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Air pollution emissions and damages from energy production in the U.S.: 2002–2011

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HIGHLIGHTS

- Social costs of emissions from energy sector decreased between 2002 and 2011.
- Emissions from power generation are the major contributors to social costs.
- Policies to control SO_2 emissions may produce the largest social costs reductions.

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ABSTRACT

This paper uses air pollution emissions data for the years 2002, 2005, 2008, and 2011 to estimate monetary damages due to air pollution exposure for $PM_{2.5}$, SO_2, NO_x, NH_3, and VOC from electric power generation, oil and gas extraction, coal mining, and oil refineries. In 2011, damages associated with emissions from these sectors totaled 131 billion dollars (in 2000$), with SO_2 emissions from power generation being the largest contributors to social damages. Further, damages have decreased significantly since 2002, even as energy production increased, suggesting that, among other factors, policies that have driven reductions in emissions have reduced damages. The results of this analysis highlight the spatial heterogeneity of the impacts associated with the emissions of a given pollutant. In the past, environmental regulations have assumed that the benefits of air emissions reductions are homogenous across source location. This analysis suggests that policy designs that account for spatial differences in the impacts of air emissions could result in more effective environmental regulation. Accounting for such spatial heterogeneity in the benefits of policies would be akin to accounting for differences in compliances costs across states, which the EPA did when establishing the state emissions standards for the Clean Power Plan rule.

1. Introduction

The various ways in which society extracts fuels and uses those fuels to produce energy have important repercussions for the environment. This analysis focuses on one dimension of these impacts: air pollution. The paper uses air pollution emissions data for the years 2002, 2005, 2008, and 2011 to estimate monetary damages due to air pollution exposure for the following five pollutants: fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and volatile organic compounds (VOC). The paper covers all emissions in the contiguous United States (U.S.) from the following industries: electric power generation, oil and gas extraction, coal mining, and oil refineries. Although some of these industries face binding environmental regulatory constraints, such sources, of course, still produce emissions. As such, we tabulate the external cost, or monetary damage, from the reported emission levels.

By tracking these sources of air pollution over four reporting years (spanning 10 calendar years, inclusive), the paper shows how emissions and damages changed. In the period between 2002 and 2011, the U.S. faced a combination of regulatory and macroeconomic conditions that make this period an excellent setting in which to test for changes in air pollution impacts from the U.S. energy production system. First, the Clean Air Interstate Rule (CAIR) was developed during this period. CAIR represented a significant change to federal air pollution policy governing electric power generators by requiring significant cuts to both NO_x and SO_2 emissions from these facilities. Thus, in anticipation of CAIR and its replacement, the Cross State Air Pollution Rule, many facilities

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installed abatement devices. Demand for fuels of differing grades and types also changed as a result of CAIR. Although CAIR was never implemented, this paper will show that emissions of both NO_x and SO_2 dropped precipitously between 2005 and 2011. Second, in 2008 the U.S. economy was entering the Great Recession. As wealth and income effects took hold, demand for energy fuels fell accordingly. By 2011, however, electricity generation had rebounded to levels close to those before the recession hit.

In addition to evaluating the changes in emissions from the energy sector, this paper focuses on the spatial distribution of these changes and the associated monetary damages. The paper is able to track the changes in emissions and impacts by using an integrated assessment model that is highly resolved spatially. In particular, the paper uses the AP2 model (Muller, 2011). AP2 is an updated version of the Air Pollution Emission Experiments and Policy analysis model (APEEP), which has been used in many earlier papers (Cohon et al., 2010; Henry et al., 2011; Michalek et al., 2011; Muller, 2014; 2011; Muller and Mendelsohn, 2012; 2009; 2007). For large stationary sources, AP2 tracks emissions from individual facilities. For ground level sources, such as oil extraction and mines, the model attributes emissions to the county in which they occur in accord with how the U.S. Environmental Protection Agency (EPA) reports these data. This approach is able to account for emission changes at different mines, refineries, and large power plants. For all sources, receptors are defined as counties in the contiguous U.S. As a result, the paper is able to track changes in emissions and damages by county across the four years in the analysis.

The current paper is not the first to explore external, or social, costs associated with energy production and use. One of the earliest efforts in this area was the work of Freeman (1982). Viscusi et al. (1994) provided an early set of estimates for air pollution damages expressed in per unit terms by fuel type. Matthews and Lave (2000) discussed the need for economic valuation of pollution and summarized available methods and estimates. Sundqvist (2004) also provided a summary of earlier papers that explored and estimated the external costs due to power production. More recently, Levy et al. (2009), Fann et al. (2009), and Buonocore et al. (2014) reported damages from air pollution emissions from various source types. Finally, in 2010 the National Academies of Science (Cohon et al., 2010) explored air pollution damages from energy extraction and use.

The goal of this paper is to build on the work done by these earlier researchers to estimate the external costs (damages) associated with air pollution emissions from coal mines, oil and gas extraction sites, petroleum refineries, and electric power generation in the U.S. The application of AP2 in the present paper differs from prior uses of the model in the literature in two primary ways. In earlier work, Muller et al. (2011) cross-sectionally applied the earlier version of the model (APEEP) to all industries in the U.S. economy. Other work has applied the model to multiple years, but such studies reported results for highly aggregated sectors. In contrast, this paper applies AP2 across four data years in highly spatially resolved manner within the energy fuel extraction and power generation sectors. Thus, the contribution of the present analysis with respect to earlier studies in the field is three-fold. First, the current paper reports emission intensity and damages for four data years: 2002, 2005, 2008, and 2011. Our aim is to report and identify trends in total pollution damages across these four years. The second contribution of this paper lies in reporting damages by county and state of emission, for each data year. Because of the spatially heterogeneous incidence of regulatory changes between 2002 and 2011, we expect to observe concomitant patterns in emissions and damage. Further, the Great Recession imparted variable effects on regional economic systems in the U.S. How these two changes manifest in damages across the U.S. is part of the focus of this analysis. Third, we report damages normalized by fuel extracted or energy produced. We thus compare marginal external cost for each sector from 2002 to 2011.

2. Methods and data sources

2.1. Air pollution emissions

The National Emission Inventory (NEI) database, maintained by the EPA, includes annual emissions of all criteria air pollutants and hazardous air pollutants from U.S. sources, including power plants, oil refineries, coal mines, and oil and gas extraction sites (EPA, 2014a, 2014b). EPA releases NEI data every three years so this analysis relies on NEI data that is currently available for 2002, 2005, 2008, and 2011. The NEI database reports emissions by sector using the North American Industry Classification System (NAICS). Table S1 in the Supporting information (SI) shows the detailed sectors included in this analysis.

2.2. Integrated assessment model

AP2 (and its predecessor, APEEP) is a standard integrated assessment model that connects emissions within the contiguous U.S. to monetary damages using six modules: emissions, air quality modeling, concentration, exposure, dose-response, and valuation (Muller, 2014; 2013; 2011; Muller and Mendelsohn, 2007). The model relies on the baseline emissions reported by the USEPA through the NEI, so it implicitly includes emissions of $PM_{2.5}$, SO_2, NO_x, NH_3, and VOCs from non-point, on road, non-road, and point sources in the U.S. Separate runs of the AP2 model result in marginal damages for 2002, 2005, 2008, and 2011 based on the NEI for each of those years. Using the NEI data, AP2 tracks emissions from individual sources for over 600 of the largest electric generating units in the contiguous U.S. The model also aggregates emissions from other point sources based on the county in which the source is located. Finally, the model differentiates emissions from such facilities according to two effective height categories because this parameter has an important effect on the physical dispersion of emissions. AP2 also includes ground-level emission sources. In the NEI, USEPA aggregates these sources to the county level, so AP2 maintains this feature.

In order to connect emissions to ambient concentrations, AP2 uses an air quality model that is a modified Gaussian Plume. The primary modification is the use of a reduced form chemistry module for conversion of precursor emissions, such as SO_2 and NO_x, into ammonium sulfate and ammonium nitrate which are important components of secondary $PM_{2.5}$. AP2 also connects emissions of NO_x and VOC to concentrations of tropospheric ozone (O_3) (see the Supporting information for a series of model performance tests regarding the predicted ambient concentrations from AP2). After producing ambient concentration estimates, by county, AP2 uses detailed population inventories for each county for each model year to estimate exposure. These population inventories include human population, crop and timber yield inventories, and man-made materials that are sensitive to acid deposition. AP2 incorporates peer-reviewed dose-response functions to translate exposures into physical effects. Paramount among the dose-response functions are those governing the mortality-$PM_{2.5}$ relationship. For adult mortality, AP2 uses the results from Pope et al. (2002). For infants, the model uses the results from Woodruff et al. (2006). Finally, for O_3-mortality, AP2 uses the results from Bell et al. (2004).

The final step in the AP2 model converts physical effects to monetary damages. This step is straightforward for impacts that society is accustomed to valuing; crop yield impacts, for example,