also points out how the ecological footprint can be reduced: through lower population, lower consumption, more efficient technologies (as long as gains are not re-spent — see below), higher ecological productivity, or a combination of these four parameters.

For example, our conservative estimates show that the average person living in an industrialized country presently needs the equivalent of 2–5 hectares of productive land to sustain his or her material consumption, Japan being at the lower end, Canada and the US at the upper (Wackernagel and Rees, 1995; Wada, 1995). This figure is derived from the resource flows embodied in goods and services consumed. However, there are only 1.5 hectares per capita of ecologically productive land on Earth (only about 0.3 hectare per capita in central European countries) (World Resources Institute, 1994, p. 268, 284). Of these 1.5 hectares, less than

[3] The term 'carrying capacity' is used slightly inaccurately here. Carrying capacity is typically defined as the population that can be supported indefinitely by a given habitat. 'Appropriated carrying capacity' is really the inverse (habitat required to support a given population), but seems to transmit meaning better than a more accurate term such as 'appropriated bioproductive stock'.

[4] Here, long-term means generations (> 100 years) while short-term refers to few decades (> 10 years).

Table 1
Toward a taxonomy of barriers to investing in natural capital

Characteristics and behavior of individuals or society [a]	Effects on natural capital [a]
(A) IGNORANCE, FUNDAMENTAL BELIEFS AND SOCIAL DENIAL	
ignorance	
(i) people cannot perceive slow but steady changes;	(i) long-term and aggregated capital deterioration is ignored; the public underestimates the threat of slow exponential growth ('boiled frog syndrome');
(ii) uncertainty about the causes of ecological deterioration and about future effects of current activities supports 'business-as-usual' strategies;	(ii) lacking 'hard evidence' allows avoidance and sanctions natural capital depletion;
(iii) the predominant paradigm in decision-making excludes ecological reality;	(iii) decision-making process becomes blind to the implications of natural capital depletion;
beliefs	
(iv) behaviors and beliefs which are shaped by culture, spiritual traditions and gender relations feed into the acceptance and rationalization of the exploitative relationship between industrial society and nature;	(iv) industrial society assumes possessing the right to delete natural capital; myth of 'man subduing nature' perpetuates human and ecological exploitation; Earth perceived as a tool to society (e.g., natural capital concept) rather than as home and origin of life (e.g., Mother Earth concept);
(v) belief that the ultimate policy goal is to maximize utility (i.e., 'more is better'), rather than to minimize suffering and future regrets (i.e., the precautionary principle) dictates current thinking;	(v) there is no political process to check economy's scale; the maximization principle inherently rejects any concept of 'enoughness';
(vi) belief that industrialization is beneficial to all parts of society characterizes dominant development ideology ('trickle-down effect');	(vi) benefits from industrialization flow mainly to investors, while many costs are externalized; resource extraction is accelerated, leading to social and ecological stress;
denial	
(vii) body–mind and people–nature split helps people ignore human dependence on nature (exemptionalism or mental apartheid);	(vii) human-nature split gives false sense of independence from natural capital; feeling separate detracts from accepting responsibilities and can lead to paralyzing finger-pointing;
(viii) ambiguity of scientific information allows decision-makers to ignore ecological reality;	(viii) lacking 'scientific evidence' undermines political support for public investment in natural capital;
(ix) social denial and faith in human ingenuity suppresses ecological knowledge from the knowledge base that informs policy and decision-making;	(ix) public investment in natural capital is politically resisted as it would acknowledge the urgency of the situation;
(B) ECONOMIC ABSTRACTIONS, DEVIANT OPERATING MODELS AND KNOWLEDGE	
(i) money...	(i) blinds society from its obligate dependence on natural capital;
– has become the dominant measure of wealth;	– the amount of money wealth increases while that of ecological wealth vanishes;
– makes all commodities commensurable;	– commensurability engenders the belief in total substitutability;
– is detached from the biophysical reality: e.g., does not perish, is easily dividable and transferable;	– money fakes continuity, long-term values and security; it is quicker, more versatile, and easier to handle than biological wealth;
(ii) resource prices have become society's main indicator for resource scarcity;	(ii) prices only reflect the costs to the global economy for accessing resources, but not their biophysical abundance; i.e., economic scarcity does not gauge biophysical scarcity;
* (iii) marginal (and not total) value determines the market price; business and public policy focus nearly exclusively on monetarized effects, while neglecting non-monetarized impacts;	* (iii) market prices do not reflect ecological necessities of life-support functions; therefore natural capital is systematically undervalued and does not attract investment;
(iv) the gap between what we need to know about the fast evolving global system and what we actually do know is growing; the social stigma of science cements the unsustainable status-quo;	(iv) science provides powerful analytical tools for clearly confined problems; but the scientific analysis is weak in understanding the complexities of global systems; science is effective for developing profitable technology benefiting those who have access to higher education, while offering less to the development of sustainable living;

Table 1 (continued)

Characteristics and behavior of individuals or society [a]	Effects on natural capital [a]
(v) technology amplifies individual effectiveness and efficiency; technological achievements give rise to the positivist belief that technology can overcome any barriers and that sustained growth is possible;	(v) human activities cumulative impact exceeds productive and absorptive capacity of natural capital; technological fixes limp behind the problems that industrialization causes; technological rationality on the individual scale becomes irrational at the global scale;
(C) THE SOCIAL MIMICRY OF INDIVIDUAL RATIONALITY	
(i) individuals and societies operate as open systems without size constraints; also scientific successes encourage the predominant technical (open systems) worldview which is pertinent to small scale applications but which is incompatible with the large scale (closed system) reality;	(i) as the ecosphere is a closed system with a limited bioproductivity/carrying capacity, economic forces operating like open systems accelerate overshoot of local and global carrying capacity; this is not recognized as a danger;
(ii) emotional reality of decision-makers is individual rather than societal; in current market buyers cannot distinguish sustainably from non-sustainably harvested resources;	(ii) jet-set elites with access to abundance are blind to natural capital depletion; their salary's increasing purchasing power is feeding into the illusion of expandable carrying capacity;
(iii) individuals prefer present to future values (discounting); these discount strategies are also adopted for public policy making;	(iii) opposes the necessity of ecological continuity; this leads to the depletion of long-term capital ('killing the goose that lays the golden egg'); people living at the margins (e.g., poor in the South) are forced into undermining their long-term livelihood (high discount rates for natural capital);
(iv) similar to individual capital accumulation, maximizing national economic (or monetarized) production is society's major preoccupation;	(iv) leads to faster resource depletion and an overshoot of the available carrying capacity;
(v) to attract investment, profit accruing to private investors must exceed bank rates;	(v) natural capital cannot compete economically with human-made capital and does therefore not attract investment;
* (vi) efficiency improvements are society's main strategy for resource conservation;	* (vi) efficiency improvements on the individual scale accelerate resource throughput on the societal scale;
(D) PHYSICAL AND STRUCTURAL MANIFESTATIONS OF MODERN SOCIETY	
(i) industrial lifestyle disassociates society spatially, politically and psychologically from the bioproductivity that supports it; markets, urbanization and trade removes consumers from human and ecological production;	(i) today, economic actions are largely exempt from ecological and social responsibilities as actions are separated in time and space from their wanted and unwanted effects (e.g., 'pervasive externalities'); corrective feedback loops are disconnected and the loss of political and economic control over local carrying capacity is ignored;
(ii) 'TV mentality' determines how the majority of people perceive their reality; TV view distorts issues by delivering simplistic rather than holistic stories; its one-way communication discourages questioning and participation;	(ii) TV detracts from ecological constraints through the celebration of abundance and wants, 'innumeracy', disconnection, and artificiality; e.g., it promotes a superficial conservation ethics;
(iii) globalization of economies is encouraged; participation in the global economy has become a 'moral obligation'.	(iii) globalization of problems, complex and fast changing web of linkages lead to an unpredictable system dynamics;
– all currencies become convertible; economic reality drives individuals and corporate bodies into realizing highest profit rates;	– a globally unified monetary and pricing system generates competitive pressures leading to uniform and upward-trending expectations of returns to capital; local resources lose their importance to the local economy destroying incentives to protect them; economic surpluses which might otherwise be available for maintenance of natural capital are dissipated;
– restrictions to capital movement are eliminated;	– local investments decline as they have to compete with international investments; while local investors are interested in positive externalities of their investment, international investors focus only on their realized profit;
* – interregional risk pooling is assisted;	* – people become less risk-averse to depleting local natural capital;

Table 1 (continued)

Characteristics and behavior of individuals or society [a]	Effects on natural capital [a]
– increasing international competition in economic production is accepted as a given;	– global competition accelerates resource consumption and becomes a negative-sum game
* – trade is assumed to be mutually beneficial;	* – importing resources that are locally limiting appear to increase local carrying capacity while actually lowering it; hence, prevailing trade undermines the local and ultimately the global ecological stability;
(iv) individual property rights are sacrosanct;	(iv) integrated life-support services cannot be subdivided into individual property rights; exploitation and consumption rights remain largely separated from conservation duties;
(v) super individuals (TNCs) are promoted while mini societies (communities) are discouraged	(v) commons for communities are privatized and fragmented, while enclosures by TNCs are encouraged.

[a] Read across corresponding numbers; barriers with * are discussed in the paper.

0.3 hectare is suitable for agricultural production (Corson, 1990, p. 75).

These numbers speak for themselves. The difference between the land-base needed to maintain high human consumption levels and actual land availability represents a 'sustainability gap' and explains why the current human economy lives in part on natural capital depletion rather than on sustainable flows (i.e., Hicksian natural income). They also imply that the natural income (or ecological flow) requirements of industrialized economies can be met only as long as these economies are able to buy or appropriate through biogeochemical cycles the necessary resource flows and waste sinks from distant 'elsewheres.' In fact, our rough calculations suggest that the ecological footprint of all industrialized nations, representing less than 20% of the world population, is larger than the available ecologically productive land on Earth (Wackernagel and Rees, 1995). In other words, it would take one entire Earth to sustain the ecological flows that industrialized countries currently require.

The use of these sources and sinks by industrial economies obviously pre-empts their use by developing economies. The data indicate that it is simply not possible, ecologically or thermodynamically, for everybody in the world to consume at current industrial levels without risking irreversible resource depletion and ecospheric collapse (Rees and Wackernagel, 1994). In the absence of new ecologically benign technologies that dramatically shrink their ecological footprints, the populations of industrialized countries will have to reduce their material standards of living that others might live at all (Rees, 1990) (note that these concepts apply to both commercially traded commodities and non-market flows of common-pool ecological goods and services. For example, under prevailing conditions, the affluent countries have already appropriated more than twice the ecosphere's entire capacity for anthropogenic CO_2 uptake).

2. A taxonomy of barriers to investing in natural capital

Even without an operational definition of 'natural capital', most scholars would agree that many critical stocks are being depleted rapidly. Few incentives or policies operate to maintain our natural assets. Even though the conservation of natural capital stocks would require investments to compensate for net losses, the present economic environment discourages investment in, or even maintenance of, natural capital.

For economists, investment means capital formation that will produce a stream of goods and services for future consumption. Given the unquestioned monetary value of many ecological goods and the fact that certain ecological services are essential for life, why does humankind not even maintain, let alone invest, in natural capital stocks? Table 1 presents our preliminary classification of barriers to such investment. The left-hand column lists qualities and behaviors of individuals and society. The right-hand column provides the corresponding effects that mitigate against investment in nature. Four main classes are identified:

(A) *Ignorance, fundamental beliefs, and denial*: Much husbanding of natural capital is foregone because most people, from the general public to elected and corporate decision-makers, understand neither the nature of the problem nor the crucial role of natural capital stocks. Others who do understand are in denial, or are unwilling or incapable of taking necessary action. Still others are confident that human ingenuity and technological progress will be able to substitute for ecological losses. Unfortunately, nature itself seems to give support to the resultant inaction – systemic lag effects, ecosystems resilience, and large cumulative stocks let us get away with natural capital depletion in the short run (and humans tend naturally to discount future costs).

(B) *Economic abstraction, deviant operating models and knowledge* (the social construction of reality): People act out their lives guided by mental models, including a shared, culturally-induced perception of the nature of reality and humankind's place in the scheme of things. Our personal experiences are always interpreted through such socially constructed 'world views.' As the nature of humankind-environment linkages evolves, the question is whether our dominant economic models are compatible with the biophysical reality *out there*. Table 1 shows that some of our socioeconomic abstractions are barriers to investment in natural capital because they bear little relation to ecological reality (see also below).

(C) *The social mimicry of individual rationality*: An overriding consideration in the depletion of natural capital can be traced to a 'fallacy of composition.' A global economic regime is being created in which what has become accepted as 'rational' economic behavior by individuals is ever more being emulated at higher organizational scales at the expense of public goods and communal values. Ferdinand Tönnies recognized this trend over one hundred years ago in his influential treatise *Community and Society*. He traced the growing alienation and exploitation of people to the socio–historical transformation from *Gemeinschaft*, traditional societies which are community-based, to *Gesellschaft*, modern societies in which rational self-interest operates to weaken traditional human bonds (Martindale, 1960, pp. 82–86).

(D) *Physical and structural manifestations of modern society*: Undoubtedly, structural features of the modern economy have also accelerated natural capital depletion. The physical separation between consumption and production, further reliance on electronic media rather than direct experience, the fast-paced integration of the global economy, energy intensive settlements infrastructure and the loss of local political autonomy reduce corrective feedback for the maintenance of natural capital and amplify the dilemma between economic expansion and ecological integrity.

The reality today is that much deterioration of the global 'commons' can be attributed to the unforeseen consequences of deliberate policies that extend self-interested individualistic behavior and rights to government and intergovernment agencies, transnational corporations, and various other multinational organizations operating in the global arena. Many such policies reflect and facilitate the transition to a global marketplace. [5] Examples include international agreements for the division and exploitation of the sea-bed and similar 'undeveloped' common-pool (open-access) resources, the extension of property rights including the privatization of public lands (along with their common-pool ecological functions), regional and global trade agreements that favor corporate interests at the expense of local and even national autonomy, and the creation of an increasingly uniform monetary and pricing system.

To argue that globalism and self-interested individual behavior is a dominant factor in the depletion of natural capital is to underscore a particularly pernicious form of market failure. While economists have long acknowledged market failures against society's collective interest, development policy still reflects the conventional myth that net social benefits invariably flow from the workings of Adam Smith's 'invisible hand.' In fact, the invisible hand, which is said to lead "private interests and passions of men" (sic) in the direction which is most beneficial to the interest of society as a whole, might well be the most effective strategy for maximizing material well-being in an unlimited environment. However, in a finite, materially-closed system like the ecosphere, the competitive forces guiding the invisible hand be-

[5] Global monetary and trade agreements can be interpreted, in part, as instruments to extend the reach of industrialism to the world's remaining stocks of natural capital at the lowest possible cost.

come positively destructive. Not all individuals, corporations, and nations can simultaneously maximize their individual use of global sources and sinks without overexploiting or destroying the common-pool life-support functions that are essential to their mutual survival (see Ophuls, 1992; Homer-Dixon et al., 1993).

Note that not all the classical market failures are represented in Table 1. In fact, apart from pervasive externalities [6], market failures may not increase the rate of natural capital depletion. Perfect markets allocate resources in a Pareto efficient manner and maximize aggregate consumption. [7] Thus, it is conceivable that some market failures actually reduce natural capital depletion by compromising an economy's aggregate purchasing power and reducing material consumption — even though this may not be the most useful way to reduce natural capital depletion.

To summarize, prevailing beliefs, resultant economic behavior, and mainstream development theory all mitigate against maintenance or investment in natural capital. Current global development models implicitly assume an infinite world. The corresponding economic strategies are those of individual materially open systems at all organizational and spatial scales as reflected in the expansionist rhetoric of globalism. From this perspective, increasingly liberal world markets and expanded international trade are seen as the keys to sustained global prosperity. Investment emphasis is on growth, both of the manufactured capital necessary to exploit and transform the natural capital, and on individual consumption. Unfortunately, the real world is finite and the invisible hand of the market has nothing to say about the appropriate scale of an entropic economy operating under such a constraint. The inevitable results are global sinks filled to overflowing and depletion of the world's ecological capital.

Clearly neoclassical market-based 'rationality' must be complemented by other principles (see Daly and Cobb, 1989; Daly, 1989). Ecological economics, for example, does recognize the economy as a subsystem of a finite and materially closed ecosphere. This perspective forces a shift from development policies that emphasize material growth to strategies that acknowledge both the role of natural capital in maintaining planetary life support and the risks associated with its (irreversible) loss. Many natural capital stocks and functions are 'common pool' assets for which everyone is responsible and to which everyone should have more or less equitable access. Here policy emphasis would be on mechanisms and incentives both to attract more investment in essential natural capital and to reduce material consumption, the real challenge being not to compromise perceived quality of life. Markets alone are unlikely to achieve these ends — the international community will have to negotiate some form of "mutual coercion, mutually agreed upon". [8] This in turn may require a fundamental shift in prevailing economic assumptions and social values.

3. Exploring four issues in more detail

Many barriers to investment in natural capital are discussed elsewhere in the literature. We therefore concentrate only on the following four problems marked with an asterisk (*) in Table 1, and discuss them from an ecological footprint perspective:

- marginal pricing (market valuation does not reflect ecological necessity — in Part B iii);
- interregional risk pooling (creates incentives for resource liquidation — in Part D iii);

[6] Pervasive externalities are externalities which are general in scope (i.e., not localized) and which cause non-monetarized losses (Daly and Cobb, 1989, p. 37, 55).

[7] However, they neither encourage a more equitable distribution, nor ensure that an economy remains within nature's carrying capacity.

[8] Note that Hardin (1968) misinterpreted the historic meaning of 'commons' in his classic analysis of "The Tragedy of the Commons." As Hardin himself later acknowledged, he was not in fact describing a commons regime in which rights and authority are vested in members of a community, but rather an open access regime in which ownership and authority is vested nowhere (The Ecologist, 1992, p. 127). In short, Hardin's essay should have been entitled, "The Tragedy of Open Access" (or the Tragedy of Common-pool Resources). Ironically, Hardin (1968, p. 1247) advocated resolving the tragedy through 'mutual coercion, mutually agreed upon' which is, in fact, a concise definition of a 'common property' regime.

· inter-regional trade (can undermine both local and global ecological resilience — in Part D iii); and
· efficiency improvements (may increase rather than reduce consumption-related throughputs — in Part C vi).

3.1. Marginal pricing and economic valuation

Marginal pricing is a core concept of conventional economics. Economists refer to the open market price for the next (or the last) unit of a given product or commodity as its 'marginal price.' In theory, this price is set by the (mostly unconscious) interplay of buyers' and sellers' preferences and the diminishing marginal utility (satisfaction) experienced by consumers from purchases of successive increments of a given commodity. Ideally, a knowledgeable consumer should be able to maximize the total utility extracted from a given income by adjusting his/her expenditures so that there would be no gain in satisfaction from any alternative pattern of expenditure. At this point, the marginal utility of all the goods and services in question would be identical. The beauty — as well as the danger — of market prices is that they seem to make resources commensurate, enabling us to trade apples for oranges.

One danger is the fact that the market price for a given commodity does not reflect its ultimate worth when scarce, nor the 'total value' of the commodity (Daly, 1968/1993, p. 254). It reveals only what people are willing to pay today for the next unit of that commodity. This price is influenced by many things including total income, available alternatives (opportunity costs) and current fashion. Accordingly, market pricing can often equate the terminally frivolous to the absolutely essential. Certainly, today's low food prices provide no hint of either the biological necessity of food or the land necessary to produce it. Neither do market prices indicate anything about temporal lags, ecological thresholds, or the irreversibilities of natural processes, all of which impinge on the future supply of natural goods and services.

This enigma is called the Paradox of Values and puzzled even Adam Smith (Samuelson and Nordhaus, 1985, p. 416). It describes the situation in which diamonds, which are less essential to humans than water, are generally more expensive at the

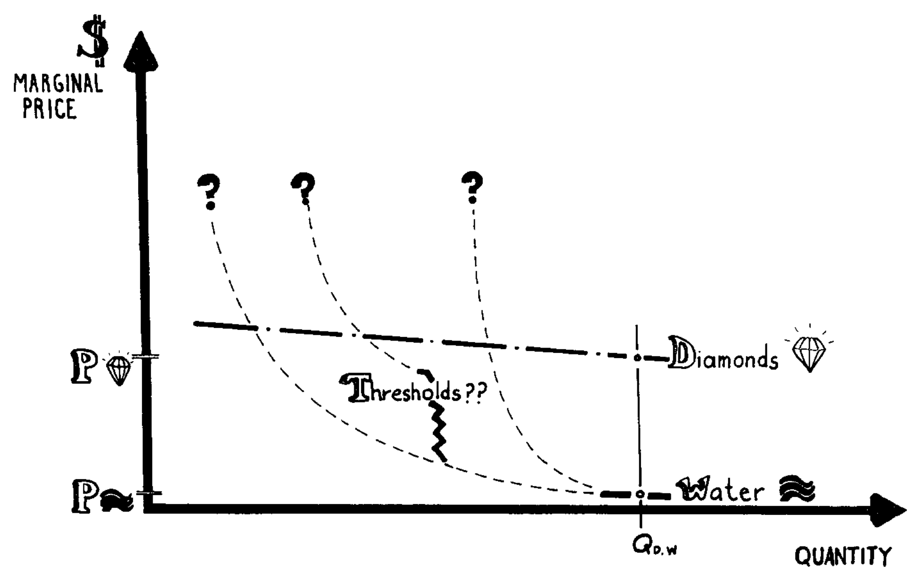

Fig. 3. The 'Contradiction of Values'. From an ecological perspective, the Paradox of Values is not a paradox, i.e., an apparent contradiction, but a real contradiction between ecological constraints and human decision-making. At the margin, expandable goods are valued more highly than ecological necessities, while ecological prices do not indicate irreversibilities, threshold effects of life-support functions (Iliana Pámanes).

margin. We are not willing to pay as much for our next liter of water as for the smallest cut diamond because the marginal utility of water (when we have plenty) is much lower than that of diamonds. Paradoxically, were we are stuck waterless in the middle of a desert, we would perceive a single gulp of water to be worth more than all the world's diamonds combined (see Fig. 3).

If we value bioproductivity only by its dollar price at the margin, we are completely misled about the magnitude of nature's contribution to human welfare. For example, agriculture may account for only 2–4% of industrialized nations' GDP, while their ('non-material') information industries can generate 50%. However, these figures reflect neither the necessity for agriculture nor its true relative worth compared to the information sector. Stephen Viederman comments:

> [Economics] is broke when a leading economist, William Nordhaus, can argue that declines in agriculture and forestry as a result of global warming would be of little consequence because they represent only 3% of the US economy. David Orr has suggested this is equivalent "to believing that since the heart is only about two percent of the body's weight, it can be removed without consequences for one's health" (Viederman, 1992, p. 2).

In short, marginal prices for the products of natural capital convey a sense that nature's total value is finite, when, in fact, ecological necessity dictates that the total social utility of many forms of natural capital is infinite: without water, no life; without air, no life; without photosynthesis, no life, etc. In contrast, the total value of the information sector would probably not be substantially higher than the sum suggested by marginal prices, and would certainly fall far short of infinity.

To summarize: from an ecological perspective, the Paradox of Values is not so much a paradox as a real contradiction between human preference at the margin and ecological necessity at the limit. In contrast to ecological footprint analyses, market prices for ecological resources are blind to the necessity of maintaining the functional integrity of relevant ecosystems. They do not reflect the size of remaining natural capital stocks nor whether a certain minimum stock must remain intact to ensure systems integrity. Commodity prices simply do not account for ecological functions — a thousand logs (or the equivalent in lumber or pulp) are not the ecological equivalent of a thousand trees as forest. For these reasons, marginal prices systematically undervalue natural capital and encourage its overexploitation. The increasingly competitive global marketplace (and the lower prices it brings) is therefore itself a barrier to investment in natural capital and thus undermines ecological sustainability.

3.2. Interregional risk pooling

Given the option, most people would prefer to reduce the uncertainty in their lives. Through risk-sharing, individual uncertainty is lowered and problems are more manageable when they occur. Modern societies are characterized by institutionalized risk-pooling, not only between individuals, but also between regions (Beck, 1986, 1988). Most risk-pooling is facilitated by the market — insurance (Samuelson and Nordhaus, 1985, pp. 498–500), bonds and stocks (Lipsey et al., 1988, p. 654; Samuelson and Nordhaus, 1985, p. 657), and mobility of capital, labor and commodities. Also, industrial safety standards are influenced by access to risk pools: when potential damages do not endanger the whole enterprise they may become acceptable to the often remote corporate headquarters (e.g., Union Carbide in Bophal). Finally, the state provides some risk-sharing mechanisms through its welfare institutions.

When assessing risks, economists adopt an individual perspective. Large scale risks are considered equal to the aggregation of many small scale risks (see Fritsch, 1991, pp. 156–167). Generally, economists argue that risk-pooling is beneficial to individuals and, therefore, also for society. If individuals are too risk-averse, they miss opportunities, misallocate resources, or under-consume. Economists like to use the example of Robinson Crusoe who, in the absence of trade, has to overproduce food to even out good and bad harvests to survive the worst years.

However, pooling risks can have ecological drawbacks. For example, coastal communities whose survival is dependent on traditional fisheries generally evolve harvest strategies that conserve fish stocks. Only when they acquire the option of pooling risks with the outside through accessing other regions' carrying capacity and moving their capital elsewhere do they adopt more aggressive fishing strategies that could lead to resource exhaustion. Having access to others' resources effectively reduces the perceived present value of local natural capital. Because extinction of the local stock no longer immediately endangers survival or the local economy, it may even make economic sense to exploit that stock unsustainably and to invest the returns in a more profitable venture elsewhere (this is the case even if the stocks are privately owned (see Clark, 1973)).

Similarly, global risk-pooling may encourage entire nations to raise the short-term aggregate productivity of their renewable resources (income flows) at the expense of capital stocks. In other words, with international risk-pooling, the value of future ecological productivity at home is more rapidly discounted. The long-term effect, of course, is to reduce total productive potential, weaken ecospheric integrity, and undermine prospects for global sustainability.

In summary, risk-pooling shortcuts the important feedback function associated with risk aversion. Ecological risks that cannot be externalized or shared with others make people cautious and are therefore an incentive to conserve local resources. By contrast, by giving comparative advantage to short-term profit over long-term sustainability, risk pooling becomes a barrier to the maintenance of, or investment in, natural capital.

3.3. Trade and limiting factors

While most of the trade and environment debate restricts its focus to the compatibility of international pollution standards (e.g., Kirton et al., 1992; Bengtsson et al., 1994), this section of the paper explores the role of trade in depleting natural capital. Other social and ecological problems of trade liberalization have been discussed elsewhere (e.g., Sinclair, 1992; Coote, 1992; Daly and Goodland, 1992).

David Ricardo's theory of comparative advantage provides a model of trade in which mutual benefit accrues to individuals and firms who specialize in those things they produce most efficiently (Daly and Cobb, 1989, p. 209–218; Samuelson and Nordhaus, 1985, pp. 831–856). This model, which is often assumed to apply to nations, presumes that:

(a) The trading partners are engaged only in barter trade and that their national currencies are not freely exchangeable.

(b) Economic production is proportional to labor input alone. Thus while an economy might be limited by labour shortages, there is no consideration of limits imposed by finite resources and sinks.

In the modern world of convertible currencies, this model deflates with the violation of its first assumption. Investment flows are now governed by comparing potential absolute profitability between countries, not by the 'comparative advantage' of particular industries within countries (Daly and Cobb, 1989, p. 214). Some countries (and their workers) lose out as capital leaves in search of absolute advantage. Moreover, it is apparent that natural capital is once again more likely to impose limits on the scale of the economy than are labour shortages. This makes the ecological 'Law of the Minimum' and the concept of appropriated carrying capacity essential to any interpretation of the sustainability implications of international trade.

In the middle of the last century, the German agro–chemist Justus von Liebig postulated the 'Law (or Doctrine) of the Minimum' for plant growth. He observed that essential plant nutrients occur naturally in varying concentrations from superabundance to insufficiency in cultivated fields. However, he found that "it is by the minimum that the crops' [growth is] governed" (von Liebig, 1863, p. 207).

This insight, that systems and processes are governed by that *single necessary factor* in least supply, led to the use of more specific fertilizers in agriculture. For example, if plant growth is stunted by the lack of phosphate, one need only fertilize with phosphate. The crop can now continue growing and accessing more of its required nutritive substances until some other factor becomes limiting; the next limiting factor for this crop might be water, so still higher productivity will need irrigation, etc.

For modern industrial farmers, supplying only the limiting factors seems to make farming more efficient: farmers overcome ecological barriers to crop productivity by adding those few factors which are scarce in the natural environment. However, there are ecological drawbacks. In nature, limiting factors serve inadvertently to regulate production systems. The shortage of only one essential requirement prevents plant growth from exhausting the entire resource base. The effect of chemical fertilization, therefore, is to accelerate the depletion of successive components of the soil, a potentially renewable form of natural capital, while creating dependencies on non-renewable, manufactured capital. This amounts to the short-circuiting of natural biological fuses.

The Law of the Minimum can also be applied to economic growth: economies seem to expand until they reach some limiting factor. Thus, an economy might be stunted by inadequate human capital (e.g., labour and education); cultural capital (e.g., social institutions and political stability); human-made capital (e.g., plant, machinery, physical infrastructure); or natural capital (e.g., resources and biodiversity) (see Berkes and Folke, 1992; Ekins et al., 1992, pp. 43–61). Conventional economics however, considers only labour and human-made capital to be potentially limiting: ''...the tacit justification has been that reproducible capital is a near-perfect substitution for land and other exhaustible resources'' (Nordhaus and Tobin, 1972). Today, however, natural capital is emerging as a major bottleneck and more liberal trade is perceived as the best way to overcome related local limits (Catton, 1980, p. 158).

Unfortunately, unregulated trade acts like excessive fertilizer: it can short-circuit ecological fuses which historically kept economic throughput in balance with local bioproductivity. Most economists explicitly support unrestricted trade precisely because it enables local economies to overcome any material barriers to growth. This contributes to our prevailing cultural mythology which assumes a world in which ''carrying capacity is infinitely expandable''.

Consider a model of two economies dependent on two resources. Economy 'B' can produce surplus foodstuffs, but lacks adequate energy supplies; economy 'A' has abundant hydrocarbon reserves, but little agricultural potential. Obviously, it is to their mutual advantage if B can import oil from A in exchange for food (see Fig. 4). This commercial exchange allows both economies to expand further until some other factor becomes limiting. The growth of these economies most likely entails higher populations, greater resource throughputs, accelerated stock depletion, and intensified pollution. The question is, at what point do their people cease being better off than before? Each economy is still contained by a (second) limiting factor, and in addition is now dependent on an essential resource supplied by another economy. To this extent the gains are only transitional: a short period of economic growth during which distributional conflicts are eased.

In the modern world, of course, both A and B can find new trading partners to overcome the latest limiting factor, and so on. The result is, just as

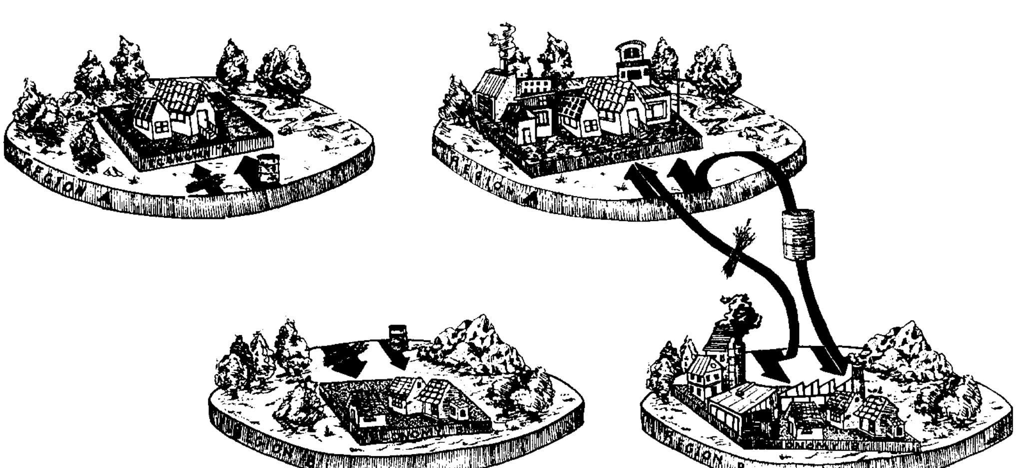

Fig. 4. Ecological implications of trade in a two-resources economy: From self-sufficiency (left) to trade (right). Importing resources that are locally limiting appears to increase local carrying capacity while actually lowering it. As a result, trade induced expansion undermines the local and ultimately the global ecological stability (Iliana Pámanes).

economists expect, expansive growth of the various economies as successive locally limiting factors are eliminated. Both economies expand their economic footprint (represented in Fig. 4 by increased size of the economies). However, once again important ecological consequences flow from global economic integration. First, material growth anywhere necessarily increases the throughput of energy and material resources, including those which have not historically been limiting (see Table 2). This raises the general level of both consumption and residuals output. Second, globalization exposes all local resource stocks to the largest possible market. In the case of regionally unique or generally scarce resources, this may increase demand, driving up prices and exploitation rates. Conversely, in a competitive market, it may drive down prices, encouraging both overconsumption by importers and overexploitation of stocks as exporters strive to maintain revenue flows. In either case, the result is more rapid natural capital depletion. Third, trade acts as a special case of risk-pooling. For example, access to low-priced agricultural imports makes people less averse to the long-term risks associated with the urbanization of locally limited agricultural land. In the absence of negative feedback on their economy or lifestyles, there is no direct incentive for local people to resist conversion of such land to activities that yield higher short-term economic returns.

The net effect is becoming self-evident in the modern world. 'Surplus' natural capital stocks everywhere are drawn down and global sinks are filled to over-flowing. Our global safety net is being shredded as the 'Tragedy of the Commons' is played out on a

Table 2
The ecological trade deficit of industrialized countries

Countries	Ecologically productive land (in ha)	Population (1995)	Ecol. productive land per capita (in ha)	National ecological deficit per capita	
	a	*b*	$c = a/b$	$d =$ Footpr. $- c$ (in ha)	$e = d/c$ (in % available)
Countries with 2–3 ha footprints				*assuming a 2 ha footprint*	
Japan	30 340 000	125 000 000	0.24	1.76	730%
Korea	8 669 000	45 000 000	0.19	1.81	950%
Countries with 3–4 ha footprints				*assuming a 3 ha footprint*	
Austria	6 740 000	7 900 000	0.85	2.15	250%
Belgium	1 987 000	10 000 000	0.20	2.80	1400%
Denmark	3 270 000	5 200 000	0.62	2.38	380%
France	45 385 000	57 800 000	0.78	2.22	280%
Germany	27 734 000	81 300 000	0.34	2.66	780%
Netherlands	2 300 000	15 500 000	0.15	2.85	1900%
Switzerland	3 073 000	7 000 000	0.44	2.56	580%
				assuming a 3.74 ha footprint	
Australia	584 000 000	18 000 000	32.4	(28.7); use of local capacity: 12%	
Countries with 4–5 ha footprints				*assuming a 4.3 ha footprint*	
Canada	433 000 000	29 000 000	14.9	(10.6); use of local capacity: 30%	
				assuming a 5.1 ha footprint	
United States	714 000 000	262 000 000	2.7	2.4	60%

This table shows that most industrialized countries run a significant ecological deficit. The last two columns represent low estimates of these per capita deficits. Even if their land was twice as productive as the world average (stimulated by significant fossil fuel inputs), European countries would still run a deficit more than three times larger than their natural capital income. Canada and Australia are among the few industrial countries that consume less than their domestic natural capital income. However, their natural capital stocks are depleted by exports of energy, forest and agricultural products, etc. In short, they accommodate ecological footprints of people in other high-consumption countries.

The table is calculated from FAO, 1994, 1995) and World Resources Institute (1994) data. Footprint sizes are inferred from studies by Hall et al. (1994), Infras (1995), Neumann (1994), Simpson et al. (1995), Wada (1995) and our own analyses, using mainly World Resources Institute (1994) data. Adapted from Wackernagel and Rees, 1995, p. 97.

global scale. All countries now face the same potentially limiting factors simultaneously (e.g., ozone depletion, exhausted fisheries, potential climate change) in a geopolitically uncertain world.

To summarize, for both individuals and entire economies, trade maximizes economic output and thereby accelerates natural capital depletion. Indeed, in some circumstances the liquidation of local stocks may seem advantageous, if not absolutely necessary, to maintaining growth and competitiveness. Thus, trade only appears to extend carrying capacity. In fact, by encouraging all regions to exceed local limits, by reducing the perceived risk attached to local natural capital depletion, and by simultaneously exposing local surpluses to global demand, uncontrolled trade eventually reduces global carrying capacity, increasing the risk to everyone (Rees and Wackernagel, 1994).

3.4. Efficiency

Many economists and environmentalists believe that advances in technological efficiency is a potential panacea for the global crisis. This follows Buckminster Fuller's reasoning of 'doing more with less' and contains the hidden assumption that efficiency gains lead to resource savings and reduced consumption. For example, Schmidheiny lauds the 50% energy efficiency gains by the chemical industry, forgetting that chemical production has doubled in the same period (Schmidheiny, 1992, p. 38). Also many official reports on environment and development (including the 1987 Brundtland report) chant what Sachs (1988, p. 33) has called "the gospel of global efficiency."

As effective as these strategies might seem on the micro scale, however, increasing the ratio between output and input does not necessarily lead to lower resource use. On the contrary, technological efficiency may actually lead to increased net consumption of resources.

Various authors have already recognized variations on this theme. *The Limits to Growth* team (Meadows et al., 1972) pointed out that a doubling of agricultural productivity would extend limits by only 20 years and leave future generations with a more intractable problem. Similar arguments are advanced in their 1992 follow-up study (Meadows et al., 1992, pp. 179–185). Lester Brown et al. (1991, p. 83) states that "continuing growth in material consumption — the number of cars and air conditioners, the amount of paper used, and the like — will eventually overwhelm gains from efficiency, causing total resource use (and all the corresponding environmental damage) to rise." For example, U.S. data show that despite the improving fuel efficiency of cars, aggregate fuel consumption is rising again (Fig. 5). Finally, *The Ecologist* observes that although energy use per dollar Gross National Product decreased by 23% in OECD countries between 1973 and 1987, total annual energy consumption by these countries increased by 15% between 1975 and 1989 (The Ecologist, 1992, p. 168).

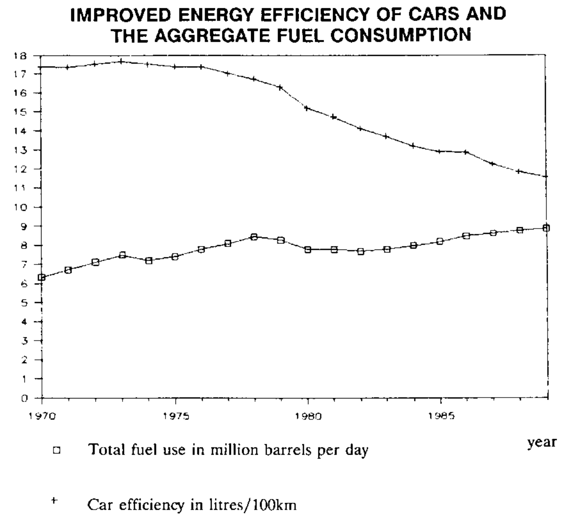

Fig. 5. American cars as an efficiency example. Efficiency improvements of the US American car fleet has not been able to reduce aggregate fuel consumption. It is an example of the efficiency improvements on the individual scale which accelerate resource throughput on the societal scale (data sources: MacKenzie, 1991, p. 7, Energy Information Administration, 1992, p. 53).

This should not come as a surprise. Economist Stanley Jevons argued as early as 1865 in *The Coal Question* that "it is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth" (Jevons, 1865, p. 140). He states that inefficient machinery consumes little, because the rate of consumption is too high and hence uneconomical (Jevons, 1865, p. 143). By contrast, "the reduction of the consumption of coal, per ton of iron, to less than one-third of its former amount, was followed, in Scotland, by a tenfold increase in total consumption, between the years 1830 and 1863, not to speak of the indirect effect of cheap iron in accelerating other coal-consuming branches of industry'' (Jevons, 1865, p. 154). The expansion effect in the total throughput of energy brought about by technical efficiency gains is probably valid for other resources too, as pointed out by the five following effects.

3.4.1. On the micro-level

• Improved energy or material efficiency may enable firms to raise wages, increase dividends, or lower prices, all of which may lead to higher net consumption. Similarly, technology-induced savings by individuals are usually redirected to other forms of consumption, canceling some of the initial gain. As Hannon (1975, p. 99) points out, the environmentally conscious ''traveller who [switches] from urban bus to bicycle would save energy (and dollars) at the rate of 51 000 Btu per dollar. If he were not careful to spend his dollar savings on an item of personal consumption which had an energy intensity greater than 51 000 Btu per dollar then his shift to bicycle would have been in vain.'' Most energy analysts have focused on these income and price effects, summarized under the name of 'the rebound effect' (Jaccard, 1991, p. 2).

3.4.2. On the meso (or regional) level

Typically, industrialized countries import the bulk of their energy, mostly in form of fossil energy. Such imports weaken local economies through the loss of direct spending (leakage) and the loss of the spending's re-spending (multiplier effect) (Davis, 1990, p. 11). By contrast, the money for both the energy-saving equipment as well as the amounts saved through improved energy efficiency will more likely be spent locally, thus stimulating the local economy.

3.4.3. On the macro-level

• Some of the money saved through efficiency gains is invested. Samuelson and Nordhaus (1985, p. 796) maintain that about 25% of the 2.3% annual average per capita growth of the US since 1900 can be attributed to capital growth. A higher GDP may result in higher net resource throughput even if the resource throughput per unit GDP declines. In fact, various studies reject the claim that GDP and energy consumption have ever been decoupled in industrialized countries (Cleveland et al., 1984, pp. 892–894, Costanza, 1980, pp. 1221–1224, Hall et al., 1986, pp. 51–59). Energy analyst Robert Kaufmann (1992, pp. 54–55) concludes that ''substitution and technical change have had relatively little effect on the amount of energy used to produce a unit of real GDP in France, Germany, Japan, and the UK during the post-war period. (..) [T]hese results imply that the link between economic activity and energy use is stronger than believed by most neoclassical economists.''

• Technical innovations account for the other 75% of GDP growth (Samuelson and Nordhaus, 1985), again contributing to increased aggregate resource throughput. Sanders uses various neoclassical growth models with energy and technology as separate factors of production to analyze the effect of efficiency gains, and comes to the conclusion that ''energy efficiency gains can increase energy consumption by two means: by making energy appear effectively cheaper than other inputs; and by increasing economic growth, which pulls up energy use'' (Sanders, 1992, p. 143).

• Technical efficiency gains that can improve returns to capital attract investment to the activity involved. Moreover, as Jevons long ago pointed out, ''the progress of any branch of manufacture excites a new activity in most other branches and leads indirectly, if not directly, to increased inroads upon our seams of coal'' (Jevons, 1865, p. 142). In other words, profitable efficiency gains contribute to upward-trending expectations of returns to capital, accelerated growth, and increased demand for resources. [9] Overall, innovation stimulated by competition generally accelerates global economic performance and with it, entropic throughput.

Ironically then, it is precisely the economic gains from improved technical efficiency that increase the rate of resource throughput. Micro-economic reality

[9] The profit rate defines the market value of capital. Investors are therefore not only interested in maximizing profits for direct gain, but also in securing capital from potential depreciation (Binswanger, 1991, p. 98).

demands that these efficiency gains be used to short-term economic advantage. Far from conserving natural capital or decreasing ecological footprints, this leads to higher consumption. In a globally interlinked economy, the question then becomes: Can we afford cost-saving energy efficiency? The answer is 'yes' only if efficiency gains are taxed away or otherwise removed from further economic circulation. Preferably they should be captured for reinvestment in natural capital rehabilitation.

4. Implications for investing in natural capital

The prime challenge for economic development is to meet present human needs "without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 8). Basic human needs are not only physical in nature, such as food, shelter, and health care, but also psychological, such as dignity and self-esteem, love and social connectedness, self-realization and control over one's life. In other words, decent human life presupposes some basic securities.

This paper started out by explaining why maintaining natural capital becomes the ecological bottom-line for securing decent human life. Maintenance of natural capital and its productivity requires investments. However, many forces detract today from investing in natural capital. And its depletion continues. The paper showed why monetary analyses are blind to this dilemma, and, by using various examples, argued for a biophysically based economics. For analyzing ecological constraints and their implications for human well-being, such an economics could be based on the ecological footprint

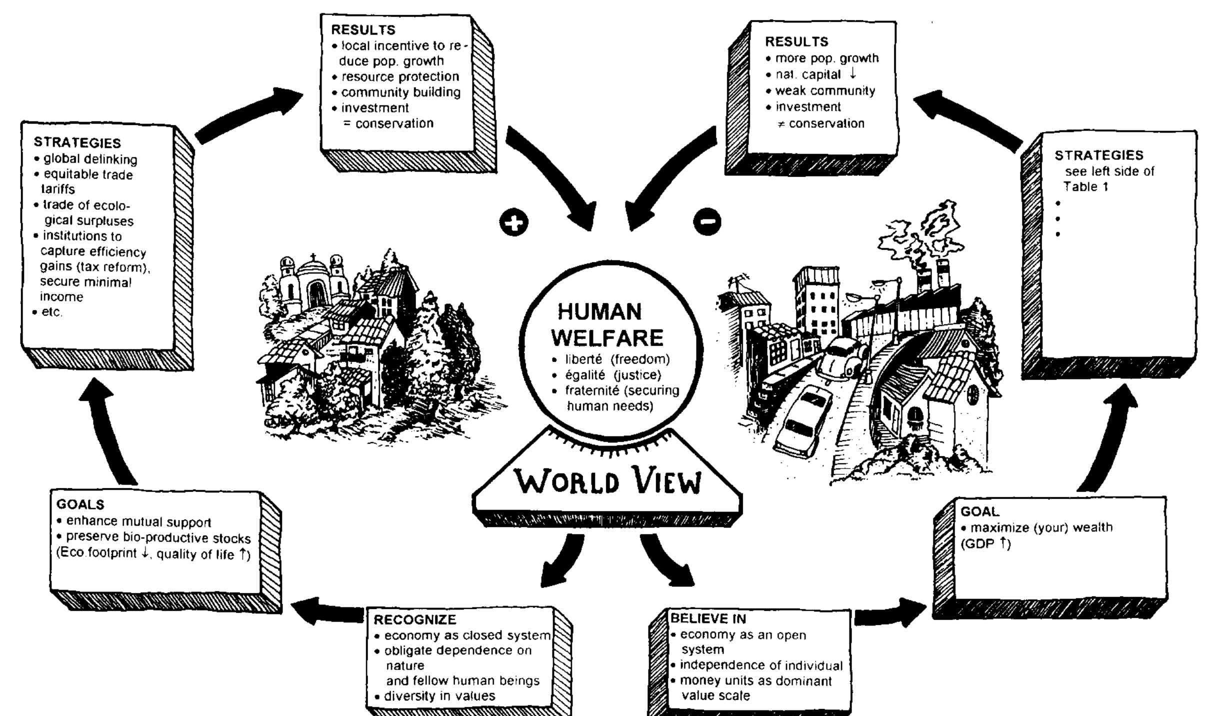

Fig. 6. Implications. Either we continue on our current unsustainable path (circle on the right), or we recognize that we need to change it (circle on the left). However, most policies which would lead to a sustainable future remain politically unacceptable if not heretical (Iliana Pámanes).

perspective. Only with economic theories that are grounded in an understanding of biophysical flows, and of stocks necessary to secure these flows, will we be able to accept the economic necessity to invest in natural capital, and by that maintain its capacity.

The question then becomes how we will be able to provide these basic securities for human survival. We face a difficult choice (see Fig. 6):

Either we continue on our current path...: The dominant world view assumes an open economy independent of nature, that human beings are selfish atoms devoid of social relationships, and that all values are commensurate on a unidimensional monetary scale. From this perspective, the appropriate strategy to meet human needs is to maximize individual wealth and strive for Pareto efficiency at the societal level. Our contemporary role models are the competitively and materially successful, our heroes those people who contribute most to the country's GDP. Appropriate economic policies and strategies for maximizing individual wealth can be found in any standard economics textbook (e.g., Lipsey et al., 1988; Samuelson and Nordhaus, 1985).

Unfortunately, as this paper with its ecological footprint approach shows, prevailing economic logic and development strategies discourage investment in natural capital. Indeed, economic globalization deepens the alienation between humankind and nature and, through the destruction of community, among human beings themselves. Current development patterns reinforce the primacy of human-made capital over natural capital because the former 'reproduces' faster than the latter. Investment has become the opposite of conservation and ultimately threatens human welfare. People everywhere are faced with a complex paradox: the dominant strategy promises to enhance human welfare, but increasingly seems responsible for eroding it.

... Or we recognize the need to change direction: By contrast, the ecological world view recognizes that the human economy operates *within* the ecosphere, a thermodynamically closed system powered (nearly) exclusively by 175 000 TW of low entropy solar energy, that human beings live in obligate dependency on nature as well as on each other, and that market prices cannot be the sole criterion for value or necessity (and are particularly unreliable as the signal of ecological scarcity). From this perspective, providing the biophysical and social security necessary for human life requires development strategies that preserve the Earth's bioproductive stock and the life-support services it delivers, and which reinforce a sense of human community. Our role models should be the socially committed and our heroes those who enrich the potential of human life on as little appropriated carrying capacity as necessary. Corresponding strategies include a development framework that emphasizes the need for investment in natural capital and in new social institutions for strengthening community life and related mutual support mechanisms. In much of the world a necessary corollary would be to devolve significant control over local resources to resident populations. Indeed, any significant change of direction would likely be accompanied by some degree of global de-linking.

While there are today no practical examples of formal comprehensive development programs incorporating these qualities, it is certainly possible to speculate on the form they might take (Daly and Cobb, 1989; Milbrath, 1989). Rees (1992c) outlines some basic elements of a strategy to restore ecological balance and social equity to global development. The emphasis is on reducing humanity's ecological footprint and industrial countries' appropriation of the global commons (see also Goodland and Daly, 1993). The following components are particularly relevant to the theme of this paper:

- A reassertion of community and social values and responsibilities to restore balance with the present emphasis on individual rights. This would be accompanied by greater appreciation of cooperative activity to balance industrial society's current worship of competitive behavior.
- A shift from the present emphasis on global economic integration and inter-regional dependence toward greater regional autonomy and self-reliance (if all regions were in ecological steady-state the aggregate effect would be global stability). The well-developed models of bioregionalism provide a useful conceptual starting point.
- Negotiation of a General Agreement on the Integrity of (Ecological) Assets (a *GAIA* agreement) to regulate economic activities affecting the global life support system, including patterns of commercial trade in ecologically significant commodities. Such

an agreement would set the ecological 'bottom line' for such instruments as the GATT/WTO and might include...

· An international framework of regulatory and economic incentives to ensure that commodity trade flows are based on sustainable ecological surpluses and a policy of no net loss of natural capital stocks (i.e., sustainable rates of supply) rather than on global market demand.

Related policy measures include: formalizing agreements to ensure fair trade in carrying capacity (Rees, 1992b); establishing selective international barriers to capital movement as proposed by Tobin (Ekins et al., 1992, p. 150); and implementing natural capital depletion taxes to stimulate conservation and capture efficiency gains (Costanza and Daly, 1992; von Weizsäcker, 1994). In the social, sphere a guaranteed minimum income (or other alternative form of entitlement) could significantly lower resource consumption by meeting basic security needs without everybody having to amass excessive personal wealth.

Any successful alternative development path would both protect essential natural capital and improve net social welfare. Most importantly, it would remove the conflicts between individual and social well-being. The fact remains, however, that no such alternative strategy is yet on the agenda of any major government or opposition party. Current political practice entrenches the current development path. Indeed, the very integration of the global economy mitigates against any individual country adopting the ecological alternative: the marginal global benefits resulting from one nation's restraint would quickly be dissipated by non-cooperating countries, all of which have open access to the ecosphere.

Such is our present dilemma: politically acceptable policies for sustainability would be ecologically ineffective, while ecologically meaningful policies remain politically impossible (if not heretical). This situation is likely to remain as long as social schizophrenia and denial outweighs public awareness that our current mode of living is self-destructive. Only widespread agreement that the situation is serious will induce the value changes and political will required to enable humanity to exit our developmental cul-de-sac with dignity.

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