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Review article

Accountability studies of air pollution and health effects: lessons learned and recommendations for future natural experiment opportunities

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ABSTRACT

To address limitations of observational epidemiology studies of air pollution and health effects, including residual confounding by temporal and spatial factors, several studies have taken advantage of 'natural experiments', where an environmental policy or air quality intervention has resulted in reductions in ambient air pollution concentrations. Researchers have examined whether the population impacted by these air quality improvements, also experienced improvements in various health indices (e.g. reduced morbidity/mortality). In this paper, I review key accountability studies done previously and new studies done over the past several years in Beijing, Atlanta, London, Ireland, and other locations, describing study design and analysis strengths and limitations of each. As new 'natural experiment' opportunities arise, several lessons learned from these studies should be applied when planning a new accountability study. Comparison of health outcomes during the intervention to both before and after the intervention in the population of interest, as well as use of a control population to assess whether any temporal changes in the population of interest were also seen in populations not impacted by air quality improvements, should aid in minimizing residual confounding by these long term time trends. Use of either detailed health records for a population, or prospectively collected data on relevant mechanistic biomarkers coupled with such morbidity/mortality data may provide a more thorough assessment of if the intervention beneficially impacted the health of the community, and if so by what mechanism(s). Further, prospective measurement of a large suite of air pollutants may allow a more thorough understanding of what pollutant source(s) is/are responsible for any health benefit observed. The importance of using multiple statistical analysis methods in each paper and the difference in how the timing of the air pollution/outcome association may impact which of these design features is most important is also discussed. Based on these and other lessons learned, researchers may provide a more epidemiologically rigorous evaluation of cause-specific health impacts of an air quality intervention or action.

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1. Introduction

Numerous studies have reported associations between air pollution and cardiorespiratory mortality and morbidity (Brook et al., 2004; Brook et al., 2010; United States Environmental Protection Agency (US EPA) and NCEA - Office of Research and Development, 2009; Bell et al., 2014; Dominici et al., 2006), primarily focusing on respiratory outcomes (e.g. asthma exacerbation, asthma incidence, wheezing), cardiovascular outcomes (e.g. myocardial infarction, stroke, arrhythmia, heart failure), and lung cancer. More recently they have also studied reproductive (e.g. preterm birth, fetal growth restriction, stillbirth, pregnancy complications) and neurologic outcomes (e.g. autism). Others have studied air pollution and adverse changes in relevant biomarkers of physiological and biochemical function (e.g., heart rate variability, lung function, inflammation, oxidative stress) (Brook et al., 2004; Brook et al., 2010; United States Environmental Protection Agency (US EPA) and NCEA - Office of Research and Development, 2009). However, criticisms of these studies have included exposure misclassification and its resulting bias towards the null, and residual confounding by both temporal and spatial factors including time trends in exposure and health (e.g. hour of the day, weekday, season, long term time trends), socioeconomic status and access to health care, smoking, other neighborhood factors, exposures to other toxicants, and occupational exposure to pollution. A central limitation of these epidemiology studies is that they are observational in nature, and the investigator cannot control who is exposed and who is not, and therefore can only measure many of these potential confounders and try to control for them in his/her analytic models.

However, other studies have taken advantage of 'natural experiments' where a large scale air pollution reduction or composition change was observed in a community, region, or country following a legislative mandate, during a large scale sporting event, during an employee strike at a large industrial facility, etc. Investigators then examined whether improvements in morbidity/mortality were observed concurrent to these periods of lower air pollution levels. These natural experiments come as close to a laboratory-controlled experiment as possible in epidemiology/observational science, and allow one to observe whether the same pollutant/health endpoint associations observed in the studies described above (increased pollution concentrations associated with increased morbidity and/or mortality) exist when pollution is reduced (i.e. decreased pollution concentrations associated with decreased morbidity and/or mortality).

These "accountability" studies evaluate the extent to which an air pollution improvement or regulation in a city or region beneficially impacted human health. Most were opportunistic in nature and used already existing health and pollution data to evaluate whether an action resulted in air quality and/or health improvements in impacted populations. In 2003, the Health Effects Institute published a monograph providing a conceptual framework defining the 'chain of accountability' and outlining how such studies can be done (Fig. 1) (Samet et al., 2003). For example, that chain describes how a regulatory action can impact emissions, ambient air quality, exposure/dose, and then human health. Accountability studies can ask a series of questions based on this chain. For example, has a regulatory action or controls reduced emissions? Have pollutant concentrations been reduced due to source controls and emissions reductions? Has this led to reduced subject exposures? Have these reduced subject exposures led to reduced doses? Have health risks declined as a result of any of these actions on previous components of the chain? In 2010, HEI hosted a workshop to discuss the current state of accountability research conducted by investigators funded by HEI, with a summary of lessons learned described by van Erp et al. (2012). Currie et al. (2011) also provided a review of 10 such studies assessing whether such air pollution reductions impacted infant's and children's health. This review provides an update, describes both older and more recent studies, and provides a set of epidemiologic recommendations for future investigators that want to conduct such studies when a new natural experiment opportunity arises. Studies were identified using www.pubmed.org and search terms such as natural experiment, accountability, PM, air pollution and health, etc. Others studies were identified if they were discussed in one of the papers found via this PubMed search.

Although studies have assessed whether dramatic increases in air pollutant concentrations due to accidents/disasters (e.g. World Trade Center attacks in New York City, oil tank explosion in Gulen, Norway) have impacted health (Granslo et al., 2012; Thomas et al., 2008), these are not included in this review. The focus of this paper is a discussion of those natural experiments where an air pollution *reduction* was observed or expected, and whether that reduction resulted in a health benefit was examined. Below I summarize accountability studies assessing health effects of 1) industrial pollution sources and large industrial shutdowns, 2) residential heating fuel and changes in fuel type, 3) traffic pollution and changes in motor vehicle fuel composition or plans to reduce traffic congestion, 4) national or state wide air pollution reductions, and 5) reductions in air pollutant levels during large scale sporting events. Listed in Table 1 and discussed below for each study, are descriptions of the study location, the natural experiment scenario, the 'chain of accountability' question assessed, study objective(s), the study's main findings, and its key strengths and limitations. The strengths and limitations (i.e. sources of bias and residual confounding) listed in Table 1 may not be a complete list for each study. There may be other sources of residual confounding in these observational studies, even though each study has made attempts to identify them, minimize their effects, and/or discuss potential impacts on their effect estimates. Last, a discussion of key problems/strengths across these studies and recommendations for the designs of future accountability studies, if such opportunities arise, is provided.

2. Industrial pollution sources and industrial shutdowns

2.1. Utah Valley Steel Mill

One of the first such natural experiments used to assess air pollution/health associations occurred when a large steel mill closed in the Utah Valley from August 1986 to September 1987 (13 months) in

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