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Investigating the mixture of air pollutants associated with adverse health outcomes

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Abstract

Most investigations of the adverse health effects of multiple air pollutants analyse the time series involved by simultaneously entering the multiple pollutants into a Poisson log–linear model. Concerns have been raised about this type of analysis, and it has been stated that new methodologies or models need to be developed for investigating the adverse health effects of multiple air pollutants. To this end, it has recently been stated that it may be more reasonable to assume that there is a mixture of pollutants considered harmful to health and that assessing the adverse health effects of an air pollution mix may be both more meaningful and more tenable than attempting to isolate the effects of individual pollutants. In this paper, a new model is introduced that is able to reveal the mixture of pollutants associated with an adverse health outcome and the effect of this mixture on the adverse health outcome. The model is shown to have a number of advantages over the traditional method of estimating the adverse health effects of multiple air pollutants. In addition, the model is also shown to be an improvement over a previously proposed, and somewhat ad-hoc, method for estimating the mixture of pollutants associated with an adverse health outcome.

Keywords: Air pollution; Mortality; Time series; Multiple pollutants

1. Introduction

Numerous time series studies have investigated the association between daily adverse health outcomes and daily ambient air pollution concentrations (Chock et al., 2000; Cifuentes et al., 2000; Goldberg et al., 2003; Kelsall et al., 1997, 2000; Kwon et al., 2001; Moolgavkar, 2000; Ostro et al., 1999; Roemer and van Wijnen, 2001; Smith et al., 2000a, b; Stieb et al., 2002; Styer et al., 1995). These studies typically fit a Poisson log–linear model to concurrent time series of daily mortality or morbidity, ambient air pollution and meteorological covariates. The fitted models are then used to quantify the adverse health effects of ambient air pollution. Because the US Environmental Protection Agency regulates pollutants independently, most of the current time series research on the adverse health effects of air pollution has focused on estimating the effects of an individual pollutant

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(Dominici and Burnett, 2003). However, due to the potentially high correlation between ambient air pollutants, the results from studies that focus on a single pollutant can be difficult to interpret in practice (Vedal et al., 2003). For example, an observed positive association could occur because the single air pollutant is a proxy for another air pollutant or for a mixture of air pollutants.

To overcome the limitations of single-pollutant time series studies, a number of studies have investigated the concurrent adverse health effects of multiple air pollutants (Moolgavkar, 2000; Wong et al., 2002). In the majority of studies of this nature, the multiple air pollutants are simultaneously entered into a single Poisson log–linear model. The results from these studies are used to isolate the adverse health effects of the individual pollutants. However, one important question that these multiple pollutant studies do not answer is whether there is a mixture of pollutants that is associated with the adverse health outcome. Moreover, it has recently been stated that it may be more reasonable to assume that there is a mixture of pollutants that is considered harmful to health (Dominici and Burnett, 2003; Moolgavkar, 2003; Stieb et al., 2002). Assessing the adverse health effects of an air pollution mix may, therefore, be both more interpretable and more feasible than attempting to isolate the effects of individual pollutants. The development of new methodology or models to concurrently estimate the adverse health effects of multiple air pollutants has been identified by statisticians, epidemiologists and policymakers as an important area of future research (Cox, 2000; Dominici and Burnett, 2003).

In this paper, a new model is introduced that reveals the mixture of pollutants associated with an adverse health outcome and the effect of this mixture on that outcome. This new model uses time series data to assign each air pollutant a weight which indicates the pollutant's contribution to the air pollution mixture that is associated with the adverse health outcome under investigation. The model is illustrated by applying it to time series data from nine United States counties for the period 1987–2000.

2. Materials and methods

2.1. Materials

The data used in this paper were obtained from the publicly available National Morbidity, Mortality, and Air Pollution Study (NMMAPS) database. The data extracted consists of concurrent daily time series of mortality, weather and air pollution for nine cities in the United States for the period 1987–2000. The nine cities selected had a relatively large number of days with measurements for all five air pollutants considered. Many of the cities in the NMMAPS database do not collect data on all five air pollutants and/or have a large number of days with missing air pollutant concentrations.

The mortality time series data, aggregated at the level of county, are non-accidental daily deaths of individuals aged 65 and over. Deaths of non-residents were excluded from the mortality counts. The weather time series data are 24 h averages of temperature and dew point temperature, computed from hourly observations.

The five air pollutants considered are particulate matter of less than 10 μm in diameter (PM), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO) and nitrogen dioxide (NO_2). For PM, SO_2, CO and NO_2 average daily concentrations were used. For O_3, the maximum hourly concentration for each day was used. In the analyses that follow, each of the pollutant time series was standardised to have a unit variance.

2.2. Methods

The majority of time series studies that concurrently investigate the adverse health effects of multiple air pollutants simultaneously enter the pollutants into a single Poisson log–linear model. Under this model, the daily adverse health outcome counts are modelled as independent Poisson random variables with a time varying mean μ_t where

$$\log(\mu_t) = \text{confounders}_t + \beta_1 X_{1t} + \beta_2 X_{2t} + \cdots + \beta_k X_{kt}, \quad (1)$$

and where confounders$_t$ represents other time-varying variables which are related to the adverse health outcome, $X_{it}, i = 1, \ldots, k$, represent the k pollutants that are being investigated, and $\beta_i, i = 1, \ldots, k$, measure the adverse health effect of pollutant i. Hereafter, model (1) will be referred to as the "*standard model*".

As discussed above, one important question that the *standard model* cannot answer is whether there is a mixture of pollutants that is associated with the adverse health outcome under investigation. To answer this question, we propose fitting the following model which, like the *standard model*, models