STATEMENT

Synopsis of Research Report 168

HEALTH EFFECTS INSTITUTE

Evaluating the Effects of Title IV of the 1990 Clean Air Act Amendments on Air Quality

BACKGROUND

As our understanding of the adverse health effects associated with exposure to particulate matter (PM) ≤ 2.5 µm in aerodynamic diameter ($PM_{2.5}$) has grown, ambient $PM_{2.5}$ concentrations have been increasingly regulated in the United States and Europe. Although it is desirable to verify that air quality regulations have resulted in improved air quality, improved health, and reduced mortality, evidence for verification — particularly in terms of health outcomes — has not often been systematically collected and is difficult to establish retrospectively.

In 2000, HEI launched an initiative to improve the evidentiary and methodologic bases for assessing the health impact of regulations and other actions or situations resulting in improved air quality; since then it has funded nine studies through four Requests for Applications (RFAs) issued between 2002 and 2004. The current study, led by Dr. Richard D. Morgenstern of Resources for the Future, was funded under RFA 04-4, which sought proposals for studies of the health effects associated with planned actions to improve air quality (or other situations resulting in marked air quality improvements). Morgenstern and his team analyzed the effects of reductions in pollutants from power plants on $PM_{2.5}$ concentrations in the eastern United States between 1999 and 2005 using a statistical model linking emissions and air quality monitoring data.

Title IV of the Clean Air Act of 1990, entitled "Acid Deposition Control," called for a permanent 10-million-ton reduction in sulfur dioxide (SO_2) emissions from 1980 levels and required installation of continuous monitoring equipment for SO_2 emissions to ensure compliance and track improvements. Beginning with the 1997 National Ambient Air Quality Standards for PM, the U.S. Environmental Protection Agency (EPA) set standards for $PM_{2.5}$ concentrations, and $128 million was appropriated for a nationwide array of $PM_{2.5}$ monitoring stations known as the Air Quality System monitoring network.

When evaluating a regulatory action intended to improve air quality, either prospectively or retrospectively, EPA scientists frequently employ a chemical transport model, such as the Community Multiscale Air Quality (CMAQ) modeling system. One key limitation to the use of such models is that they are based on modeling estimations and not monitoring data. For the current study, Morgenstern and his team proposed a novel model that was data-driven, in that it depended on measured values of emissions and pollutant concentrations and was inherently observational. The statistical models that the investigators developed to link changes in emissions of SO_2 and nitrogen oxides (NO_x) to changes in ambient $PM_{2.5}$ concentrations were broadly based on source–receptor models that are widely used for source apportionment. More specifically, the investigators based their work on a "spatial econometric" approach, incorporating a statistical accounting of emissions in the manner of economic analysis, adapted for the current purposes of associating emissions and air pollution levels.

APPROACH

The investigators' specific aims for the study were as follows:

1. To assess what portion, if any, of the observed reductions in ambient concentrations of $PM_{2.5}$ that occurred in the United States in the years 1999–2005 could be credited to emissions reductions resulting from the implementation of Title IV Phase 2 of the 1990 Clean Air Act Amendments; and

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Richard D. Morgenstern, of Resources for the Future, and colleagues. The complete report, *Accountability Analysis of Title IV Phase 2 of the 1990 Clean Air Act Amendments* (© 2012 Health Effects Institute), can be obtained from HEI or our Web site (see last page).

2. To develop a statistical modeling approach to link observed changes in emissions of SO_2 and NO_x from power plants to changes in $PM_{2.5}$ concentrations.

The models for the study were built using three datasets. Two of these, the EPA's Clean Air Markets database and the National Emissions Inventory database, provided inventories of source emissions of SO_2 and NO_x. The third, modeled as receptor data, consisted of air quality monitoring data from the EPA's Air Quality System.

For emissions, the Clean Air Markets data were classified by location and date and adjusted for any important National Emissions Inventory database variables (e.g., industrial emissions sources that opted in to the Acid Rain Program during the study period). The Air Quality System dataset was also sorted by date and location, and monthly average values were calculated.

Based on the location of the 193 Air Quality System monitors used to build the model, the investigators defined circular zones of radius up to 500 miles for tabulating emissions. The monthly average $PM_{2.5}$ readings at the monitors, the emissions in the zones surrounding the monitors, meteorologic variables from the Air Quality System database, and a large array of dummy variables and interaction variables (referred to as fixed-effects variables) to account for unmeasured emissions and factors influencing $PM_{2.5}$ concentrations were combined in the statistical modeling framework relating emissions of SO_2 and NO_x to measured $PM_{2.5}$.

Morgenstern and his team used a linear regression model to explore the statistical relationships between source emissions of SO_2 and NO_x and the monitored concentrations of $PM_{2.5}$. In these models, monthly average monitored concentrations of $PM_{2.5}$ were the "outcome," or "dependent," variable, modeled as a function of power plant emissions of SO_2 and NO_x in the circular zones and of the fixed-effects variables. The investigators first constructed a relatively simple model in which monthly average $PM_{2.5}$ measured at the monitors was modeled as a function of monthly power plant source emissions in the circular zones, monitor-site temperature (measured as deviation from mean temperature for the study period), and fixed-effects variables for monitor site, year, and month. Because the emissions of SO_2 and NO_x were highly correlated, the investigators chose to drop NO_x from their models.

The investigators then built more complex models that included interaction terms combining such factors as temperature and emissions or site and year, exploring the effects of zone rings of various sizes around the monitors, of the inclusion of fixed-effects variables for season, and so on. Their preferred model contained the main SO_2 emission variable, an interaction variable for temperature and emissions, circular emission zones up to 400 miles from the $PM_{2.5}$ monitors, a set of dummy variables for the effect of calendar month, and statistical adjustments for known violations of linear regression assumptions.

In addition to the use of mean squared error (MSE) as a measure of model fit, Morgenstern and colleagues also performed various external comparisons of their models. As an initial check, they applied the model to data for the year 2006, which had not been included in the data used to build the model. The investigators also compared the performance of the source–receptor model with the results of an EPA Regulatory Impact Analysis that used the CMAQ model to predict changes in ambient $PM_{2.5}$ based on reductions in emissions expected from implementation of the Clean Air Interstate Rule.

In order to evaluate the impact of the emissions reductions that occurred under Title IV of the Clean Air Act, the investigators simulated a counterfactual situation in which no mandated reductions in SO_2 occurred over the time period of the study. This simulation assumed that electric power plants covered under the Acid Rain Program continued to emit SO_2 at the same rate as before the regulations and that consumption of electric power was the same as the actual consumption for the time period. They then ran their preferred model, built from the source–receptor analysis of actual 1999–2000 SO_2 emissions and ambient $PM_{2.5}$ data, with the counterfactual SO_2 emissions data and compared the results with the actual measurements.

RESULTS

The investigators' preferred model, which included a temperature–emissions interaction term and monthly dummy variables, predicted monthly average $PM_{2.5}$ concentrations at the Air Quality System monitoring locations with reasonable precision (MSE = 9.37 for emission zones within a 400-mile radius, indicating a mean prediction error at a "typical" monitor of $\sqrt{9.37} = \pm 3.06\ \mu g/m^3$). The model performed even more favorably when applied to actual data for the 164 monitors in the 2006 dataset that corresponded to monitors in the 1995–2005 dataset, producing more precise predictions (MSE = 7.85 for 2006 versus 9.37 for the 1999–2005 data). When the model was applied to 2006 data for the remaining 445 monitors that did not provide data for the original model-building exercise, prediction improved even further (MSE = 7.19). By comparing their counterfactual scenario with the actual regulatory scenario, the investigators calculated that

Title IV of the Clean Air Act resulted in an estimated reduction in ambient $PM_{2.5}$ concentrations (averaged across the eastern United States) of 1.07 μg/m^3 between 1999 and 2005 (or 0.89 μg/m^3 on a population-weighted basis).

CONCLUSIONS

In its independent review of the study, the HEI Health Review Committee found that the primary strength of the study was that it was data-driven and observational, rather than simply using complex modeling techniques to assess the impact of a regulatory intervention. The Committee believed that the authors were appropriately careful about the inferences they drew from their work and reasonably cautious about their findings. It also found that Morgenstern and his team made a good-faith effort to address the general scientific questions about the effects of regulations on air quality that they had set out to address.

The Committee expressed a number of concerns about the development of the models and their potential application to datasets other than those used to build them. Although the Committee felt there was some value to the investigators' overall approach, the Committee found it difficult to fully assess the potential application of these models to air quality management or impact assessment.

Despite these limitations, it was the Committee's judgment that the investigators' work contributed to the discussion of what portions of PM reductions can be attributed to an emissions reduction program, with an approach that might be a useful alternative to atmospheric models in some applications. The Committee also noted that a model that estimates ambient air quality changes secondary to emissions changes might also be applied to estimating changes in criteria pollutants secondary to regulations aimed at reducing industrial emissions or even greenhouse gas emissions. This research and these models might also be able to provide useful information to organizations that want a quick estimate of how much specific emitting facilities affect specific pollutant monitors or even communities, although atmospheric pollution dispersion models might be more readily applied.

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Accountability Analysis of Title IV Phase 2 of the 1990 Clean Air Act Amendments

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