Environmental Accounting

NICHOLAS Z. MULLER

Abstract

While metrics such as gross domestic product (GDP) constitute important means to gauge the value of production, it is widely recognized that indices that focus exclusively on market production are incomplete. Omitted environmental assets include (i) those that have the capacity to act as a source of valuable inputs to production such as timber, subsurface minerals, or fisheries; and (ii) media that serve as a sink for anthropogenic residuals such as air, water, or soil. The human health impacts depend crucially on two parameters in the integrated asset models (IAMs): the effect that exposures to fine particles have on adult mortality rates and the value attributed to small changes in mortality risk. This essay focuses on recent research that augments standard measures of output to include damages from air and greenhouse gas pollution into national output.

INTRODUCTION

The development of a standardized set of tools to track national income and output remains an important achievement in the field of economics.

> While the GDP and the rest of the national income accounts may seem to be arcane concepts, they are truly among the great inventions of the twentieth century. Samuelson, P.A. and Nordhaus, W.D. (as quoted in Landefeld, 2000).

Some 80 years after their development, tools such as gross domestic product (GDP) are used by nations and governments throughout the world to estimate economic performance.

The value in such mensuration is manifold. Time series measurement of a particular nation's output, expressed in real terms, provides society with a sense of trends in output. Cross-sectional comparisons on purchasing power parity bases facilitate assessment of the relative wealth of nations. The impact of policy interventions, cyclical or episodic downturns, international or civil conflict, among other factors, is gauged with metrics such as GDP.

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Conversely, policymakers rely on national output statistics when designing fiscal and monetary policies.

While metrics such as GDP constitute important means to gauge the value of production, it is widely recognized, and has been for some time, that indices that focus exclusively on market production are incomplete. In the most basic sense, GDP focuses on goods transacted in markets. The problem then is that much economic activity occurs *outside* of formal markets.

Although Pigou (1932) arguably first tackled the problem of external economies, Nordhaus and Tobin (1972) were the first to point this out in the context of the national accounts. Emphasizing aspects of production outside the purview of GDP such as leisure time, home production, and environmental goods and services, Nordhaus and Tobin (1972) reported that in 1965, their proposed (more comprehensive) measure differed from standard measures by a factor of two. Clearly, they raised an important set of questions.

More recently, Stiglitz (2009) argued, in addition to recognizing that GDP is incomplete, that policies that formulate objectives *around* GDP may be counterproductive.

> If we have poor measures, what we strive to do (say, increase GDP) may actually contribute to a worsening of living standards. (Stiglitz, 2009)

Thus, it is the use of GDP to guide national priorities that is problematic. One of the particular concerns raised by Stiglitz (2009), which was also part of Nordhaus and Tobin's proposed extension to GDP, was the value of environmental assets. Using a measure of national output that omits natural capital, Stiglitz argues that:

> [w]e may also be confronted with false choices, seeing trade-offs between output and environmental protection that don't exist. (2009)

What aspects of the environment are omitted from standard measures of national output? The literature in this area typically characterizes environmental assets as (i) those that have the capacity to act as a source of valuable inputs to production such as timber, subsurface minerals, or fisheries; and (ii) media that serve as a sink for anthropogenic residuals such as air, water, or soil (Hecht, 2005).

Clearly, one may argue that the value of timber for building or making paper and minerals such as coal, oil, and gas are embedded in GDP. This is only partially true. These assets appear in GDP only when privately owned and when they provide (or may generate in the future) financial benefit to owners. Publics lands, and resources therein, as well as wild areas and native species are assets not tracked by the conventional accounts (Hecht, 2005).

Conventional measures provide an incomplete glimpse at the value of natural resources.

Are assets such as air and water *really* valuable? That is, do they belong in an augmented measure of national output? To explore this important question, consider how a firm disposes of nontoxic solid waste. Typically, the firm pays a fee to a carting service to transport the waste to either a landfill or an incinerator. Both destinations typically require fees to dispose of the waste. The important point here is that there are payments for waste disposal. Why is that the case?

This is because for a landfill, property rights for land are well defined. Even without policy constraints, a firm would not be able to simply dump waste on property that someone else owns. That is a damaging act. When we do observe illegal dumping it tends to be in vacant lots or other properties that are not closely monitored by owners, or the ownership of which is ambiguous. Firms must pay to dispose of solid waste. It consumes valuable space. It is a cost of doing business.

Now consider a firm that produces smoke as it makes its products. In the absence of regulation, the firm generates smoke free of charge. Note that this contrasts with the case of solid waste in which a firm must pay for disposal. Why is there this difference? The problem reduces to one of property rights. Airborne effluent disperses across space. Particles and gases cross municipal, state, regional, and national boundaries. These substances may affect multiple parties, raising concerns of public good. They may mingle with pollution from other firms, making attribution unclear. And, in the case of long-lived greenhouse gases, damages manifest many years after emission, obfuscating the link between perpetrator and impact.

So, do environmental assets that serve as a repository for waste belong in a system of national accounts? Well, if the case of solid waste disposal is used as a conceptual guide, the answer is clearly yes. Long-term storage of waste is a valuable service. And when property rights are established, firms (and households) have revealed a willingness to pay for such services.

The remainder of this essay focuses on recent research that augments standard measures of output to include damages from air and greenhouse gas pollution into national output. It highlights aspects of current research related to this topic and it then proposes new directions for this field of inquiry.

AIR POLLUTION IN A SYSTEM OF EXTENDED ACCOUNTS

In its 1999 *Nature's Numbers* report, the National Research Council of the National Academies of Science (NAS NRC) identified air pollution damages as a top priority for extending conventional measures of output:

> In the panel's view, no other area of natural-resource and environmental accounting would have as great an impact as the potential correction for air quality. The magnitude of this impact indicates that the development of the supplemental accounts for air quality is a high priority. (National Academy of Sciences, National Research Council [NAS NRC], 1999, p. 148)

Part of the motivation for this statement was the finding by the United States Environmental Protection Agency (USEPA) that the benefits from air pollution control were on the order of $1 trillion (United States Environmental Protection Agency [USEPA], 1999). Another impetus for the Academies' position was that the measures reported by USEPA were incomplete (NAS NRC, 1999).

With the impetus for inclusion of air pollution damage into the NIPAs established, the question of how to augment the accounts arises. As noted by Abraham and Mackie (2006), one way in which pollution externalities may be treated in the NIPAs is as a cost of production. Polluting firms require disposal of residuals resulting from production. In the absence of property rights on the atmosphere firms face no cost or fee for this disposal. The role of an augmented accounting system is to provide a structure in which national income reflects these costs. Such a framework would deduct these costs from extant measures of output. In accordance with this treatment, recent work in this area deducts pollution damage from conventional measures of output (Bartelmus, 2009; Muller, 2014; Muller, Mendelsohn, & Nordhaus, 2011). One concern with this approach is that these costs of disposal are already in the accounts. However, prior research has shown that the vast majority of air pollution damages are comprised of premature mortality risks, and, therefore, they lie beyond the market boundary (Muller *et al.*, 2011; USEPA, 1999, 2011).

The fact that firms are often not charged for the use of public waste sinks such as air, water, and soils means that production, generally, is more costly than is implied by measures such as GDP. This could, in principle, have two effects. First, if the adverse consequences of using these sinks manifests in markets, then it is only the distribution of GDP across sectors that is incorrectly measured. For example, if manufacturing firms producing smoke primarily affect firms producing crops, then the value of manufacturing output is artificially high while that of crop production is suppressed. If, however, the deleterious consequences of pollution occur outside of the market boundary, then both the allocation of GDP *and its level* are wrong. Making the former correction to GDP alters the perceived productivity of different sectors in the economy. Making the second deduction also means gross output is lower.

A third issue that was raised conceptually some 15 years ago is how measures of growth are affected by the augmentations discussed above. In terms of pollution, the effects on growth depend on the trajectory of damages. The NAS NRC panel made the following statement when considering the effects of a period of improving air quality:

> The result might be a substantial increase in the estimate of growth of comprehensive consumption over this period. (NAS NRC, 1999, p. 147)

By the same logic, if air quality conditions deteriorate, augmented measures of growth will fall relative to their market counterpart.

A final conceptual point worth noting is how *total* damages are calculated. In estimating the total value of market output, GDP multiplies the current price of each good by the quantity produced. In pursuit of a seamless integration of pollution damages into this extant system of accounts, measures of total damage are typically tabulated by estimating marginal damage (the extra harm caused by one more unit of emissions) and multiplying that by the quantity of emissions produced (Abraham & Mackie, 2006; Nordhaus, 2006). Thus, in the methodological section below, significant emphasis is placed on the estimation of *marginal* damages.

HOW ARE DAMAGES MEASURED?

Over the past 15 years, many papers have developed advances in modeling techniques that facilitate measuring air pollution damages (Banzhaf, Burtraw, & Palmer, 2004; Fann, Fulcher, & Hubbell, 2009; Heo, Adams, & Gao, 2016; Jaramillo & Muller, 2016; Kerl *et al.*, 2015; Levy, Baxter, & Schwartz, 2009; Muller, 2014; Muller & Mendelsohn, 2007, 2009; Tessum, Hill, & Marshall, 2015; USEPA, 1999). Collectively, these papers suggest that (i) air pollution damages comprise a significant share of GDP, (ii) the majority of the air pollution damages are comprised of adverse consequences on human health, and (iii) damages hinge critically on two parameters that are discussed below. Additionally, Muller (2014) finds that the *changes* in damages have an appreciable effect on measures of growth.

How are these damages calculated? Damages from air pollution are typically computed using integrated assessment models (IAMs). An IAM uses findings from engineering, atmospheric chemistry and physics, epidemiology, and economics to link the production of residuals to final, monetized consequences. Although the earliest examples of IAMs date back to the late 1970s and early 1980s (Mendelsohn, 1980), the recent literature has made a number of advances in these devices (Fann *et al.*, 2009; Heo *et al.*, 2016; Kerl *et al.*, 2015; Muller & Mendelsohn, 2007, 2009; Tessum *et al.*, 2015).

Most IAMs focusing on air pollution connect emissions of common air pollutants to estimates of ambient concentrations, exposures, physical impacts, and monetary damage so that the impacts can be incorporated directly into the national accounts. The air pollutants covered often include nitrogen oxides (NO_x), sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), ammonia (NH_3), and volatile organic compounds (VOCs). The first step in an IAM for air pollution relies on emissions data, which reveal where, when, and in what quantities these substances are produced. In developed economies, public environmental regulatory agencies typically provide these data. (Often these agencies are charged with environmental enforcement, which depends on tracking emissions. So they have the data anyway.)

In the United States, emissions data are reported by the USEPA. In an IAM, these data are fed through an air quality model that links emissions to ambient concentrations. Exposures are tabulated by tracking populations of sensitive receptors (human populations and crops, for example). Physical impacts, such as reduced crop yields and increased rates of illness, are estimated through the use of concentration–response functions gleaned from peer-reviewed publications. Valuation uses either reported market prices (for impacts on crops) or non-market valuation techniques.

As mentioned above, most environmental accounting exercises tabulate total damage as the product of marginal damages and emissions. One of the advances made in the design of IAMs lies in spatial resolution. Source-specific damages are now computed for particular power plants and manufacturing facilities. For example, recent work indicates that the per ton damage from emissions of sulfur dioxide (a common air pollutant produced when coal is burned) varies by over 100 times within the contiguous United States (Muller & Mendelsohn, 2009, 2012). Figure 1 shows this stunning range of impacts. Because the impact of emissions of local air pollution varies a lot according to where it is emitted, the enhanced resolution is a critical advance. After all, if total damages are computed as the product of marginal damage times total emissions, then getting the total damage figure right depends on having the margins correctly estimated. And, if the marginal damages vary drastically across space, then an accurate estimate of total damage depends on having source-specific marginal damages.

Figure 1 also indicates that the largest damages on a per ton basis are due to emissions produced in cities. This stems from the importance of human health effects in pollution damage. The robust finding that the largest share of damage is due to human health impacts depends crucially (as noted above) on two parameters in the IAMs: the effect that exposures to fine particles have on adult mortality rates, and the value attributed to small changes in mortality risk. Because of the importance of these parameters in tabulating damages, both are discussed in the following paragraphs.

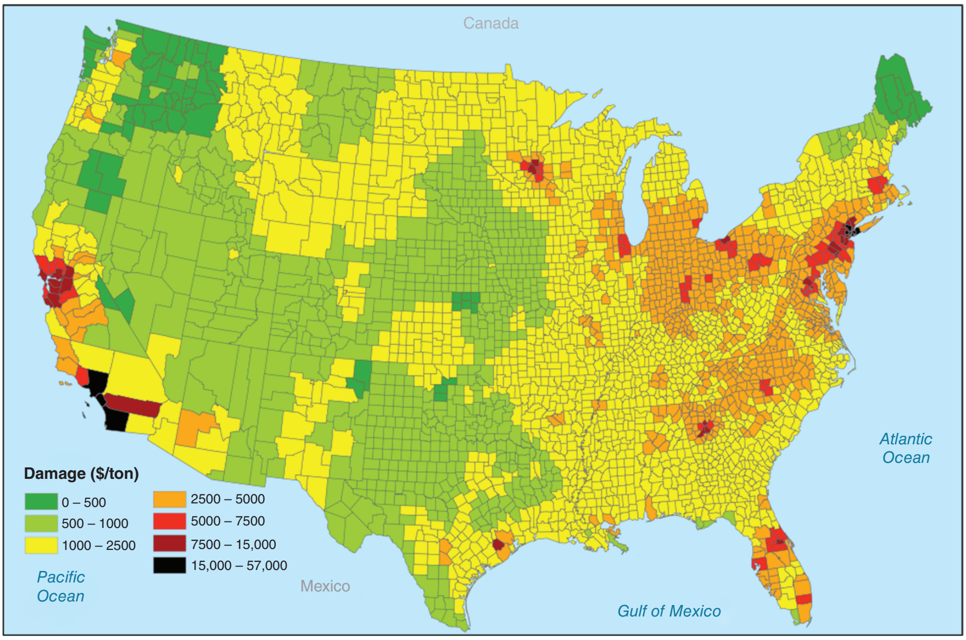

Figure 1 SO_2 marginal damages. *Source*: Muller and Mendelsohn (2012).

Traditionally, evidence about the effect of exposure to pollution on human health is obtained from peer-reviewed research in the epidemiological literature. And, in terms of the effects of exposure to fine particles on premature mortality in the United States, two studies are most frequently used (Krewski *et al*., 2009; Lepeule, Laden, Dockery, & Schwartz, 2012). Damages computed using these two studies (holding all else in the IAM fixed) differ by more than a factor of two. How do policymakers or academic researchers conducting environmental accounting resolve these differences? Typically, both parameters are used in a sensitivity analysis in order to bound or bracket damage estimates (USEPA, 1999, 2011).

A second point related to this issue is worthy of discussion; recent research in environmental economics has brought more sophisticated econometric techniques to the question of how exposure to environmental pollutants affects mortality rates. This research has raised two critical questions. First, do the epidemiological studies effectively control for a range of pollutants such that regulators are confident that risks attributed to particulate matter are, in fact, due to exposures to that pollutant (Beatty & Shimshack, 2011; Currie, Neidell, & Schmeider, 2009)? Second, is the magnitude of the effect that particulate matter has on mortality rates different when researchers use quasi-experimental models that estimate a causal effect of particulates on mortality rates (Chay & Greenstone, 2003)? Because mortality effects play such a large role in the damages from air pollution, new findings on whether the toxicity of particulate matter holds up to different empirical methods have potentially significant ramifications for integration of pollution damage into national accounts.

For a number of years, the most common approach to valuing mortality risk uses the value of a statistical life (VSL). One common empirical approach to estimating the VSL uses hedonic wage models to identify the marginal implicit price of risk of death on the job (Viscusi & Aldy, 2003). The use of these results to value risks due to air pollution exposure is controversial for several reasons. First, hedonic wage studies rely on a sample of people from the workplace. Hence, they neglect the elderly and the very young. This is problematic because most of the premature deaths from air pollution manifest among the elderly and infants. The VSL is extrapolated to these non-working populations. Second, risks on the job are typically, though not always, acute or accidental events. In contrast, risks from air pollution involve chronic, long-term exposure. Thus, the nature of the risks differs.

In part because of the concerns related to transferring risk valuation estimates from hedonic wage studies to the context of air pollution, environmental economists have estimated VSLs in different contexts. For example, employing variation in vehicle air-bag requirements, researchers have found a range of VSLs quite similar to those estimated from hedonic wage models (Rohlfs, Sullivan, & Kneisner, 2015). Other authors explore trade-offs between risks of death while driving and time savings implied by speed limits (Ashenfelter & Greenstone, 2004). In addition, economists have exploited data from the Alaskan crab industry to estimate a VSL (Schneir, Horrace, & Felthoven, 2009). Environmental economists are actively engaged in exploring new ways to elicit the trade-off between money and risk, which is very important in the estimation of pollution damage.

RECENT RESULTS AND FUTURE DIRECTIONS

A number of recent papers have contributed to the empirical environmental accounting literature that specifically focuses on air pollution damage (Bartelmus, 2009; Muller *et al.*, 2011; Muller, 2014, 2016; Jaramillo & Muller, 2016). Bartelmus (2009) estimated the costs due to consumption of environmental capital in various parts of the world for a collection of years between 1990 and 2006. In the European Union environmental costs were under 1% of GDP. In the United States this figure was under 3%. Intuitively, environmental costs were much higher in developing economies. In China, Bartelmus estimated environmental impact at up to 12% of GDP in 2006. In Africa as a whole, this metric was over 25%. These values, while highly uncertain, are illustrative in the cross section and the time series dimensions. In every region covered, environmental costs rise over time.

While Bartelmus' work is highly aggregated, a more recent paper drilled down in great detail in the U.S. economy. Muller *et al*. (2011) calculated the air pollution damage for every industry in the U.S. economy. Why should an economic system be explored at this level of detail? A modern, developed economy consists of a wide range of productive activities: from heavy manufacturing at iron foundries to financial services and insurance. Accordingly, pollution intensity varies dramatically across sectors; the importance of augmenting national accounts varies across sectors as well.

In the United States in 2002, pollution damage as a fraction of sector value added ranged from 0.38 for agriculture/forestry to 0.01 for manufacturing, and to 0 for sectors such as finance and insurance (Muller *et al*., 2011). Within sectors, great variation in pollution intensity was also reported. For example, while electric power generation using coal produced damages over two times larger than value-added, natural-gas-based power generation produced damages less than 10% of value-added (Muller *et al*., 2011).

What does it mean to have an industry generate greater environmental pollution damage than its value-added? It may be tempting to say that such industries are doing more harm than good and therefore should be shut down. That position is incorrect. If the external costs were internalized by the firm (perhaps through an efficiently calibrated emission tax) it is quite likely that output produced by the industry would fall. That is, if no viable end-of-pipe pollution controls exist (as is the case for CO_2), then the firm would either switch to cleaner, more expensive inputs, or they would reduce emissions by reducing production. If abatement technology exists, then they would substitute away from some productive inputs toward abatement devices. In either case output will fall, ceteris paribus. If the *entire sector or industry* adopts such responses to internalized costs, then prices will adjust and value-added will rise. Concurrently damages will fall and the damage to value-added ratios will fall.

A particularly exciting area of research in this space focuses on measures of growth in GDP versus growth in measures of output that deduct pollution damage. Why is this focus on growth? First, the primary value of measures such as GDP lies in examining changes over time. Academics, policymakers, and the general public draw inferences regarding national economic performance from changes in GDP rather than levels. As such, a pressing question in environmental economics is how inclusion of pollution damage into an augmented system of accounts affects comprehensive growth rates. Second, from the perspective of public policy, macroeconomic regulatory agencies often base policy choices on quarterly or annual changes in aggregates such as GDP. Prior rates of change in GDP are clearly linked to monetary and fiscal policy; one needs to look no further than the Federal Reserve's response to the Great Recession for evidence of this claim. In principle, measures of augmented growth could be used in the same way with one additional dimension. Beyond the standard monetary policy toolkit, macroeconomic regulators basing policy choices on the adjusted output measure could prescribe reductions to damage as a means to enhance growth. That is, if pollution damage has a significant effect on augmented measures of growth, as the NAS NRC panel suggested, does this not merit consideration of pollution control as a viable lever for growth enhancements?

Recent research using data from the United States suggests that the difference between conventional and environmentally adjusted growth rates is appreciable. For example, over the period 1999 to 2011, GDP in the United States expanded at annualized rates of between 1.2% and 2.8%. When corrected for both air pollution and carbon dioxide (CO_2) damage, national output grew by about 0.3 percentage points faster (Muller, 2014, 2016).

Drilling down further, from 2005 to 2008, the U.S. economy was barreling toward the Great Recession. Annual GDP growth over this period fell to just over 1%. However, as conventional measures of growth receded, air pollution damages did too. Thus, the measure that recognized this reduction in damage expanded more rapidly. In particular, from 2005 to 2008, growth adjusted to account for air pollution and CO_2 emissions was about 0.4% more rapid than growth in GDP (Muller, 2016).

The contribution of these results is twofold. First, periods of improvement in air quality *can* have an appreciable and positive effect on growth. The intuition of the NAS NRC panel cited above was confirmed. Second, these results highlight Stiglitz' position that focusing on market-centric measures of output may foster the illusion of a trade-off between investments in environmental quality and growth in market production.

The difference in growth discussed above is largest between 1999 and 2002. One reason for this finding is that Phase II of the Acid Rain Program began in 2000. Because of this policy, emissions of SO_2 from regulated power plants fell by 2.3 million tons between 1999 and 2002. Importantly, costs of compliance with the regulation are embedded in GDP, while reduced damages are not. The finding that the benefits of pollution control are large enough to affect national growth during this time period suggests the need to amend official measures of output to include the benefits from environmental policy.

Exciting work in this space is occurring in areas beyond air pollution and greenhouse gas emissions. For example, research is currently ongoing to construct an IAM for water pollution in the United States with resolution akin to that of modern air pollution IAMs. Once operational, a model such as this will facilitate, among other topics, the ability to engage in multimedium pollution control analyses. For example, in modern economies one central aspect of water pollution control is municipal sewage treatment. While on the surface this appears to be beneficial, sewage treatment generates copious amounts of airborne ammonia emissions. Ammonia is an important catalyst in the formation of secondary fine particulate matter, which elevates mortality risk. What is the value of waste removal from water? What is the damage caused by airborne emissions from this treatment? What is the optimal mix of air and water pollution emissions from sewage treatment? Intriguing and as of yet unanswered questions such as these will form the basis of future research in the field of environmental economics. And, as an ever greater range of pollution damages are added to the environmental accounts, our measures of economic performance will do a better job of measuring welfare.

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NICK Z. MULLER SHORT BIOGRAPHY

Nick Z. Muller joined the Middlebury College economics faculty as an assistant professor in the fall of 2007. He completed his dissertation at Yale University in May of 2007, where his advisors included Robert Mendelsohn, William Nordhaus, and Nathaniel Keohane. His dissertation focused on using integrated assessment models to measure the damages from air pollution in the United States, and to propose alternative market-based policies intended to govern the criteria for air pollutants. Dr. Muller also attended the School of Public and Environmental Affairs where he studied environmental policy and public finance in pursuit of a master's degree in public administration. His current research includes measuring the damages due to emissions from each industry in the U.S. economy, the design of market-based environmental policies, and the construction price indices for air pollution. His research has been published in the *American Economic Review, Science, the Journal of Environmental Economics and Management*, and *Environmental Science & Technology*, among other outlets.

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