**Introduction**: Measuring and Accounting for Environmental Public Goods: Building expanded National Accounts. Nicholas Z. Muller, Eli P. Fenichel, and Mary Bohman

This NBER Conference on Research on Income and Wealth (CRIW) focused on measuring and accounting for environmental public goods using a national accounts perspective was originally proposed by V. Kerry Smith and Richard T. Carson, two longstanding leaders in environmental economics. In part, the motivation was to coincide with the 50th anniversary of William D. Nordhaus and James Tobin's seminal paper "Is Growth Obsolete" (1972). The papers in this volume, along with much of the related literature since the 1970s, depend on the conceptual basis established by Nordhaus and Tobin. However, as methods, models, computing power, and data availability have improved, both the scope and the depth of the work on environmental accounting has grown, as evidenced by the papers in this volume. Hence, this research represents a new research agenda that has been a long time in the making. At the same time, the new research responds to policy makers' calls for linked economic-environmental statistics to track progress and make decisions about climate, air, water and other sectors (OSTP 2023).

Measurement of the economy is a core concern for the field of economics, though the question of what the economy encompasses is not separable from what gets measured. Human activities have always been sensitive to environmental change (Brander and Taylor, 1998; Hsiang, Burke, Miguel, 2013), but in the past 70 or so years it has become overwhelmingly clear that economic activity influences environmental change affecting production and income. Meanwhile, the role of economic measurement has expanded to provide information for fiscal and monetary policy. These applications, while clearly important, are a mere subset of the questions that motivated assessments of national income and welfare. For fundamental questions related to economic progress, output or market consumption are not sufficient metrics and welfare consistent measures are also needed (Jorgenson 2018). As Nordhaus and Tobin (1972) argue, "There are other serious consequences of treating as free things which are not really free. This practice gives the wrong signals of the direction of economic growth." Therefore, economic measurement requires us to think of the biosphere as a collection of, often mispriced, assets that provide services to the economy and that exist within its boundaries.

The origins of accounting for natural resources extend deep into human history.[1] The magna carta has rules for the management of game and fishes, suggesting some measure of accounting. By the early 1900s, academics such as Fisher (1906) defined fish as wealth and argued that "it would be wrong, however, that because we cannot value them accurately, public parks or freeman cannot be called wealth." This influenced political leaders of the time. For example, Theodore Roosevelt (1910) argued that, "The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased, and not impaired, in value; and behaves badly if it leaves the land poorer to those who come after it." During and after the Great Depression, the United States, the United Kingdom, and other countries began developing national income accounts to provide a systematic unified overview of the economy. During the development of national accounts in the 1940s and World War II, natural resources and the environment were not considered major concerns. Factory output and "paying for the war," (Coyle 2015) were the primary areas of focus. In the years after the war, welfare economics developed a richer understanding of the importance of natural resources and contributions of the environment to welfare (Banzhaf 2019; Krutilla 1967).

[1] The origins of writing, counting, and coins are all tied up with early methods of accounting for livestock and ownable natural resources (Evertt 2017).

Modern discussion about environmental-economic accounting was pushed to the fore by the anti-growth stance of Meadows (1972) and a rejoin by Nordhaus and Tobin (1972). In 1992, following a flurry of theoretical developments (including Weitzman 1976; Maler 1991; Solow 1986), the United States Bureau of Economic Analysis (BEA), the U.S. agency responsible for the U.S. national accounts, initiated a set of environmental and economic satellite accounts, first published in 1994.[2] In 1993, the international community published revised guidelines to the international standard for the System of National Accounts (SNA). These revisions included a new treatment of natural resources, such as non-produced and non-financial biological assets. In 1994, the U.S. Congress directed the Department of Commerce (which houses the BEA) to suspend production of the integrated environmental and economic satellite account pending a peer review of the methods.[3] The following, year in 1995, the U.S. Congress passed the 1995 Paperwork Reduction Act, which overhauled the U.S. Statistical System, reformed the office of the Chief Statistician of the United States, within the Office of Management and Budget, and gave that position the authority to coordinate efforts like the integrated environmental and economic satellite account. Meanwhile, the National Research Council of the National Academies of Science published “Nature’s Numbers” (Nordhaus and Kokkelenberg 1999) satisfying Congress’s instructions. Around the same time, research at the World Bank was beginning to develop approaches to adjustments in net savings for the environment (Hamilton and Clemens 1999).

In the decade following “Nature’s Numbers”, there was another flurry of activity. The World Bank (2005), The National Research Council (2005), The National Bureau of Economic Research (Nordhaus 2006), and U.S. Government Accountability Office (2007) all published reports emphasizing the importance of including natural resources and the environment in the national income and product accounts. Some of these reports provided specific guidelines, but all left details to be resolved. At the same time, academic research continued to advance (Arrow et al. 2004; Arrow, Dasgupta, and Maler 2003; Sefton and Weale 2006). In 2008, the SNA were again revised (European Commission et al. 2009), with little change to the instructions for including natural resources and the environment. These revisions included passage 1.46, “Natural resources such as land, mineral deposits, fuel reserves, uncultivated forests or other vegetation and wild animals are included in the balance sheets provided that institutional units are exercising effective ownership rights over them, that is, are actually in a position to be able to benefit from them. Assets need not be privately owned and could be owned by government units exercising ownership rights on behalf of entire communities. Thus, many environmental assets are included within the SNA.” However, these revisions do not provide detailed guidance on how to include such environmental assets. This difficulty led to the System of Environmental-Economics Accounting (SEEA) Central Framework (United Nations et al. 2014) and the start of a SEEA experimental ecosystem accounting process (United Nations et al. 2021).[4] Research continued to evolve, featuring advances in empirical measurement (Muller 2014; Muller, Mendelsohn, and Nordhaus 2011; Arrow et al. 2012; Fenichel and Abbott 2014; Fenichel et al. 2016). At around the same time the World Bank and the United Nations Development Program started the Changing Wealth

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[2] Satellite accounts is a term of art that refers to a subsection or articulating accounts that relate to the main national income and product accounts.

[3] U.S. House of Representatives. (n.d.). H. Rept. 103-708 (Conference Report) accompanying the Departments of Commerce, Justice, and State, the Judiciary and Related Agencies Appropriations Act, 1995 (Pub. L. 103-317). U.S. Government Publishing Office, 61

[4] The physical flow accounting in the SEEA ecosystem accounts became an international standard in 2021, but the valuation component is still considered experimental.

of Nations (2011) and Inclusive Wealth (2012) reports. These go beyond environmental-economic statistics. However, their grounding is clearly in the tradition of environmental-economic statistics. By this point there was already a growing international push to augment existing national accounts to consider the environment and perhaps other policy goals (Stiglitz, Sen, and Fitoussi 2010).

The SEEA process led to many countries developing environmental-economic accounting experiments and programs. In 2011, The European Union passed regulation (EU) 691/2011 establishing a requirement for member states to begin developing some environmental economic accounts and to report to EuroStat. These accounts focused mostly on industrial flows deemed to be related to the environment, including waste products. They also included air emissions accounts. This process continues to expand with a growing number of accounts required.[5] In 2014 the United Kingdom started its natural capital accounts and included those as official experimental accounts in the 2020 Blue Book of statistics. The need for national economic statistics to inform measures beyond output continued to become clear from an academic perspective (Jorgenson 2018) and a policy perspective as the OECD and UN both embarked on ambitious "Beyond GDP" agendas. The Dasgupta Review (2021) further accelerated interest in environmental-economic accounting. In 2023, the U.S. renewed its effort in environmental economic accounting through the development of a U.S. strategy (OSTP 2023).

The papers in this volume advance the conceptual and empirical basis for adding natural capital to the suite of economic and environmental statistics that inform public policy. They provide insights into valuation of natural capital including the need to address heterogeneity in measurement across types of capital, heterogeneity of geography, and in the distribution of individuals. Cropper and Park's paper builds on Maureen Cropper's keynote address at the conference. All the other papers are accompanied by brief comments and reflection from a discussant.

The first three papers advance the conceptual measurement of environmental-economic accounts following the U.N. SEEA framework and provide directions for use.

Cropper and Park tackle the issues associated with incorporating local air pollution, greenhouse gases, and water pollution into the national accounts. The authors focus on data needs and modeling approaches required to develop satellite accounts for air pollution. For greenhouse gases, the authors focus on issues pertaining to valuation using the social cost of carbon. Their work on water pollution emphasizes the more primitive state of data inventories and in the ability to connect such emissions to monetary damage.

Agarwala et al. develop a framework to use natural capital accounts as a tool for forward-thinking policy challenges in order to improve outcomes related to inequality, productivity, and net zero transition. The authors develop and report empirical estimates of productivity growth in the U.K. adjusted for environmental pollution damage. They also provide a simple model to incorporate risk to natural capital assets from degradation or loss. Nick Muller provides a discussion. Similarly, in the spirit of providing a tool for policy makers to predict future well-being, McLaughlin et al introduce a new database of historical Genuine Savings (GS), an indicator of sustainable development. GS derives from the theoretical work on wealth accounting, and addresses shortcomings in conventional metrics of

[5] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Environmental_accounts_-_establishing_the_links_between_the_environment_and_the_economy#Introduction_to_environmental_accounting and https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3746

economic development by incorporating broader measures of saving and investment, including human capital (education), and natural resource depletion. This article provides consistent historical estimates of GS since 1850 for 25 countries and compares the estimates to other economic indicators to assess the ability of GS to predict future well-being. Stefanie Onder provides a discussion.

To provide consistent data to incorporate heterogeneity into analysis of economic-environmental issues, Colmer and Voorheis introduce a new prototype of a microdata infrastructure: the Census Environmental Impacts Frame (EIF). The EIF provides detailed individual-level information on demographics, economic characteristics, and address-level histories – linked to spatially and temporally resolved estimates of environmental conditions at the micro (individual) level – for most residents in the United States over the past two decades. This linked microdata infrastructure provides a unique platform for advancing our understanding about the distribution of environmental amenities and hazards, when, how, and why exposures have evolved over time, and the consequences of environmental inequality and changing environmental conditions. They discuss the opportunities and limitations of these new data. The authors conclude with a measurement example showing the difference in exposure to tree canopy at the individual level versus aggregation to the Census Block Group level. This paper points one possible direction of the rich future for environmental-economic statistics.  Corbett Grainger provides a discussion.

The next four chapters look to apply lessons learned and develop strategies to implement specific environmental-economic accounts. These papers investigate developing estimates tied to the United Nations SEEA Central Framework (SEEA-CF). The analysis is also consistent with U.S. strategy.

Addicott turns his attention to developing an environmental-economic account for geologic beach structures. He analyzes the role of geographic heterogeneity as a key determinant of the value and productivity of natural assets with a study of coastal beaches. To address differences in the arrangement of sand along the coastline, he conducts three case studies using high-resolution, remotely sensed data and information on property attributes and transactions. He draws on these estimates to assess how estimates of beach width—a coastal environmental attribute--can provide a way forward for natural capital accounting. This analysis could possibly link to future implementation of a coastal ecosystem account aligned with the U.S. National Strategy for Environmental-Economic Accounts. Justin Contact provides a discussion.

Fixler et al develop a proof-of-concept environmental activity account for the U.S. to quantify the environmental goods and services sector (EGSS) devoted to protecting, rehabilitating or managing the environment. They follow the principles and methods outlined in the SEEA-CF and draw on the US Bureau of Economic Analysis (BEA) satellite account approach. Their analysis provides insights into classification, measurement challenges, and data gaps. Their estimates roughly track comparable European country statistics and the authors conclude that additional work and resources would result in high quality U.S. statistics. They identify methodological improvements that are needed to advance this sort of account for the United States. David Evans provides a discussion.

Warziniack et al create a first set of forest natural capital accounts following the SEEA-CF and demonstrate how these accounts can be integrated with general equilibrium models of the economy to capture the integrated ecological processes that constitute a forest and the associated ecosystem services. They focus on the Colorado River Basin and estimate the direct implications of deforestation for the forest industry and indirect impacts on the economy through water treatment costs and the carbon stock. Andie Creel provides a discussion.

The Wielgus et al paper builds on work by the U.S. National Oceanic and Atmospheric Administration (NOAA) and BEA to build a Marine Economy Satellite Account (MESA). They draw on extensive NOAA data and research to develop approaches to incorporate natural capital considerations using the SEEA-CF framework. Wielgus et al identify three key aspects of natural capital that require measuring both additions and reductions in natural capital stocks: offshore oil and gas, commercial fishing, and beach recreation. Andrew Scheld provides a discussion.

The papers in this volume raise several cross-cutting themes, two of which are highlighted here. A foundational concept of the national income and product accounts is the expression of economic activity in monetary units. Conversion of the disparate goods and services that comprise output into a common unit of account critically enables aggregation into (and subsequent reporting of) our commonly cited barometers of economic activity: value-added, gross output, and gross domestic product. It would be meaningless, and potentially misleading, to simply aggregate and report physical units of goods produced.

Valuation, or conversion of physical stocks and flows into monetary units, is also necessary in the context of natural capital accounting. Consider the task of tracking emissions of carbon dioxide and primary particulate matter; each of these pollutants impacts distinct aspects of the economy including public health and premature mortality risk, natural disasters and risks to man-made capital, agricultural yields, and species loss. Yet, firms, industries, and economies commonly produce these pollutants. So, the problem facing natural capital accountants is analogous to that facing national income accountants. Physical flows must be converted to a common unit of account to measure pollution damage.

In the context of the national accounts, valuation mostly relies on market prices.[6] Despite the conceptual and practical appeal of using market prices to value economic activity, this approach does not always work in the context of natural capital accounting. If the entities being tracked in natural capital accounts are not traded in markets, then quite clearly, no market prices exist[7]. In such cases, economists turn to non-market valuation techniques. These now well-established tools are categorized into two groups: revealed and stated preference approaches. The former extracts evidence on the value of the natural environment from related market transactions (see Addicott). The value of parkland can be estimated by its effect on proximate property transactions. Stated preference tools ask people directly about the value they place on the natural environment using highly structured surveys. Participants may be asked about their willingness-to-pay to reduce mortality risk. While both approaches have been used widely and critically evaluated in the academic literature (Johnston et al. 2017; Bishop et al. 2020; Bateman and Kling 2020; Lupi, Phaneuf, and von Haefen 2020; Evans and Taylor 2020) and in policy contexts, it is critical to recognize that these tools *estimate* values. In contrast,

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[6] Valuation for owner occupied housing is imputed. Hedonics are used to value the various components of computers.

[7] Consider that reduced populations of a particular species due to habitat loss may not be directly recorded in markets if that particular species is not the subject of exchange. For example, while well-defined prices exist for harvested Bluefin Tuna, they do not for the Greenland Shark. However, the shadow value of the loss of species may influence other prices in the market. For example, the loss of bats from disease can reduce agricultural yields and thus total volumes and possibly prices (Manning and Ando 2022).

reliance on market prices (as is more common in the national accounts) depends, more straight-forwardly, on observing and gathering pricing data and appropriately summarizing such data.

Despite these important differences, valuation suffers from key shortcomings in the national accounts and the natural capital accounting contexts. First, prices often reflect averages rather than true *marginal* values. This is because they are most often recorded from observing total value added over a period of time and dividing by observed quantities transacted. Consider that prices of, say, food or gasoline used in the accounts necessarily reflect averages over both time and space. Likewise, values derived from either of the non-market valuation approaches above embody sample averages. Second, uniform application of these average values to marginal and infra-marginal units of goods and services produced renders aggregates as fundamentally disconnected from microeconomic conceptualizations of welfare, namely, producer and consumer surplus.[8]

Heterogeneity is a ubiquitous feature in economic and environmental data. This raises the following question: how to deal with goods and services that are similar, but not quite the same? The U.S. national accounts use the North American Product Classification System (NAPCS) to decide what goods get grouped together.[9] In this system, for example, fluid milk, non-frozen yogurt , and cheese are all separate products. However, distinctions within these product categories are lost; cheese is cheese whether it is artisanal or mass produced. Cat food and dog food are separate goods, but all other types of pet food are combined into a single category. These sorts of decisions are the result of a deliberative process that has not happened for many environmental goods or services.

That lack of an agreed-upon approach to aggregating services makes addressing heterogeneity in environmental economic accounts challenging. But, that is not the only reason heterogeneity matters. For example, Colmer and Voorheis point out that matching individuals to natural capital, and its associated services, is scale dependent. Addicott attempts to address this challenge using attributes of detailed remote sensing and property value data along with numerous aggregation decisions. Furthermore, while numerous goods and services are considered to be the same anywhere in the United States, services from the environment are not (Muller and Mendelsohn 2007; Plummer 2009; Addicott and Fenichel 2019).

The differences among goods and services within the market boundary are measured by their prices. However, when prices are imputed, the analyst needs to consider potential quality differences within a type of service. For example, in the context of estimating pollution damage, one of the central determinants of such damage is the value of mortality risk reductions, or the Value of a Statistical Life (VSL). Considerable empirical evidence suggests that the VSL-income elasticity is positive. Hence, the VSL varies along the income distribution[10]. While this result is intuitive, it presents particularly thorny issues for natural capital accounting. One strategy is to employ the observed income elasticity to impute group-specific values and group-specific damages from pollution exposure. An alternative approach is to rely on a sample average value, a uniform VSL, for instance, and to calculate group-specific damages holding the valuation parameter fixed. While the former may be supported or informed by empirical research it raises two issues that must be addressed. First, using population subgroup-specific values in

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[8] Index number theory can be used to realign the concepts, when the focus is on specific changes (Diewert 1992).
[9] https://www.census.gov/naics/napcs/
[10] This result is observed across countries with different income levels and across different income groups within countries.

a cross-sectional setting departs from standard practice by government agencies conducting policy analysis to use an average value. Second, this tack gives the impression that the practice of natural capital accounting attributes greater weight to outcomes amongst higher income groups. The research in this volume provides context and analysis showing the need for future research to address these issues in the context of the natural capital accounts (for example, Comer and Voorheis).

This conference took place in March, 2023 as the international statistical community worked to prepare guidelines for the 2025 revisions to the SNA that update the 2008 standards. The United Nations Statistical Commission (UNSC) meeting that will take place from February 27 to March 1, 2024 will consider approving the new guidelines. The proposed changes (UN Economic and Social Council) include multiple new standards and clarifications related to natural capital accounts. The UNSC meeting will also consider further advances to the SEEA.

The 2025 revisions raise the importance of net measures of domestic product by recommending more visibility for net domestic product adjusted for both consumption of fixed capital and depletion of natural resources. This shift in emphasis provides incentives for countries to increase investments in measuring natural capital. In addition, the 2025 SNA recommendations propose expanding coverage in areas that will support development of specific natural capital and environmental services accounts. For example, they propose to explicitly include renewable energy resources (such as solar and wind electricity generation) and the recommendations provide more consistency in delineation and calculation of net present values for mineral and energy resources by aligning with the SEEA central framework.

The 2025 revisions and advances in SEEA have the potential to expand the number of countries producing natural capital and environmental services accounts. The most recent analysis of the adoption of SEEA (2022 Global Assessment) indicated that 92 countries currently implement at least part of the SEEA framework.[11] The categories published by the largest number of countries are energy accounts, followed by air emissions, environmental protection and management expenditure, material flow and water accounts. The U.S. has not released official statistics using the SEEA framework, but has published a National Strategy to produce environmental-economic statistics consistent with SEEA (OSTP 2023).

The conference and this volume provide papers from U.S. agencies that fall under the National Strategy to develop U.S. accounts for environmental services (Fixler et al), marine (Wielgus et al) and forestry (Warziniack et al). Each of the papers illustrates the challenges, especially those involving data, to develop the accounts. However, all the authors conclude that work to date shows promise for producing the accounts and they identify specific data needs and challenges.

This conference's cross-cutting theme of valuation represents an important component of the 2025 SNA and SEEA plans. While not yet included in official statistics, a priority is developing methods to value ecosystem services that can be replicated across different locations within and across countries. Challenges to adoption include the heterogeneity of services by location in addition to determining appropriate valuation methods. The Addicott and Colmer and Voorheis papers address relevant strategies and were discussed earlier in this introduction.

[11] https://seea.un.org/content/2022-global-assessment-results

The papers and comments in this volume build on the Nordhaus and Tobin paper published more than 50 years ago as well as the intervening advances in methods, models, data and computing power. The demand by policy makers to include links between the environment and economic activity have grown over this same period. Notably in 2025 as this book is published, the new SNA guidelines provide expanded coverage for environmental accounts as well as more detailed guidance. These papers inform ongoing challenges tied to valuation of nonmarket assets as well as heterogeneity across both market and nonmarket goods and services. They also provide pilots to measure natural capital for key sectors. Throughout the volume, authors raise issues for future research that we hope shapes future work. With all the research and statistical development underway, the next conference on this topic will not need to wait 50 years.

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