The Role of Prices in Conserving Critical Natural Capital

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Abstract: *Until recent decades, economic decision makers have largely ignored the nonmarket benefits provided by nature, resulting in unprecedented threats to ecological life-support functions. The economic challenge today is to decide how much ecosystem structure can be converted to economic production and how much must be conserved to provide essential ecosystem services. Many economists and a growing number of life scientists hope to address this challenge by estimating the marginal value of environmental benefits and then using this information to make economic decisions. I assessed this approach first by examining the role and effectiveness of the price mechanism in a well-functioning market economy, second by identifying the issues that prevent markets from pricing many ecological benefits, and third by focusing on problems inherent to valuing services generated by complex and poorly understood ecosystems subject to irreversible change. I then focus on critical natural capital (CNC), which generates benefits that are essential to human welfare and have few if any substitutes. When imminent ecological thresholds threaten CNC, conservation is essential and marginal valuation becomes inappropriate. Once conservation needs have been met, remaining ecosystem structure is potentially available for economic production. Demand for this available supply will determine prices. In other words, conservation needs should be price determining, not price determined. Conservation science must help identify CNC and the quantity and quality of ecosystem structure required to ensure its sustained provision.*

Keywords: critical natural capital, ecological thresholds, ecosystem services, marginal value, monetary valuation, prices

El Papel de los Precios en la Conservación del Capital Natural Crítico

Resumen: *Hasta hace unas décadas, los tomadores de decisiones económicas han ignorado los beneficios no mercantiles proporcionados por la naturaleza, lo que ha resultado en amenazas sin precedentes a las funciones ecológicas básicas para la vida. El reto económico actual es decidir cuanto de la estructura económica puede ser convertido en producción económica y cuanto debe ser conservado para proporcionar los servicios esenciales del ecosistema. Muchos economistas y un creciente número de científicos esperan atender este reto mediante la estimación del valor marginal de los beneficios ambientales para luego usar esta información para tomar decisiones económicas. Evalué este método, primero examinando el papel y la efectividad del mecanismo de precios en una economía de mercado sana; segundo mediante la identificación de temas que previenen que los mercados fijen precios a muchos beneficios ecológicos y tercero mediante el enfoque de problemas inherentes a los servicios de valoración generados por ecosistemas complejos y poco entendidos que están sujetos a cambios irreversibles. Posteriormente abordo el capital natural crítico, que genera beneficios que son esenciales para el bienestar humano y que tiene pocos sustitutos. Cuando los umbrales económicos inminentes amenazan al capital natural crítico, la conservación es esencial y la valoración marginal se vuelve inapropiada. Una vez que se han alcanzado las metas de conservación, la estructura del ecosistema restante está potencialmente disponible para la producción económica. La demanda por esta oferta disponible determinará los precios. En otras palabras, las necesidades de conservación deberían ser determinantes de los precios, no determinadas por los precios. La ciencia de la conservación debe ayudar a identificar el capital*

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natural crítico y la cantidad y calidad de la estructura del ecosistema que se requiere para asegurar un abastecimiento sostenido.

Palabras Clave: capital natural crítico, precios, servicios del ecosistema, valor marginal, valoración monetaria, umbrales ecológicos

Introduction

Economic activity, ranging from fossil fuel consumption to habitat conversion and attendant biodiversity loss, threatens vital ecosystem services. For a given set of technologies, the link between economic activity and ecological degradation is explicit. The laws of physics tell us it is impossible to make something from nothing—all economic production requires the transformation of raw materials provided by nature. It is also impossible to do work without energy, which in modern society is predominantly derived from fossil fuels. Entropy increases over time and simply maintaining a fixed stock of economic infrastructure demands constant inputs of energy and raw materials (Georgescu-Roegen 1971).

These physical laws are intimately connected to Commoner's (1971) four laws of ecology. First, everything is connected to everything else. The raw materials provided by nature alternatively serve as the structural building blocks of ecosystems, and removing them has repercussions throughout the ecosystem. Second, everything must go somewhere. In nature's solar-powered systems there is no such thing as waste, but a fossil-fuel-powered economy increases entropy faster than solar power can reduce it, resulting in a steady flow of high-entropy waste back into the environment. Third, nature knows best. Human intervention in natural systems, fine tuned by natural selection for eons, is generally detrimental to ecosystem function. Fourth, there is no such thing as a free lunch—all activities have ecological costs. Ecosystem structure generates ecosystem functions; those of value to humans are known as ecosystem services and include vital life-supporting services essential to human society. When we convert the structural building blocks of ecosystems for economic production, returning waste to the ecosystem in the process, we pay an opportunity cost of lost ecosystem services. The larger the physical size of an economy with a given technology is, the greater is the cost.

The basic laws of economics tell us that when the diminishing marginal benefits of an activity equal the increasing marginal costs, we should cease that activity. Continuing the activity beyond this point is not economical (Daly 2007). Markets measure the relative marginal benefits of different economic products but fail to measure the marginal costs of ecological degradation. As a result, our economy fails to solve the macroallocation problem: How much ecosystem structure should be apportioned toward the production of human-made goods and services and how much should be left intact to provide ecosystem services (Daly et al. 2007)?

Many economists and an increasing number of ecologists seek to solve the macroallocation problem by estimating the monetary value of ecosystem services, then internalizing these values in economic decisions, typically via cost-benefit analysis (CBA) or economic incentives such as taxes and subsidies. Market decisions in theory can then determine how much conservation is appropriate. I examined this approach to determine its suitability for conservation decisions first by assessing the role of marginal valuation in market economies and then by assessing its extension to nonmarketed ecosystem goods and services, including critical natural capital (CNC).

Economic Value and Its Role in a Market Economy

To assess the usefulness of monetary valuation of nonmarket goods and services, one must understand the role of prices in a market economy. Market prices reflect value in only a limited way. The classic illustration of this is the diamond-water paradox—diamonds contribute little to human welfare, but are very expensive, whereas water is essential to life but is generally very inexpensive. The value of diamonds is determined more by their scarcity than their inherent value, which led classical economists to distinguish between use value and exchange value. The use value of something is its total value, the sum of the marginal values of each unit across all units consumed. As the first units of water consumed have essentially infinite value, the use value of water must also be infinite, but knowing this gives us little guidance in allocation decisions. As we consume more water, each unit is used for less important purposes and has less value. Exchange value is equal to marginal value, the value of the last unit used. Because typical economic decisions are made at the margin, decision makers follow the dominant theory of neoclassical economics focusing primarily on marginal values. In an ideal free market, marginal values are equivalent to price.

Prices serve a critical role in a competitive free-market economy, acting as a fulcrum that balances supply with demand, costs with benefits, and what is possible with what is desirable in three basic ways. First, prices signal scarcity. When market demand for a resource exceeds market supply, consumers bid up the price leading producers to supply more or create substitutes. When supply for a resource exceeds demand, suppliers lower their prices until the market again clears. Second, prices maximize net monetary value captured by all producers by allocating factors of production to whatever industry is willing to pay the most for them, which is the industry that generates the most profit from that factor. Third, prices maximize net monetary value captured by all consumers by rationing commodities to the individuals willing to pay the most for them. Market prices maximize the monetary value of both inputs and outputs. The outcome in theory is a competitive equilibrium in which it is impossible to improve the welfare of any one individual without making another individual worse off, a condition known as Pareto efficiency. This result is enshrined as the first fundamental theorem of welfare economics. Everything is driven by the decentralized, voluntary decisions of economic actors.

Prices are also used in CBA to make more centralized investment or policy decisions. For example, a CBA could tell us if the stream of benefits from a conservation decision outweighs the costs or if one conservation decision has greater net present value than another. Cost-benefit analysis typically ignores questions of distribution—who gets what. If the benefits outweigh the costs, a potential Pareto improvement is possible—those made better off by a decision could potentially compensate any losers. Economists justify their focus on total wealth rather than its distribution by the second fundamental theorem of welfare economics, which states that through lump-sum transfers of wealth, competitive markets can achieve any possible Pareto efficient outcome. Economists consider CBA an objective decision-making tool and leave the normative decision of actual compensation up to the politicians.

The goal of environmental valuation is to "get the prices right" where the market fails to do so spontaneously. Unfortunately, in real life, prices may not always achieve the same outcomes as the theoretical models. In the first place, markets are unlikely to achieve these outcomes unless certain rigid assumptions are met, such as the axioms of consumer choice, which treat humans as selfish, consistent in choices, nonsatiable, and able to allocate a limited income among an array of desirable goods in a way that uniquely maximizes total utility (Gowdy 2004*a*). Abundant empirical research refutes these axioms, raising serious issues about both market outcomes and valuation (Tversky & Kahneman 1991; Knetsch 1992; Loomes & Caron 1992; Spash & Hanley 1995; Gowdy 2007). Even when markets function as intended, the normative desirability of maximizing monetary value is debatable and markets may fail to signal and respond appropriately to scarcity. In addition, economists recognize an abundance of market failures that prevent markets from functioning as intended.

Functioning Markets, Questionable Outcomes

It is an objective statement that if the real world functioned like idealized, neoclassical, microeconomic models, then market prices would allocate resources in a way that maximized monetary value, given the initial distribution of resources. The choice of maximizing monetary value as a desirable end for society, however, is normative and worth examining with a brief case study.

Aventis developed a compound, eflornithine, with promising pharmaceutical characteristics. Scientists discovered in 1979 that eflornithine killed trypanosomes, the parasite responsible for African sleeping sickness, a debilitating disease transmitted by the tsetse fly that threatens 70 million Africans. Although the only other treatment for second-stage sleeping sickness is extremely painful to administer, often ineffective, and often lethal, Aventis could not profit from selling the drug to poor Africans and discontinued production for that purpose. At the same time, however, Bristol Myers Squibb and Gillette were profitably producing eflornithine to remove unwanted facial hair in women. Aventis and Bristol Myers Squibb agreed to again produce eflornithine for the treatment of African sleeping sickness only after the NGO Médecins Sans Frontières threatened to publicize the issue (Gombe 2003; WHO 2006). Had the market been left to its own devices, the rationing function of price would have continued apportioning eflornithine to rich, hirsute women rather than destitute, diseased Africans. The allocative function of price still apportions few resources toward cures for lethal diseases that afflict the poor (Trouiller et al. 2002). Although most people would presumably think saving lives is a more valuable use of resources than developing cosmetics, market demand is a function of preferences weighted by wealth and income. Markets allocate resources toward those who have money and unmet wants, not toward those who have unmet needs.

My point here is not that maximizing monetary value is never a desirable end—it has clearly played a role in generating modern society's unprecedented standard of living—but rather that it is not always the most desirable end. If we are to use the price mechanism to allocate nonmarketed environmental resources, we must do so cautiously.

Prices may also fail to signal scarcity in the real world (Norgaard 1990). Take the example of oil, a finite resource and one of our most important commodities. Over the past 100 years, we have depleted supplies and developed thousands of new uses for oil and few substitutes. Oil has grown steadily scarcer. Oil's mean price, however, though showing considerable fluctuation, remained relatively unchanged in real terms between 1879 and 2002, with the notable exception of the oil embargoes and Middle East crises of the 1970s (Williams 2007). At least for oil, price does not appear to reflect the scarcity of the resource in the ground—not surprising because even the experts cannot agree on how much is left (Campbell & Laherrere 1998).

Do prices at least signal producers to increase or decrease supply and develop new substitutes? They certainly seem to do this for human-made commodities, resulting in their unprecedented abundance, and a high price for natural resources in most circumstances is likely to increase the rate of extraction or harvest. Nevertheless, when we increase the harvest of living ecosystem structure, we often diminish its capacity to reproduce itself, reducing not only the potential supply in the future, but also the ecosystem services that structure would otherwise provide. When high prices spur more cost-effective extraction technologies, we run the serious risk of exhausting the resources, many of which may have no substitutes.

A major problem here is that future generations cannot bid on resources, so current prices fail to reflect future scarcities (Bromley 1989). It is essentially impossible to accurately price irreproducible resources unless we assume future generations have no rights whatsoever to natural resources (Georgescu-Roegen 1975; Gowdy & O'Hara 1995). Any effort to solve the macroallocation problem with environmental valuation must at least consider these issues.

Market Failures

In addition to concerns with well functioning markets, economists recognize a number of serious failures that lead markets to send the wrong price signals and systematically exacerbate the macroallocation problem. Markets are only possible when resources are excludable, which is to say that someone can be prevented from using them. If people cannot be prevented from using a resource, they are unlikely to pay for its use, and the market will fail to produce or preserve appropriate amounts. The elements of ecosystem structure, such as timber, fish, and land, are excludable, whereas many of the most important ecosystem services generated by that structure are inherently not excludable, particularly supporting and regulating services. (For more details on the classification of ecosystem services, see, for example, Costanza et al. [1997] and Millennium Ecosystem Assessment [2005].) As a result, markets systematically favor the conversion of ecosystem structure to economic production rather than its conservation for the provision of ecosystem services, even when the nonmonetary benefits of conservation outweigh the monetary benefits of conversion. Those who convert gain all the benefits of conversion but share the costs with the rest of the world. This problem is often referred to as an externality—a positive or negative impact of an economic activity on others without compensation.

Furthermore, markets are only efficient when resources are rival, that is, use of a resource by one person reduces the availability to another person. Ecosystem structure is generally rival, but most ecosystem services are not (with the notable exception of waste-absorption capacity). For example, my use of the ozone layer or the genetic information provided by biodiversity leaves no less for someone else. As explained above, one function of price is to ration the use of resources, but if use of a nonrival resource does not diminish the quantity available, if use provides utility and the goal is to maximize utility, then using prices to ration consumption is inefficient. To take a real-life example relevant to conservation, corporations have patented refrigerants that do not deplete the ozone, which allows them to charge monopoly prices that ration their use to those who can afford them. China and India are therefore more likely to use ozone-depleting HCFCs as refrigerants, and as a result 2006 saw the worst depletion of the ozone layer in history (UNEP 2006). In other words, markets lead to a suboptimal supply of nonexcludable resources and suboptimal demand for nonrival resources.

Resources that are both nonrival and nonexcludable, such as climate stability, the ozone layer, and the ecosystem resilience provided by biodiversity, are known as public goods. Public goods generally require collective provision. Valuation in theory can help society decide how much to provide. But rivalness also affects valuation. The marginal value of a rival resource is determined by the greatest amount any individual is willing to pay for the last unit provided, but that of a nonrival resource is determined by the amount all beneficiaries together are willing to pay for one more unit, information that markets fail to divulge. Although estimating the marginal value of nonrival resources may help determine how much of them society should supply, the marginal price should be zero, so markets remain an inefficient way to supply them (Samuelson 1954).

Valuing Natural Capital

Society unquestionably faces difficult trade-offs concerning macroallocation and needs to decide whether conservation and restoration efforts are worth the direct costs of establishment and protection, as well as the opportunity costs—the alternative use to which protected areas and resources can no longer be dedicated. The problem would be easier to resolve if all the benefits and costs of conservation decisions could be measured in the same units. Environmental valuation techniques attempt to estimate a monetary value for which society would be willing to exchange a nonmarketed environmental benefit, typically by inferring how much consumers would be willing to pay for them. There appears to be growing demand from conservationists for monetary valuation and a steady supply of valuation studies by economists, often in collaboration with life scientists. The more we rely on monetary valuation, the more important it becomes that we critically assess its strengths and weaknesses. Critical questions include: Can we meaningfully measure the multiple attributes of complex ecosystems by a single metric? If so, is willingness to pay (WTP) an appropriate metric? How can we value essential resources for which substitution is difficult or even impossible?

Can a Single Metric Provide a Meaningful Value?

Ecosystems provide an enormous variety of goods and services, each with different attributes and each conventionally measured in a variety of different units. Summarizing all this information in monetary units confronts several distinct problems.

Our knowledge of ecosystem function is plagued by ignorance and uncertainty. Even the best-informed scientists cannot confidently describe all the benefits provided by a given species or ecosystem or the impacts of human activities on them. Many contributions of ecosystems are essentially beneath perception, cognitively invisible (Vatn & Bromley 1994). Yet typical valuation studies demand average consumers quantify these benefits.

One reason for our ignorance is that ecological–economic systems exhibit highly complex, dynamic, and nonlinear behavior in which a clear understanding of the part rarely translates into a clear understanding of the whole. In such systems everything is indeed connected to everything else. How can we value one component of such a system when a change in that component will have ripple effects throughout the system? Marginal activities, such as the conversion of a forest landscape or even a hectare of forest to pasture, may lead to reasonably linear changes in the value of ecosystem services over some range, yet highly nonlinear changes over another range. Nonlinear changes may include the presence of abrupt, irreversible thresholds (Farber et al. 2002; Limburg et al. 2002; Folke 2006). At such thresholds marginal actions have nonmarginal impacts and marginal analysis becomes inappropriate.

For example, research shows that the Amazon rainforest recycles much of the rain that falls on it. Torrential rains strike the forest canopy, dissipating their energy. Rain evaporates directly from the canopy or falls to the ground as a fine mist, where it readily percolates into soils aerated by the extensive roots systems. Trees absorb more water, returning it to the atmosphere through evapotranspiration, where enough accumulates to form clouds and fall again. When forest cover is removed, rain falls on bare soil, compacting it, then swiftly runs off into the river systems to flow downstream and leave the system forever. Research suggests that if as little as 30% of the total forest cover is lost, the forest will no longer be able to recycle enough rain to regenerate itself (Salati & Vose 1984; Salati 1987). Without active restoration efforts, the system is likely to flip into an alternative state, such as savannah grassland (Nepstad et al. 2007). The Amazon is a driver of global climate and the resulting disruptions from its loss could be catastrophic (Flannery 2005).

Compounding our uncertainty, time lags between loss of an ecosystem or species and the noticeable loss of services may be greater than a human lifespan. For example, scientists hypothesize that when Passenger Pigeons went extinct, the abundance of acorns led to booms in deer and mouse populations followed by booms in deer tick populations and finally in the spirochetes that fed on them, resulting 100 years later in an epidemic of Lyme's disease (Blockstein 1998). By the time we are aware of a problem, it may be irreversible. Scientists believe that even if we ceased all greenhouse gas emissions today, climate change would continue for another century (Meehl et al. 2005). As Vatn and Bromley (1994:133) point out, "the precise contribution of a functional element in the ecosystem is not known—indeed is probably unknowable—until it ceases to function"—and even then, with a sample size of one unique ecosystem, the resulting knowledge is merely anecdotal.

Even with absolute certainty, if the different attributes of natural capital assets are incongruous or fundamentally at odds with each other in the minds of assessors, then a single measure such as hypothetical price will not reflect all important information (Vatn & Bromley 1994; Gowdy 1997; Martinez-Alier et al. 1998). Incommensurable values cannot be ranked on a specific cardinal scale. People may exhibit lexicographic preferences (Georgescu-Roegen 1954), particularly concerning moral values, so that no amount of money can compensate for the benefit in question. The U.S. Endangered Species Act originally placed conservation above any economic considerations, and people frequently refuse to respond to questions about the monetary value of endangered species or important ecosystem services on moral grounds. Some valuation studies simply ignore such protest votes that contradict the axioms of consumer choice, whereas others use formats that force environmental features into the framework of market goods (Stevens et al. 1991; Sagoff 1994; Spash & Hanley 1995; Gowdy 2004*b*). Aldred (2006) summarizes the many arguments for and against commensurability and concludes that arguments in favor do not withstand scrutiny. Monetary valuation may be simply unacceptable for certain things.

Even without incommensurability and uncertainty, valuation studies would likely fail to reflect the full contributions of ecosystem services to human welfare. There is little doubt that human preferences are profoundly affected by advertising, and it only pays to advertise market goods. The result is asymmetric information flows that systematically alter our preferences in favor of market goods. Given finite income, this must reduce our expressed values for nonmarket goods (Farley et al. 2002; Daly & Farley 2004).

Is Willingness to Pay an Appropriate Metric?

Whether or not a single metric is appropriate for measuring environmental benefits, there are serious concerns with the predominant form of monetary valuation—WTP for a marginal unit of benefit. The axioms of consumer choice maintain that consumer preferences are smooth and continuous, so at the margin measures of WTP should equal measures of willingness to accept (WTA) compensation for the loss of a benefit. Empirical studies show however that WTA almost always exceeds WTP (Hanneman 1991) even for market goods. A review of 45 studies comparing the two measures showed that the mean ratio of WTA to WTP is seven, with the discrepancy increasing as goods become less like ordinary market goods (Horowitz & McConnell 2002). This discrepancy appears to be due to an endowment effect, whereby people prefer what they have to what they do not have (Tversky & Kahneman 1991). If we believe people have rights to environmental benefits, then WTA is the appropriate measure, although WTP may be appropriate for activities such as nonessential ecological restoration. Few economists appear to dispute these results, but for some reason WTP remains the dominant approach to valuation (Bromley 1995; Knetsch 2005).

Not only can WTP seriously underestimate the value of environmental features, it also makes strong normative assumptions concerning who is entitled to participate in decisions regarding nature. Like market demand, WTP is determined by preferences weighted by income. A person with little income or wealth has little economic demand and hence has little influence on allocation decisions. In determining value, markets–real and hypothetical–apply the principle of one dollar, one vote rather than one person, one vote. The eflornithine example shows how this approach distorts the meaning of value, but it is even more questionable when deciding how to use gifts of nature. Furthermore, conventional valuation methods ignore rights and preferences of future generations.

Finally, in direct contrast to the axiom that people are always selfish and competitive, research shows people are frequently altruistic and cooperative (Fehr & Gachter 2000; Wilson & Wilson 2007) and may make different decisions as individuals than as members of a group (Sagoff 1988). Most valuation studies elicit bids from individuals in social isolation, which may differ from the values they would offer as part of a group (Wilson & Howarth 2002). Even more worrisome, research shows that when people are primed to think of money, they are less likely to ask for help from others and less likely to offer help (Vohs et al. 2006); although providing public goods requires cooperative action, valuation studies could potentially reduce the likelihood of cooperation.

How Can We Value Essential Resources with No Substitutes?

Critical Natural Capital (CNC) consists of those resources of nature essential for sustaining human welfare and for which substitution is difficult or impossible. When resources are degraded or destroyed to the extent they no longer provide the services essential to human welfare or are no longer capable of reproducing themselves, we have encroached on CNC (De Groot et al. 2003; Ekins et al. 2003). Current major threats to CNC include biodiversity loss and climate change.

Unfortunately, the notion of CNC is contentious among mainstream economists. Many believe nature has very little value (as discussed in Dasgupta 2008) and that human ingenuity can develop substitutes for anything (e.g., Beckerman 1995; Barro & Sala-i-Martin 2003; Helpman 2004). Some even claim that climate change will have little impact on human welfare because it primarily affects agriculture, which generates only 3% of gross national product (GNP), which implies that even food has substitutes (Beckerman 1995; Schelling 2007). In contrast, the transdisciplinary field of ecological economics is premised on biophysical limits to growth (e.g., Daly & Farley 2004; Dasgupta 2008). For those who accept its existence, CNC is invaluable by definition. We do not, however, know precisely what elements of natural capital are critical, and the valuation of natural capital that may be approaching critical but uncertain limits is particularly challenging.

Demand curves plot the marginal value of a resource against quantity. Figure 1 depicts a hypothetical demand curve for natural capital that becomes critical beyond some uncertain threshold. Examples could include the world's major rainforests, biodiversity, freshwater supply, and climate regulation. I divide the curve into three distinct regions relevant to valuation.

In region I, relatively abundant natural capital is used for relatively unimportant marginal activities with low marginal values. Given the level of redundancy present in many ecosystems and their resulting resilience, marginal values change slowly. Monetary valuation may be useful here, although appropriate methods should account for recent advances in behavioral economics as described by Gowdy (2004*b*) and Knetsch (2005), and should recognize the other problems previously described.

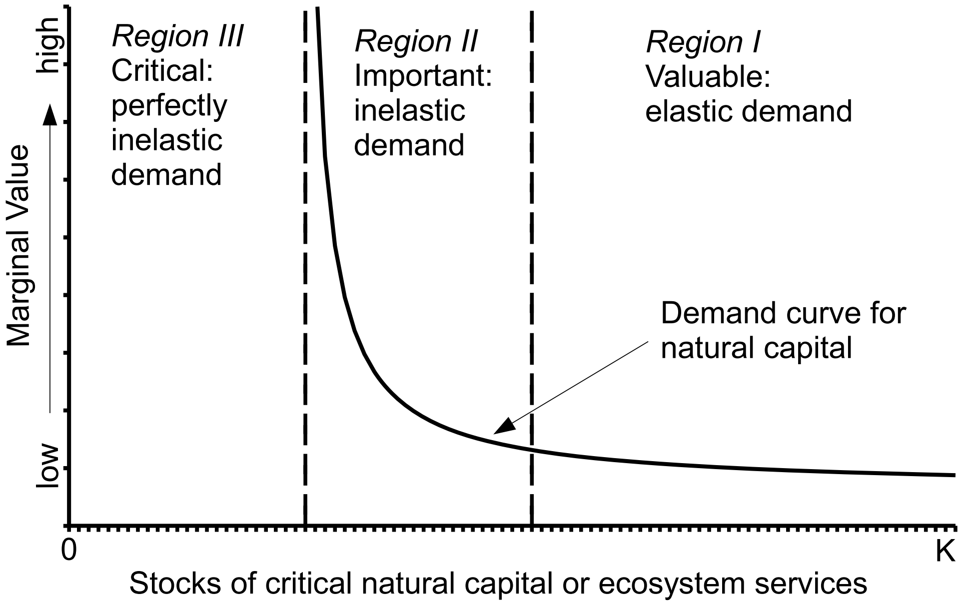

Figure 1. A conceptual framework for the valuation of natural capital stocks. The marginal value is the value of one additional unit (or optimal price) of the capital stock. The K *is carrying capacity. In region I, stocks are healthy and resilient, marginal uses are not essential, and demand is elastic, which means marginal values are insensitive to small changes in stocks. Monetary valuation may facilitate decisions on allocation between conservation and conversion. In region II, capital stocks are less resilient and approaching a threshold beyond which they cannot spontaneously recover from further loss or degradation. Marginal uses are increasingly important, and values are increasingly sensitive to small changes in stocks (inelastic demand). Conservation needs should determine the supply of the stock available for conversion and hence the price. In region III, capital stocks have passed critical ecological thresholds. Marginal values are essentially infinite, and restoration of natural capital stocks essential.*

Underestimates of value are unlikely to lead to irreversible damage.

In region II, as the quality or quantity of the capital stock declines, society must forego increasingly important marginal benefits. Ecological redundancy and resilience decline, threatening nonmarginal impacts from marginal activities. As natural capital approaches the threshold of criticality, society risks the loss of essential marginal benefits, with limited opportunities for substitution. In economic jargon, essential resources with limited possibilities for substitution exhibit price inelastic demand, which means that a 1% decrease in quantity leads to a greater than 1% increase in marginal value. In the time it takes to conduct a valuation study, publish results, and then feed the results to decision makers and await action, natural capital stocks are likely to change and the calculated marginal value will no longer be appropriate. Updating valuation estimates is slow and expensive. Rather than using prices to determine the appropriate level of resource use in region II, it would be better to fix the supply of ecosystem structure on the basis of ecological constraints and moral obligations to future generations. Market prices can adjust rapidly to ecological constraints, whereas ecosystems may require millennia to adjust to economic exploitation. In the face of inelastic demand, quantity is generally a better regulation tool than prices (Weitzman 1974).

As described above, the Amazon rainforest may be approaching a critical threshold beyond which it can no longer generate enough rainfall to sustain itself. Brazil's forest code (which unfortunately is not enforced) mandates that 80% of all holdings in the Amazon be maintained in a natural state as a legal reserve. In theory this determines the supply of timber and cleared land, which interacts with demand to determine their price. Protecting CNC, however, is the minimum mandatory level of conservation and does not tell us much about desirable levels of conservation. Once CNC has been protected, valuation studies might help determine appropriate taxes or subsidies to achieve a more desirable level of conservation. For example, estimating the value of global ecosystem services provided by the Amazon might convince the wealthy nations to pay for them, providing Brazil with the incentives necessary to protect the forest.

In region III natural capital has passed the criticality threshold and either human welfare or the ecosystem collapses in the absence of intervention. Marginal valuation becomes meaningless and ecological restoration essential. Economists should instead work together with conservation biologists to determine the most cost-effective approach to restoration—the supply curve rather than the demand curve. Where political will for restoration is lacking, scientists must work to convince decision makers of the importance of natural capital and the risks of its irreversible degradation.

Environmental Policy: How Do We Proceed?

For the first time in history, humanity may be confronting a variety of ecological thresholds on the global scale—some such as climate change are widely recognized by the general public, whereas others such as biodiversity loss have barely begun to register. We are entering unfamiliar waters and need new approaches. Blind faith in technological solutions is inappropriate (Czech 2008 [this issue]; Dasgupta 2008).

A general approach is to minimize the maximum possible loss (minimax) via the application of safe minimum standards or the precautionary principle (e.g., Ciriacy-Wantrup 1952; Bishop 1978), which demand that we do not risk crossing uncertain thresholds that could lead to potentially catastrophic and irreversible outcomes. As Gowdy (2004*b*) points out, the fact that people are more sensitive to losses than to gains justifies this approach. Nevertheless, we may now live in a world in which the status quo guarantees irreversible and catastrophic outcomes. Massive monetary expenditures may be required to prevent ecological disaster. In trade-offs between losses, loss aversion provides little guidance.

Take the example of global biodiversity loss or climate change. Current rates of species loss are 100–1000 their prehuman levels (Pimm et al. 1995). If we lose enough diversity, we risk catastrophic collapse of the ecosystem and with it almost all ecosystem services (Millennium Ecosystem Assessment 2005). Climate change threatens us, for example, with sea level rise, water shortages, plunging food production, and accelerated biodiversity losses.

How much should wealthy nations contribute to protecting biodiversity and mitigating climate change? Monetary CBA built on hypothetical models of the future provides one answer. For example, Nordhaus conducted a CBA for climate change, and concludes that the costs of serious action now outweigh the benefits. Nordhaus strongly condemns the Stern Review on the economics of climate change (Stern et al. 2006), which calls for spending 1% of global GNP on the problem, as alarmist (Nordhaus 2008). With roughly 2% global per capita GNP growth, a 1% annual expenditure would require us to accept living standards from 6 months ago in exchange for greater climate stability. James et al. (2001) calculate that $317 billion per year would be required to maintain global biodiversity and evolutionary potential, but current expenditures are in the neighborhood of only $10 billion annually (Pearce 2007). Rough qualitative analysis built on empirical facts provides strikingly different recommendations. We know that in 1969 the U.S. per capita GNP was 47% of what it is today (Bureau of National Economic Accounts 2007), poverty rates were lower (U.S. Census Bureau 2007), and subjective levels of well-being were higher (Lane 2000). Wealthy nations could dedicate 50% of GNP to conserve and restore natural capital and still sustain a 1969 quality of life. Failing to solve these problems risks global catastrophe. Put in these terms, the choice is not difficult; we must act. We should not waste further efforts trying to precisely quantify the benefits of action, but rather figure out the most cost-effective way to solve our problems.

Summary and Conclusions

As global natural capital stocks come dangerously close to critical thresholds, we must learn how to solve the macroallocation problem. Monetary valuation attempts to estimate the marginal values of environmental benefits, then internalize them into market decisions to determine how much conservation and restoration is appropriate. This approach may be appropriate when we are far from critical thresholds, but under current circumstances, we should frequently adopt an opposite approach: To slightly paraphrase Daly (2007), conservation needs should be price determining rather than price determined. Conservation biologists and their colleagues can help identify the quantity and quality of ecosystem structure required to ensure the sustained provision of vital ecosystem services. Once we have protected or restored adequate ecosystem structure to sustain vital services, “surplus” supply is available for conversion to human-made products. The intersection of this supply with economic demands will determine prices for ecosystem structure.

After we have met sustainability requirements, we can use valuation to improve efficiency. Valuation can also play a role in calling attention to the problem, as was effectively done by Costanza et al.’s (1997) study valuing global ecosystem services at $33 trillion.

Where critical ecological thresholds have already been surpassed, we must take advantage of time lags that may allow us to restore a system before it is too late. Here, marginal valuation is completely inappropriate, and existing studies that integrate these monetary values often call for minimal action. Roughly assessing costs and benefits of alternative paths as measured by quality of life suggests that dedicating vast resources to conservation and restoration would require minimal sacrifice in exchange for immeasurable benefits.

Conservation biologists and their colleagues have an important role to play in educating economists, policy makers, and the public about the importance of biodiversity and the ecosystem services it sustains. They must also educate these groups about the laws of ecology, stressing the constraints these impose on economic growth. They should also help to identify potential ecological thresholds (Rosales 2008 [this issue]) and the minimal restoration efforts necessary to avoid them. In today's world estimating criticality thresholds for natural capital is far more important than estimating marginal values. Given the pervasive uncertainty we face, however, science is not enough: we must also be guided by our moral obligations to future generations.

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