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ENVIRONMENTAL ECONOMICS

Accounting for the increasing benefits from scarce ecosystems

As people get richer, and ecosystem services scarcer, policy-relevant estimates of ecosystem value must rise

By **M.A. Drupp*[,1], M.C. Hänsel[2,3], E.P. Fenichel[4], M. Freeman[5], C. Gollier[6], B. Groom[7,8], G.M. Heal[9], P.H. Howard[10], A. Millner[11], F.C. Moore[12], F. Nesje[13], M.F. Quaas[2,14], S. Smulders[15], T. Sterner[16], C. Traeger[17], F. Venmans[8]**

Governments are catching up with economic theory and practice by increasingly integrating ecosystem service values into national planning processes, including benefit-cost analyses of public policies. Such analyses require information not only about today's benefits from ecosystem services, but also on how benefits change over time. We address a key limitation of existing policy guidance, which assumes that benefits from ecosystem services remain unchanged. We provide a practical rule that is grounded in economic theory and evidence-based as a guideline for how benefits change over time: they rise as societies get richer, and even more so when ecosystem services are declining. Our proposal will correct a substantial downward bias in currently used estimates of future ecosystem service values. This will help governments to reflect the unique importance of ecosystems more accurately in benefit-cost analyses and policy decisions they inform.

Besides nature's intrinsic value, ecosystems provide diverse benefits to humans (*1,2*). We regularly exchange goods derived from ecosystem services, such as fruits, fish, and timber, in market economies, and can see the values of those benefits in the market prices people pay. Ecosystems also provide non-market goods or services that have real value to humans without involving market transactions. Examples include water and air purification by forests, soil nutrient cycling by earthworms, the enjoyment of natural areas through recreation or aesthetic appreciation, and the importance people attach to the existence of diverse species (*1,2*).

While there are many philosophical and practical challenges involved in putting dollar values to ecosystem services, the main motivation for doing so is that policy processes require an analysis of trade-offs, for instance using benefit-cost analyses. Here, the absence of a monetary value is often equated to having no value at all, which leads society to underinvest in healthy ecosystems. The benefits of these non-market goods can be assessed in monetary terms using what economists refer to as "shadow" prices (2). We can estimate current shadow prices from information on current marginal "willingness to pay" (WTP) for changes in ecosystem services. WTP for ecosystem services can be estimated with non-market valuation techniques using revealed consumer behavior (e.g. in housing markets, travel behavior, or donations) or surveys (*3,4*).

Governments are making progress integrating the value of ecosystem services in policy planning frameworks as they implement the Global Biodiversity Framework under the United Nations (UN) Convention of Biological Diversity and work towards the UN Sustainable Development Goals. Policy guidance on benefit-cost analysis already recognizes the principle of relative scarcity. For example, as real income grows, the benefits that people derive from their health or from reduced travel time grows, and policy guidelines account for this (*5*). Yet, with few notable exceptions (*6*), the changing benefits from scarce ecosystem services are so far overlooked in policy guidance.

One of the barriers to including ecosystem services in benefit-cost analysis is the lack of a straightforward approach for adjusting future WTPs in response to growing real incomes and changing scarcities. Several recent initiatives have put the issue on the policy agenda. The UK Treasury recently convened an expert Working Group to develop guidance on this matter (*7*) (authors M.A.D., M.F., C.G., B.G., A.M., and T.S. were members). The US Office of Management and Budget (OMB) proposed guidance on "Assessing Changes in Environmental and Ecosystem Services in Benefit-Cost-Analysis" (authors E.P.F. and F.C.M. contributed while seconded to the government), which is under revision at the time of writing. Relatedly, the US National Science and Technology Council has established a new Subcommittee on Frontiers of Benefit-Cost Analysis, which has flagged ecosystem services effects as a key priority area. These movements reflect a window of opportunity to rectify how governments account for ecosystem services in regulatory guidance and policy decisions. Here, we propose a simple and transparent rule for estimating future WTPs that can be applied independent of how current WTP is estimated.

RECOGNIZING THE INCREASING RELATIVE SCARCITY OF NATURE

While real incomes, and thus the consumption of market goods, continue to grow—reflected in real per-capita GDP growth of around 2% per year (*8*)—the supply of ecosystem services is far from keeping pace. Many ecosystem services are in decline because of habitat destruction, over-harvesting, and climate change (*2*). Global forest areas and populations of threatened species are on a downward trend. Even if nature is preserved in current conditions (denoted as "Environmental Stagnation"), ecosystem services would become scarcer relative to real income or market goods, both of which continue to grow (Figure 1A).

Rising real incomes coupled with a stagnation or decline of ecosystem services means that the benefits society derives from scarce ecosystem services increase over time. This is conceptually similar to how people's WTP for ecosystem services increases with income (*4,9,10*): if people get richer, they want to spend more on all types of goods and services, such as additional Netflix shows and trips to natural parks. The market responds by supplying more TV shows. Nature, however, does not respond to people's demand. If natural parks

[1]Department of Economics and Center for Earth System Research and Sustainability (CEN), University of Hamburg, Hamburg, Germany. [2]Faculty of Economics and Management Science, Leipzig University, Leipzig, Germany. [3]Potsdam Institute for Climate Impact Research (PIK), Leibniz Association, Potsdam, Germany. [4]School of the Environment, Yale University, New Haven, CT USA. [5]School for Business & Society, University of York, York, UK. [6]Toulouse School of Economics, Toulouse, France. [7]Dragon Capital Chair of Biodiversity Economics, LEEP Institute, Department of Economics, University of Exeter, Exeter, UK. [8]Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, London, UK. [9]Columbia Business School, New York, NY USA. [10]Institute for Policy Integrity, New York University School of Law, New York, NY USA.[11]Department of Economics, University of California (UC) - Santa Barbara, Santa Barbara, CA USA. [12]Department of Environmental Science and Policy, UC-Davis, Davis, CA USA. [13]Department of Economics, University of Copenhagen, Copenhagen, Denmark. [14]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany. [15]Department of Economics, Tilburg University, Tilburg, The Netherlands. [16]Department of Economics, University of Gothenburg, Gotheenburg, Sweden. [17]Department of Economics, University of Oslo, Oslo, Norway. E-mail: moritz.drupp@uni-hamburg.de

do not expand, people may value them more in the future, expressing a higher WTP to extend or preserve these parks. This increase in WTP, for the same ecosystem service, is thus due to ecosystem services becoming scarcer relative to market goods (or real income). WTPs will increase even more if ecosystem services are declining, like coral reefs or threatened species, and thus become absolutely scarcer. Estimates of future WTPs that do not reflect the increasing relative scarcity of ecosystem services due to growing incomes, or the changing real scarcity due to ecosystems loss, will systematically undervalue the ongoing contribution of ecosystem services to society. As a result, the increasing importance of the natural environment for future generations will be overlooked and society will underinvest in measures to safeguard nature (*9-11*).

Economic theory provides a path for governments to reflect the changing relative and absolute scarcity of ecosystem services in benefit-cost analysis (*9-14*). To derive a simple rule for estimating future WTPs using relative price change (RPC) adjustments, we follow the standard constant elasticity framework that typically underpins guidance on benefit-cost-analysis (see Supplementary Materials (SM)).

The RPC adjustment of future WTPs depends in particular on the rate at which WTP for ecosystem services changes with income (the income elasticity of WTP, denoted by ξ). In the standard framework (*9-15*), the income elasticity of WTP is directly related to the degree to which people consider market and non-market goods as complementary, rather than as substitutes for one another (see SM): If people feel that market goods provide a good substitute for, say, a walk in a national park, then the elasticity ξ is low. Conversely, a high degree of complementarity implies a high ξ (*9-11,15*). The more ecosystem services serve as complements to, rather than substitutes for, market goods, the faster WTP for ecosystem services rises as income grows.

The RPC adjustment depends on two ingredients that interact with the income elasticity. First, it depends on the growth rate of market consumption goods, g_C, measured as GDP per capita. As real incomes grow, the larger is the budget people can spend on any good, market and non-market. This describes the "real income effect" ($\xi \times g_C$). Second, the adjustment depends on the growth rate of ecosystem services, g_E. WTPs for ecosystem services rise more when ecosystems are in decline, and thus do not only become scarcer relative to market goods but also scarcer in absolute terms. This describes the "real scarcity effect" ($-\xi \times g_E$). Combining both effects yields the RPC rule: $\mathrm{RPC} = \xi \times [g_C - g_E]$ (Figure 1B). When growth rates remain constant, WTPs increase exponentially with the RPC (Figure 1C). Thus, as incomes grow and ecosystems decline, the benefits from ecosystem services reflected in policy analysis must rise. To this end, policy guidance should incorporate the RPC rule to adjust estimates of future WTPs for scarce ecosystem services.

The first necessary step for integrating the RPC rule into policy guidance is to account for the real income effect. This is already routine practice for other non-market goods, such as health or travel time. In a functioning market, when the demand for a good increases due to greater wealth in the economy, firms have an incentive to produce more of the good. Such an increase in supply counteracts the price increase. By contrast, ecosystems do not respond to (shadow) prices. It is the job of policy to account for the real income effect. The second step is to account for the real scarcity effect.

Our proposal relates closely to two standard concepts in benefit-cost analysis: discounting (a method to make future monetary benefits or costs comparable with today's) and benefit transfer. First, an alternative to estimating future WTPs adjusted for relative price changes is to instead use different discount rates for ecosystem services and market goods *(9-14*). This, however, would also require changing the standard discount rate. The alternative we propose here, which is mathematically equivalent (see SM), is to adjust future WTPs and use a single discount rate schedule. This proposal is simpler, more transparent, and often more compatible with how guidelines deal with other non-market goods (*5-7, SM*). Second, benefit-cost analysis routinely draws on benefit transfer to estimate missing WTPs, using WTP estimates from a study site to transfer or scale it to another geographical setting. Benefit transfer "in space" commonly adjusts for differences in average incomes across locations (*15*). The RPC rule can be thought of as a dynamic extension to perform benefit transfer "in time", adjusting past or current WTP estimates to future dates where real incomes and real scarcities have changed.

A NEW DEFAULT FOR POLICY GUIDANCE AND ACTION

Most current policy guidance implicitly assumes that WTP for ecosystem services does not increase with income over time ($\xi = 0$). This ignores both income and scarcity effects—in stark contrast to empirical evidence (*4,9,10*). It also produces an inconsistency in the treatment of non-market goods when adjustments for real income effects are considered for time and health effects but not ecosystem services. We propose to shift policy guidance to a new default, in which benefits from ecosystem services are considered to increase proportionally with real income or the consumption of market goods ($\xi = 1$). This strikes a balance between indirect evidence from non-market valuation studies, yielding elasticity estimates of around 0.4 to 0.8 (*4,9,10*), and expert judgments that employ values of up to 2 (*9,11*), and accords with what governmental bodies use for valuing reductions in mortality risk (*5*) or travel time. Under the new default, future WTPs for stagnating ecosystem services would rise in proportion with real income (Figure 1C). For declining ecosystem services, future WTPs would rise faster, accounting also for the larger absolute scarcity of ecosystems (Figure 1C).

Figure 1D illustrates how shifting from current valuation practice to our proposed RPC rule affects today's value of ecosystem changes over a century. We compare the present value (i.e., the discounted sum) of future WTPs using the new default from Figure 1C for RPC adjustments to the present value of unadjusted WTPs as in current policy guidance (see SM). Against the backdrop of expected increases in real incomes, we first consider the case of "Environmental Stagnation". Here, a proportional increase of WTP with real income—the new proposed default—results in WTP for ecosystem services increasing by 2% per year (Figure 1B). Considering adjustments to future WTPs over a century (Figure 1C), at a discount rate of 2% as in the US OMB Circular A-4, the RPC rule adjustment yields an increase in the present value of ecosystem services of 131% (Figure 1D). Projecting forward the decline rate of global forest areas, populations of the International Union for the Conservation of Nature (IUCN) Red List Index for threatened species, or biodiversity according to the Living Planet Index, the increase in present values would be more than 140%, 180%, and 1200%, respectively (Figure 1D). Accounting for the effects of growing real income and increasing real scarcities of ecosystems thus clearly matters and will make projects that have long-term positive effects on ecosystem services more attractive. In a benefit-cost analysis of climate change, for instance, neglecting such relative price changes underestimates the social cost of carbon (an estimate of the cost of damage resulting from each additional ton of carbon emissions) by more than 50% (*9*).

To put this shift in guidance into action, we recommend that governments in their policy analyses immediately start accounting for the real income effect with a proportional increase of WTPs as real incomes grow. Focussing on the real income effect is a pragmatic starting point, as it is common for all ecosystem service benefits and closely aligned with how guidelines commonly value benefits of travel time reductions and of health (*4*). Forecasts for GDP growth are also available (*8*), while forecasts for

ecosystem services require further research (*10*). Real scarcity effects should be integrated whenever forecasts for ecosystem services are available.

Policy guidance should be periodically revised as more evidence becomes available. Governments may consider creating advisory groups (*7*) to distil evidence on income and scarcity effects, including growth rates of various ecosystem services, and to inform setting income or substitution elasticities, which may vary across ecosystems and geographies. Elasticities are likely heterogeneous, and estimates of elasticities and growth rates are also inherently uncertain (*13*). Furthermore, ecosystem services are impacted by expanding economies, yet they also provide inputs to producing market goods. Their increasing scarcity may thus also change the growth rate of GDP (*14*). Future refinements should seek to reflect these complexities.

Our proposal helps level the playing field so that ecosystem services are treated more consistently with other goods, whose (shadow) prices, or WTP estimates, change over time. As governmental guidelines in Germany, the UK, and the US are undergoing major updates, our proposal would help governments operationalize guidance on assessing the changing values of ecosystem services. Applying a simple relative price change rule, as we propose here, would ensure that the importance of scarce ecosystems for future generations is appropriately reflected when deliberating over public investments, evaluating regulatory change and meeting sustainability requirements.

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Supplementary Materials

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Figure 1: Scarce ecosystems and increasing ecosystem-service values

(**A)** Relative to growth in market goods (or real income, reflected by GDP per capita), there is increasing scarcity of many ecosystem services (reflected by global forest area, populations of the IUCN's Red List Index for threatened species, and biodiversity as reflected by the Living Planet Index, all of which are on a declining trend that is projected forward (*10*)). An "Environmental Stagnation" scenario reflects ecosystem services remaining unchanged. (B) The relative price change (RPC) rule maps growth rates into yearly relative price adjustments against the rate at which willingness-to-pay (WTP) for ecosystem services changes with income, i.e. the income elasticity of WTP (ξ). We contrast the current, old, default ($\xi = 0$), and the proposed new default ($\xi = 1$). (**C)** WTPs increase over time when applying the RPC adjustments using the new default ($\xi = 1$) from Panel **B**. **(D)** Use of the RPC adjustment increases the present value of ecosystem services over a century compared to current government guidance on benefit-cost analysis. A 2% discount rate is used. The present value increase of 131% in the "Environmental Stagnation" scenario captures the real income effect. This is the part of the RPC adjustment that is common to all ecosystem service values and that we suggest to integrate into policy guidance in a first pragmatic step. See SM for details and further analyses.