Institution: University of Bath

Unit of Assessment: 10: Mathematical Sciences

Title of case study: Strengthening air pollution standards in the USA

1. Summary of the impact

Air pollution poses significant threats to both the environment and to human health and the World Health Organization estimates that 800,000 deaths per year could be related to ambient air pollution. Formulating air quality legislation and understanding its effect on human health requires accurate information on ambient concentrations of air pollution and how these translate into exposures actually experienced by individuals (personal exposures).

Our research provides a framework for estimating personal exposures for specific susceptible sub-populations, such as the elderly and those suffering from respiratory diseases. This framework also provides novel means of assessing uncertainty associated with the estimates of exposures. Furthermore, it allows changes in exposures to be assessed under hypothetical scenarios reflecting potential regulatory changes.

These models were used in the US Environmental Protection Agency's (EPA) recent review of ozone standards that resulted in a reduction in the statutory limits of ozone in the United States. The EPA stated that "These changes will improve both public health protection and the protection of sensitive trees and plants" [C].

2. Underpinning research

Direct measurement of personal exposures requires an exposure monitor to be worn. Whilst accurate, this is extremely costly and time-consuming. As a consequence, in studies using this approach, sample sizes are small and the information provided may therefore be limited. In order to provide accurate data for larger samples, an indirect method has been developed in which concentrations of pollutants in specific micro-environments, such as the home, workplace or car, are modelled. When combined with models of human behaviour that estimate the time spent in the different microenvironments, these provide an integrated framework for estimating personal exposures.

Early approaches to combining micro-environments and time activity were deterministic and did not have means of assessing the uncertainty associated with the resulting estimated exposures. In [1], we provide a theoretical model framework for estimating personal exposures stochastically with full integration of the uncertainties inherent in the process.

Based on this framework, stochastic models, known as 'exposure simulators', have been developed which predict the exposures to a pollutant experienced by individuals together with quantification of the associated uncertainties. These individual exposures may then be aggregated over demographic groups. Estimating individual personal exposures is performed by sampling individuals from each demographic group and randomly associating to each individual a time activity pattern that matches the subject in terms of personal characteristics, day of the week, temperature, season, etc.

In [2] we describe pCNEM (Personal Computer National Exposure Model), a specific computational implementation of the framework developed in [1]. pCNEM comprises a large-scale computer simulation model that provides a flexible platform for developing a wide variety of models and produces distributions of predicted exposures. It can be formulated to produce estimates for a range of pollutants, and has been used for both particulate matter and ozone. For registered users, pCNEM can be accessed via the internet [2]. This allows users to define their own models for the levels of pollution in individual micro-environments and incorporate data on ambient levels of pollution from specific areas.

The US Environmental Protection Agency (EPA) has commissioned two implementations based on the framework in [1, 2]: SHEDS (Stochastic Human Exposure and Dose Simulation) and APEX (Air Pollution EXposure model).

An important application of the personal exposure simulation framework is to help quantify the possible effects of abatement strategies, e.g., regulations and mandatory surveillance, by running them before and after the hypothetical change. For example, the effects of a potential decrease in ambient concentrations of a pollutant due to a new law, known as ‘rollbacks’, can be assessed in terms of the changes in exposures actually experienced by individuals. In [2] it is shown how the effects of such ‘rollbacks’ can be assessed.

The underpinning research was carried out by Shaddick at Bath where he has been Lecturer, Senior Lecturer and Reader in Statistics since 2001. The work was produced in collaboration with Professor Jim Zidek of the University of British Columbia (UBC) and colleagues within the departments of Mathematical Sciences at Bath (Chatfield) and Statistics at UBC. Large parts of the work have been performed during long-term visits by Prof. Zidek to Bath which have been funded by an EPSRC travel grant (2002/3), the EPSRC funded Bath Institute for Complex Systems (2005, 2007) and the Canadian National Science and Engineering Research Council (2004-2013). Work has also been performed during visits by Shaddick to UBC with funding including a Peter Wall Institute for Advanced Studies Personal Fellowship (2004).

3. References to the research

References that best indicate the quality of the underpinning research are starred.

[1]* Zidek, J. V., Shaddick, G., Meloche, J., Chatfield, C. and White, R., 2007. A framework for predicting personal exposures to environmental hazards. *Environmental and Ecological Statistics*, 14 (4), pp. 411-431. DOI 10.1007/s10651-007-0028-x

[2]* Zidek, J. V., Shaddick, G., White, R., Meloche, J. and Chatfield, C., 2005. Using a probabilistic model (pCNEM) to estimate personal exposure to air pollution. *Environmetrics*, 16 (5), pp. 481-493. DOI: 10.1002/env.716

Both papers contain developments of work which first appeared in a technical report: Zidek, J.V., Meloche, J., Shaddick, G., Chatfield, C. and White, R.A., 2003. A Computational Model for Estimating Personal Exposure to Air Pollutants with Application to London's PM10 in 1997, Technical Report TR#2003-3, *Statistical and Applied Mathematical Sciences Institute*, Research Triangle Park, NC.

4. Details of the impact

Regulation of air pollution has important effects on human health and it has recently been estimated that the 1990 Clean Air Act in the US prevented 160,000 premature deaths, 1.7 million asthma attacks and 13 million lost work days per year - with these figures set to increase over time [A].

The Clean Air Act requires the Environmental Protection Agency (EPA) to set national ambient air quality standards (NAAQS) for ozone and five other pollutants considered harmful to public health and the environment (the other pollutants are particulate matter, nitrogen oxides, carbon monoxide, sulfur dioxide and lead). As mandated by the Clean Air Act, the EPA must periodically review the scientific bases (or criteria) for the various NAAQS by assessing newly available scientific information for each of the pollutants listed above. This process occurs every ten years for each pollutant.

Models for estimating personal exposures based on [1] and [2] were used extensively as part of the scientific basis for the most recent changes in the NAAQS for ozone. The goal was to determine the effect of ambient regulatory strategies on human exposure by observing how different ambient concentration scenarios changed the predicted personal exposure for different demographic groups.

The review of the standards for ozone was announced in 2008 and resulted in a reduction of the primary standard level (8-hour average) for ozone from 0.08 to 0.075 parts per billion [B, C, D]. This reduction “significantly strengthened its national ambient air quality standards (NAAQS) for ground-level ozone, the primary component of smog. These changes will improve both public health protection and the protection of sensitive trees and plants” [C]. After a series of petitions and legislation, the final stage in the implementation of the new limits, which refers to methods for designating areas as either in accordance or in non-attainment was passed in 2012 [D, E].

During the process of formulating the new limits for ozone, three volumes of scientific background information were released for consultation, “Air Quality Criteria for Ozone and Related Photochemical Oxidants” [F]. These linked the underpinning research to the subsequent formulation of the legislation. Over 20 pages of the summary (Volume 1) are related to estimating personal exposures together with a 70 page technical appendix (Volume 2). The methods derived in [1] provide “the underpinning theoretical probabilistic framework underlying these exposure simulators” as referenced in [G] (in which 3rd and 4th authors are members of the EPA). Our work [1,2], in particular pCNEM, is extensively discussed in Section 3, Vol.1 and Chapter 3, Vol. 2 of [F], with its advantages noted specifically in terms of its ability, in contrast to other methods, to provide a coherent approach to incorporating “uncertainties in the predicted distributions” and “its ability to estimate the effects of reductions in ambient levels of pollutants” (Section 3, Vol.1, pages 3-61 and 3-62).

To summarise:

- Detailed information is required on the potential exposures experienced by individual members of the population to provide scientific support for potential changes in air quality standards. The research developed in [1,2] provides a convenient framework that can be used to generate this information.

- Our work had impact on public policy and changes to legislation and regulations. Models for estimating personal exposures based on [1] and [2] were used extensively as part of the scientific basis for the most recent changes in air quality standards for ozone.

- Our research has impact on the management of environmental risk. The result of the 2008 EPA review was to make the standards for ozone more rigorous. Areas classified “nonattainment” may have to impose more stringent emission controls.

- According to the EPA these changes “will improve both public health protection and the protection of sensitive trees and plants.” [C]

5. Sources to corroborate the impact

[A] U.S. EPA. The Benefits and Costs of the Clean Air Act from 1990 to 2020. (http://www.epa.gov/oar/sect812/feb11/summaryreport.pdf).

[B] Federal Register. http://www.gpo.gov/fdsys/pkg/FR-2008-03-27/pdf/E8-5645.pdf

[C] FACT SHEET FINAL REVISIONS TO THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR OZONE (http://www.epa.gov/glo/pdfs/2008_03_factsheet.pdf)

[D] March 2008 Final National Ambient Air Quality Standards for Ground-level Ozone. http://www.epa.gov/glo/pdfs/2008_03_text_slides.pdf

[E] EPA Final Area Designations for 2008 Ground-level Ozone Standards (issued May 2012). http://www.epa.gov/glo/designations/2008standards/final/qandafinal.htm

[F] U.S. EPA Report “Air Quality Criteria for Ozone and Related Photochemical Oxidants, Volumes 1 and 2, EPA/600/R-05/004aF and EPA/600/R-05/004bF, 2006. http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_cd.html

[G] Berrocal, V. J., Gelfand, A. E., Holland, D. M., Burke, J. and Miranda, M. L., 2011. On the use of a $PM_{2.5}$ exposure simulator to explain birthweight. *Environmetrics*, 22, pp. 553–571. DOI 10.1002/env.1086