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Ecosystem services: The economics debate

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ABSTRACT

The goal of this paper is to illuminate the debate concerning the economics of ecosystem services. The sustainability debate focuses on whether or not ecosystem services are essential for human welfare and the existence of ecological thresholds. If ecosystem services are essential, then marginal analysis and monetary valuation are inappropriate tools in the vicinity of thresholds. The justice debate focuses on who is entitled to ecosystem services and the ecosystem structure that generates them. Answers to these questions have profound implications for the choice of suitable economic institutions. The efficiency debate concerns both the goals of economic activity and the mechanisms best suited to achieve those goals. Conventional economists pursue Pareto efficiency and the maximization of monetary value, achieved by integrating ecosystem services into the market framework. Ecological economists and many others pursue the less rigorously defined goal of achieving the highest possible quality of life compatible with the conservation of resilient, healthy ecosystems, achieved by adapting economic institutions to the physical characteristics of ecosystem services. The concept of ecosystem services is a valuable tool for economic analysis, and should not be discarded because of disagreements with particular economists' assumptions regarding sustainability, justice and efficiency.

1. Introduction

One of the most basic laws of physics is that it is impossible to create something from nothing. All economic products result from the transformation of raw materials provided by nature. Furthermore, it is impossible to create nothing from something. All human-made products eventually break down, wear out and fall apart, returning to the ecosystem as waste (Georgescu-Roegen, 1971). The extraction of raw materials from nature and the return of disordered waste are known as throughput (Daly, 1977). We also know from physics that the transformation of raw material inputs into economic products and waste requires low entropy energy, irreversibly converted through use into high entropy waste. Finite stocks of fossil fuels account for nearly 90% of all energy used for economic production (International Energy Agency, 2011), creating steady flows of carbon dioxide and other pollutants into the atmosphere. Society controls the rate at which fossil fuels are extracted, and hence the flow of waste into the ecosystem from their combustion.

Many of the raw materials physically transformed into economic products (e.g. plants, animals, water, minerals and so on) alternatively serve as the structural building blocks of ecosystems. Like fossil fuels, society can largely determine how fast to deplete available stocks. For example, we can clear cut a million-tree forest in one year, or harvest 100,000 trees a year for 10 years. This means that we can stockpile ecosystem structure. If we refrain from cutting down trees for a decade, we have more trees available at the end of the decade.

A healthy ecosystem emerges from a particular configuration of ecosystem structure. Ecosystems function as a fund capable of generating a flux of ecosystem services over time. Ecosystems are not physically transformed into the services they generate, society has little control over the rate at which a fund generates services, and services cannot be stockpiled. For example, a forest is not physically transformed when it purifies water and regulates flooding. A given forest can purify or regulate only a limited amount of water per period of time. If there is no rainfall for a month or if humans refrain from using water purification and flood regulation for a month, more services are not available at the end of the month (Malghan, 2011). Note that much of the literature treats many provisioning services as a stock of raw materials (Fisher et al. 2008; Millennium Ecosystem Assessment, 2005). By the definition proposed here, however, provisioning services are the reproductive capacity of ecosystems. Plants and animals are only capable of reproducing at a given rate over time, are not physically transformed into their offspring (except for the material in the seed, egg, or newborn), and reproductive capacity cannot be stockpiled (Farley and Costanza, 2010).

When ecosystem structure is converted into economic products and the resulting waste returned to the ecosystem, often in

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novel forms to which ecosystems have not had an opportunity to adapt, ecosystem services are affected. Economic production unavoidably affects the provision of ecosystem services.

Economics is frequently defined as "the study of the allocation of limited, or scarce, resources among alternative, competing ends" (Daly and Farley, 2010, p. 3). This definition does not presuppose market mechanisms. One of the central challenges in economics is to determine how much ecosystem structure should be converted into economic products, and how much left intact to generate ecosystem services. Before society can decide how to answer this question, however, it must prioritize the desirable ends, and must also have a firm understanding of the nature of the scarce resources.

These three issues — the desirable ends of economic activity; the nature of ecosystem services and particular configuration of ecosystem structure that gives rise to them; and the question of how to allocate — have given rise to a number of important debates on the economics of ecosystem services. The goal of this article is to illuminate these debates. The article is organized around three desirable ends that are taken as axiomatic: sustainability, justice and efficiency.

Desirable ends are ultimately normative value judgments. Sustainability assumes that we have ethical obligations to future generations. Certainly few people would argue that we have no such obligations, or that sustainability is not a high-order desirable end. Philosopher John Rawls argued that "Justice is the first virtue of social institutions, as truth is of systems of thought" (Rawls, 1999, p. 3). Increasing evidence suggests that people have an innate concern for justice and fairness, and that high levels of inequality strongly correlate with a range of health and social problems (Wilkinson and Pickett, 2009). Furthermore, it is difficult to defend justice towards unborn future generations (i.e. sustainability) without concern for justice towards the current generation. While there is considerable debate about what constitutes justice, few would argue that justice is not important. Finally, given finite resources and unmet needs, it is important to use resources efficiently to satisfy both needs and wants. Virtually all economists accept the importance of efficient allocation. Sections 2–4 will describe the debates surrounding these goals, followed by some brief conclusions.

2. Sustainability

Sustainability has two central components. First is ecological sustainability, loosely defined here as the capacity of ecosystems to remain diverse, resilient and productive over time, and to maintain the flow of ecosystem services essential for humans and other species. We must of course recognize that ecosystems, including their human components, are inherently complex, adaptive, and continually evolving systems (Liu et al., 2007). It is highly unlikely that human activity could destroy planetary ecosystems in any meaningful sense, but it could lead to dramatic reconfigurations that lead them to flip into alternate states.

A related component is economic sustainability, loosely defined as the capacity of an economic system — at any scale from individual households to the global economy — to remain diverse, resilient and productive over time. Some ecosystem services are essential to human welfare, and their loss could have unacceptable economic impacts. For example, agriculture and civilization evolved during the Holocene, a geographic era characterized by an unusually stable climate. We have now entered the Anthropocene, an era in which the impacts of human activities on ecosystems are on the scale of geological forces (Crutzen, 2002). Anthropogenic climate change is a threat to both ecological and economic sustainability (Battisti and Naylor, 2009; IPCC, 2007a), but the loss of other ecosystem services may pose dire threats to the economy without threatening a dramatic reconfiguration of global ecosystems. For example, drugs used on sick cattle that are lethal to the vultures threaten India and Europe's vultures with extinction (Lemus and Blanco, 2009; Proffitt and Bagla, 2004). Vultures' consumption of carrion is an important disease regulation service (Markandya et al., 2008), and their elimination could hypothetically result in a catastrophic global pandemic that fundamentally disrupts human civilization with otherwise relatively minor impacts on global ecosystems. Alternatively, individual households or small communities may depend on local ecosystem services such as water purification, disturbance regulation, or pollination. Ecosystems may be disrupted in such a way that the generation of these specific services is disrupted for long enough to destroy the economies that depend on them, even if the ecosystem itself remains resilient and eventually recovers.

There are at least three closely related central debates concerning the relationship between economics, ecosystem services and sustainability. The first is whether or not some ecosystem services are essential to human welfare and have no substitutes on the scale required to sustain civilization in their absence. This is known as the strong vs. weak sustainability debate (Ekins et al., 2003b; Neumayer, 2003). The second is over the existence of ecological thresholds, beyond which positive feedback loops will lead ecosystems to flip into alternative states potentially far less conduce to human welfare, and how close we might be to such thresholds (Meadows, 2008; Muradian, 2001). These thresholds present limits to marginal analysis, the dominant tool of conventional economics (Farley, 2008b). The third debate is whether or not ecosystem services impose limitations on endless economic production, either because we must conserve enough ecosystem structure to sustain them, which reduces the amount available for conversion to economic products, or else because losing critical ecosystem services will result in an end to growth (Daly, 2007; Meadows et al., 2004).

2.1. *Strong vs. weak sustainability*

Probably the most widely cited description of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987). This is widely interpreted by economists as the need to leave the future no less capital (defined as a stock that provides a flow of benefits over time) per person than the current generation enjoys.

Proponents of weak sustainability believe that natural capital (the goods and services provided by nature) and human made capital (including built, human and social capital) are substitutes. The current generation can leave the future any combination of different capitals as long as the total value of the capital passed on is non-declining (Pearce and Turner, 1990). As a result, many economists believe that natural resources play a negligible role in economic output (Dasgupta, 2008). From this perspective, all resources have substitutes. Schelling, the winner of the Nobel Memorial Prize in economics, argues that "agriculture and forestry are less than 3% of the total output, and little else is much affected [by climate change]. Even if agricultural productivity declined by a third over the next half century, the per capita GNP we might have achieved by 2050 we would still achieve in 2051" (Schelling, 2007). Even food is substitutable.

Proponents of strong sustainability in contrast believe that natural capital and human made capital are rarely substitutes and often complements. Ecosystem services are essential to the survival of humans and all other species. No amount of human made capital can fully replace them (Costanza et al., 1991;

Costanza et al., 1997b; Daly and Farley, 2010). Natural capital stocks that generate essential ecosystem services are known as critical natural capital (CNC) (Ekins et al., 2003a). We do not however always know what elements of natural capital are critical, and what elements can be lost without seriously reducing human welfare (Farley, 2008b). Aldo Leopold argued that we should in fact treat all natural capital as critical: “If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering.” (Leopold, 1993, pp. 145–146). If this is true, then the debate over whether we should adopt an anthropocentric or biocentric world view is moot: humans depend on the deeply interconnected web of biodiversity for their own survival, and we must protect other species to protect ourselves.

If strong sustainability holds, two basic rules apply. First, humans cannot degrade or deplete any element of ecosystem structure (e.g. fish, forests, or fresh water) faster than it can restore itself without eventually crossing some threshold beyond which that component of the structure is gone (e.g. a tree species goes extinct), or else the ecosystem as a whole crosses an irreversible threshold (e.g. the forest losses the capacity to regenerate). As a corollary to this rule, enough structure must be left intact to maintain the flux of ecosystem services upon which humans depend. Second, humans cannot emit waste into any finite system at rates greater than it is absorbed, or else waste stocks will accumulate, causing increasing harm to humans and the ecosystem. Unfortunately, economists’ and decision-makers’ failure to acknowledge the importance of natural resources has led us past these limits (Daly, 1990). It is now essential to reduce resource extraction below regeneration rates and waste emissions below absorption rates until stocks are restored to levels compatible with ecological and economic sustainability.

2.2. *Marginal analysis and thresholds*

Another important debate concerns the existence of ecological and economic thresholds, and hence the limits of marginal analysis. Conventional economic analysis is based on the evaluation of very small (marginal) changes in economic costs and benefits. Complex systems, including coupled human–natural systems, are characterized by high levels of non-linearity, emergent phenomena and surprises (Liu et al., 2007). A threshold, or phase transition, is a sharp boundary that delimits qualitatively different configurations of a system. When a system crosses a threshold, a very small change in economic activity can have enormous impacts. Crossing such thresholds can lead to the irreversible loss of critical natural capital (CNC), with unacceptable costs to society (Meadows, 2008). In the vicinity of thresholds, marginal analysis is inappropriate (Farley, 2008b).

There is overwhelming theoretical and empirical support for the existence of ecological and biological thresholds. Phase transitions in mathematical or computer models of dynamic complex systems are very common. Such systems may fluctuate around an attractor, a set of qualitatively similar configurations. Small perturbations may lead the system away from the attractor, but when they are removed, it returns. A large enough perturbation however can lead the system away from one attractor basin and towards another that is qualitatively different (Kauffman, 1995; Meadows, 2008).

Potentially critical global ecological thresholds include climate change, biodiversity loss, deforestation and so on. As long as green house gasses are emitted into the atmosphere faster than they can be absorbed by ecosystems, atmospheric stocks will accumulate, likely exacerbating climate change. A threshold in this case might be caused by positive feedback loops, when reduced albedo from melting ice or increased methane emissions from thawing tundra leads to additional warming that causes more ice melt and methane release. At this point, even eliminating anthropogenic emissions may fail to reverse the positive feedback loop, and the climate may move towards a different configuration that is less suitable for agriculture and hence human civilization (IPCC, 2007b).

Specific ecosystems may also confront thresholds. The Amazon forest currently recycles an estimated 50% of its rainfall when rain evaporates from trees or evapotranspiration transfers soil moisture into the air. When enough tree cover is removed, rain may strike bare ground and flow rapidly into the rivers, where it is flushed from the system forever. Eventually, there may be too little rainfall to sustain the forest, leading to further depletion by drought and fire, and greater drying. Brazil’s Atlantic forest is 93% deforested, and it may already have passed a critical ecological threshold. Biologists and ecologists expect a significant decline in biodiversity that will work itself out over decades to centuries, with potentially profound impacts on the ability of the ecosystem to reproduce itself. The loss of forest may also lead to drying out of the climate and increasing forest fires that threaten forest remnants (Farley, 2008a).

Individual species confront thresholds in terms of minimum viable populations. For example, passenger pigeons, once the most abundant bird species on the planet, depended on huge colonies for successful reproduction. Once colonies fell below some critical size, their natural mortality rates might have exceeded their reproduction rates even if hunting and habitat destruction had halted, leading to their inevitable extinction (Firth and Blockstein, no date). The loss of keystone species may lead to a cascade of extinctions (Curtsdotter et al., 2011), and the loss of enough critical species could potentially lead to a major extinction event.

It may be impossible to know ahead of time exactly where an ecological threshold lays, what will be the implications of crossing it, and how long it will take for those implications to reveal themselves. We do not know what level of climate change will lead to runway feedback loops, what new climate equilibrium might emerge, and when it will be reached. No one predicted ahead of time that passenger pigeons would go extinct. Scientists now think that passenger pigeons may have provided important disease regulation services. The lack of competition for acorns from passenger pigeons may have led to a surge in mouse and deer populations, in the tick populations that fed on these mammals, and in the spirochete populations hosted by the ticks, resulting in an epidemic of Lyme disease 100 years after the extinction of the bird (Blockstein, 1998). This uncertainty makes it difficult to determine when marginal analysis ceases to be appropriate.

Relevant economic thresholds can be treated as physiological thresholds, the failure to satisfy basic needs. They occur when the economic unit — from household to global economy — cannot reproduce or even maintain itself, resulting in death or collapse. Economic thresholds are affected by ecosystem services associated with food provision, water provision and purification, disease regulation and disturbance regulation, among others. The economy may cross a critical threshold, even if the ecosystem itself does not: an extensive drought could destroy a civilization without otherwise doing irreversible damage to an ecosystem. As is the case with ecosystems, humans are resilient. We can fall below the minimum number of calories to sustain life for a long time and recover when more calories become available. However, living close to thresholds can make us highly susceptible to exogenous shocks, such as disease.

In economics, supply and demand curves are based on marginal analysis. A supply curve is a graphical depiction of marginal costs, while a demand curve depicts marginal benefits; benefits and costs are respectively positive and negative values. Value is typically measured in terms of opportunity costs, or trade-offs: what must be sacrificed when the quantity of CNC declines by one unit? Economists define a resource as abundant when there is enough for all desired uses, and hence no competition for use. Probably few ecosystems enjoy this status. When ecosystems are far from ecological or biological thresholds, ecosystem structure can be allocated towards relatively unimportant benefits. As the stock of CNC declines, however, we must forgo increasingly important benefits, including resilience, the ability of the system or human populations to recover from exogenous shocks (e.g. a drought that reduces food production or ecosystem regeneration). As the system nears ecological or biological thresholds, its marginal value will climb rapidly. A small percentage drop in quantity leads to a large percentage increase in marginal value. On the border of the threshold (which is unknown and potentially unknowable in advance) a marginal loss of ecosystem structure can lead to the loss of life sustaining benefits, or of the ability of the ecosystem to restore itself. We have left the domain of marginal value, and moved into the domain of total value, which is perhaps best illustrated by the diamond–water paradox. Diamonds have a high marginal value because they are scarce, but the world would suffer little if they disappeared. Total value is low. Water has a low marginal value because (in many parts of the world) it is not very scarce, but if it disappeared even for one week, we would quickly realize that its total value is infinite. Fig. 1 depicts a demand curve for CNC measured in terms of physiological or ecological values.

This analysis of course assumes the existence of CNC. Marginal values only rise precipitously for resources that are essential and non-substitutable. Demand for such resources is said to be inelastic. Demand becomes perfectly inelastic at the biological or ecological threshold, when access to an additional unit of the resource is essential for survival. If in contrast we can find a limitless substitute for any type of natural capital, known in economic jargon as a back-stop technology (Dasgupta and Heal, 1979), its marginal value cannot exceed the price of the substitute, and marginal analysis remains appropriate.

2.3. Limits to physical growth

The third sustainability debate centers on limits to growth. If the economy is a physical system, then economic production must remove resources from nature and return waste. Continuous exponential growth of any physical sub-system of a finite system is impossible. As Kenneth Boulding reputedly stated, "anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist." The strong sustainability paradigm, the existence of ecological and biological thresholds, and our high levels of ignorance suggest that we may reach and even surpass limits without realizing it. Many scientists believe we have already crossed critical thresholds, and have a narrow window of opportunity to engage in extensive restoration before it is too late. Critics of the belief in limits to growth generally argue that Malthus has been disproven, and new technologies will overcome all resource constraints (Diamandis and Kotler, 2012; Simon, 1996). Perhaps the central debate concerns the burden of proof: should we pursue growth until we have proof that it leads to ecological and economic collapse, or should we conserve nature until we have proof of technological substitutes at the necessary scale?

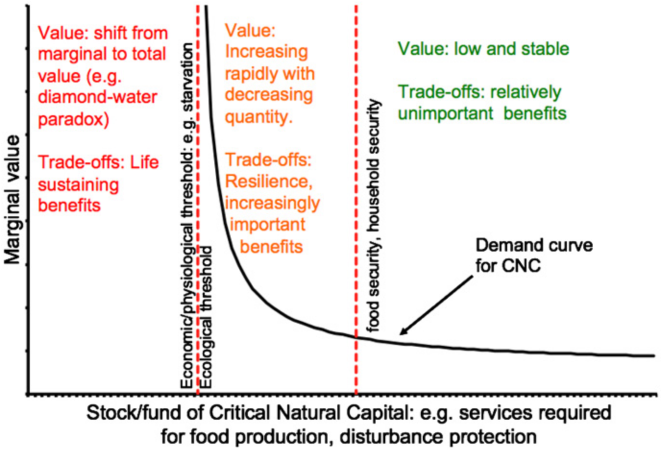

Fig. 1. The ecological/physiological demand curve for critical natural capital.

A limit to physical economic growth does not necessarily imply a limit to improvements in human welfare or quality of life, which is generated by the fulfillment of a variety of different human needs (Costanza et al., 2007). However, a singular focus on economic growth may come at the expense of fulfilling other human needs that would make a greater contribution to quality of life.

3. Justice

Distributive justice — the proper allocation of resources among groups and individuals — is particularly important in economics. In the case of ecosystems services, justice concerns entitlements to both the structural building blocks of ecosystems and the services they generate. The two of course are frequently in conflict. If one individual has the right to the timber in a forest, this may conflict with the right of another individual to enjoy the water purification, flood regulation, climate regulation and other services provided by that forest. The economic debate in ecosystem services focuses largely on how to reconcile this conflict.

3.1. Biological demand and utility maximization

There is a long history in economics, emerging from utilitarianism, of a consequentialist approach to justice: distributive justice is determined by whatever generates the best outcome for society (Mill, 1871).

Measured in physiological terms as discussed in Section 2.2, CNC is likely to be much more valuable to the poor than to the rich, especially at the local level. When a stock of CNC passes a threshold locally, substitutes from other areas may still be available. For example, if the ecosystem is no longer capable of providing food and water, or of regulating diseases, it is possible to bring in food and water from other regions (or purify water by filtration or boiling) and purchase medicines against disease. If eroded barrier islands and damaged wetlands no longer offer adequate protection against storm surges and hurricanes, it is possible to build more fortified and elevated buildings, or to flee an advancing storm and relocate to a different area. However, such substitutes require purchasing power, and are likely to be more available to the rich than the poor. They may in fact be completely inaccessible to the poor, as we saw in the case of Hurricane Katrina, when the rich fled the city while many poor (by US standards) suffered and died. Fig. 2 depicts differing biological demand curves for local CNC for the rich and the poor. Many local ecosystem services are not in fact invaluable to the rich, and hence not critical. Their maximum marginal value is limited by the existence of adequate substitutes, so called back-stop technologies.

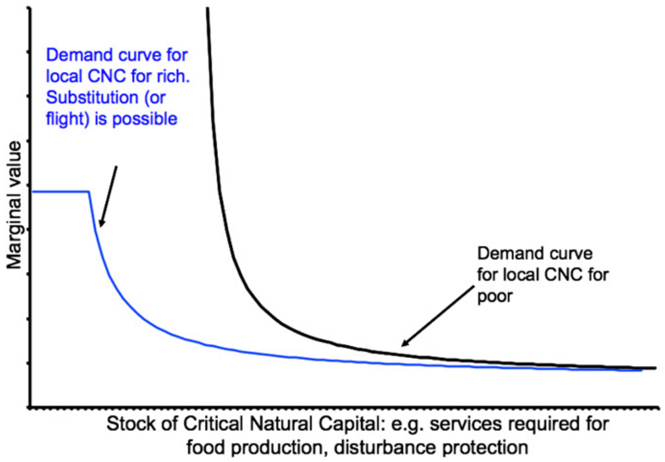

Fig. 2. The demand for local critical natural capital for the rich and for the poor.

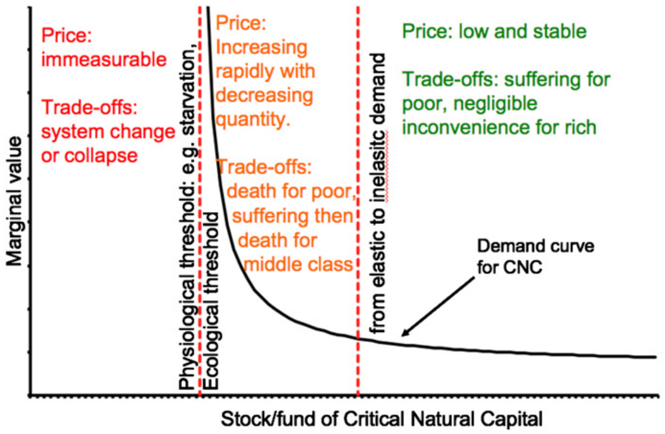

Fig. 3. The market demand curve for CNC in an economy characterized by an unequal distribution of purchasing power.

From the consequentialist perspective, allocation decisions relevant to ecosystem services should give greater weight to the preferences of those who depend the most upon them, which will generally be the poor, who cannot afford substitutes.

3.2. *Shared inheritance and equal rights for all*

Economists also frequently argue for the notion of just deserts: we are entitled to what we produce with our own labor, capital, and entrepreneurial ability. However, ecosystem services and ecosystem structure were not produced by human effort, but are rather our shared inheritance from nature, to which everyone is entitled an equal share (Barnes, 2006). In the case of ecosystem services that cannot be privately owned, this would translate into an equal say for all in allocation decisions concerning ecosystem services. This implies a democratic decision making process.

Note that conventional economists typically treat the loss of ecosystem services as a negative externality of the use of ecosystem structure and resulting waste emissions. A negative externality occurs when an action by one party causes an unintended loss in welfare to another party, and no compensation occurs. If decisions concerning economic activities are made democratically by all those who benefit from the ecosystem services affected by the decision, by definition there can be no externalities. For example, society could cap the conversion of ecosystem structure then auction off use rights to individuals, with resulting revenue dedicated to the common good. The associated loss of ecosystem services would also affect society as a whole, which would therefore naturally strive to balance costs with benefits.

3.3. *Market demand and willingness to pay*

Finally, economists frequently take a property rights approach to distributive justice, arguing that whatever distribution emerges from voluntary transactions (e.g. market transactions) is just. The initial distribution of wealth, power and resources prior to the voluntary market transactions is typically considered the domain of other disciplines or other social institutions (e.g. the political system) or else assumed to be just. This is perhaps the most prevalent economic perspective.

There are two ways this plays out in practice: the monetary valuation of ecosystem services based on estimates of willingness to pay (e.g. through contingent valuation, hedonic pricing, travel cost, etc.) and the use of market based instruments for allocation decisions concerning ecosystem services. Both approaches are based on market demand curves, estimated or actual. Market demand is determined by preferences weighted by purchasing power. The preferences of the wealthy are weighted heavily, and the preferences of the destitute are virtually ignored. The willingness to pay approach is virtually the opposite of the consequentialist approach. To reconcile the two, one must assume either that it is impossible to compare utility between different individuals (discussed below), or that poor people are inconsequential.

Fig. 3 depicts a market demand curve for CNC. It looks the same as the ecological/physiological demand curve depicted in Fig. 1, but the story behind it is somewhat different. The ecological/physiological demand curve is based on objective physiological or ecological necessities. As the supply of critical ecosystem services diminishes, people stop allocating the resources towards less important wants in order to meet critical needs, driving marginal values steeply upwards. A market demand curve in contrast is inherently subjective because it depends on purchasing power. As the quantity of CNC diminishes, physiological demand remains the same for rich and poor, but the rich outbid the poor for access to the diminished resources. When inequality is high, satisfaction of minor wants for the rich take precedence over basic necessities for the poor. In other words, market economies characterized by high levels of inequality stop allocating CNC towards the people it implicitly deems least important, the poor.

Examples of the market approach of course abound, for marketed as well as non-marketed ecosystem services. Grain prices doubled to tripled between 2006 and 2007 in response to an increase in demand for biofuels, a small decrease in supply, and speculation. Another bubble is predicted in 2013 (Lagi et al., 2012). Most people in wealthy nations hardly noticed. Wholesale wheat prices account for perhaps $0.10 in a $2.00 loaf of bread,[1] and food expenditures account for less than 15% of income. When grain prices triple, food costs in a wealthy nation might increase by 10%, which is less than 2% of income. Demand is almost unaffected. For poor people in poor countries, grains account for a much higher share of domestic food purchases, and food expenditures can account for 50% of income. Tripling grain prices might double food costs. As a result, wealthy societies continue to waste large quantities of grain (Gustavsson et al., 2011) at the same time

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[1] A 60 lb. bushel of wheat sold for $7.79 in March, 2012 (http://www.indexmundi.com/commodities/?commodity=wheat), or a bit over $0.10/lb. According to the US Bureau of Labor Statistics, a 1 lb loaf of whole wheat bread averaged $2.044 in February, 2012 (http://www.bls.gov/ro3/apmw.htm).

that rising prices cause increasing malnutrition and worse among the poor (AAH, 2009).

While society largely accepts this approach to distribution for market goods and services, it does not automatically follow that we should take the same approach for the distribution of ecosystem services. The inhabitants of the best-preserved ecosystems that generate the most important services are frequently not part of the market economy, and rely on alternative economic institutions with different concepts of value. Justice also concerns the distribution of power, and we must question the right of market nations to impose their definition of value on other cultures.

A property rights approach also raises serious issues because property rights to ecosystem services rarely exist, and in many cases it would be impossible to create individual property rights, particularly for regulating services.

4. Efficiency

Given finite resources and unmet needs, efficiency is a central issue in economics. In general, efficiency implies maximizing some desired output (e.g. quality of life, monetary value) obtainable from the available inputs required to produce it (e.g. natural capital, labor, energy, etc.), or minimizing the costs required to achieve a desired goal. Economic institutions can be evaluated by how efficiently they allocate resources. However, there are different types of allocation problems, and economic institutions that allocate resources efficiently (however defined) for one type of problem may be inefficient for another type of problem. Specific definitions of efficiency, often based on specific definitions of value, can therefore lead to dramatically different policy recommendations.

This article addresses two types of efficiency and two types of allocation. Pareto efficiency is defined as a situation in which no other allocation of resources could make at least one individual better off without making anyone else worse off, where 'better off' and 'worse off' are defined explicitly in terms of monetary value. The other type of efficiency is less rigorously defined, but focuses on the greatest level of quality of life that can be achieved while restoring the damaged ''cogs and wheels'' of the global ecosystem, and hence is dubbed here ecological economic efficiency (EEE). As described in the introduction, we confront a macro-level allocation problem focused on the apportionment of ecosystem structure between economic products and ecosystem services. We also face a micro-level allocation problem that concerns the apportionment of natural resources, labor and capital among different market products, and those products among different consumers.

4.1. *Pareto efficiency, monetary value and the commodification of nature*

Conventional economists focus primarily on Pareto efficiency and micro-allocation. Under a number of restrictive assumptions about human behavior, resource characteristics, and existing institutions, it can be shown mathematically that voluntary exchange in free markets is Pareto efficient. Subject to the existing distribution of purchasing power, a Pareto efficient allocation maximizes economic surplus, a monetary measure of net benefits to consumers and producers. Free markets achieve this through the price mechanism, which allocates raw materials towards those firms and industries willing to pay the most for them, maximizing monetary value on the production side; it then allocates market goods and services towards those consumers willing to pay the most, maximizing monetary value on the consumption side.

For the price mechanism to function, all factors of production and all economic products must be market commodities. However, many ecosystem services are non-excludable, which means that one person or group cannot use the resource while preventing others from doing so. Since use of a non-excludable resource cannot be made contingent upon payment, no one is likely to pay for the resource, nor factor the social costs of using the resource into their decisions. Decisions regarding non-excludable resources are external to market logic, and impacts on them are referred to as externalities. For non-excludable resources that are also rival (i.e. depleted through use) or degraded by excessive throughput, the typical result is unsustainable overuse; unjust distribution based on first come, first served; and inefficient exploitation that fails to maximize monetary value. This dynamic is in fact largely responsible for the global loss of the ecosystem structure that generates ecosystem services, and for excessive waste emissions, including greenhouse gasses (Hardin, 1968).

Most market economists believe that ecosystem services and the ecosystem structure that generates them should be integrated into the market system in order to achieve Pareto efficient outcomes. This requires that they be treated as market commodities, either by estimating their monetary value and including that signal in market prices or decisions, or else by making the resources excludable commodities subject to market allocation. The principles that guide micro-allocation can then be used to solve the macro-allocation problem as well.

4.1.1. *Monetary valuation of non-excludable resources as an approach to commodification*

There are numerous methods for estimating the monetary value of ecosystem services, which have been discussed so extensively in the literature that there is no need to describe here either the methods or the extensive debate over their replicability and accuracy (e.g. Costanza et al., 1997a; Daily and Ellison, 2002; Michael Getzner et al., 2005; Pearce and Turner, 1990). Most monetary valuation efforts however implicitly take sides in the sustainability and justice debates described in Sections 2 and 3. First, valuation implies either weak sustainability or a safe distance from ecological thresholds. The fact that monetary values are exchange values certainly implies some degree of substitutability or non-essentiality. If strong sustainability holds true and the ecosystem service in question is near an ecological threshold — and a growing number of studies suggest that many ecosystem services, ranging from climate regulation to fisheries production, are indeed in a critical state (IPCC, 2007c; Millennium Ecosystem Assessment, 2005; Rockstrom et al., 2009; Worm et al., 2006) — then demand will be highly inelastic, and we would expect large changes in monetary value in response to small changes in quantity. Even when systems appear relatively far from threshold, the accumulative impact of thousands of isolated and decentralized marginal decisions to extract more resource or emit more waste quickly add up to non-marginal changes, and can rapidly bring a system to steeper part of the demand curve. Any claims for the efficiency of including monetary values into market decisions must account for the costs of continually re-estimating the change in value and adjusting the relevant policies. If the system has already passed an ecological threshold or is likely to do so, then the value of the ecosystem service would be immeasurably high, and could not be integrated into price signals. Second, valuation implies the property rights approach to justice, as most valuation methods are based on willingness to pay.

4.1.2. Integrating non-excludable resources into markets

Another approach to the commodification of nature is based on the Coase Theorem. Economist Ronald Coase argued that in the presence of well-defined property rights and zero transaction costs, voluntary bargaining could efficiently solve the externality problem without government intervention. Furthermore, the results would be the same regardless of the initial assignment of property rights, unless there are wealth effects that would prevent one actor from compensating the other for harm done or rewarding the other for benefits received (Ronald, 1960).

For some currently non-excludable ecosystem services, such as waste absorption capacity, it is possible to create public or private property rights that make them excludable by regulating access. Many critical ecosystem services ranging from climate regulation to disturbance regulation are inherently non-excludable: if the service exists, it is impossible to prevent those in the service shed (i.e. the geographical area affected by the service) from benefitting. However, even non-excludable services flow from a particular configuration of ecosystem structure, and it is generally possible to create some form of excludable property rights to that structure (Farley, 2010). Several market-like instruments rely on this approach.

Payments for ecosystem service (PES) schemes assume that landowners have the right to degrade ecosystem services, in which case beneficiaries must pay them for switching to land uses that provide ecosystem services or halt their degradation (Engel et al., 2008; Wunder, 2005). When the service provided is itself excludable, market forces determine both price and quantity through the interaction of supply and demand. However, in many cases the services generated are inherently non-excludable, and theoretically only a collective institution representing all beneficiaries will be willing to pay for the Pareto efficient level of services. When the benefit sheds correspond to political boundaries, governments can and do play this role, but in many cases there are no collective institutions at the appropriate scale.

Even within the commodification model, there are too many major debates concerning PES to cover in detail, but several deserve mention. One is whether or not the transactions costs of creating, monitoring and enforcing payment schemes are so high that they outweigh the gains from market solutions. Coase himself believed this would frequently be the case, noting that "[t]he world of zero transaction costs has often been described as a Coasian world. Nothing could be further from the truth. It is the world of modern economic theory, one which I was hoping to persuade the economists to leave" (Coase, 1988, p. 174). Due to the number of providers, the number of beneficiaries and their public good nature, the provision of ecosystem services is likely to confront high transactions costs regardless of the mechanisms used, but we cannot a priori assume that markets will have lower transaction costs and greater efficiency than government regulation. Another is whether market payments, known as extrinsic incentives, will crowd out a landowner's intrinsic incentive to provide ecosystem services for the public good. Numerous studies suggest that inadequate payments could even result in reduced provision of the services (Gneezy and Rustichini, 2000; Vatn, 2010). A third is whether PES schemes actually achieve their goals (Muradian et al., 2010; Porras et al., 2008; Sierra and Russman, 2006; Vatn, 2010; Wunder et al., 2008).

In another property rights approach known as cap and trade, the government places quantitative caps on the ecosystem structure that generates ecosystems services, or directly on ecosystem services. Property rights or temporary use rights can then be distributed to individual corporations (as was done for carbon emissions in the European Union Emission Trading Scheme (EU-ETS) (Clò, 2010) and the US cap and trade program for SOx (Napolitano et al., 2007)) or auctioned off (as is done by states in the Regional Greenhouse Gas Initiative (RGGI Inc., 2011)). Carbon offset schemes that frequently accompany cap and trade allow polluters to pay for carbon offsets elsewhere. When these offsets are in the form of carbon sequestration by ecosystems, they are examples of PES.

A third approach that implies public property rights is taxes on throughput, which can be considered a fee for the use of publicly owned waste absorption capacity or natural resources.

In the case of cap and trade, the government determines supply, and market demand determines price. In the case of taxes, governments determine price, and market demand determines supply. For every cap on supply, there is an equivalent tax that would lead to the same outcome, though with potentially different distributional outcomes unless the cap is auctioned off. Theoretically, a tax equivalent to the marginal external costs of the taxed activity, or a cap that leads permits to trade at this price, is Pareto efficient. In reality, both caps and taxes are typically a compromise between political feasibility, revenue needs, and ecological concerns, in which case they are cost effective but not necessarily efficient. There is a significant debate in the economics literature about the relative advantages of the two approaches; Kahn and Franceschi (2006) provide a good overview of the case for taxation, while Daly and Farley (2010) do the same for cap and trade.

In summary, advocates of Pareto efficiency generally believe that placing the correct monetary values on nature and incorporating these into economic decisions will lead to the optimal allocation of ecosystem structure between economic production and ecosystem services. The issue of just distribution is best left to policy makers, but has little relevance to efficiency, and efficient allocation will ensure the greatest possible wealth available for distribution. Efficiency is the dominant goal of economic activity, and takes priority over sustainability and distribution.

4.2. Ecological-economic efficiency, incommensurable values and macro-allocation

The debates between the proponents of Pareto efficiency and proponents of ecological-economic efficiency (EEE) are far more substantial than those within the Pareto efficiency approach. EEE also takes sides in the sustainability and efficiency debates discussed in Sections 2 and 3. Proponents of EEE favor preserving and restoring every "cog and wheel" because natural capital and the services it generates are essential to sustaining human welfare with only limited possibilities for substitution at the margin (i.e. strong sustainability), and/or because nature has intrinsic value independent of human preferences. While it can be difficult to define quality of life precisely, failure to meet basic biophysical needs leads to an unacceptable quality of life, and a given increment of goods and services (ecological or economic) is likely improve quality of life more when allocated to those who currently have the least. Maximizing quality of life therefore rules out the property rights view of justice. Any system that weights preferences by purchasing power will in general allocate resources towards the wealthiest individuals, who will gain the least value measured in terms of biological needs or quality of life. In other words, Pareto efficiency is very inefficient from the EEE perspective. In fact, to reconcile the consequentialist approach to justice out of which modern economics emerged (Mill, 1871) with the property rights approach, economists were forced to assume that we cannot meaningfully compare welfare between individuals. For example, if a region loses the ecosystem service of water purification, we cannot assume the change in welfare for a rich person forced to drink bottled water is less than that of a destitute mother forced to watch her children die of dysentery.

The interacting elements that contribute to quality of life cannot all be measured with the same yardstick. Converting these diverse elements to monetary values simply masks the underlying ethical choices and difficult decisions about tradeoffs between ecological resilience, human life and health, species loss, obligations towards future generations and so on (Ackerman and Heinzerling, 2004). In a complex system with uncertain facts, high stakes, urgent decisions and competing ethical values, there is no such thing as an objectively 'optimal' solution in any case (Funtowicz and Ravetz, 1994; Simon, 1983). Instead, making intelligent choices about the tradeoffs inherent to economic activity requires a pragmatic, adaptive approach. Society should make decisions based on the best scientific evidence and participatory, democratic discussion about available choices while fully recognizing inherent uncertainty (Prugh et al., 2000). The scale of the problem, which in the context of ecosystem services can range from small watersheds to the global community, determines who should participate in decision-making. The implementation of each decision should be treated as a scientific experiment that can help prove or disprove the underlying hypotheses concerning nature, society and even the ethical values that led to the decision. Decisions must also adapt to the continuous influx of new information about the complex ecological-economic system (Norton, 2005).

The Montreal Protocol on substances that deplete the Ozone layer provides a reasonable example of participatory adaptive management at the global level: the treaty was signed when our understanding of ozone depletion was very incomplete, it evolved continuously as knowledge improved; and it had a dramatic impact on a serious global problem (Norman et al., 2008). Brazil's forest code provides a potential example at the national scale. Since the 1960s, when knowledge of ecosystem services was even more rudimentary than today, the code has mandated forest cover on a percentage of rural properties (varying with the ecosystem) and in ecologically sensitive areas. Full compliance would likely protect many key ecosystem services (Metzger, 2010). The code has been modified to meet the needs of small farmers. Current efforts to modify the code in favor of agro-industry however go strongly against public opinion (Datafolha, 2011), and have not been informed by science (Silva et al., 2011).

One serious debate within this framework is over the use of the terms ecosystem services and natural capital, which many critics consider equivalent to the commodification of nature (e.g. McCauley, 2006). It certainly is possible that these concepts contribute to an over-emphasis on market solutions (Norgaard, 2010), but one goal of this article is to illustrate the usefulness of the ecosystem service concept even when considering non-market economic institutions.

That said, EEE does not rule out the use of monetary valuation, green taxes, cap and auction schemes or payments for ecosystem services in all cases. For example, restoring ecosystem services in urban watersheds can dramatically reduce costs of water utilities and storm water projects, and a monetary estimate of such savings is an important facet of the value of ecosystem services. In pragmatic terms, valuation can also help call attention to the overall importance of ecosystem services. However, the recognition that only some facets of ecosystem service value can be monetized means that we should be very wary of confusing these partial values with exchange values (Kumar, 2010).

In many cases, non-monetary valuation may be preferable. A valuation study for example might first determine whether the local ecosystem service in question is essential, which would make it potentially critical. Water purification for example is a critical service. The study would next determine whether the actual quantity of the resource available is abundant, meaning that there is enough to satisfy all desired uses, economic and ecological; scarce, meaning that competition exists for the resource (i.e. for the service itself or the ecosystem structure that provides it); or critical, meaning that competition is fierce enough that at least some individuals do not get enough to satisfy basic needs, thus crossing physiological thresholds. It would also be important to determine scarcity trends, based on both supply and demand. Is the resource growing scarcer (decreasing supply and/or rising demand), staying the same, or becoming less scarce? Critical resources would be essentially invaluable. Economic analysis should focus on the lowest cost approaches to restoring the service, or on ways to provide substitutes for populations that could not otherwise afford them. If resources are scarce and becoming scarcer, society should focus on halting conversion by capping the land use change or the extraction of ecosystem structure. Prices of land and raw materials could then adjust to these caps.

Both taxes and cap and auction schemes are fully compatible with common ownership of our shared inheritance from nature, as long as the revenue is dedicated to the common good (Barnes, 2006; Barnes et al., 2008). Taxes however are a liability rule and cannot guarantee sustainability. Caps in contrast can be set at a level that awards future generations and other species with inalienable rights to a healthy, resilient ecosystem. Many people are concerned that speculators will be able to manipulate the market for tradable permits (Andrew, 2008); to prevent such rent-seeking behavior, auctioned permits for throughput should probably be temporary and non-tradable.

Concerning PES, there are real costs to preserving and restoring ecosystem services, and it makes sense that the service beneficiaries pay these costs. In many cases however the services themselves are public goods, and public sector investments are required to promote the land uses that protect them, such as agroecology (De Schutter, 2010; Farley et al., 2011). In such circumstances, PES might take the form of public sector to public sector transfers (also known as intergovernmental fiscal transfers; Kumar and Managi, 2009; Ring, 2008)). In other circumstances, cooperative investments in stewardship that share risk and stimulate reciprocity may be more appropriate than compensation conditional upon service provision (van Noorwijk and Leimona, 2010).

Furthermore, PES schemes are likely to be very inefficient for non-rival resources, which are not depleted through use are not scarce in the economic sense of the word, and should not be rationed. Perhaps the only ecosystem service that fits this description is genetic information, to which the convention on biodiversity created national property rights. The problems with this approach are best illustrated with a case study. In 2007, Indonesia discovered a new strain of avian flu, which could potentially have led to a global pandemic. The historic approach to the discovery of such diseases was to give a sample to the World Health Organization, then let whoever wished to do so attempt to create a vaccine or cure. Typically, dozens of corporations might compete to find a vaccine, with the first one to do so winning a patent. The patent would allow the corporation to charge monopoly profits on the vaccine, which would make it unaffordable to the world's poor. This would decrease the likelihood of achieving herd immunity, and hence increase the likelihood of a pandemic and evolution of the virus into new forms. Recognizing this dynamic, Indonesia threatened to auction off the virus to a single corporation (McNeil, 2007), presumably with the understanding that the corporation would also provide Indonesia with access to the vaccine at an affordable price. While Indonesia's approach certainly made sense from a national perspective, allowing only one corporation to seek a cure would presumably reduce the likelihood of finding one.

Paradoxically, maximizing the economic surplus from genetic information or of a vaccine requires charging a price of zero. The information underlying green technologies that will contribute to solving many environmental problems is also non-rival, and is likely in fact to improve through use. Putting a price on such resources however rations access to those who can afford to pay, reducing societal benefits from additional use without reducing societal costs. There is in fact no efficient market solution for the allocation of non-rival resources (Kubiszewski et al., 2010).

In summary, advocates of EEE believe that ecological sustainability and just distribution cannot be achieved through market mechanisms, and both are prerequisites for efficient allocation. Humans and all other species rely for their survival on ecosystem services, which mean that economic institutions must ensure both their sustainable provision and just distribution.

5. Conclusions

The concept of ecosystem services is extremely valuable when deciding how to allocate the resources provided by nature among alternative desirable ends, whether or not the end receiving highest priority is monetary value, quality of life, or the preservation of nature for its intrinsic values. Many conventional economists do use the concept of ecosystem services in their efforts to commodify nature, but this is a function of the discipline, not the concept. Ecological economists and others use the concept of ecosystem services to illustrate why market allocation fails to achieve ecological sustainability or just distribution. Most ecosystem services cannot and should not be integrated into the market framework. Instead, alternative economic institutions must ensure ecological sustainability and the just distribution of resources before markets can possibly be efficient, and even then market efficiency cannot be taken for granted.

Economic analysis of ecosystem services generally begins with implicit assumptions about the nature of sustainability, the definition of justice, and the values that should be maximized. The main conclusion of this paper is that these underlying assumptions must be made explicit as the starting point in any economic analysis. While the debates over sustainability may one day be resolved by science, until then the debate inevitably has a normative component concerning the treatment of uncertainty and acceptable risks to future generations. The debate over just distribution will always be normative. Though many economists claim that Pareto efficiency is a value neutral, objective decision rule, it is perhaps the most value-laden of the debates discussed here despite its mathematical framework. As a social science, economic analysis of ecosystem services must be based on normative values, and can only aspire to any level of scientific objectivity if it makes those values explicit.

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