Evaluating exported and imported health damages from emissions across U.S. counties

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Overview

U.S. federal air pollution policy manages both ambient concentrations and emissions. Standards for the former are ostensibly set to equitably protect human health and welfare in every county in the U.S., while emissions are managed to facilitate compliance with these standards. In some cases, non-local emissions appreciably affect air quality. That federal jurisdictions in air pollution policy span municipal, county, and state borders is evidence of an axiom in policy design: that the appropriate authority lies with the level of government whose jurisdiction encompasses the geographic reach of the regulated pollutant.

This paper focuses on inter-jurisdictional flows of air pollution. For every U.S. county in the lower 48 states, we compute damages exported to other counties, damages imported from other counties, and damages incurred within a county. These computations stand to inform air pollution policy design and to help target federal efforts to identify violations of the good neighbor provision. We focus our attention on particulate matter with aerodynamic diameter of 2.5 µm ($PM_{2.5}$), which can either be directly emitted or formed from precursors by reactions in the atmosphere.

In this work, we use a reduced complexity air quality model to assess the following research questions:

1. How have $PM_{2.5}$ related health damages from emissions in the U.S. changed over the period of 2008-2014?
2. How can we use metrics on self-inflicted, exported, and imported damages to understand the transport of emissions across U.S. counties?
3. What factors are associated with differences across the metrics for imported and exported damages across counties?

We explore these questions by looking at emissions damages and transport metrics in 2008, 2011, and 2014. We select those years to capture damages before and after the recession, using every three years based on the availability of emissions data.

Methods

We use AP3, an updated version of the AP2 model, which is an integrated assessment model developed to estimate monetary damages from emissions in the continental United States (1–3). The model includes emissions of $PM_{2.5}$ as well as gases that are $PM_{2.5}$ precursors, including sulfur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3), and volatile organic compounds (VOCs) from both anthropogenic and biogenic sources, all taken from the National Emission Inventory. To translate emissions into concentrations, the AP3 model simulates atmospheric transport, chemical transformation of precursors, and deposition across all U.S. counties. A source-receptor matrix based on a modified Gaussian plume model from the Climatological Regional Dispersion Model (CRDM) is used for the dispersion of pollutants from the point of emission as well as for the conversion of $PM_{2.5}$ precursors (4,5). The Gaussian plume dispersion model accounts for average wind patterns, weather conditions, vertical dispersion, deposition, and distances between source and receptor, with meteorological conditions represented by averages from the period from 1995-1999 using National Oceanic and Atmospheric Administration's (NOAA) Integrated Surface Hourly data.

Exposed population is translated to health effects using baseline all-cause mortality rates and estimates for the dose-response function relating $PM_{2.5}$ concentration and increased mortality, using data from the Centers for Disease Control (CDC) and the Census. The dose-response relating average annual $PM_{2.5}$ concentration to mortality is taken from Krewski *et al.* for adults over 30 and from Woodruff *et al.* for infants less than 1 year old (6,7). Finally, increased mortality is valued using a Value of Statistical Life (VSL) applied uniformly to all age groups (8). We use the Environmental Protection Agency (EPA) recommended VSL of $7.4 million in USD 2006, adjusting for inflation using the consumer price index (CPI) to current dollars in 2014.

We employ a marginal approach to isolate the flows of damages into and out of specific counties. To do this, we first use the model to calculate baseline damages for every county with all emissions (D_i), where *i* indexes by county. Next, we select a single county (county *x*) and set its emissions to zero. We then re-run the model, assessing new annual average $PM_{2.5}$ concentration values by county (C_i') and the damages occurring in each county (D_i'). This process allows us to estimate imported, exported, and self-inflicted damages for each county in the U.S, as well as the ratio between each of these damage metrics for each county.

Results

Total damages from emissions have fallen steadily since 2008, decreasing by approximately $140 billion, equivalent to approximately 16,000 fewer premature mortalities annually. This reduction in health damages and mortalities comes even as GDP has continued to grow over the same period. Gains in health benefits from reduced emissions since 2008 have been driven largely by reduced damages from point sources, which have fallen by close to $155 million from 2008 to 2014, a decrease of almost 39%.

Despite a positive national trend for reducing health damages from emissions, however, benefits have not accrued uniformly across U.S. counties. In general, counties in the Northeast have benefited the most from reductions in damages, largely as a result of increased emissions controls and shutdowns of coal power plants and other point sources in the Northeast and neighboring Rust Belt. In contrast to these gains, counties in states along the Mississippi River Valley and central U.S. tended to experience an increase in health damages per person from 2008 to 2014. The upward trend in damages in some of these areas seems largely attributable to increased emissions from natural gas and oil extraction; from 2008 to 2014 NOx from oil and gas production activities increased nationally by 97%, while VOCs increased by 80% and primary $PM_{2.5}$ by 210%.

We find a relatively high degree of damage transfer between regions in the Northeast section of the country. New England is the largest importer, incurring damages from emissions upwind in the New York area, Mid-Atlantic states, and even as far as the Midwest. The Midwest is the largest exporter of damages; emissions in that region are down from 2008 but estimated to have caused close to 36,000 deaths in 2014, with close to 19% of those mortalities occurring outside the region. Looking at the distribution of ratio of exports to imports, we note that almost all counties in New England and the New York regions have ratios less than one, identifying them as net importers; many counties in the Mid-Atlantic and Southeast regions also have ratios less than one. In contrast, counties in the Mountain region of the U.S. are heavily skewed toward being exporters, followed by counties in the South, Midwest, Great Plains, and West Coast states. A future step of this work is to conduct a regression analysis of these results to identify trends outside the model that might be associated with a propensity to export or import damages.

Conclusions

Our model confirms the reduction in health externalities from reduced emissions from 2008 to 2014, but also illustrates how the inequitable distribution of these welfare gains. While the Northeast has benefited greatly from emissions reductions, other parts of the country (including the South and Midwest) have deteriorated in terms of health damages from air quality. Ironically, these areas parallel parts of the country that tend to be struggling economically and less supportive of emissions regulations. An analysis of imports and exports indicates that non-local emissions still pose a substantial issue for counties in the Northeast, and further improvements to air quality are likely to require increasingly legal and economic cooperation with exporting areas like the Midewst.

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