Towards the Measurement of Net Economic Welfare: Inter-temporal Environmental Accounting in the US Economy.

Preliminary Draft

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Abstract

This analysis employs environmental accounting methodology to measure the Gross External Damage (GED) due to air pollution emissions in the United States (U.S.) economy in 2002, 2005, and 2008. The paper measures three indices: the GED, the GED-to-Value Added ratio (GED/VA), and Net Value Added (NVA), defined as Value Added minus the GED. Each of these indices is computed for each sector of the U.S. economy in 2002, 2005, and 2008. Real GED is estimated to be $440 billion in 2002, $430 billion in 2005, and $335 billion in 2008. Most of the reduction in GED from 2005 to 2008 is due to fewer emissions in the utility, manufacturing, agriculture, and transportation sectors. The GED/VA begins in 2002 at 0.043, drops to 0.039 in 2005, and then declines significantly to 0.029 in 2008. The empirical time-series estimation of NVA is an important augmentation to standard measures of growth. From 2002 to 2005 VA grew at an annual rate of 2.86 percent. Over the same period NVA grew at 3.01 percent. Between 2005 and 2008 VA grew at 1.24 percent while the NVA increased by 1.58 percent. Thus, the reduction in the GED over these time periods results in growth rates in the NVA greater than VA by 0.15 and 0.34 percent.

Keywords: Environmental accounting, national income and product accounts, air pollution. *JEL codes:* Q56, Q51, E01, E27.

Introduction.

Environmental accounting addresses some of the limitations of conventional National Income and Product Accounts (NIPA) by measuring the value of natural resources and environmental damage. The goal is to gain a more complete picture of national welfare. There are two dimensions to this extension: levels and changes. In terms of levels, environmental accounts estimated in any one time period provide estimates of the value that various nonmarket goods and services contribute to national welfare at a given point in time. Static augmented accounts constitute an important step toward a fully integrated system of accounts because they provide a glimpse of what the NIPAs overlook. In tracking changes, time series augmented accounts provide a more complete view of trends in economic activity than do the NIPA. In particular, time series environmental accounting estimates rates of growth (or contraction) in the stocks of valuable natural resources and the magnitude of environmental damage from market production. Including these measures into augmented accounts is a critical step in closing the gap between the current production-based measures of output and a more complete picture of national economic welfare.

This analysis pursues the second aspect of environmental accounting, time series measurement, 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 (U.S.) economy in 2002, 2005, and 2008. Computing the GED in multiple years is an important extension to static environmental accounting. While the magnitude of the GED is important to estimate, it is clear that including the GED into the accounts in any one time period will shrink conventional, static measures of output such as Gross Domestic Product (GDP) or Value-added (VA). After all, the GED is comprised of external costs neither reflected in market prices nor included in the NIPA.

In contrast, the inclusion of 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 NVA 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 NVA are equal. And, third, NVA growth may exceed VA growth if the GED grows more slowly (or contracts) than the VA; this would cause the augmented NVA measure to accelerate estimated rates of growth because the benefits of reduced GED act as a source of growth in the NVA measure. This paper reports levels and rates of change of the VA and the NVA for each sector and the entire U.S. economy over the period 2002 to 2008.

As structural changes in economic activity occur, either in the form of sectoral composition of an economy or in terms of the pollution intensity of production, intertemporal estimates of GED clarify the link between conventional measures of growth and welfare. This latter point, changes in pollution intensity, raises 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.

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. 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 the expenditure. The NIPAs capture returns to these expenditures either through the transfer to firms that 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 non-market 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 which are not measured or reflected in market transactions. This highlights the importance of the augmented NVA measure. The NVA 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 non-market benefits). The NVA accounts for this source of growth.

Inter-temporal accounting also follows the historic progression of the national accounts from annual measures expressed in current dollars to indices tracking changes expressed in real terms; just as the national accounts evolved into indices that permit comparisons of production across time, this paper adapts the GED to an index of environmental damage expressed in real terms which facilitates or enables tracking the social cost of production through time.

The development and implementation of the NIPAs in the 1930s began with a focus on measurement of current dollar estimates of national income from 1929 to 1932. Consistent annual accounts were developed in the 1940s, though these were also reported in current dollars. 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 (US BEA, 2011). Now changes in GDP are the primary focus, not levels.

The value of relative measurement also holds for the non-market accounts. Although a paucity of data, measurement difficulties, and the codified structure of the current, market-oriented NIPAs make even annual, one-shot estimates of non-market 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, Jorgensen, 2007; Muller, Mendelsohn, Nordhaus, 2011). This paper takes the next step by tabulating the change in environmental pollution damage over multiple years. This yields extensions in the measurement of three indices of air pollution damage: the GED, the GED-to-Value Added ratio (GED/VA), and Net Value Added (NVA), defined as Value Added minus the GED. Each of these indices is computed for each sector of the U.S. economy in 2002, 2005, and 2008.

The GED and GED/VA were developed in a prior paper (Muller, Mendelsohn, Nordhaus, 2011). The NVA measure provides an important extension both to the existing NIPAs and the GED measures. The NVA is an adjusted aggregate index and as such it resembles the environmentally-adjusted net domestic product (or EDP) developed in Bartelmus (1998, 2009), Net Economic Welfare (NEW), Nordhaus and Tobin 1972, and that what is codified in the System of Integrated Environmental and Economic Accounts (SEEA) that was developed by the United Nations (2003).

In a modern, developed economy, such as the U.S. or countries in the European Union, measurements of pollution *quantities* are (and have been) established since the implementation of environmental policies. The primary challenge then to conducting or implementing environmental accounts for pollution is valuing emissions. The degree to which valuation is a difficult task depends primarily 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 then since estimates need not vary by source. Second is the nature of impacts: market versus non-market effects. And third is the time horizon of impacts: effects may occur relatively soon after emissions or they may span many years. For the pollutants encompassed by the GED, the impacts tend to occur within a year of emission. As a result, issues related to discounting do not arise. These pollutants are not well-mixed; this suggests that source-specific shadow prices for emissions should be used. Finally, the majority of adverse impacts from these pollutants involve increased mortality risks. Valuation of mortality risk is both difficult and contentious.

With quantities of emissions reported by the U.S. Environmental Protection Agency (USEPA), the GED is tabulated using the source-and-pollutant-specific marginal damages produced by an integrated assessment model. Specifically, the AP2 model is used herein (Muller, Mendelsohn, 2007; 2009; Muller, Mendelsohn, Nordhaus, 2011; Muller, 2011). These shadow prices (marginal damages) are multiplied times the reported emissions in order to tabulate total damages. This approach is congruent with how the NIPAs are calculated. The GED estimates are computed for multiple years using 2005 marginal damage estimates. Thus, the reported GED is "real", in an accounting sense, and changes in the GED are therefore due to changes in the distribution and quantity of emissions not the shadow prices.

The AP2 model encompasses emissions of: ammonia (NH_3), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), volatile organic compounds (VOCs). 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. The VSL employed herein is approximately $6 million ($2005).

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 1960's (Ayres and Kneese, 1969; Leontief, 1970, Nordhaus and Tobin, 1972). More recent research in this area includes: Nordhaus, Kokklenberg (1999); Bartelmus (1998, 2009); Vardon et al. (2007); Gundimeda et al., (2007); 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 paper. First, it develops and estimates an adjusted measure of economic growth (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 U.S. and decomposed by sector in the present paper.

There are numerous reports available at the SEEA program's website that explores aspects of environmental accounting that overlap with the focus of the current paper (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 paper include reports on the mass of emissions of air pollutants, environmental tax revenue, and abatement expenditures (Germany, 2006; UK, 2006).

The methodology used to estimate the marginal damages that are ultimately used in this paper 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 et al., (2004), Tong et al., (2006), Muller and Mendelsohn (2007;2009), and Fann et al., (2009).

The empirical results indicate that the GED decreases dramatically from 2002 to 2008. Real GED is estimated using three different approaches to deflation of the pollution shadow prices. These deflators are discussed in section 1.1. Using the preferred deflator, real GED is estimated to be $440 billion in 2002, $430 billion in 2005, and $335 billion in 2008. On an annualized basis, the GED decreases by approximately 1% from 2002 to 2005 and then the GED declines by nearly 8% from 2005 to 2008. Much of this decline stems from reductions in the GED attributable to the agriculture, utility, construction, manufacturing and transportation sectors. In contrast, the GED/VA, economy-wide, between 2002 and 2008 does not vary by nearly as much; in 2002 the total GED/VA is approximately 0.043, and in 2008 the GED/VA is 0.029.

The GED/VA index shows considerable variation within sectors between 2002 and 2008. The utility sector shows a GED/VA of 0.75 in 2002. In 2008, the utility GED/VA drops to less than 0.46. Similarly, the agriculture and forestry sector begins in 2002 with a GED/VA of 0.75 and this index declines to less than 0.50 in 2008. In contrast, many sectors have nearly constant levels of the GED/VA. For example, the manufacturing sector begins in 2002 with a GED/VA of 0.049 and in 2008 the manufacturing GED/VA is estimated to be 0.028. This is not to suggest that the level of the manufacturing GED remains necessarily fixed; in 2002 the manufacturing GED was $66 billion while in 2008 the GED for this sector was $44 billion. Clearly the level of damage has changed for this sector. However, the damage intensity, relative to VA, has not by the same amount.

The paper argues that two general factors drive the changes in the GED from 2002 to 2008. First, the macroeconomic conditions were very different over this time period; the U.S. economy was emerging from a recession in 2002 largely brought on by the collapse or 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 2005 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 paper 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 paper attempts to parse the effects of these two factors on GED and GED/VA.

Finally, the paper provides evidence of a significant divergence between standard measures of economic growth and performance (such as VA) and the augmented NVA measure. In particular, the economy-wide NVA (defined as VA-GED) grows at greater annual rates from 2002 to 2005 and from 2005 to 2008 than VA. Between 2002 and 2005, the NVA grew at an annual rate of 3.01 percent while conventionally measured VA grew at 2.85 percent. Thus, incorporating the GED into this measure of growth alters (increases) the ex post estimate of growth by 0.15 percent. From 2005 to 2008, VA grew at an annual rate of 1.24 percent and the NVA grew at 1.58 percent per year. The divergence between the rates of growth in VA and NVA was just over 0.3 percent from 2005 to 2008. While including the GED into the NIPAs reduces the level of VA, in the U.S. economy between 2002 and 2008, including the GED *increases* estimates of growth since the GED decreased over this time period.

1. Accounting Framework

The nominal GED are tabulated by multiplying the emissions (E) 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}.

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

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 1 provides a diagrammatic treatment of the GED calculation. Tonnage abated increases from left to right, with an arbitrary (current) 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. The GED is given by abcd. Note that the GED tabulation has no bearing on considerations of efficiency.

The GED_{jsit} are then aggregated up to the industry and sector level by summing across all pollutants emitted by a source and across all sources within a sector as shown in (2).

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

Then, for sector (i), the NVA is tabulated by subtracting the GED_{it} from the reported Value Added (VA_{it}).

$$NVA_{it} = VA_{it} - GED_{it} \quad (3)$$

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

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

1.1 Deflation and Real Values.

Since the empirical analysis spans multiple years, nominal versus real reporting is an important consideration. The paper reports real GED, VA, and hence, NVA. The tabulation of real VA relies on the U.S. Bureau of Economic Analysis (BEA) data and deflators (USBEA, 2011). (VA is reported in real 2005 U.S. dollars.) Two approaches are pursued. First, VA is expressed in real terms by deflating the nominal values using the USBEA's GDP deflator. This metric changes annually (with respect to the 2005 benchmark) but it is applied uniformly across sectors in a given year. Second, sector-specific chain-type price indices (also reported by USBEA, 2011) are used to deflate each sector's VA.

Recall that GED is computed by multiplying source-and-pollutant specific marginal damages, or shadow prices, times reported emissions as in equations (1) through (4). Exploring nominal versus real GED rests on whether and how the shadow prices change through time. Muller (2012) documents changes in the shadow prices for 2002, 2005, and 2008. Primarily, two factors dictate changes in the marginal impacts of these pollutants: emission levels and proximal population densities. The critical point for the current analysis is that the shadow prices *do in fact* change between 2002 and 2008 (see Muller, 2012). Thus, some attempt at deflating the shadow prices is critical.

The empirical 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.

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

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

Second, pollution shadow price index numbers (estimated in Muller, 2012) 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 (with indices equal to 100). The indices are tabulated using the Fisher (or ideal) index number formulae (see Muller, 2012).

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

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 alternative deflators on the GED is tested in a sensitivity analysis.

Third, the USBEA's GDP deflator (USBEA, 2011) is used to express the GED in real terms. This approach ensures that the rate of price appreciation (depreciation) is assumed to be the same for both market VA and the pollution shadow prices.

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

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

The use of GDP deflators does not allow for different rates of appreciation (depreciation) across pollutants.

2. Empirical Model.

The paper uses the Air Pollution Emission Experiments and Policy Analysis Model (APEEP) which has been used in numerous prior applications (Muller, Mendelsohn, 2007;2009; Muller, Mendelsohn, Nordhaus, 2011; Henry, Muller, Mendelsohn, 2011) as well as the AP2 model which is a stochastic extension of APEEP (Muller, 2011). APEEP 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 U.S. Environmental Protection Agency's (USEPA) 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 non-point stationary and mobile sources. The non-point sources encompass all emissions sources without a monitored smokestack or release point. Examples of this type of source include 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. Further, this source category includes tractors, mining equipment, and other mobile sources that are used for commercial and industrial purposes. As with the non-point 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 U.S. 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 certain acidic compounds.

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 which govern the link between human mortality rates and exposures to O_3 and $PM_{2.5}$. (That is, premature mortality effects comprise 90% 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 Value of Statistical Life (VSL) methodology (see Viscusi, 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 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, Mendelsohn (2007; 2009) and subsequently applied in Muller, Mendelsohn, Nordhaus (2011). AP2 begins by estimating baseline damages;

baseline emissions (reported by USEPA) are processed through the model to compute baseline monetary damages for 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.

For the agriculture, waste management, and utility sectors greenhouse gas emissions are valued using the social cost of carbon (SCC) methodology (Tol, 2008). The analysis employs an SCC of $27/ton carbon which translates into a marginal value of CO_2 of approximately $10/ton. The exploration of GHG damages is limited to these three sectors because of the limited emissions inventory for GHGs; although reporting extends beyond these three sectors, including for instance transportation, only the emissions reported for these three sectors can be attributed appropriately to the matching sector.

3. Results.

Table 1 displays the real GED by sector for 2002, 2005, and 2008. This table and each subsequent table until table 5 employs the Fisher pollution price indices to deflate the shadow prices. 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 $151 billion in 2002, stays at $151 billion in 2005, and then drops to $104 billion in 2008. The manufacturing sector is another clear example of the pattern. Manufacturing GED in 2002 is estimated to be $66 billion. In 2005, the GED from this sector remains at $66 billion. Finally, in 2008, the manufacturing GED decreases to $44 billion. The economy-wide GED also follows this pattern; in 2002 total GED was $440 billion, in 2005 GED decreased to $430 billion, and then in 2008 the GED declined to $335 billion. Note that the bottom five sectors in table 1 contribute less than 1 percent of the economy-wide GED in each year.

Table 2 displays the GED/VA ratio for all sectors in 2002, 2005, and 2008. Much like the GED rankings, the GED/VA rankings remain fairly constant across the three data-years. For the utility sector, the GED/VA ratio begins in 2002 at 0.75. This declines to 0.73 in 2005 and then drops to 0.46 in 2008. In 2002, the agriculture sector shows a GED/VA of 0.75. This declines to 0.62 in 2005, and 0.47 in 2008. In 2008 agriculture has the largest GED/VA ratio. The transportation sector also shows a significant decrease in its GED/VA ratio; in 2002 the GED/VA is 0.18 for this sector. In 2005, the ratio drops to 0.15. However, in 2008, the ratio drops to roughly 0.10. The construction and manufacturing sectors show much less variation in the GED/VA ratios between 2002 and 2008. In 2002 and 2005, the construction GED/VA is estimated to be 0.05, while in 2008 this ratio is 0.06. The manufacturing GED/VA is within the range between 0.05 and 0.028. The economy-wide GED/VA ratio also shows limited variation. The GED/VA ratio is estimated to be 0.046 in 2002, 0.039 in 2005, and 0.029 in 2008. Although the real GED declines precipitously from 2005 to 2008 (as reported in table 1), the GED/VA doesn't show such a significant drop. Much of total output is contributed by sectors that have very low GED/VA scores. For many of these low-pollution sectors, GED and GED/VA didn't 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/high-VA sectors including finance, real-estate, and professional services.

Figure 2 shows the economy-wide GED/VA ratio between 2002 and 2008[1]. This figure indicates that the GED/VA has declined steadily, although by a relatively small degree, between 2002 and 2008 from approximately 0.045 to 0.03. Thus, the GED comprised approximately 4.5 percent of economy-wide VA in 2002 and 3 percent of VA in 2008. The GED/VA index for manufacturing, which is also shown in figure 1, tracks very closely to the economy-wide GED/VA both in levels and in trend.

Figure 3 displays the GED/VA for utilities and agriculture. Both of these sectors' GED/VA index declines significantly between 2002 and 2008, a result that was evident in table 2. The rates of change in pollution intensity differ between these two sectors. For example, between 2002 and 2005, the GED/VA for utilities is nearly constant, with some fluctuation in 2003 and 2004. However, from 2005 to 2008, the utility GED/VA index drops rapidly to under 0.50. For agriculture the rate of decrease in pollution intensity is much steadier (although there is some noise in the index for agriculture).

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[1] 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.

Table 3 displays the gross change in the GED, both in percentage and absolute terms, between 2002 and 2005, and 2005 and 2008 for all sectors. This table shows that the largest changes in percentage GED tend to occur in sectors that have small levels of GED; the finance and insurance sector GED changes by 95 percent between 2002 and 2005 while the GED for this sector changes by less than $10 million. Real estate services and information also show very large percent changes in GED with very low level changes.

In contrast, many other sectors, some with large absolute changes in GED, show smaller percentage changes. The construction sector GED decreases by $4.1 billion (or 13 percent) over the 2002-2005 period. GED for the waste management sector decreases by $6.3 billion which amounts to a one-quarter reduction. For the entire economy, the GED decreased by $11 billion from 2002 to 2005 which is a 2.4 percent decrease.

The change in GED from 2005 to 2008 tends to be much larger across sectors. Across the entire economy, the GED declines by $95 billion (22 percent) over this time period. Particularly large changes occur in the agriculture sector where GED declines by $17 billion (22 percent), the utility sector (GED drops by $47 billion, 31 percent), and transportation (the GED decreases by $18 billion, 32 percent). The manufacturing sector also shows a significant drop in the GED; damages from this sector fall by $22 billion which amounts to 33 percent.

Table 1a in the appendix shows the changes in GED for the three data-years covered in this analysis in annualized terms. Economy-wide GED declines by 0.8 percent from 2002 to 2005. From 2005 to 2008 the annualized change in the GED amounts to a 8.0 percent reduction.

Table 2a in the appendix 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 increases by $10 billion, the GED due to natural gas-fired power production decreases by $1.4 billion, and the GED from oil-fired power generation rises by $900 million. From 2005 to 2008, the GED from coal-fired power decreases by $45 billion, which comprises a reduction of over 30 percent from 2005. In contrast, the GED due to natural gas-powered electric production increases by $4.0 billion; this is nearly a three-fold increase in the GED from this industry from 2005. Oil-fired power generation declines in 2008 by $2.5 billion. This amounts to a 55 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

U.S. 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, 2012). Over the same time period, NO_x emissions decreased by approximately 840,000 tons for facilities governed by the NBP. The result is an 8 percent increase in the coal-fired power GED[2]. In contrast, between 2005 and 2008, emissions 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, 2012). The GED correspondingly declines by one-third 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, 2012). 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[3]. Concurrently, many regulated firms invested heavily in pollution control equipment to provide a means to achieve long-term compliance. 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 2a and 1.

For coal-fired generators, power production over the time periods considered in this study was weakly correlated with both emissions and the GED. The U.S. Department of Energy reports that between 2002 and 2005, coal-fired capacity net generation increased from 1.91 MMWH to 1.99 MMWH. The GED increased by 8 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 30 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.

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[2] It is instructive in this case to explore the changes in GED when the fixed year-2005 marginal damage deflator is used. This approach isolates the pure quantity change. Using the year 2005 shadow prices, the GED from coal-fired power plants increases by just $1 billion between 2002 and 2005; which is roughly proportional to the change in net generation. Notice also that the total GED for oil, gas, and coal-fired plants does not equate to the reported utility total in table 1. The difference stems from electric power generation sources that do not use either of these three primary fuels and from non-power generation sources. These include power distribution, steam and air conditioning supply, and sewage treatment, among others.

[3] This behavior lead to the well-known and documented run-up in permit prices at this time. See CCX, 2008.

Table 5a. in the appendix reports the differences in the GED in 2002 and 2005 for electric power generation using the Fisher index method and nominal GED relative to the case in which 2005-ficed shadow prices are employed. The thrust of this table is to isolate the key factors at work in the changes in real GED reported in table 2a. The comparison of nominal GED to the fixed-2005 shadow price GED embodies differences in *both* the level and the relative prices. The comparison of deflated GED to fixed-2005 shadow price GED reveals differences in relative prices, as the level differences are removed by the deflator.

Beginning with 2002, for coal-fired facilities, both real and nominal GED are *smaller* than the GED computed using 2005-fixed shadow prices. The fact that real GED is less than the GED computed using 2005-fixed shadow prices is intuitive given that table 4a shows the Fisher price indices for 2002 are all greater than unity. The deflators bring nominal GED in 2002 down. (Note that this comparison holds emissions fixed; the only factor changing within each cell of table 5a are the shadow prices.) The result that nominal GED in 2002 is less than the GED using fixed shadow prices (by 2.1 percent) means that *relative shadow prices* have changed between 2002 and 2005. That is, the Fisher price indices in table 4a indicate that the general shadow price level for each pollutant is higher in 2002 than in 2005. Therefore, the fact that nominal GED for coal-fired plants is smaller in 2002 implies that the spatial distribution of shadow prices have changed in a non-negligible manner. The results for oil-fired plants in 2002 support this hypothesis as both nominal GED and real GED in 2002 are less than the GED tabulated using the fixed year-2005 shadow prices.

For natural gas facilities, table 5a shows that both nominal and real GED in 2002 *are larger* than the GED computed using year-2005 fixed shadow prices. Nearly all of the GED from natural gas facilities is due to NO_x emissions, whereas the GED from coal and oil-fired plants is mostly due to SO_2. Table 4a shows that the price index for NO_x (2002/2005) is estimated to be 1.19. This dramatic difference in nominal shadow prices is evident in table 5a as the nominal GED for gas plants is over 12 percent greater than 2002 GED using fixed 2005 shadow prices. Deflation using the Fisher indices cuts this difference in half.

In 2008, the shadow prices for SO_2 are roughly 10 percent greater than in 2002. This is roughly two-times larger of a difference than in 2002 (relative to 2005). Thus the nominal GED in 2008 is considerably larger than the GED in 2008 computed with the year-2005 shadow prices. For the case of coal-fired plants, any difference in relative prices (spatially) appears to be overwhelmed by the increase in price level; the nominal GED in 2008 is 30 percent greater than the GED computed using year-2005 shadow prices. Deflation cuts this difference in half. As in the case of 2002, oil-fired facilities show a similar pattern. The results for gas-powered facilities look much like the results in 2002. Both the nominal and real GED in 2008 exceed the GED computed using the fixed 2005 shadow prices.

Table 2a also decomposes the GED from the transportation and manufacturing sectors for five industries with the largest changes in the GED. Beginning with transportation, commercial marine vessels produced about $9 billion more GED in 2005 than in 2002. In 2008 damages from this industry dropped by over $12 billion. For truck transportation, the GED declined in both periods: by $6 billion and $2 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 15 percent and then the GED from this industry declined by 45 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 paper 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 2a also breaks down the GED from the manufacturing sector. Petroleum refineries produced GED in 2005 that was about $1 billion less than the GED in 2002. This decline continued in 2008. Cement manufacturers produced a small increase in GED in 2005 and then significantly less GED in 2008 than in 2005. For the next two industries, namely, paperboard mills and newsprint mills, the GED increases from 2002 to 2005, but then decreases in 2008. Finally, paper mills generated GED in 2005 that was 40 percent less than in 2002. In contrast, the GED from this industry grew by 30 percent in 2008.

Table 4 shows the annualized rates of change for VA (conventionally measured) and the NVA, which is the VA minus the GED, by sector. For the time period 2002 to 2005, economy-wide VA grew by 2.85 percent on an annual basis. NVA grew by 3.01 percent. This implies that when the GED are incorporated into the NIPAs, over this time period, production grew more quickly than when only market goods and services are valued. The evidence reported in table 4 suggests that the reduction in social cost associated with air pollution emissions is a valuable component of production, one that contributes approximately 0.15 percent point of growth on an annual basis between 2002 and 2005. Reporting measures of growth that fail to reflect the GED *underestimates* growth between 2002 and 2005.

An accounting framework that recognizes the GED, the air pollution externality, reduces the level of VA. The NVA is smaller than the VA because the NVA is a *net* measurement. 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 2005, although the level of VA declines when GED are included to report NVA, the rate of growth increases. One way to characterize this difference is through the GED/VA index; between 2002 and 2005 the economy produces smaller values of the GED/VA. (Recall from table 2 that economy-wide GED/VA decreases from 4.3 percent in 2002 to 3.9 percent in 2005.) By construction of the index this means that the GED is falling *relative to the VA*. Therefore, NVA is growing relative to VA. And, the difference between the NVA measure and market VA boils down to the inclusion (in the NVA) 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[4]. All else equal regulated industry's VA declines as a function of these expenditures. Abatement expenditures 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[5]. However, the NIPAs, by definition, miss non-market 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 which are not measured or reflected in market transactions. This highlights the importance of the augmented NVA measure. The NVA encompasses an important missing (from VA) measure of the benefit of these investments in environmental quality.

[4] 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.

[5] This is the classic example of externality; a firm produces an output via processes that generate smoke which 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.

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 non-market benefits). The NVA accounts for this source of growth, and the empirical results in table 4 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[6].

Between 2005 and 2008 the divergence between VA and NVA is even greater; VA grew at a 1.24 percent annual rate while NVA grew by 1.58 percent. The difference is nearly 0.4 percent annually. Again, although the level of VA exceeds that of the NVA measure, the rate of growth in the NVA outstrips that of the VA because of the substantial decline in the GED from 2005 to 2008. Much like for the 2002 to 2005 period, VA *underestimates* actual growth from 2005 to 2008. These subtle differences in growth rates are reflected in figure 4 which maps the VA and the NVA for the entire economy between 2002 and 2008. Although the VA and the NVA roughly parallel one another, a slight convergence of VA and NVA is clear after 2007 as the recession takes hold. The NVA and the VA converge precisely because the GED shrinks as shown in tables 1 and 3.

Table 4 indicates that annualized rates of growth in the VA and the NVA are quite different for some sectors and nearly identical for others. The utility NVA grew by 30 percent between 2005 and 2008 (as the GED dropped dramatically) while the VA grew by 2.9 percent. This striking difference is evident in figure 5; after 2005, utility NVA increases much more rapidly than the conventionally measured VA. Connecting these results to tables 3 and 2a, the utility GED dropped significantly from 2005 to 2008 and the spread between the VA and NVA (which is the GED) therefore decreases noticeably from 2005 to 2008. Table 4 shows that the transportation sector VA grew by just over 2 percent between 2005 and 2008 while the NVA for this sector grew by 4 percent. The convergence of the VA and the NVA for this sector is shown in figure 6. Congruent with the results for the utility sector shown in figure 5, the NVA and VA for the transportation sector begin to converge after 2005 when VA is basically constant while the NVA increases as the GED atrophies. Figure 7 shows the NVA and VA plots for the manufacturing sector. For most of the time period covered by the analysis, the NVA and VA parallel each other: the GED is basically fixed. However, after 2007, the NVA and VA converge. Figure 7 suggests that this

[6] 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.

might be due to the recession; VA growth becomes sharply negative and the gap between VA and the NVA shrinks noticeably around 2008.

Figure 1a in the appendix plots the VA and the NVA for the agriculture sector against time. These two indices roughly track parallel through 2005; this reinforces the result in table 1 that the GED for this sector was constant between 2002 and 2005. However, after 2005, the GED declines and the NVA grows more quickly than the VA. Figure 3a in the appendix shows the same information for the waste management sector. First, both the NVA and the VA are growing throughout the 2002 to 2008 period. Second, the difference between the NVA and the VA appears to decrease from 2002 to 2005 *and then increase* from 2005 to 2008. Thus the GED decreases from 2002 to 2005 while it increases between 2005 and 2008.

Table 4 indicates that some sectors such as real estate, management, and professional services have almost no difference between the rates of VA and NVA growth. This should be expected given that these sectors produce almost no GED. For these cases, augmented accounts that focus on environmental damage make really no difference since most of their activities and, hence, the value of their production lies within the bounds of the conventional NIPAs.

Table 4 shows that conditions in the construction sector were very different from the sectors highlighted in the discussion above. Between 2002 and 2005, the construction NVA contracted at a rate of 0.1 percent and the VA for this sector contracted at 0.3 percent. While both the NVA and VA measures imply shrinkage in output, including the GED into the NVA *reduces* the rate of contraction (in absolute value). Indeed, table 1 indicates that the GED declined for this sector between 2002 and 2005. However, between 2005 and 2008 the NVA decreased by 5.5 percent annually while the VA decreased by 5.1 percent per year. In this case, NVA 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 NVA suggests an even greater rate of contraction that does the market VA. Figure 2a in the appendix plots the VA and the NVA against time. The dramatic downturn in both VA and NVA is evident in this figure. The figure shows that the differences in rates of growth between the NVA and the VA are subtle for this sector.

The 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 borne by the construction sector. Hence, the construction VA contracted rapidly after 2007. And the greater *negative* growth of the NVA suggests that VA was clearly contracting more rapidly than the GED over this time period.

Table 5 displays the results from the experiments that test the impact of different deflation techniques on the pollution shadow prices. Since year 2005 GED comprise the base year (and therefore unaffected by deflation) table 5 only reports GED for the years 2002 and 2008. The Fisher price indices are the default case (shown in equation 6); the fixed 2005 shadow prices employ year 2005 marginal damages for both 2002 and 2008 (see equation 5); the GDP deflator applies the USBEA GDP deflator which differs in magnitude for 2002 and 2008 (see equation 7).

In the default case, economy-wide GED is estimated to be $440 billion in 2002 and $335 billion in 2008. Using the fixed year-2005 shadow prices increases the GED in 2002 to $460 billion. However, estimated GED in 2008 is slightly lower at $322 billion. By deduction, shadow prices appreciate more rapidly between 2002 and 2005 using the Fisher deflator than when using the fixed-2005 assumptions. Conversely, prices appreciate more when using the fixed-2005 deflator between 2005 and 2008. Economy-wide GED is estimated to be $509 billion in 2002 using the market deflator. This approach clearly assumes that pollution prices were much higher in 2002 (that the rate of change in the pollution shadow price level was smaller) than for either of the other two deflators. Note that this assumption pegs changes in the pollution shadow prices to changes in prices for market goods and services. The rate of change in pollution prices between 2005 and 2008 when using the GDP deflator is nearly identical to when the fixed-2005 deflator is used. Figure 4a in the appendix displays the implications of the different deflators for the economy-wide GED/VA index. As table 5 indicates, the greatest divergence in the GED estimates occurs in the years prior to 2005; the GED/VA indices range from 0.05 for the GDP deflator to 0.043 for the Fisher deflator. After 2005, all three deflators yield GED/VA index values that are very similar.

Table 5 also reports the different GED estimates for the five heaviest polluting sectors. Two patterns are evident. For all sectors except for transportation, the GED in 2002 is estimated to be smallest when using the Fisher deflator, with larger values for the fixed-2005 prices, and the largest values produced using the GDP deflator. This is not the case for the transportation sector; GED is greatest when using the GDP deflator, however it is estimated to be smallest when employing the fixed-2005 prices 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 5. For agriculture and manufacturing, the largest GED is produced using the fixed-2005 deflator. For utilities, construction, and transportation, this deflator produces the smallest GED estimates in 2008.

Figure 5a shows the GED/VA indices for the transportation, agriculture, utilities, and manufacturing sectors. In the top-right panel, the GED/VA for manufacturing sector diverges between 2002 and 2005. Following 2005, the GED/VA index values produced by the different deflators converge and follow the same downward trend to 2008. For utilities, the GDP deflator yields consistently larger GED/VA estimates than either of the other two deflators. Prior to 2005, the Fisher deflator yields the lowest GED/VA index, while after 2005, the fixed-2005 deflator produces the smallest GED/VA estimate. This pattern in the relative rankings of the GED/VA indices produced by the different deflators is broadly similar to that observed for the transportation sector. The GED/VA for agriculture follows a different pattern. Beginning in 2002, the GDP deflator yields the largest GED/VA index. The other two deflators produce very similar GED/VA values through 2005. However, after 2005, the GDP deflator yields the smallest GED/VA index, while the fixed-2005 deflator generates the greatest GED/VA score.

4. Conclusions.

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 U.S. economy for 2002, 2005, 2008. The time series measurement of the GED, the GED/VA, and the NVA (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 non-market accounts are very important, the estimation of the air pollution damage indices over multiple years provides researchers and policymakers with the opportunity to assess how the social costs from air pollution change relative to the size of the economy.

The empirical results indicate that the GED changes dramatically from 2002 to 2008; the GED decreased annually by roughly 1 percent from 2002 to 2005 and by 8% from 2005 to 2008. Much of the steep decline from 2005 to 2008 stems from reductions in the GED attributable to the agriculture, utility, and transportation sectors. The GED/VA, economy-wide, between 2002 and 2008 does not vary as much. In 2002 the total GED/VA is approximately 0.043, and in 2008 the GED/VA is just less than 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 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 0.75 in 2002. In 2008, the GED/VA drops to 0.46. Similarly, the agriculture and forestry sector has a GED/VA of over 0.75 in 2002 and this index declines to less than 0.50 in 2008. However, some sectors have nearly constant levels of the GED/VA; the manufacturing sector begins in 2002 with a GED/VA of 0.049 and in 2008 the manufacturing GED/VA is estimated to be 0.028. This is not to suggest that the level of the manufacturing GED remains necessarily fixed. In 2002 the manufacturing GED was $66 billion while in 2008 the GED for this sector was $44 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 U.S. 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 paper also reports that the NVA (VA-GED) grows at greater annual rates between both 2002 and 2005 and 2005 and 2008 than VA. Between 2002 and 2005, the NVA grew at an annual rate of 3.01 percent while VA grew at 2.85 percent. Incorporating the GED increases the ex post estimate of growth by 0.15 percent. From 2005 to 2008, VA grew at an annual rate of 1.24 percent and the NVA grew at 1.58 percent per year. Including GED in the accounts yields a divergence between the rates of growth of nearly 0.4 percent from 2005 to 2008. While including the GED into the NIPAs reduces the level of VA, in the U.S. economy between 2002 and 2008, including the GED *increases* estimates of growth since the GED decreased over this time period.

While the paper finds that in the U.S. economy over the period from 2002 to 2008 the augmented measure of growth and performance (the NVA) suggests higher rates of growth, it is certainly feasible or possible for the NVA and VA annual rates of change to relate differently in other economies (in different stages of development) or in the U.S. economy in other time periods. For example, an economy with VA growth less than its GED growth would have NVA 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 manufacturing. In this setting standard measures of growth *overestimate* actual growth.

The case of the U.S. economy from 2002 to 2008 exemplifies NVA growth which exceeds VA growth. In this setting, the GED decreases. Contracting GED with (even modest) VA growth yields higher NVA 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 U.S. between 2002 and 2008.

This paper suggests research on a number of fronts. First, as more emissions data becomes available from 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 NVA 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 U.S. 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.

Table 1: Sector Real GED ($ billion, 2005 prices)

2002		2005		2008	
Sector	**GED**	**Sector**	**GED**	**Sector**	**GED**
Utilities	151.00[a]	Utilities	150.99	Utilities	104.00
Ag./Forestry	77.87	Ag./Forestry	78.24	Ag./Forestry	61.01
Manufacturing	65.97	Manufacturing	65.83	Manufacturing	44.16
Transportation and Warehousing	55.04	Transportation and Warehousing	54.68	Transportation and Warehousing	37.17
Construction	31.58	Construction	27.45	Construction	30.82
Admin. Waste Management	24.96	Admin. Waste Management	18.64	Admin. Waste Management	29.49
Accommodation and Food Services	9.87	Accommodation and Food Services	10.53	Accommodation and Food Services	12.15
Mining	7.13	Mining	6.76	Arts, Entertainment, and Recreation	5.33
Arts, Entertainment, and Recreation	5.21	Arts, Entertainment, and Recreation	6.39	Retail Trade	3.38
Retail Trade	3.85	Retail Trade	4.61	Mining	3.36
Wholesale Trade	2.75	Other Services (except Public Admin.)	2.32	Other Services (except Public Administration)	1.20
Other Services (except Public Administration)	2.28	Wholesale Trade	1.62	Educational Services	1.06
Health Care and Social Assistance	1.55	Educational Services	1.04	Wholesale Trade	0.88
Educational Services	0.80	Health Care and Social Assistance	0.32	Finance and Insurance	0.34
Real Estate and Rental and Leasing	0.11	Prof., Scientific, and Technical Services	0.12	Health Care and Social Assistance	0.26
Professional, Scientific, and Technical Services	0.10	Information	0.07	Real Estate and Rental and Leasing	0.19
Information	0.05	Real Estate and Rental and Leasing	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
Economy	**440.1**		**429.7**		**334.9**

a = GED deflated using Fisher Pollution Price Indices, VA deflated using sector-specific price indices.

Table 2: Sector GED/VA[a]

2002		2005		2008	
Sector	**GED/ VA**	**Sector**	**GED/ VA**	**Sector**	**GED /VA**
Utilities	0.753	Utilities	0.733	Agr./Forestry	0.474
Agr./Forestry	0.746	Agr./Forestry	0.616	Utilities	0.464
Transportation and Warehousing	0.182	Transportation and Warehousing	0.148	Transportation and Warehousing	0.095
Administrative and Waste Management	0.081	Arts, Entertainment, and Recreation	0.054	Administrative and Waste Management	0.074
Construction	0.051	Administrative and Waste Management	0.050	Construction	0.059
Manufacturing	0.049	Construction	0.045	Arts, Entertainment, and Recreation	0.044
Arts, Entertainment, and Recreation	0.047	Manufacturing	0.042	Accommodation and Food Services	0.033
Accommodation and Food Services	0.030	Mining	0.035	Manufacturing	0.028
Mining	0.027	Accommodation and Food Services	0.029	Mining	0.016
Other Services (except Public Administration)	0.007	Educational Services	0.009	Educational Services	0.008
Educational Services	0.007	Other Services (except Public Administration)	0.007	Retail Trade	0.004
Retail Trade	0.005	Retail Trade	0.005	Other Services (except Public Administration)	0.004
Wholesale Trade	0.004	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
Prof., Scientific, and Technical Services	0.000	Prof., Scientific, and Technical Services	0.000	Health Care and Social Assistance	0.000
Information	0.000	Information	0.000	Real Estate and Rental and Leasing	0.000
Real Estate and Rental and Leasing	0.000	Real Estate and Rental and Leasing	0.000	Information	0.000
Finance and Insurance	0.000	Finance and Insurance	0.000	Prof., 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	**0.043**		**0.039**		**0.029**

a = GED deflated using Fisher Pollution Price Indices, VA deflated using sector-specific price indices.

Table 3: Gross Change in GED by Sector

Sector	2005 - 2002 Δ GED (%)	2005 - 2002 Δ GED ($, billion)	2008 - 2005 Δ GED (%)	2008 - 2005 Δ GED ($, billion)
Agriculture/Forestry	0.5	0.37	-22.0	-17.23
Mining	-5.2	-0.37	-50.3	-3.40
Utilities	0.0	-0.01	-31.1	-46.99
Construction	-13.1	-4.13	12.3	3.38
Manufacturing	-0.2	-0.14	-32.9	-21.67
Wholesale Trade	-41.1	-1.13	-45.9	-0.74
Retail Trade	19.7	0.76	-26.6	-1.23
Transportation and Warehousing	-0.6	-0.35	-32.0	-17.51
Information	52.9	0.02	-12.8	-0.01
Finance and Insurance	95.0	0.00	5112.7[a]	0.33
Real Estate and Rental and Leasing	-36.5	-0.04	176.1	0.12
Professional, Scientific, and Technical Services	11.2	0.01	-22.6	-0.03
Management of Companies and Enterprises	-1.6	0.00	13.1	0.00
Admin. and Waste Management	-25.3	-6.32	58.2	10.85
Educational Services	30.0	0.24	1.9	0.02
Health Care and Social Assistance	-79.1	-1.23	-19.4	-0.06
Arts, Entertainment, and Recreation	22.6	1.18	-16.5	-1.05
Accommodation and Food Services	6.7	0.66	15.4	1.62
Other Services (except Public Administration)	1.4	0.03	-48.0	-1.11
Economy	**-2.4**	**-10.46**	**-22.0**	**-94.72**

[a]= This large percentage increase stems from NAICS code 524298, "All other insurance related activities." The U.S. Census Bureau reports that: "This U.S. industry comprises establishments primarily engaged in providing insurance

services on a contract or fee basis (except insurance agencies and brokerages, claims adjusting, and third party administration). Insurance advisory services and insurance ratemaking services are included in this industry." (US Census, 2012).

Table 4: Annualized Change in Value Added and Net Value Added.

Sector	2005 - 2002		2008 - 2005	
	Δ NVA[1,2] (%)	**Δ VA (%)**	**Δ NVA (%)**	**Δ VA (%)**
Agriculture/Forestry	22.69	6.80	11.49	0.42
Mining	-10.53	-10.27	3.02	2.36
Utilities	3.52	0.89	29.79	2.86
Construction	-0.07	-0.29	-5.54	-5.07
Manufacturing	5.15	4.91	1.01	0.51
Wholesale Trade	4.24	4.16	2.45	2.41
Retail Trade	1.43	1.45	-1.10	-1.14
Transportation and Warehousing	8.31	6.86	4.10	2.02
Information	7.29	7.30	3.59	3.59
Finance and Insurance	2.92	2.92	-2.50	-2.49
Real Estate and Rental and Leasing	2.13	2.13	3.41	3.42
Professional, Scientific, and Technical Services	3.79	3.79	4.42	4.42
Management of Companies and Enterprises	-1.02	-1.02	0.48	0.48
Admin. and Waste Management	7.55	6.37	1.51	2.37
Educational Services	0.08	0.15	1.43	1.42
Health Care and Social Assistance	3.06	3.00	3.44	3.43
Arts, Entertainment, and Recreation	1.75	2.01	1.11	0.76
Accommodation and Food Services	3.47	3.43	-0.28	-0.13
Other Services (except Public Administration)	-0.80	-0.79	-0.76	-0.88
Economy	3.01	2.85	1.56	1.24

[1] NVA: (VA – GED)

[2] Annual rate of change = $100 \times ((NVA_{2008}/NVA_{2005})^{(1/3)} - 1)$

Table 5. Alternative Deflation of Pollution Shadow Prices.

Deflator	Fisher Indices		Fixed 2005		GDP Deflator	
Sector	**2002**	**2008**	**2002**	**2008**	**2002**	**2008**
Economy	440.1[a] (0.043)[b]	335.3 (0.030)	461 (0.046)	321.8 (0.028)	509.0 (0.050)	318.6 (0.028)
Agriculture	77.9 (0.746)	61.0 (0.474)	78.1 (0.749)	66.6 (0.518)	85.7 (0.822)	34.9 (0.271)
Utility	151.0 (0.753)	104.0 (0.464)	162.9 (0.813)	92.6 (0.413)	175.0 (0.873)	109.0 (0.487)
Manufacturing	66.0 (0.049)	44.2 (0.028)	72.4 (0.053)	45.5 (0.029)	76.7 (0.056)	44.7 (0.028)
Construction	31.6 (0.051)	30.8 (0.059)	31.9 (0.052)	29.9 (0.057)	36.8 (0.060)	31.9 (0.061)
Transportation	55.0 (0.182)	37.2 (0.095)	51.2 (0.169)	30.9 (0.079)	66.5 (0.220)	48.4 (0.124)

a = GED ($, billion)
b = GED/VA

Figure 1: Gross External Damage Graphical Depiction.

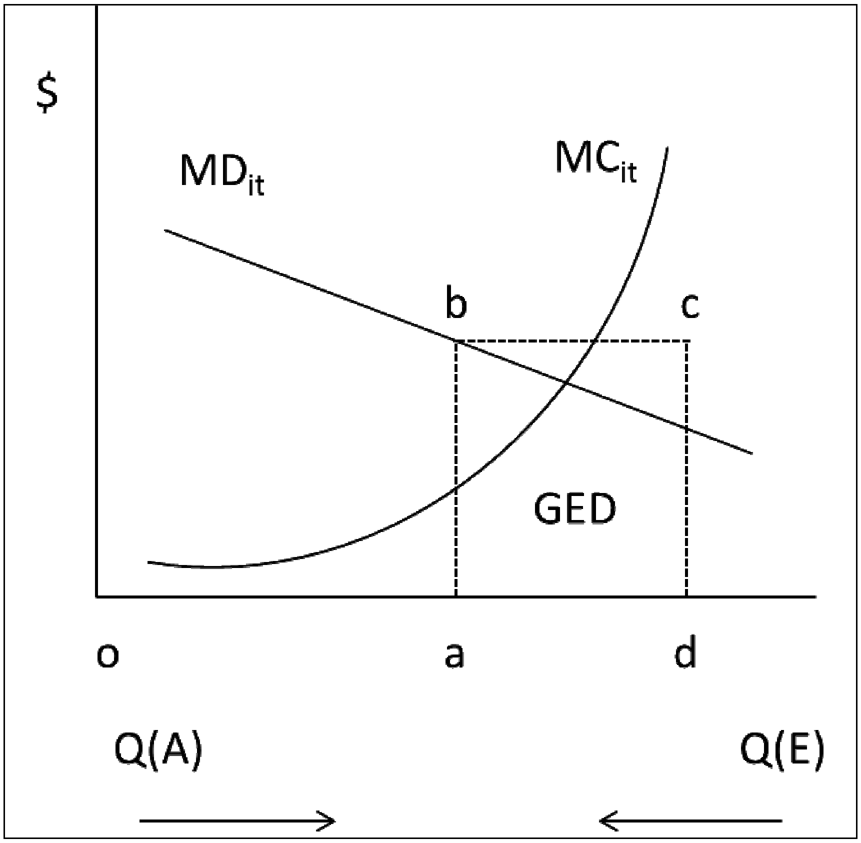
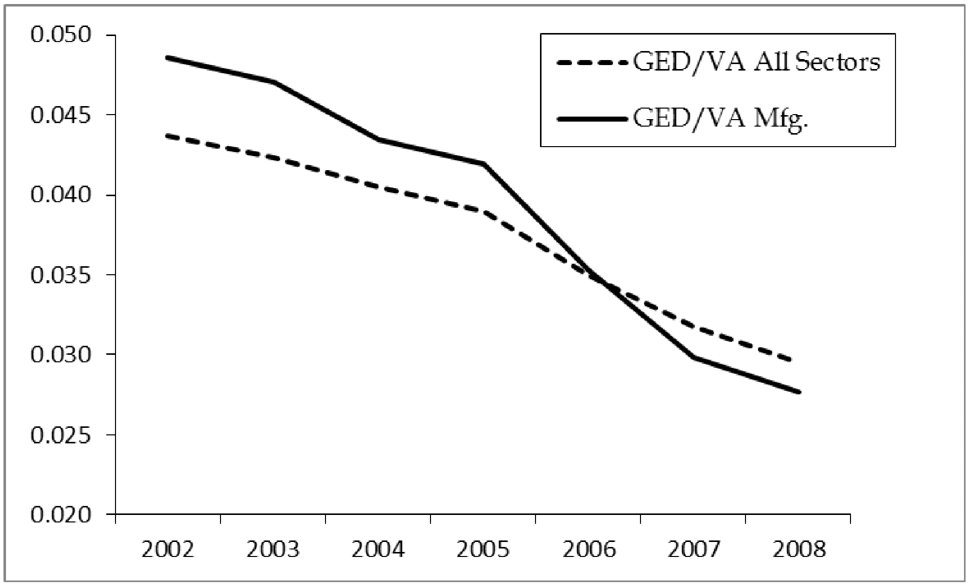


Figure 2: GED/VA: Economy and Manufacturing Sectors.



GED deflated using fixed year 2005 shadow prices.

Figure 3: GED/VA: Utility and Agriculture Sectors.

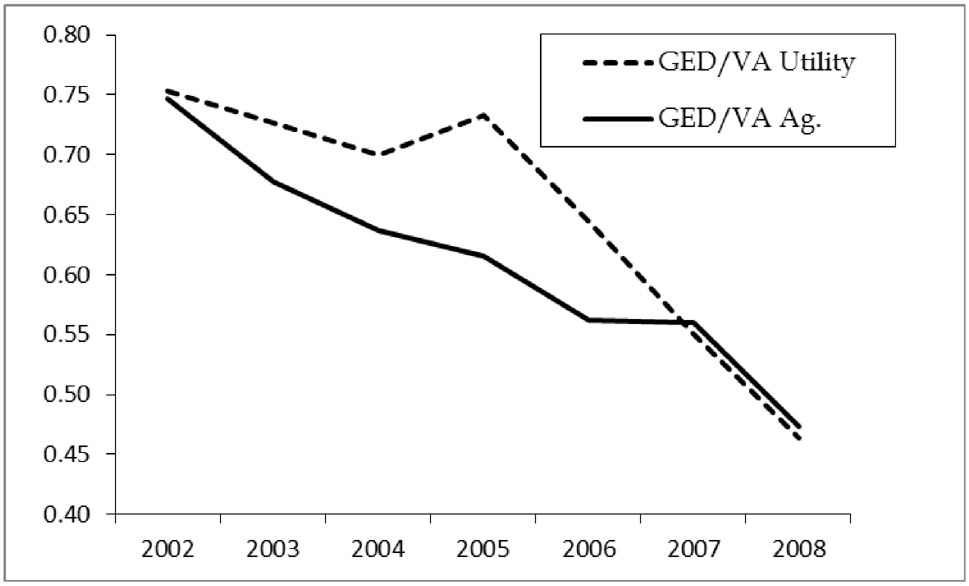
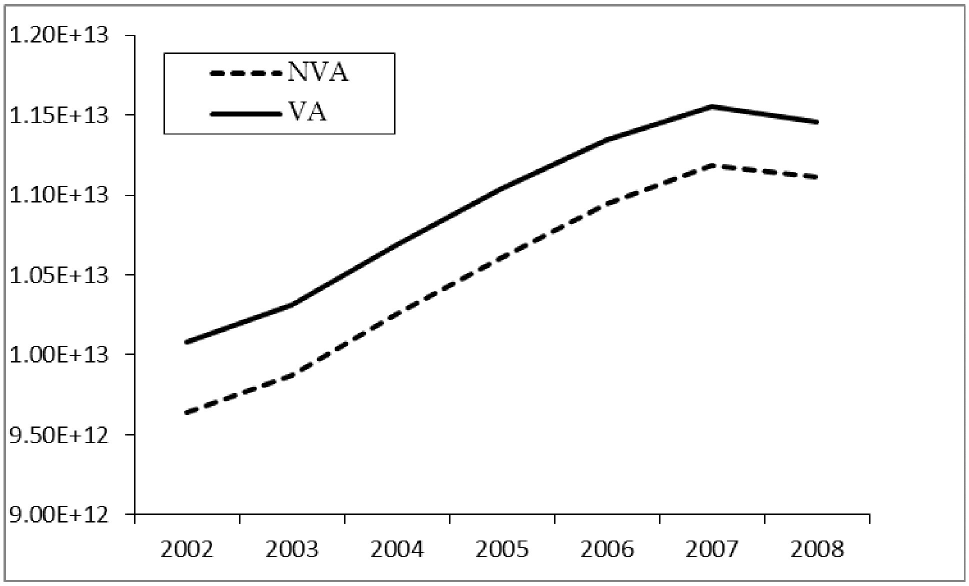
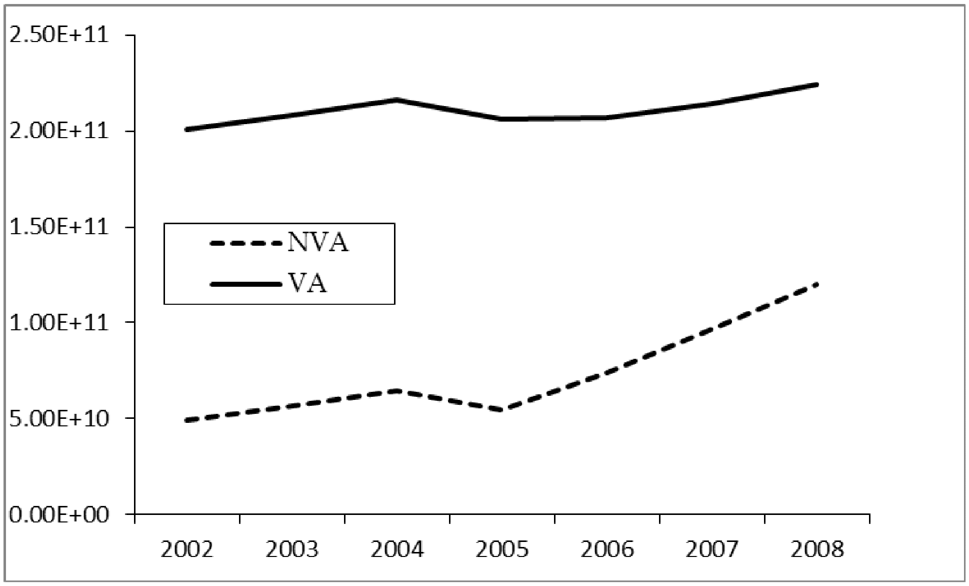


Figure 4: Value Added and Net Value Added: All sectors.



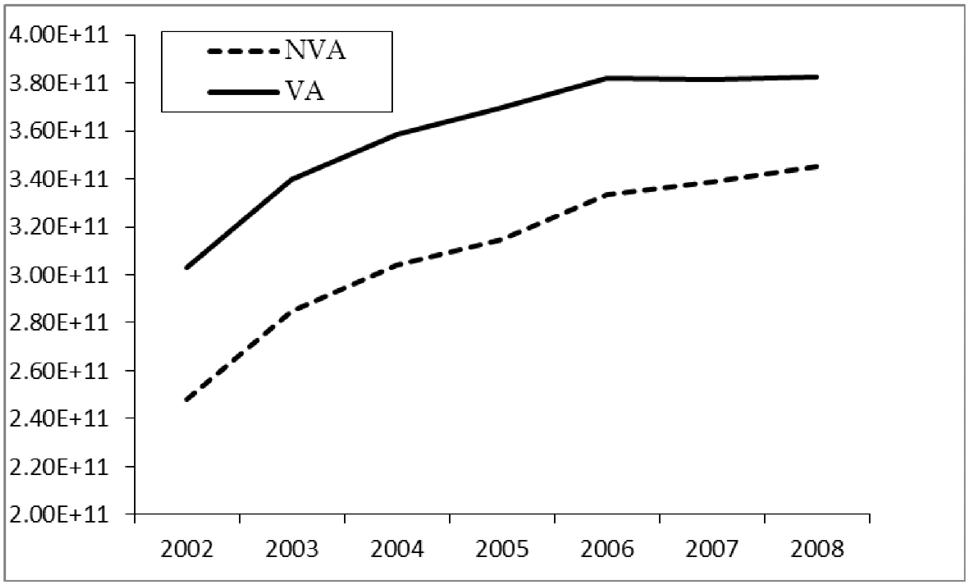
Values on vertical axis are ($, 2005).

Figure 5: Value Added and Net Value Added: Utility sector.



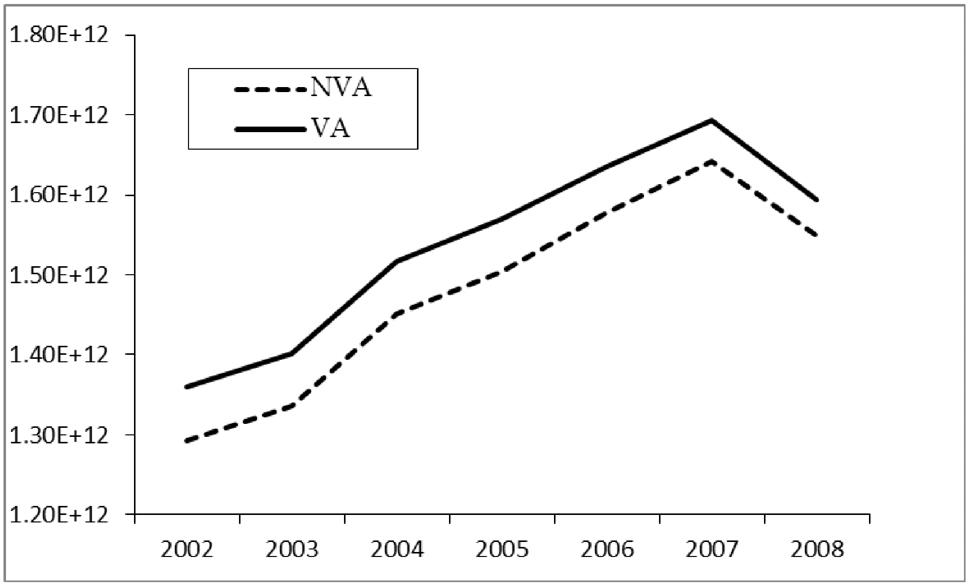
Values on vertical axis are ($, 2005).

Figure 6: Value Added and Net Value Added: Transportation sector.



Values on vertical axis are ($, 2005).

Figure 7: Value Added and Net Value Added: Manufacturing sector.



Values on vertical axis are ($, 2005).

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Appendix

Table 1a: Annualized Percentage Change in GED

Sector	2005 - 2002 Δ GED (%)	2008 - 2005 Δ GED (%)
Agriculture/Forestry	0.2	-8.0
Mining	-1.8	-20.8
Utilities	0.0	-11.7
Construction	-4.6	3.9
Manufacturing	-0.1	-12.5
Wholesale Trade	-16.2	-18.5
Retail Trade	6.2	-9.8
Transportation and Warehousing	-0.2	-12.1
Information	15.2	-4.5
Finance and Insurance	24.9	273.6
Real Estate and Rental and Leasing	-14.0	40.3
Professional, Scientific, and Technical Services	3.6	-8.2
Management of Companies and Enterprises	-0.5	4.2
Admin. and Waste Management	-9.3	16.5
Educational Services	9.1	0.6
Health Care and Social Assistance	-40.7	-7.0
Arts, Entertainment, and Recreation	7.0	-5.8
Accommodation and Food Services	2.2	4.9
Other Services (except Public Administration)	0.5	-19.6
Economy	-0.8	-8.0

Table 2a: Industry Decomposition of GED Change:
Utility, Manufacturing, and Transportation Sectors.

Sector	Industry	2005-2002	2008-2005
Utility	Coal-fired Power Generation	10.0[a] (7.8)[b]	-44.9 (-32.3)
	Natural Gas-fired Power Generation	-1.4 (-38.4)	4.0 (183.5)
	Oil-fired Power Generation	0.9 (26.4)	-2.5 (-55.5)
Transportation	Marine Transport	8.76 (50.84)	-12.66 (-48.70)
	Truck Transport	-5.57 (-24.02)	-1.52 (-8.64)
	Railroad Transport	0.85 (14.98)	-2.92 (-45.02)
	Pipeline	-1.43 (-72.18)	0.09 (15.73)
	Airport	-3.46 (-95.29)	-0.02 (-12.09)
Manufacturing	Petroleum Refineries	-0.80 (-7.21)	-4.17 (-40.49)
	Cement Mfg.	0.15 (4.24)	-2.31 (-62.60)
	Paperboard Mills	0.84 (66.1)	-1.54 (-73.22)
	Newsprint Mills	1.03 (493.3)	-1.05 (-84.4)
	Paper Mills	-1.32 (-40.74)	0.54 (28.13)

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

Table 3a: Percentage Change in Net Value Added and Value Added: Comparison of Deflators.

Deflator	**Fisher Price Indices**		**Fixed 2005 Prices**		**GDP Deflator**	
Sector	**2005-2002**	**2008-2005**	**2005-2002**	**2008-2005**	**2005-2002**	**2008-2005**
Economy	2.85[a] (3.01)[b]	1.24 (1.62)	2.85 (3.08)	1.24 (1.62)	2.85 (3.25)	1.24 (1.61)
Agriculture	6.80 (22.69)	0.42 (11.49)	6.80 (23.10)	0.42 (8.32)	6.80 (37.92)	0.42 (24.29)
Utility	0.89 (3.52)	2.86 (29.79)	0.89 (13.48)	2.86 (33.78)	0.89 (29.14)	2.86 (27.97)
Manufacturing	4.91 (5.15)	0.51 (1.01)	4.91 (5.33)	0.51 (0.98)	4.91 (5.44)	0.51 (0.99)
Construction	-0.29 (-0.07)	-5.07 (-5.54)	-0.29 (-0.06)	-5.07 (-5.48)	-0.29 (-0.23)	-5.07 (-5.60)
Transportation	6.86 (8.31)	2.02 (4.10)	6.86 (7.76)	2.02 (4.71)	6.86 (10.03)	2.02 (2.99)

a = Annual rate of change VA (%)
b = Annual rate of change NVA (%)

Table 4a: Pollution Shadow Price Fisher Index Numbers.

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

All index numbers computed with 2005 as base year.
Values in parentheses are bootstrap standard errors.
Source: (Muller, 2012).

Table 5a: Deflation and GED from Electric Power Generation.

Sector	Industry	2002	2008
Utility	Coal-fired Power Generation	-8.4[a] (-2.1)[b]	13.6 (30.0)
	Natural Gas-fired Power Generation	5.2 (12.6)	0.7 (6.8)
	Oil-fired Power Generation	-6.8 (-1.0)	15.2 (22.8)

a = Percentage difference between deflated GED using Fisher index and fixed-2005 shadow prices.

b = Percentage difference between nominal 2008 GED and fixed-2005 shadow prices.

Figure 1a: Value Added and Net Value Added: Agriculture sector.

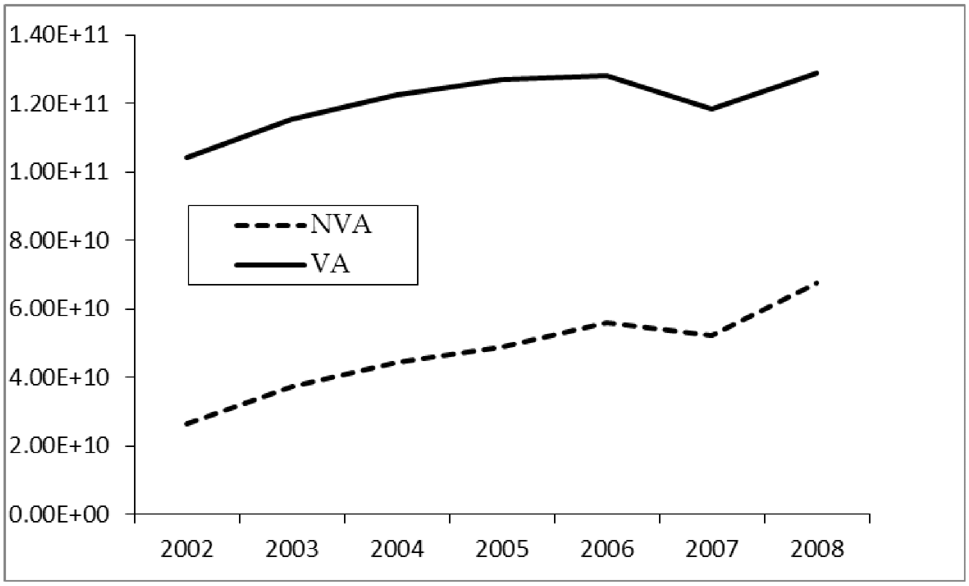

Figure 2a: Value Added and Net Value Added: Construction sector.

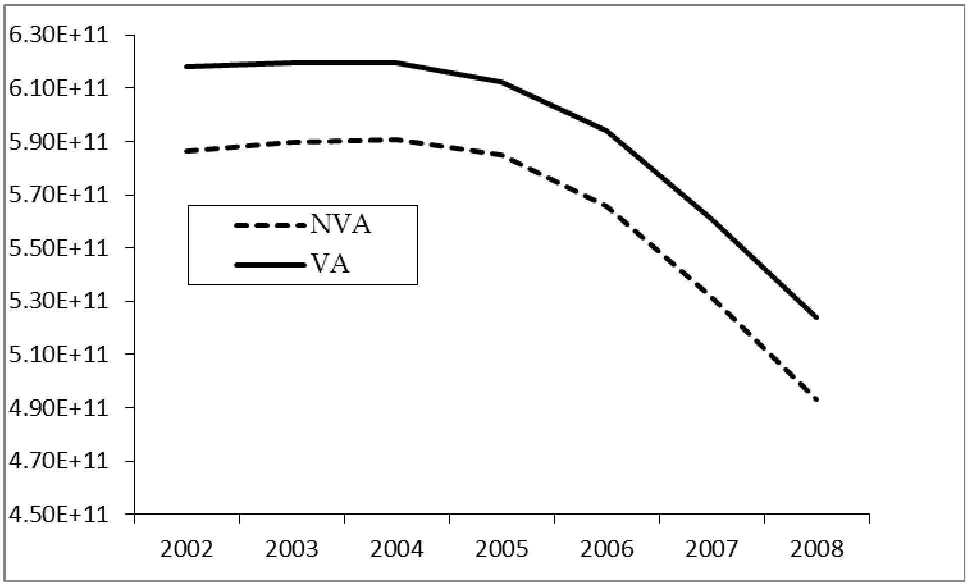

Figure 3a: Value Added and Net Value Added: Waste management sector.

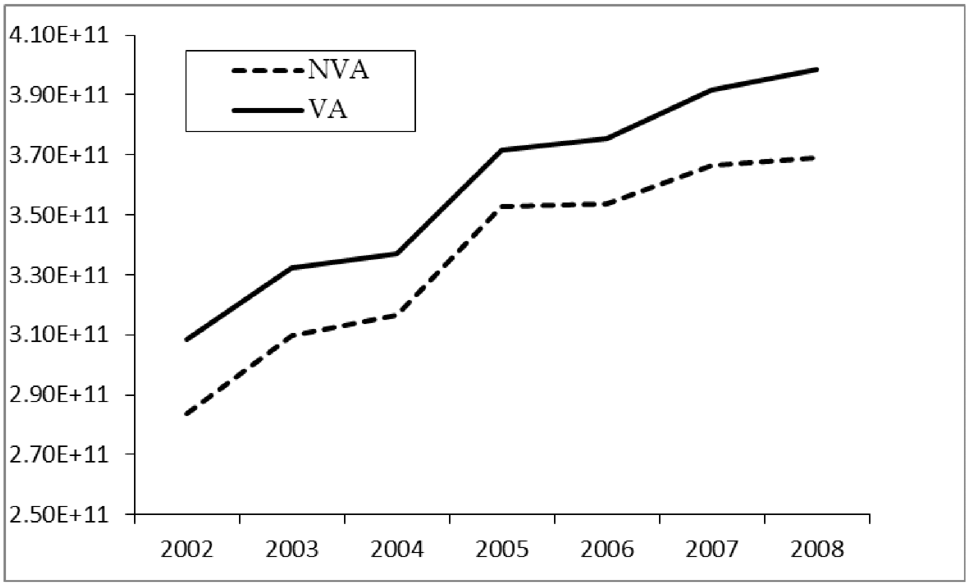

Figure 4a: Shadow Price Deflator Comparison: GED/VA All sectors.

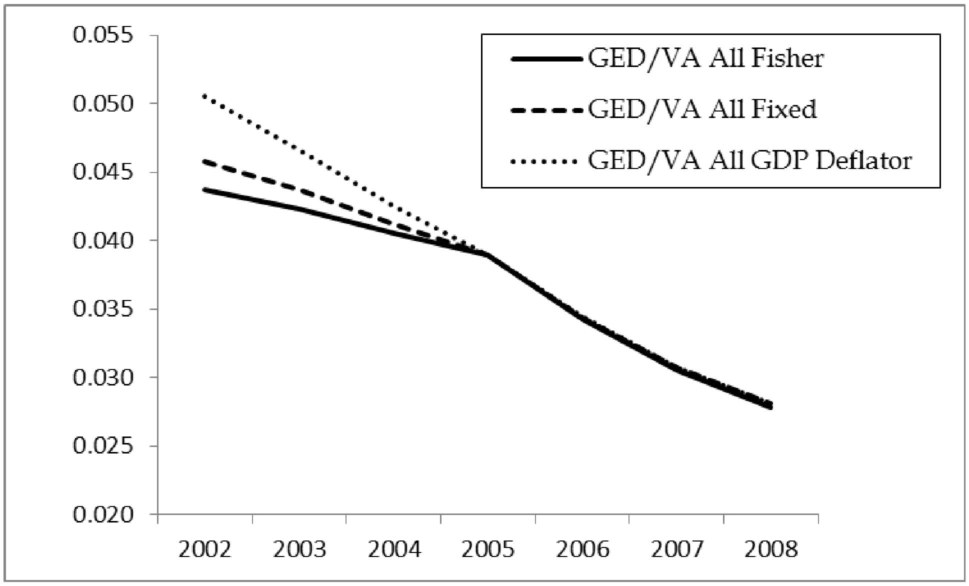

Figure 5a: Shadow Price Deflator Comparison: GED/VA Utility, Manufacturing, Construction, and Agriculture.