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Chapter Author(s): Nicholas Z. Muller

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Toward the Measurement of Net Economic Welfare
Air Pollution Damage in the US National Accounts—2002, 2005, 2008

Nicholas Z. Muller

13.1 Introduction

Environmental accounting expands the accounting boundaries established in the conventional National Income and Product Accounts (NIPAs) by measuring the value of natural resources and environmental damage. The goal is to gain a more complete picture of national wealth and welfare. Prior research has developed static environmental accounts (Ho and Jorgensen 2007; Muller, Mendelsohn, and Nordhaus 2011). Static environmental accounts constitute an important step toward a fully integrated system of accounts because they provide a glimpse of what the NIPAs overlook: the value that various nonmarket goods and services contribute to national welfare at a given point in time.

This chapter argues that environmental accounts should follow the historic progression of the national accounts from annual measures expressed in current dollars to indices tracking changes expressed in real terms. The development and implementation of the NIPAs in the 1930s began with a focus on measurement of current dollar estimates of national income. Ultimately, in recognition that the NIPAs' primary value is not as an absolute but rather a relative measurement, price deflators were introduced to the NIPAs in 1951 (USBEA 2011). Now, changes in gross domestic product (GDP) are the primary focus, not levels. Similarly, dynamic augmented accounts comprise an improvement over static measurement. In particular, time series environmental accounting provides insights in three areas: changes in gross

Nicholas Z. Muller is assistant professor of economics at Middlebury College and a faculty research fellow of the National Bureau of Economic Research.

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pollution damage and resource stocks, changes in resource consumption and pollution intensity, and differences in rates of growth with and without augmentation. Including these measures into augmented accounts is a critical step in closing the gap between the current market-based measures of output and a more complete picture of national economic welfare.[1]

This analysis conducts times series environmental accounting by applying the methods developed in Muller, Mendelsohn, and Nordhaus (2011) to measure the gross external damage (GED) due to air pollution emissions in the United States (US) economy in 2002, 2005, and 2008. Intuition suggests, and prior research confirms, that including the GED into the accounts in any one time period will shrink conventional, static measures of output such as GDP or value added (VA). After all, the GED is comprised of external costs neither reflected in market prices nor included in the NIPAs. Air pollution (and other types) is a residual of the production process and the atmosphere acts as a repository for waste disposal. When well-defined property rights exist for waste disposal (as in the case of a landfill), firms are charged per unit disposal. In the case of air pollution, firms often consume this valuable input free of charge; the role of environmental accounting, then, is to include the cost of consuming this scarce input into the NIPAs. To this end, this chapter computes environmentally adjusted value added (EVA), which is the value-added analogue to Bartelmus's (2009) environmentally adjusted gross output (EDP). EVA is defined as VA less GED.

While including GED into the NIPAs in any one time period will reduce measures of output, folding GED into the accounts over time can affect conventional measures of growth in either direction. Whether GED attenuates or augments conventional measures of growth depends on the relative rates and direction of change in market production and the GED. Three cases are both important and illustrative. First, an economy with VA growth less than its GED growth would have EVA changing at rates less than VA. In this case, augmented accounts ratchet back estimates of growth. Second, if the GED and the VA are changing at the same rate, growth rates for the VA and the EVA are equal. And, third, EVA growth may exceed VA growth if the GED grows more slowly than the VA (or if the GED contracts); this would cause the augmented EVA measure to enhance estimated rates of growth because the benefits of reduced GED act as a source of growth in the EVA measure. This chapter reports levels and rates of change of the VA and the EVA for each sector and the entire US economy over the period 2002 to 2008.

The value of relative measurement also holds for the nonmarket accounts. Although a paucity of data, measurement difficulties, and the codified structure of the current, market-oriented NIPAs make even annual, one-shot

1. Here, and in the title, net economic welfare is meant in the sense of Nordhaus and Tobin (1972): it is a proposed measure of national income and production that values many external costs overlooked by the NIPAs. One among these is air pollution damage, which is the exclusive focus of the chapter.

estimates of nonmarket accounts significant achievements, most meaningful are elicitations of rates of change in the value of goods and services outside the purview of the standard accounts. Prior work in the current context (measuring the damages from environmental pollution) developed annual estimates of the air pollution externality (Ho and Jorgensen 2007; Muller, Mendelsohn, and Nordhaus 2011).

Environmental accounts in multiple time periods may detect structural changes in economic activity: either in the form of sectoral composition of an economy or in terms of the pollution intensity of production in the extant sectoral mix. This latter point, changes in pollution intensity, highlights an additional benefit of measuring the GED across time. It is often the case that changes in pollution intensity arise due to regulation. Insofar as this is the case, the GED can provide an important way to measure the benefits of environmental policies. As regulated firms purchase, install, and operate pollution control devices, these capital and operating and maintenance costs are entered into the (existing) NIPAs as a cost of doing business.[2] Regulated industry's VA declines as a function of these expenditures, ceteris peribus. Abatement expenditures are often conventionally viewed as a drag on growth for firms, industries, and sectors that make such expenditures. The NIPAs capture returns to these expenditures either through the transfer to firms that produce and market abatement technology, or through any improvements to the production of market goods and services due to the reduced pollution flow. However, the NIPAs, by definition, miss nonmarket benefits that may arise from their use. This happens to be quite important for the case of air pollution since the vast majority of the GED is comprised of impacts to human health, which are not measured or reflected in market transactions. This highlights the importance of the augmented EVA measure. The EVA encompasses an important missing (from VA) measure of the benefit of these investments in environmental quality. Namely, the corresponding reduction to the GED that is comprised almost entirely of reduced mortality risk and incidence rates of chronic illness (both examples of nonmarket benefits). The EVA accounts for this source of growth.

Measuring the damages of air pollution necessitates having information on quantities of emissions *and* the marginal value of such emissions. In a modern, developed economy, such as the United States or countries in the European Union, measurements of pollution *quantities* have been established since the implementation of environmental policies. The primary challenge then to conducting or implementing environmental accounts for pollution is valuing emissions. With quantities of emissions reported by the US Environmental Protection Agency (USEPA), the GED is tabulated using the source- and pollutant-specific marginal damages produced by an

2. Fixed capital costs enter the NIPAs through measures of consumption of fixed capital (CFC). This analysis reports market VA net of CFC as reported by the USBEA (USBEA 2011).

integrated assessment model, the AP2 model (Muller and Mendelsohn 2007, 2009; Muller, Mendelsohn, and Nordhaus 2011; Muller 2011, 2012; NAS NRC 2009). The AP2 model encompasses emissions of and estimates marginal damages for: ammonia (NH_3), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), and volatile organic compounds (VOCs). An important feature of AP2 is that it estimates marginal damages for specific source locations. This spatially tailored approach allows for heterogeneity in the marginal values.

The methodology embedded in the AP2 model uses assumptions that tend to be viewed as standard in the literature that measures the damages from air pollution. Critical among these assumptions are the dose-response parameter that links mortality rates to exposures to fine particulate matter, and the value attributed to small changes to mortality risks. The dose-response relationship from Pope et al. (2002) is employed by AP2, and the value of a statistical life (VSL) methodology is used to value mortality risks (Viscusi and Aldy 2003). The VSL employed herein is approximately $6 million ($2005). The marginal damages produced by AP2 are multiplied times reported emissions in order to tabulate total damages. This approach is congruent with how the NIPAs are calculated (Nordhaus 2006).

Computationally, the degree to which valuation is a difficult task depends on three factors. First is the extent of mixing of the pollutant; a well-mixed pollutant's impact does not vary according to location of emissions. Measuring such a pollutant's impact is relatively straightforward since value estimates do not vary by source. Second is the nature of impacts: market versus nonmarket effects. Impacts in markets have well-defined prices. Nonmarket effects require imputation. And third is the time horizon of impacts: effects may occur relatively soon after emissions or they may span many years. If pollutants persist in the environment, the issue of discounting arises. How do these parameters relate to the pollutants encompassed by the GED?

First, these pollutants are not well mixed; this suggests that source-specific marginal damages for emissions should be used. Evidence of the degree of heterogeneity in the marginal damages is provided by Muller and Mendelsohn (2009) and Fann, Fulcher, and Hubbell (2009). Second, the majority of adverse impacts from these pollutants involve increased mortality risks. Valuation of mortality risk is both difficult and contentious. Third, the impacts of the pollutants encompassed by the GED tend to occur within a year of emission. As a result, issues related to discounting do not arise.

The valuation of environmental damage, and in particular premature mortality effects, has received a mixed welcome in the environmental accounting literature. On one hand, Nordhaus and Kokkelenberg (1999) argue that valuation of environmental damage is essential to environmental accounting. On the other hand, the System of Environmental-Economic

Accounting (SEEA) (all versions) effectively exclude welfare-based valuation of environmental damage due to its controversial nature. While it is true that valuing nonmarket services (such as human health status) is uncertain and controversial, simply measuring tonnage of the pollutants encompassed by GED may in fact be misleading. Consider that pollution emissions may increase or decrease differently across space due to regulation or the distribution of industrial production. If, for example, emissions decrease in especially high damage areas, while low damage emissions increase significantly, it is *possible* for physical accounts and the GED to move in different directions. Which tack is preferred? In the simplest sense, the spatial variation in impacts per ton of emissions is driven by population density; emissions in cities cause more harm than emissions in rural areas. Although the value-based GED relies on methods that are uncertain, it is based on an approach to damage measurement that *picks up this spatial pattern*. In contrast, physical accounts overlook this by treating all tons equally, which is clearly a mistake.

In order to make meaningful comparisons of EVA and GED across years the paper deflates the marginal damages. Three approaches to deflation are used. First, the marginal damages are held fixed at 2005 levels for 2002 and 2008. This means that the only factors changing are emissions in 2002 and 2008. The second deflation strategy applies the sector-specific deflators reported by the United States Bureau of Economic Analysis (USBEA) for market prices. In this case both the market VA and the nonmarket GED are deflated in the same manner. The third deflation tactic uses the Fisher pollution price index numbers reported in Muller (2013). These are pollutant- and year-specific Fisher index numbers computed using the marginal damages across the United States in each year of this analysis. These are reported in table 13A.2 of the appendix.

The literature that focuses on environmental accounting is large and well developed. Arguments regarding augmenting the NIPAs appear in articles as far back as the late 1960s (Ayres and Kneese 1969; Leontief 1970; Nordhaus and Tobin 1972). More recent research in this area includes: Nordhaus and Kokkelenberg (1999); Bartelmus (1998, 2009); Vardon et al. (2007); Gundimeda et al. (2007); and Muller, Mendelsohn, and Nordhaus (2011).

The work of Bartelmus (2009) is probably most similar to the current analysis. There are three dimensions to the correspondence between Bartelmus' work and the current chapter. First, it develops and estimates an adjusted measure of economic output (EDP). Second, it applies this methodology empirically. And third, the study encompasses multiple data years. However, important distinctions include the present study's use of an integrated assessment model to value pollution according to source type and location. Further, the GED is expressed in real terms whereas Bartelmus reports EDP in current dollars. Finally, the EDP are computed globally and decomposed by region, while the GED are tabulated for the United States and decomposed by sector in the present chapter.

There are numerous reports available at the SEEA program's website that explore aspects of environmental accounting that overlap with the focus of the current chapter (United Nations 2011). For example, Murty and Gulati (2006) explore *firm-level* environmental accounting for air pollution impacts in India; the authors estimate shadow prices for local air pollutants emitted from thermal power plants in a few locations in India. Also on the SEEA website, there are many reports that focus on relatively current environmental accounting efforts throughout the world. Important examples that connect to the current chapter include reports on the mass of emissions of air pollutants, environmental tax revenue, and abatement expenditures.

This chapter builds on the prior work of Muller, Mendelsohn, and Nordhaus (2011), which measured both sector and industry GED and VA. The current analysis does not drill down below the sector level of aggregation because of limitations in the data. While GED can be computed at the industry level in all three data years, the USBEA reports measures of output at the six-digit level of detail in five-year increments that do not line up with the USEPA air pollution emission reporting system. While there exists considerable heterogeneity in emission intensity within a sector, this analysis cannot relate GED to VA for specific industries because of this data constraint.

The methodology used to estimate the marginal damages that are ultimately used in this chapter to compute the GED is linked to a literature on the measurement and valuation of air pollution damages. Important papers in this literature include: Mendelsohn (1980), Burtraw et al. (1998), Banzhaf, Burtraw, and Palmer (2004), Tong et al. (2006), Muller and Mendelsohn (2007, 2009), and Fann, Fulcher, and Hubbell (2009).

The empirical results indicate that the GED decreases dramatically from 2002 to 2008. Using the Fisher pollution index, real GED is estimated to be \$480 billion in 2002, \$430 billion in 2005, and \$350 billion in 2008. On an annualized basis, the GED decreases by approximately 4 percent from 2002 to 2005 and then the GED declines by nearly 6 percent from 2005 to 2008. Much of this decline stems from reductions in the GED attributable to the agriculture, utility, manufacturing, and transportation sectors. In 2002 the total nominal GED/VA is approximately 0.054, and in 2008 the GED/VA is 0.030.

The GED/VA index shows considerable variation within sectors between 2002 and 2008. The utility sector shows a GED/VA of 0.96 in 2002. In 2008, the utility GED/VA drops to less than 0.50. Similarly, the agriculture and forestry sector begins in 2002 with a GED/VA of 0.90 and this index declines to less than 0.30 in 2008. The manufacturing sector begins in 2002 with a GED/VA of 0.056 and in 2008 the manufacturing GED/VA is estimated to be 0.032. This is not to suggest that the level of the manufacturing GED remains necessarily fixed; in 2002 the manufacturing GED was \$72 billion while in 2008 the GED for this sector was \$46 billion.

The chapter argues that two general factors drive the changes in the GED from 2002 to 2008. First, the macroeconomic conditions varied over this time period; the US economy was emerging from a recession in 2002 largely brought on by the correction in the technology sector. In 2008, by contrast, the economy was on the precipice of the Great Recession. Many sectors were experiencing outright contraction in output (or at least reduced growth) at this time. This had implications in terms of the GED as air pollution emissions were reduced along with gross output. An example of this is evident in the manufacturing sector. Annualized growth in VA was about 5 percent between 2002 and 2005. From 2005 to 2008, VA increased by just 0.5 percent, per annum. Insofar as emissions are positively correlated with output, such a slowdown is bound to yield fewer total emissions.

The second factor affecting the GED change between 2002 and 2008 is the regulatory environment. Regulatory constraints may affect gross output (or VA) through compliance costs. Such rules, by definition, impact the GED through binding emission limits. For example, utilities (especially coal-fired power plants) dramatically reduced their emission of SO_2 and NO_x between 2002 and 2008 specifically because of regulatory constraints. To an extent, the chapter is able to tease out these impacts in the calculation of GED. Further, sulfur content rules for diesel fuel used in highway vehicles as well as locomotives and marine vessels implemented in 2007 had noticeable impacts on the GED for the transportation sector. While disentangling these two factors (gross output and regulation) is difficult for many sectors, where feasible the chapter attempts to parse the effects of these two factors on GED and GED/VA.

Finally, the chapter provides evidence of a significant divergence between standard measures of economic growth and performance (such as VA) and the augmented EVA measure. In particular, the economy-wide EVA grows at greater annual rates from 2002 to 2005 and from 2005 to 2008 than VA. Between 2002 and 2005, the EVA grew at an annual rate of 3.07 percent while conventionally measured VA grew at 2.76 percent. Thus, incorporating the GED into this measure of growth alters (increases) the ex post estimate of growth by 0.3 percent. From 2005 to 2008, VA grew at an annual rate of 1.18 percent and the EVA grew at 1.47 percent per year. The divergence between the rates of growth in VA and EVA was just under 0.3 percent from 2005 to 2008. While including the GED into the NIPAs reduces the level of VA, in the US economy between 2002 and 2008, including the GED *increases* estimates of growth since the GED decreased over this time period.

The remainder of this chapter is organized as follows. Section 13.2 presents the accounting framework and tackles issues of deflation of the pollution shadow prices. Section 13.3 explores the empirical model used to estimate pollution shadow prices. Section 13.4 presents results, and 13.5 concludes.

13.2 Accounting Framework

The nominal GED is tabulated by multiplying the emissions produced by source (j) of pollutant (s), in sector (i), at time (t), denoted (E_{jsit}), by the estimated shadow price of emissions, MD_{jst} matched by source (j), pollutant (s) and time period (t). The MD_{jst} serves as an imputed price, or shadow price, for the E_{jsit}.

(1) $$GED_{jsit} = MD_{jst} \times E_{jsit}.$$

Note that the shadow price is, in effect, the marginal damage of an emission expressed in monetary terms. The empirical estimation of the MD_{jst} is discussed below. Figure 13.1 provides a diagrammatic treatment of the GED calculation. Tonnage abated increases from left to right, with a current (arbitrary) level of abatement at (a). Tonnage emitted therefore increases from right to left; the corresponding emission level is given by the distance (d–a). GED is computed using the NIPA convention in which all tonnage is valued at the marginal value (Nordhaus 2006). The GED is given by abcd. Note that the GED tabulation has no bearing on microeconomic considerations of allocative efficiency.

The GED_{jsit} are then aggregated up to the industry and sector level by

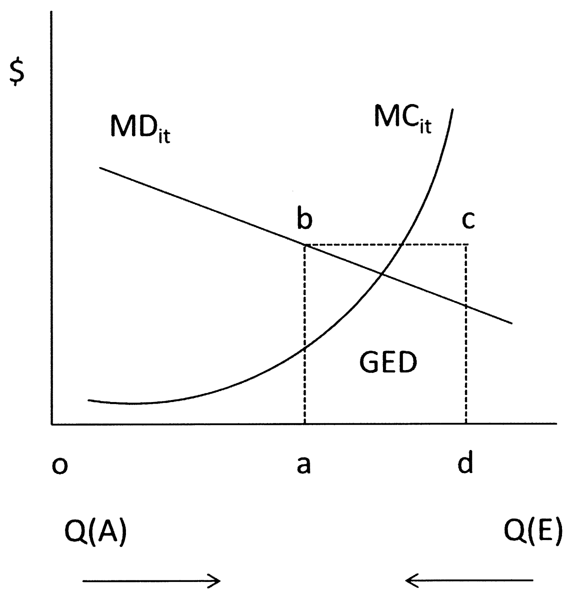

Fig. 13.1 Gross external damage graphical depiction

summing across all pollutants emitted by a source and across all sources within a sector as shown in equation (2).

$$(2) \qquad GED_{it} = \sum_{s}^{S} \sum_{j}^{N} GED_{jsit}.$$

Then, for sector (i), the EVA is tabulated by subtracting the GED_{it} and consumption of fixed capital (CFC_{it}) from the reported value added (VA_{it}).

$$(3) \qquad EVA_{it} = VA_{it} - GED_{it} - CFC_{it}.$$

Annual rates of change for VA, GED, and the EVA are computed using the following compound interest formula, which uses economy-wide GED in periods (t) and ($t + n$) as an example:

$$(4) \qquad \Delta GED_{t,t+n} = \left(\frac{GED_{t+n}}{GED_t} \right)^{1/n} - 1.$$

In this chapter, GED is related to VA (rather than gross output) because the accounting exercise conducted herein zeroes in on damages at each stage of production as opposed to the cumulative emissions in the supply chain. Hence, the appropriate measure of pollution intensity is GED relative to VA. If the GED encompassed cumulative damages at each stage of production, the correct intensity metric would compare GED to gross output (GO). For example, the GED recorded for the manufacture of steel only reflects emissions from the actual manufacturing of steel. The GED to GO approach would tabulate the emissions over the entire supply chain inclusive of the discharges and resulting GED emanating from the production inputs to steel manufacturing: coal mining and transport, iron ore mining and transport, production and delivery of electricity, and so on. This tack, while not pursued in the present analysis, may produce interesting insights into the share of GED associated with final consumption or production of a good relative to the embedded GED in the supply chain.

The EVA computed in this chapter is limited in scope to deducting the GED from air pollution. This omits other (potentially) important types of environmental damage: water pollution, toxins in soils, and greenhouse gases. Further, the chapter does not tabulate positive externalities produced by industries such as forestry, landscaping, or education, for example.

13.2.1 Deflation and Real Values

Since the empirical analysis spans multiple years, nominal versus real reporting is an important consideration. The chapter reports real GED, VA, and hence, EVA. The tabulation of real VA relies on the USBEA data and deflators (USBEA, 2011). (VA is reported in real 2005 US dollars.) The VA is expressed in real terms using sector-specific chain-type price indices (USBEA 2011) to deflate each sector's VA. As shown in equation (3), CFC is subtracted from VA as well.

Recall that GED is computed by multiplying source- and pollutant-specific marginal damages, or shadow prices, times reported emissions as in equation (1). Exploring nominal versus real GED rests on whether and how the shadow prices change through time. Muller (2013) documents changes in the shadow prices for 2002, 2005, and 2008. Two factors dictate changes in the marginal impacts of these pollutants: emission levels and proximal population densities.[3] The critical point for the current analysis is that the shadow prices *do in fact* change between 2002 and 2008 (see Muller 2013). In order to draw comparative inferences on the GED across time periods some attempt at deflating the shadow prices is critical.

The computation of the real GED uses three deflation approaches. First, the shadow prices estimated for the year 2005 are applied to value emissions from all three data years. By holding prices fixed, this tactic isolates changes in the GED due to emission (quantity) changes. The drawback is that changes in *relative* prices are not captured.

$$GED_{it} = \sum_{s}^{S}\sum_{j}^{N}(MD_{js}^{05} \times E_{jits}), \tag{5}$$

where: MD_{js}^{05} = marginal damage source (j), pollutant (s), year 2005.

Second, pollution shadow price index numbers (estimated in Muller 2013) are used as price deflators to express the GED in real terms. These price indices are reported for each pollutant and for each year, with the year 2005 taken as the base year. The indices are tabulated using the Fisher (or ideal) index number formula (see Muller 2013) and they are reported in the appendix to this chapter.

$$GED_{it} = \sum_{s}^{S}\sum_{j}^{N}((P_{fst}^{-1}MD_{jts}) \times E_{jits}), \tag{6}$$

where: P_{fst} = Fisher-type price index for pollutant (s), time (t), relative to year 2005. This approach is the default deflator used throughout the analysis. The effect of the alternative deflators on the GED is tested in a sensitivity analysis.

Third, the USBEA's sector-specific GDP deflators (USBEA 2011) are used to express the GED in real terms. This approach assumes that the rate of change is the same for both market prices and the pollution shadow prices.

$$GED_{it} = \sum_{s}^{S}\sum_{j}^{N}((P_{dts}^{-1}MD_{jts}) \times E_{jits}), \tag{7}$$

3. Muller and Mendelsohn (2009) conduct a series of experiments that estimate the marginal damage *function* for specific sources. These suggest that the marginal damage function is flat: total damages are linear in emissions. However, pertinent to welfare analysis in regard to the current computation of GED is whether the marginal damages change if, for example, all sources in a given sector nonmarginally change their output. Such experimentation, while clearly interesting, is beyond the scope of the present analysis.

where: P_{dts} = GDP deflator for time (t), sector (s), relative to year 2005.

The use of GDP deflators does not allow for different rates of appreciation (depreciation) across pollutants. Note that the GDP deflators are always used to compute real market VA.

13.3 Empirical Model

The chapter uses the AP2 model, which is derived from the Air Pollution Emission Experiments and Policy Analysis Model (APEEP), which has been used in numerous prior applications (Muller and Mendelsohn 2007, 2009; Muller, Mendelsohn, and Nordhaus 2011; Henry, Muller, and Mendelsohn 2011; NAS NRC 2009). The AP2 is an integrated assessment model that links emissions to concentrations, exposures, physical impacts, and monetary damages for emissions of five common air pollutants: ammonia (NH_3), fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC).

The model employs the USEPA's national emissions inventories for 2002, 2005, and 2008 (USEPA 2006, 2008, 2011). The inventories report emissions for point sources, which are coded according location, specifications (including properties of the smokestack), and by the North American Industry Classification System (NAICS) codes. The inventories also report emissions from nonpoint stationary and mobile sources. The nonpoint sources encompass all emissions sources without a monitored smokestack or release point. Examples of this type of source include (but are not limited to) homes, dry cleaners, and retail gasoline refueling stations. Sources of this type are matched to the corresponding NAICS code through source descriptions provided by the USEPA. Many sources cannot be linked to a NAICS code and are thus dropped from the analysis. Mobile sources include sources from on- and off-road vehicles of many different weight classes as well as railroads, airplanes, and vessels. This source category includes tractors, mining equipment, and other mobile sources that are used for commercial and industrial purposes. As with the nonpoint sources, only those source types that are able to be linked with a particular NAICS code are included in the analysis.

Beginning with these baseline emissions data, the model predicts corresponding ambient concentrations of $PM_{2.5}$, tropospheric ozone (O_3), SO_2, and NO_2 in every county in the coterminous United States. The predicted concentrations are used to estimate exposures in each county. These include human exposure, crop and timber exposure, and man-made materials exposure for substances that are sensitive to SO_2 exposure.

Peer-reviewed dose-response functional relationships are used to translate exposures into physical effects. Paramount among the dose-response functions in the model are those that govern the link between human mortality rates and exposures to O_3 and $PM_{2.5}$. (That is, premature mortality effects comprise 90 percent of total damages.) The model employs the findings from Bell et al. (2004) for the O_3-mortality link and from Pope et al. (2002) for the $PM_{2.5}$-mortality relationship.

The final stage in the AP2 model applies monetary values to the various physical effects due to air pollution exposure. For crops and timber this reduces to applying current market prices for these commodities to the predicted yield change in a given year. For impacts on human health, valuation relies on estimates of the willingness to pay to avoid either additional cases or additional mortality risks. For mortality risks, the study uses the VSL methodology (see Viscusi and Aldy 2003). This approach, which is widely applied by practitioners and academics (USEPA 1999), uses results from either (or both) revealed preference or stated preference studies to ascertain society's willingness to pay to avoid small increases to baseline risk levels. This study employs a VSL of approximately $6 million ($2005), which is the VSL used by the USEPA in their analysis of the benefits and costs of the Clean Air Act (USEPA 1999). The VSL is applied uniformly to populations of all ages. For valuation of chronic illnesses, the AP2 model uses results from studies that ask survey respondents how much they would be willing to pay to avoid a case of illness (either chronic bronchitis or chronic asthma).

The AP2 model is used to estimate the marginal damage ($/ton) for emissions of each of the five pollutants tracked by the model at the nearly 10,000 sources covered by the model. This entails the following algorithm, which was developed in Muller and Mendelsohn (2007, 2009), and subsequently applied in Muller, Mendelsohn, and Nordhaus (2011). AP2 begins by estimating baseline damages; baseline emissions (reported by USEPA) are processed through the model to compute baseline monetary damages for a given year. Then, one ton of one pollutant (perhaps NO_x) is added to baseline emissions from a specific source (perhaps a power plant in western Pennsylvania). The model is run again to compute the subsequent change in concentrations, exposures, physical effects, and monetary damages, all relative to the baseline case. The difference in damages between the add-one-ton case and the baseline comprises the marginal damage. The change in damages is strictly attributable to the additional ton (of NO_x in this hypothetical example) because everything else in the model has been held fixed by the researcher. The algorithm is then repeated for every source and every pollutant in the model for a total of 50,000 iterations. Note that after each experiment, emissions are reset to the baseline level.

13.4 Results

Table 13.1 displays the real GED by sector for 2002, 2005, and 2008. The GED shown in this table employs the Fisher pollution price indices to deflate the pollution shadow prices. Throughout the analysis the market

Table 13.1 Sector real GED ($ billion, 2005 prices)

2002		2005		2008	
Sector	GED	Sector	GED	Sector	GED
Utilities	160.38	Utilities	145.06	Utilities	108.00
Ag./forestry	83.94	Ag./forestry	78.50	Ag./forestry	64.80
Manufacturing	72.04	Transportation and warehousing	63.83	Manufacturing	46.08
Transportation and warehousing	61.72	Manufacturing	57.36	Transportation and warehousing	38.99
Construction	34.70	Construction	21.91	Construction	26.50
Admin. and waste mgmt. services	27.80	Admin. and waste mgmt. services	19.33	Admin. and waste mgmt. services	30.58
Accommodation and food services	10.61	Mining	13.96	Accommodation and food services	12.57
Mining	7.83	Accommodation and food services	10.51	Mining	9.21
Arts, ent., and rec.	5.95	Arts, ent., and rec.	6.63	Arts, ent., and rec.	5.81
Retail trade	4.49	Retail trade	4.69	Retail trade	3.74
Wholesale trade	3.17	Other services (except public administration)	2.35	Other services (except public administration)	1.31
Other services (except public administration)	2.61	Wholesale trade	1.65	Educational services	1.08
Health care and social assistance	1.66	Educational services	1.08	Wholesale trade	0.95
Educational services	0.85	Health care and social assistance	0.38	Finance and insurance	0.34
Real estate	0.12	Professional, scientific, and technical services	0.12	Health care and social assistance	0.27
Professional, scientific, and technical services	0.11	Real estate	0.11	Real estate	0.19
Information	0.05	Information	0.07	Professional, scientific, and technical services	0.09
Finance and insurance	0.00	Finance and insurance	0.01	Information	0.06
Management of companies and enterprises	0.00	Management of companies and enterprises	0.00	Management of companies and enterprises	0.00
Total	478.0		427.6		350.6

[a]GED deflated using Fisher pollution price indices; VA deflated using USBEA sector-specific price indices.

VA is deflated using the USBEA sector-specific deflators. The sectors are ranked according to the magnitude of the GED. In each of the three data years covered in the analysis, the rank ordering of sectors by GED remains remarkably similar. Utilities, agriculture, manufacturing, transportation, and construction generate the greatest GED for each year. Another clear and important pattern is that, for many industries, the GED decreases modestly from 2002 to 2005, and then decreases significantly from 2005 to 2008. For example, the utility GED begins at $160 billion in 2002, drops to $145 billion in 2005, and then drops to $108 billion in 2008. The agriculture and forestry sector is another clear example of the pattern. In 2002, GED from agriculture is estimated to be $84 billion. In 2005 agriculture GED decreases marginally to $79 billion. Then, in 2008, the GED for this sector falls to $65 billion. The transportation sector also exhibits this trend; the GED in 2002, 2005, and 2008 is estimated to be $62 billion, $64 billion, and $40 billion, respectively. The economy-wide GED also follows this pattern; in 2002 total GED was $480 billion, in 2005 GED decreased to $430 billion, and then in 2008 the GED declined to $350 billion. Note that the bottom five sectors in table 13.1 contribute less than 1 percent of the economy-wide GED in each year.

The GED for the manufacturing sector decreases more steadily over the time period covered by this analysis. Manufacturing GED in 2002 is estimated to be $72 billion. In 2005, the GED from this sector falls to $57 billion. Finally, in 2008, the manufacturing GED decreases to $46 billion.

Table 13.2 displays the nominal GED/VA ratio for all sectors in 2002, 2005, and 2008. For the utility sector, the GED/VA ratio begins in 2002 at 0.96. This declines to 0.71 in 2005 and then drops to 0.49 in 2008. These results indicate that the utility sector became much *less* pollution intensive between 2002 and 2008. In 2002, the total air pollution damage was nearly equivalent to reported VA in nominal terms. This implies the EVA for this sector was nearly zero in 2002.

In 2002, the agriculture sector shows a GED/VA of 0.90. This declines to 0.62 in 2005 and 0.25 in 2008. Much like the utility sector, agriculture EVA is quite close to zero in 2002. The transportation sector also shows a significant decrease in its GED/VA ratio; in 2002 the GED/VA is 0.22 for this sector. In 2005, the ratio drops to 0.17. However, in 2008, the ratio drops to roughly 0.13. The construction and manufacturing sectors show much less variation in the GED/VA ratios between 2002 and 2008. Between 2002 and 2008, the construction GED/VA ranges between 0.074 and 0.036. The manufacturing GED/VA is within the range of 0.056 and 0.032. The economy-wide GED/VA ratio also shows limited variation. The GED/VA ratio is estimated to be 0.054 in 2002, 0.039 in 2005, and 0.030 in 2008. Although the real GED declines precipitously from 2005 to 2008 (as reported in table 13.1), the nominal GED/VA does not show such a significant drop. A large share of total output in the US economy is contributed by sectors that have very

Table 13.2 Nominal measure of pollution intensity: Sector GED/VA

	GED/VA		
Sector	2002	2005	2008
Agriculture/forestry	0.903	0.621	0.253
Mining	0.079	0.076	0.062
Utilities	0.965	0.710	0.493
Construction	0.075	0.036	0.059
Manufacturing	0.056	0.037	0.032
Wholesale trade	0.005	0.002	0.001
Retail trade	0.006	0.006	0.005
Transportation and warehousing	0.228	0.176	0.134
Information	0.000	0.000	0.000
Finance and insurance	0.000	0.000	0.000
Real estate	0.000	0.000	0.000
Professional, scientific, and technical services	0.000	0.000	0.000
Management of companies and enterprises	0.000	0.000	0.000
Admin. and waste management	0.095	0.052	0.036
Educational services	0.009	0.009	0.008
Health care and social assistance	0.003	0.000	0.000
Arts, entertainment, and recreation	0.061	0.056	0.048
Accommodation and food services	0.037	0.029	0.032
Other services (except public administration)	0.009	0.008	0.004
Economy	0.055	0.039	0.030

[a]All values expressed in nominal terms.

low GED/VA scores. For many of these low-pollution sectors, GED and GED/VA did not change appreciably between 2002 and 2008. Therefore, although some sectors show precipitous declines in both pollution damage *and* pollution intensity, the overall change in GED/VA is attenuated by the low-GED and high-VA sectors including finance, real estate, and professional services.

The top-left panel of figure 13.2 shows the economy-wide VA and EVA measures between 2002 and 2008.[4] This figure indicates that the gap between VA and EVA, which is the GED, has decreased, albeit slightly between 2002 and 2008. The narrowing of the difference between VA and EVA is especially evident after 2005. The bottom-left panel of figure 13.2 focuses on the manufacturing sector. The overall pattern is quite similar to that for the total economy. The difference between the VA and the EVA attenuates between 2002 and 2008 as the GED declines. However, the trends in VA (and EVA) show some important differences with respect to the total economy. First,

4. The GED/VA is interpolated for the years 2003, 2004, 2006, and 2007 by projecting the annualized GED growth from 2002 to 2005 and from 2005 to 2008. These interpolated values are then matched to reported VA for the years without emissions data.

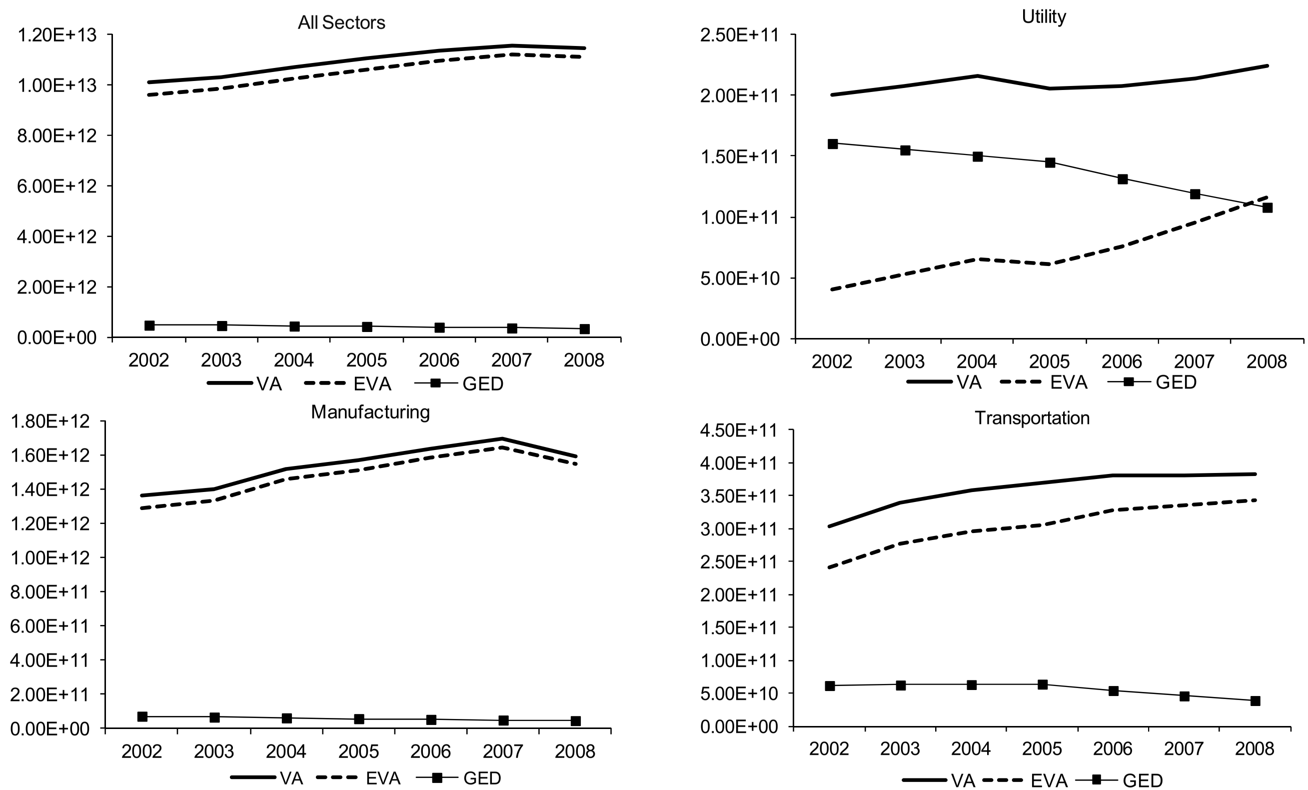

Fig. 13.2 EVA, VA, and GED, 2002 to 2008

Note: GED deflated using Fisher pollution price indices; VA deflated using sector-specific price indices. Vertical axis ($).

more modest rates of growth are evident between 2002 and 2003 as the manufacturing sector emerged from the recession following the technology sector correction. And second, manufacturing output falls after 2007 as the economy was headed into the Great Recession. The EVA basically tracks these changes, with the notable exception that the manufacturing GED shrinks appreciably after 2007.

The top-right panel of figure 13.2 shows the VA and the EVA for the utility sector. Note that in 2002, EVA is dramatically smaller in magnitude than market VA. That is, GED comprises a large share of the reported VA for this sector. Although VA is basically constant between 2002 and 2008 for this sector, EVA clearly grows over this time period. This pattern manifests because the GED is shrinking at a rate greater than market VA is increasing. This difference in growth rates is especially evident after 2005. Recall from table 13.1 that real GED decreased from $145 billion in 2005 to $108 billion in 2008. This is a gross decrease of 25 percent in real terms.

The bottom-right panel of figure 13.2 displays the VA and the EVA for the transportation sector. Like utilities, although less dramatically, the gap between the market VA and EVA decreases between 2002 and 2008. The decrease in GED is most evident after 2005, which reinforces one of the main findings from table 13.1; namely, that for many sectors, GED decreases modestly from 2002 to 2005 and then GED falls more significantly from 2005 and 2008.

Table 13.3 displays the annualized rates of change in the VA and the EVA for all sectors, between 2002 and 2005, and 2005 and 2008. Beginning with the 2002 to 2005 changes, the total economy real VA grew at an annual rate of 2.76 percent. The EVA grew by an estimated 3.07 percent. Including the GED into the NIPAs *increases* the estimated annual growth rate of the economy over this time period by 0.31 percent. This result stems from that fact that GED decreased more rapidly than VA grew over this time period. Hence, EVA and VA converged. In both 2002 and 2005 EVA is smaller than VA because a previously unmeasured cost is deducted from VA. Despite this, because the rate of change in these uninternalized costs (the GED) is sharply negative, corrected VA (the EVA) is estimated to have grown more quickly than VA.

Particularly sharp differences in rates of VA and EVA growth are found for agriculture, utilities, and transportation. The EVA is estimated to have increased at a rate of over 30 percent for the agriculture sector. Market VA increased at 6.8 percent. For the utility sector, EVA grew at 15 percent per year, while VA grew at just under 1 percent. For the transportation sector, EVA expanded at a rate of 8.2 percent and market VA increased by just under 7 percent per year.

Table 13.3 indicates that some sectors such as real estate, management, and professional services have almost no difference between the rates of VA

Table 13.3 Annualized rates of growth in EVA and market VA

	2005–2002		2008–2005	
Sector	Δ EVA[a,b,c] (%)	Δ VA (%)	Δ EVA (%)	Δ VA (%)
Agriculture/forestry	34.58	6.85	9.77	0.46
Mining	–11.85	–10.43	3.31	2.25
Utilities	15.25	0.87	24.42	2.83
Construction	0.38	–0.34	–5.60	–5.10
Manufacturing	5.51	4.90	0.77	0.50
Wholesale trade	4.26	4.16	2.45	2.41
Retail trade	1.43	1.43	–1.12	–1.15
Transportation and warehousing	8.26	6.86	4.94	1.96
Information	7.29	7.29	3.59	3.59
Finance and insurance	2.93	2.93	–2.51	–2.50
Real estate and rental and leasing	2.11	2.11	3.41	3.41
Professional, scientific, and technical services	3.79	3.79	4.42	4.42
Management of companies and enterprises	–1.01	–1.01	0.50	0.50
Admin. and waste management	7.85	6.38	1.46	2.36
Educational services	0.08	0.15	1.44	1.43
Health care and social assistance	3.06	3.00	3.44	3.44
Arts, entertainment, and recreation	1.94	2.03	1.06	0.78
Accommodation and food services	3.51	3.39	–0.30	–0.10
Other services (except public administration)	–0.78	–0.80	–0.77	–0.88
Economy	3.07	2.76	1.47	1.18

[a]EVA: (VA–GED)

[b]Annual rate of change = 100 x $((EVA_{2008}/EVA_{2005})^{(1/3)} - 1)$.

[c]GED deflated using Fisher pollution price indices; VA deflated using sector-specific GDP deflators.

and EVA growth. This should be expected given that these sectors produce almost no GED. For these cases, augmented accounts that focus on environmental damage really make no difference since most of their activities and, hence, the value of their production, lies within the bounds of the conventional NIPAs.

From 2005 to 2008, the total economy EVA is estimated to have increased by 1.47 percent per year, while market VA expanded by 1.18 percent. Again, including the GED into the NIPAs augments the estimated annual growth rate of the economy over this time period by 0.29 percent. Bringing GED into the EVA increases rates of growth for the same reason as in the 2002 to 2005 period; EVA reflects an additional cost which, while decreasing VA in each time period, enhances rates of growth because GED fell more rapidly than market VA grew.

Much like the 2002 to 2005 time period, between 2005 and 2008, the greatest divergence in growth rates between EVA and VA occurred in pollution-intensive sectors. For example, utility EVA is estimated to have grown by

24 percent per year, while market VA for this sector increased by a more modest 2.8 percent. The agriculture sector EVA grew by over 9 percent while the market VA increased by less than 1 percent. Similarly, the growth rates for EVA and VA in the transportation sector were 5 percent and 2 percent, respectively. Hence, one important point that emerges from table 13.3 is: including estimates of the GED for pollution intensive sectors can make a substantial difference in measures of output.

Not all sectors in table 13.3 show rates of change in EVA that are larger than VA. For example, table 13.3 shows that conditions in the construction sector were very different from the sectors highlighted in the discussion above. Between 2002 and 2005, the construction EVA grew at a rate of 0.4 percent and the VA for this sector contracted at 0.3 percent. Including the GED into the EVA *changes the sign of* the rate of change in output. Indeed, table 13.1 indicates that the GED declined for this sector between 2002 and 2005. However, between 2005 and 2008 the EVA decreased by 5.6 percent annually while the VA decreased by 5.1 percent per year. In this case, EVA amplifies the contraction in the construction sector; although market output in this area of the economy was contracting, the GED increased. The result is that the augmented EVA suggests an even greater rate of contraction that does the market VA.

The Great Recession was likely a major factor in driving this result. Specifically, it is well known that an oversupply of housing played a key role in the recession and that the consequences of this aspect of the recession (the correction in the housing market) were, in part, borne by the construction sector. Hence, the construction VA contracted rapidly after 2007, and the greater *negative* growth of the EVA suggests that VA was clearly contracting more rapidly than the GED over this time period.

The evidence reported in table 13.3 suggests that the reduction in social cost associated with air pollution emissions is a valuable component of production, one that contributes approximately 0.3 percentage points of growth on an annual basis between 2002 and 2008. Reporting measures of growth that fail to reflect the GED *underestimates* growth over this time period. These subtle differences in growth rates are reflected in figure 13.2, which maps the VA and the EVA for the entire economy between 2002 and 2008. Although the VA and the EVA roughly parallel one another, a slight convergence of VA and EVA is clear after 2007 as the Great Recession takes hold. The EVA and the VA converge precisely because the GED shrinks in absolute terms and relative to VA as shown in tables 13.1 and 13.2.

An accounting framework that recognizes the GED, the air pollution externality, reduces the level of VA. The EVA is smaller than the VA because the EVA is a measurement that is net of the GED. There is a previously unmeasured cost which, when included in the accounts, decreases the VA. That much is straightforward and clear. More interesting is the implication of including the GED into the accounts for measures of *growth*. Between

2002 and 2008, although the level of VA declines when GED are included to report EVA, the rate of growth increases. One way to characterize this difference is through the GED/VA index; throughout the time period covered in this analysis, GED/VA shrinks. By construction of the index this means that the GED is falling *relative to the VA*. Therefore, EVA is growing relative to VA. And, the difference between the EVA measure and market VA boils down to the inclusion (in the EVA) of the value in *reductions* to the GED, which conventionally measured VA omits.

This is an important augmentation to standard measures of growth. As regulated firms purchase, install, and operate pollution control devices, these capital and operating and maintenance costs are entered into the (existing) NIPAs as a cost of doing business either through consumption of fixed capital or operating and maintenance costs.[5] All else equal, regulated industry's VA declines as a function of these expenditures. Abatement costs act as a drag on growth for firms, industries, and sectors that make the expenditure. The NIPAs capture returns to these expenditures in two possible ways. First, through the transfer to firms that produce and/or market abatement technology, and second, through any improvements to the production of market goods and services due to the reduced pollution flow.[6] However, the NIPAs, by definition, miss nonmarket benefits. This happens to be quite important for the case of air pollution since the vast majority of the GED is comprised of impacts to human health that are not measured or reflected in market transactions. This highlights the importance of the augmented EVA measure. The EVA encompasses an important missing (from VA) measure of the benefit of these investments in environmental quality. Namely, the corresponding reduction to the GED, which is comprised almost entirely of reduced mortality risk and incidence rates of chronic illness (both examples of nonmarket benefits). The EVA accounts for this source of growth, and the empirical results in table 13.3, indicate that this makes an appreciable difference in ex post growth estimates relative to conventional measures. This measure of growth suggests that the return to society's investments in cleaner air have indeed produced a return of significant magnitude even on the scale of economy-wide VA.[7]

Although this analysis cannot relate GED to VA for industries within a

5. Note that the same argument can be made for a firm that purchases inputs that embody or contain less pollution or the capacity to yield less pollution when used for production. In either case (purchase abatement technology or clean inputs) a firm is making additional expenditures in order to comply with some regulator constraint.

6. This is the classic example of externality; a firm produces an output via processes that generate smoke that is dispersed from a smokestack. Downwind, a laundry service (for example) has its output reduced because the clean laundry is soiled by the smoke. Thus, curtailing the smoke yields an increase in production for the laundry service.

7. Clearly other estimates of the return to society's investments in environmental quality (and especially, clean air) exist. For example, the USEPA conducts regular cost benefit analyses of the entire Clean Air Act. The resulting tabulations from their reports, however, are not reflected in or related to the NIPAs, which is the goal of this study.

Table 13.4 **Industry decomposition of GED change: Utility, manufacturing, and transportation sectors**

Sector	Industry	2005 – 2002	2008 – 2005
Utility	Coal-fired power generation	–4.78[a] (–4)[b]	–34.80 (–26.4)
	Natural gas-fired power generation	–1.44 (–38)	4.05 (169)
	Oil-fired power generation	0.52 (14)	–2.23 (–52)
Transportation	Marine transport	9.95 (54)	–14.70 (–51.8)
	Truck transport	–4.20 (–16)	–5.37 (–24)
	Railroad transport	1.54 (24)	–4.15 (–52)
	Airport	–3.77 (–93)	–0.14 (–47)
Manufacturing	Petroleum refineries	4.50 (38)	–9.61 (–59)
	Cement mfg.	1.07 (53)	–4.11 (–70)
	Iron and steel mills	2.05 (45)	–1.95 (–34)

[a]Change in GED ($ billion).
[b]Percent change from GED in previous period.

sector, table 13.4 decomposes the gross GED changes between 2002 and 2005, and 2005 and 2008 for industries in the following sectors: utilities, transportation, and manufacturing. Between 2005 and 2002 the GED associated with coal-fired electric power generation decreased by about $5 billion. This comprises just a 4 percent reduction in damages. The GED due to natural gas-fired power production decreased by $1.4 billion. Although this is a small change in absolute terms, it amounts to a 38 percent drop in the GED. The GED from oil-fired power generation climbed by $500 million. From 2005 to 2008, the GED from coal-fired power decreased by $35 billion, which comprises a reduction of over 25 percent from 2005. In contrast, the GED due to natural gas-powered electric production increased by $4.0 billion; this is nearly a three-fold increase in the GED from this industry from 2005. Oil-fired power generation declined in 2008 by $2.2 billion. This amounts to a 52 percent drop from 2005.

Much of the change in the GED for coal-fired power generation is due to regulatory constraints. Both the Acid Rain Program (ARP) and the NO_x Budget program (NBP) limit aggregate emissions from most coal-fired capacity in the United States. Between 2002 and 2005 aggregate SO_2 emissions increased slightly program-wide; emissions increased by 26,000 tons (a 0.3 percent change) between 2002 and 2005 (USEPA CAMD 2012a). Over the same time period, NO_x emissions decreased by approximately 840,000 tons for facilities governed by the NBP. The result was a 4 percent decrease in the coal-fired power GED.[8] In contrast, between 2005 and 2008, emis-

8. The total GED for oil, gas, and coal-fired plants does not equate to the reported utility total in table 13.1. The difference stems from electric power generation sources that do not use either of these three primary fuels and from nonpower generation sources. These include power distribution, steam and air conditioning supply, and sewage treatment, among others.

sions of SO_2 decreased by 2.61 million tons (25 percent decrease) while NO_x emissions decreased by 640,000 tons (18 percent change) (USEPA CAMD 2012a). The GED correspondingly declines by one-quarter for coal-fired power plants.

In 2005, the USEPA issued the Clean Air Interstate Rule (CAIR). This was to serve as the replacement to both the NBP and the ARP and it proposed significant reductions to the annual emissions limits in place for the extant trading programs (USEPA 2012b). Because of the stringency of the proposed CAIR, many regulated generators bought and held large quantities of NO_x and especially SO_2 permits to ensure compliance with the proposed CAIR caps. Concurrently, some regulated firms invested heavily in pollution control equipment to achieve long-term compliance. Many of these capital intensive investments came on line after 2005; the ensuing emission reductions are evident in the reduced emission reported by USEPA and in the reduced GED in tables 13.1 and 13.4.

For coal-fired generators, power production over the time periods considered in this study was only weakly correlated with both emissions and the GED. The US Department of Energy reports that between 2002 and 2005, coal-fired capacity net generation increased by just 1 percent from 1.91 MMWH to 1.99 MMWH. The GED decreased by 4 percent over this period. From 2005 to 2008, net generation from coal capacity decreased from 1.99 MMWH to 1.97 MMWH. This comprises a 1.17 percent reduction in net power output from coal, yet the GED dropped by over 25 percent over the same time frame. By deduction, increased use of abatement technology at coal-fired power generators is likely the primary cause for the reduction in the GED in this industry.

Table 13A.3 in the appendix reports the changes in the GED for electric power generation using the 2005 shadow prices deflation method. The thrust of this table is to isolate the impact of emission changes. Beginning with coal-fired facilities, the GED change from 2002 to 2005 computed using 2005-fixed shadow prices is –\$2.46 billion. Recall from table 13.4 that the GED change for coal-fired power plants was reported to be –\$4.78 billion (using the Fisher deflators). An important distinction between the two deflation methods is that the Fisher indices allow *relative prices to change* while deflating the price level, whereas the fixed 2005 shadow prices holds both the level and the relative prices fixed. The fact that GED in 2002 is less when using 2005 fixed shadow prices implies that relative prices changed between 2002 and 2005. This change suggests that more emissions occurred in 2002 at plants that had higher shadow prices than in 2005.

For natural gas facilities, appendix table 13A.3 shows that GED in 2002, computed using the 2005 marginal damages, are smaller than the GED computed using the Fisher indices. Deflation using the Fisher indices adjusts the mean shadow prices level. The remaining gap in the GED change is due to differences in the relative prices. Like the case of coal, the higher GED computed using the Fisher pollution indices suggests more emissions were produced in 2002 by facilities with higher shadow prices than in 2005. For oil-fired plants, the change in GED from 2002 to 2005 is greater when using the 2005 marginal damages than the marginal damages deflated with the Fisher indices. This implies that emissions tended to occur in higher-damage locations in 2005. This stands in contrast to both coal- and gas-fired facilities. For the GED computed in 2008, the use of 2005 marginal damages has a very small effect on the plants of all three fuel types.

Table 13.4 also decomposes the GED from the transportation and manufacturing sectors. Beginning with transportation, commercial marine vessels produced about $10 billion more GED in 2005 than in 2002. In 2008, damages from this industry dropped by over $14 billion. For truck transportation, the GED declined in both periods: by $4 billion and $5 billion between 2002 and 2005, and 2005 and 2008, respectively. This pattern also holds for air transportation. (For this industry emissions are only tracked for evaporation of fuels and airport support vehicles, not airplanes in route.) Railroad transportation GED increased from 2002 to 2005 by about 24 percent and then the GED from this industry declined by 52 percent from 2005 to 2008.

The sharp decline in GED from the marine vessels, railroads, and trucks within transportation is evidence of a change in regulatory constraints between 2005 and 2008. Specifically, reductions in sulfur content of diesel fuels for use in vehicles operated on roadways took effect in 2006. This program, which was phased in between 2007 and 2010, is estimated to have reduced SO_2 emissions from diesel-powered vehicles by as much as 90 percent (USEPA 2012c). In addition to highway vehicles, the sulfur content of fuels used in locomotives and marine vessels was also lowered in 2007; like the policy for highway vehicles, this fuel standard is phased in over several years (USEPA 2012d). Although it is beyond the scope of this chapter to precisely parse the effect on GED of these regulatory standards, it is likely that their (partial) implementation contributed significantly to the decline in GED in the transportation sector.

Table 13.4 also breaks down the GED from the manufacturing sector. Petroleum refineries produced GED in 2005 that was about $5 billion more than the GED in 2002. Damages declined by nearly $10 billion in 2008. Cement manufacturers produced an increase in GED in 2005 of $1 billion, and $4 billion less GED in 2008 than in 2005. Iron and steel mills follow the same pattern; damages increase by 45 percent moving from 2002 to 2005, then the GED drops by 35 percent. These three high-damage industries show a pattern that is broadly indicative of the GED in the manufacturing sector as a whole; the GED decreases precipitously as the Great Recession begins to take hold in the later years of the sample.

Table 13.5 displays the results from the experiments that test the impact of different deflation techniques through the pollution shadow prices on the GED. Since year 2005 GED comprise the base year (and therefore GED in

Table 13.5 **Alternative deflation of pollution shadow prices and resulting GED**

	Deflator			
Sector	Nominal	GDP defl.	Fisher	2005 prices
		2002		
Economy	506.1	408.8	478.0[a]	472.8
Agriculture	84.7	68.4	83.9	78.1
Utility	173.4	140.1	160.4	157.0
Manufacturing	76.2	61.6	72.0	73.3
Construction	36.7	29.6	34.7	34.5
Transportation	67.8	54.8	61.7	63.9
		2008		
Economy	369.7	320.0	350.6	348.2
Agriculture	40.2	32.5	64.8	62.8
Utility	126.0	101.8	108.0	108.0
Manufacturing	51.3	41.5	46.1	46.4
Construction	36.0	29.1	26.5	26.2
Transportation	54.5	44.1	39.0	39.3

[a]GED ($, billion).

that year is unaffected by deflation), table 13.5 only reports GED for the years 2002 and 2008. The Fisher price indices are the default case; the 2005 shadow prices employ year 2005 marginal damages for both 2002 and 2008, and the GDP deflator applies the USBEA sector-specific GDP deflators that differ in magnitude for 2002 and 2008. Table 13.5 also reports nominal GED for purposes of comparison with the real values.

In the default case, economy-wide GED is estimated to be $480 billion in 2002 and $350 billion in 2008. Using the fixed-year 2005 shadow prices decreases the GED in 2002 to $473 billion. This comprises just a 1 percent difference relative to the Fisher deflators. The estimated GED in 2008 using 2005 prices is slightly lower than the GED estimated using the Fisher index at $348 billion. Economy-wide GED is estimated to be $409 billion in 2002 using the market deflator. Note that this approach pegs changes in the pollution shadow prices to changes in prices for market goods and services. For 2008, the total economy GED estimated when using the GDP deflator is about 10 percent smaller than when the other two deflators are used.

Table 13.5 also reports the different GED estimates for the five heaviest polluting sectors. Two patterns are evident. For all sectors, the GED in 2002 is estimated to be smallest when using the GDP deflator. The relative rankings in GED for 2008 across the different deflators does not show a clear pattern for the five sectors covered in table 13.5.

It is important for policymakers and national statisticians to recognize that the GED estimates are uncertain. This may stem from three sources:

parameter uncertainty, data uncertainty, and model uncertainty (Muller 2011). Table 13A.4 in the appendix focuses on parameter uncertainty in the area of mortality damages since this endpoint comprises the largest share of total damage. Specifically, table 13A.4 in the appendix shows that using the $PM_{2.5}$ mortality dose-response function reported in Roman et al. (2009) increases economy-wide GED by nearly two-thirds for each data year. In contrast, using a $2 million VSL (rather than the default value of $6 million) reduces total GED by nearly two-thirds. Hence, the GED estimates are, in fact, quite sensitive to parameter choices made by the researcher. The effect of these (and other) alternative model parameters on the GED/VA as well as on the EVA growth rates is left to future study.

13.5 Conclusion

This analysis uses the methodology developed and reported in Muller, Mendelsohn, and Nordhaus (2011) to compute the gross external damages (GED) from air pollution in the US economy for 2002, 2005, 2008. The time series measurement of the GED, the GED/VA, and the EVA (VA—GED) is an important extension to the annual measure of GED and GED/VA reported in Muller, Mendelsohn, and Nordhaus (2011). The NIPAs' primary value lies in relative measurement of indices such as GDP or VA over time. Similarly, while static nonmarket accounts are very important, the estimation of the air pollution damage indices over multiple years provides researchers and policymakers with insights in three areas: changes in gross pollution damage, changes in pollution intensity, and differences in rates of growth with and without augmentation.

The empirical results indicate that the GED changes dramatically from 2002 to 2008; the GED decreased annually by about 4 percent from 2002 to 2005 and by about 6 percent from 2005 to 2008. Much of the steep decline from 2005 to 2008 stems from reductions in the GED attributable to the agriculture, utility, manufacturing, and transportation sectors. The GED/VA, economy-wide, between 2002 and 2008 does not vary as much. In 2002 the nominal GED/VA is approximately 0.054, and in 2008 the GED/VA is 0.03. The small change in the GED/VA coupled with dramatic reductions in the GED is evidence of the recession-driven reduction in output observed in 2008. That is, as output slowed (and dropped in some sectors) in 2008 due to the recession, GED did too. The economy-wide GED intensity decreased by a relatively small amount.

Although the economy-wide nominal GED/VA index was relatively constant, the GED/VA shows considerable variation within sectors between 2002 and 2008. The utility sector's GED/VA is 0.96 in 2002. In 2008, the GED/VA drops to 0.49. Similarly, the agriculture and forestry sector has a GED/VA of over 0.85 in 2002 and this index declines to less than 0.30 in

2008. However, some sectors have less variation in levels of the GED/VA; the manufacturing sector begins in 2002 with a GED/VA of 0.056 and in 2008 the manufacturing GED/VA is estimated to be 0.032. This is not to suggest that the level of the manufacturing GED remains necessarily fixed. In 2002 the manufacturing GED was $72 billion while in 2008 the GED for this sector was $46 billion. Clearly the level of damage has changed for this sector. However, the air pollution damage intensity, relative to VA, has not changed by such a large degree. This is more evidence of the impact of the recession in the US economy in 2008. Specifically, manufacturing output declined in the latter years of this time period and GED did too. This is in contrast to a sector such as utilities in which VA grew while GED dropped precipitously. The difference is that the utility sector composition was changing with greater use of cleaner inputs such as natural gas as well as more widespread employment of air pollution abatement technology, especially at coal-fired power stations.

The chapter also reports that the EVA (VA-GED) grew at greater annual rates between both 2002 and 2005, and 2005 and 2008, than VA. Between 2002 and 2005, the EVA grew at an annual rate of 3.07 percent while VA grew at 2.76 percent. Incorporating the GED increases the ex post estimate of growth by 0.31 percent. From 2005 to 2008, VA grew at an annual rate of 1.18 percent and the EVA grew at 1.47 percent per year. Including GED in the accounts again yields a divergence between the rates of growth of 0.3 percent from 2005 to 2008. While including the GED into the NIPAs reduces the level of VA, in the US economy between 2002 and 2008, including the GED *increases* estimates of growth since the GED decreased over this time period.

While the chapter finds that in the US economy over the period from 2002 to 2008 the augmented measure of growth and performance (the EVA) suggests higher rates of growth, it is certainly feasible or possible for the EVA and VA annual rates of change to relate differently in other economies (in different stages of development) or in the US economy in other time periods. For example, an economy with VA growth less than its GED growth would have EVA changing at rates less than VA. This case describes an economy with rates of pollution intensity growth greater than absolute growth. An example might include a developing economy that is just beginning to modernize; one that features considerable resource extraction and heavy manufacturing. In this setting standard measures of growth *overestimate* actual growth.

The case of the US economy from 2002 to 2008 exemplifies EVA growth, which exceeds VA growth. In this setting, the GED decreases. Contracting GED with (even modest) VA growth yields higher EVA growth rates relative to VA. Two broad reasons for this pattern include VA growth in sectors that are not pollution intensive (finance, real estate, or professional services, for example), or a reduction in pollution intensity in sectors which, traditionally, have produced copious amounts of GED (utilities, agriculture, and transportation, for example). Both are evident in the United States between 2002 and 2008.

This chapter suggests research on a number of fronts. First, as more emissions data becomes available from the USEPA, the scope of the analysis could be extended. Particularly interesting in this area are extensions to 1999 and 2011. The former includes emissions from just prior to the implementation of Phase II in the Clean Air Act's Acid Rain Program, which featured a dramatic tightening of SO_2 emission caps for electric power producers. Tabulating GED/VA and EVA between 1999 and 2002 is likely to provide insights regarding alternative measures of the social value of that regulatory program. Extending the analysis to 2011 would also be of interest because of the opportunity to compare the pollution indices with 2008. In 2011, the US economy was growing slowly as it emerged from a significant recession; its structure was altered by the housing and financial market collapse, which likely had impacts on demand for transportation and utility services.

Appendix

Table 13A.1 Sector GED/VA[a]

2002		2005		2008	
Sector	GED/VA	Sector	GED/VA	Sector	GED/VA
Ag./forestry[a]	0.805	Utilities	0.705	Utilities	0.482
Utilities	0.800	Ag./forestry	0.618	Ag./forestry	0.479
Transportation and Warehousing	0.204	Transportation and warehousing	0.173	Transportation and warehousing	0.099
Admin. and waste mgmt. services	0.090	Mining	0.073	Admin. and waste mgmt. services	0.055
Construction	0.056	Arts, ent., and rec.	0.056	Construction	0.051
Arts, ent., and rec.	0.053	Admin. and waste mgmt. services	0.052	Arts, ent., and rec.	0.048
Manufacturing	0.053	Manufacturing	0.037	Mining	0.045
Accommodation and food services	0.032	Construction	0.036	Accommodation and food services	0.034
Mining	0.029	Accommodation and food services	0.029	Manufacturing	0.029
Other services (except public administration)	0.008	Educational services	0.009	Educational services	0.009
Educational services	0.007	Other services (except public administration)	0.008	Retail trade	0.005
Retail trade	0.006	Retail trade	0.006	Other services (except public administration)	0.004
Wholesale trade	0.005	Wholesale trade	0.002	Wholesale trade	0.001
Health care and social assistance	0.002	Health care and social assistance	0.000	Finance and insurance	0.000
Professional, scientific, and technical services	0.000	Professional, scientific, and technical services	0.000	Health care and social assistance	0.000
Information	0.000	Information	0.000	Real estate	0.000
Real estate	0.000	Real estate	0.000	Information	0.000
Finance and insurance	0.000	Finance and insurance	0.000	Professional, scientific, and technical services	0.000
Management of companies and enterprises	0.000	Management of companies and enterprises	0.000	Management of companies and enterprises	0.000
Economy	0.048		0.040		0.030

[a]GED deflated using Fisher pollution price indices; VA deflated using sector-specific price indices.

Table 13A.2 Fisher index numbers for pollution shadow prices

Pollutant	2002/2005 Fisher price index	2008/2005 Fisher price index
NH_3	1.001 (0.032)	0.500 (0.056)
$PM_{2.5}$	1.060 (0.001)	1.028 (0.004)
NO_x	1.190 (0.030)	1.884 (0.124)
SO_2	1.062 (0.002)	1.116 (0.008)
VOC	1.087 (0.002)	1.061 (0.009)
GDP deflator	92.196	108.582

Source: Muller (2013).

Note: All index numbers computed with 2005 as base year. Values in parentheses are bootstrap standard errors.

Table 13A.3 GED from electric power generation using 2005 shadow prices

Sector	Industry	2005-2002	2008-2005
Utility	Coal-fired power generation	–2.46[a] (–2)[b]	–34.4 (–26)
	Natural gas-fired power generation	–1.31 (–35)	4.15 (174)
	Oil-fired power generation	0.59 (16)	–2.36 (–55)

[a]Change in GED ($ billion).

[b]Percent change from GED in previous period.

Table 13A.4 GED tabulations using alternative mortality parameters

	Total economy GED		
Model scenario	2002	2005	2008
Default	478[a]	428	351
Roman et al. (2009)	756	680	559
Mortality dose-response	(+58.2)[b]	(+58.9)	(+59.3)
$2 million	188	169	140
VSL	(–60.7)	(–60.5)	(–60.1)

[a]GED ($ billion).

[b]Percent change relative to default case.

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