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Determinants of indoor air concentrations of $PM_{2.5}$, black smoke and NO_2 in six European cities (EXPOLIS study)

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Abstract

EXPOLIS was a large-scale population-based study of urban adult exposures to multiple pollutants, and was conducted between 1996 and 2000 in six European cities. Measurements made using standardised protocols in Athens (Greece), Basel (Switzerland), Helsinki (Finland), Milan (Italy), Oxford (UK), and Prague (Czech Republic), allow similarities and differences between contrasting European regions, climates and populations to be identified. Two consecutive days of home indoor and home outdoor measurements of fine particulate matter ($PM_{2.5}$), black smoke (BS), and nitrogen dioxide (NO_2) were carried out at the homes of adult participants on different dates and seasons during the sampling period. Regression models with interactions searched by all-possible subset method were used to assess the city effects and the determinants of home indoor $PM_{2.5}$ (adj $R^2 = 0.60$, $n = 413$), BS (adj $R^2 = 0.79$, $n = 382$) and NO_2 (adj $R^2 = 0.67$, $n = 302$) levels. Both bi-directional (positive and negative signs of associations) and unidirectional (consistently either positive or negative sign of associations) city effects on different determinants in each indoor model were shown. Smoking, gas-stove usage, outdoor temperature, and wind speed were the common determinants in all three indoor models. Other determinants, including the presence of wooden material, heating, and being located in suburb area, were also identified. They were likely linked to cultural and socio-economic factors.

Keywords: Black smoke; Exposure assessment; Indoor air pollution; Nitrogen dioxide; Particulate matter

1. Introduction

Air quality management in European cities is dominated by efforts to control outdoor sources of particulate matter (PM) and oxides of nitrogen. PM is the pollutant usually associated with the greatest effects on human health (WHO, 2000). While European air quality limit values are currently expressed in terms of PM_{10} (mass concentration of particles smaller than 10 μm), the finer particulate matter ($PM_{2.5}$) size fraction is now receiving more attention (CAFÉ, 2004). With respect to local

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emissions control for $PM_{2.5}$, the carbonaceous fraction is of most interest since it is largely of combustion origin, often measured as "black smoke" (BS). Evidence of health effects (in terms of mortality) of nitrogen dioxide (NO_2) other than at very high concentrations is less strong than that for PM (Katsouyanni et al., 2001). Nevertheless, air quality guidelines including a precautionary safety factor to protect asthmatics (WHO, 2000) include an annual average concentration of NO_2 not exceeding $40\,\mu g\,m^{-3}$, which is difficult to achieve before the target date of 2010 in many European cities. Furthermore, most people spend the majority of their time indoors. It is therefore likely that the current emphasis on compliance with outdoor limit values for NO_2 and PM_{10} is not the most effective way of reducing the effects of air pollution on health. Greater emphasis on control of exposure, including indoor exposure, could be more efficient.

In this context, EXPOLIS was a large-scale population-based study of urban adult exposures to multiple pollutants conducted between 1996 and 2000 in different European cities which represent different European regions, climates and populations (Hänninen et al., 2004). To explore possible causes of elevated exposure to air pollution, regression-based determinant analysis of air pollutant concentrations in combined population (multi-city) has been carried out using EXPOLIS data (Kousa et al., 2001; Georgoulis et al., 2002; Götschi et al., 2002), and a number of other studies in recent years have been carried out apart from EXPOLIS.

For $PM_{2.5}$, it was shown that increasing outdoor concentration (Adgate et al., 2002; Götschi et al., 2002; Kousa et al., 2002; Leaderer et al., 1999; Williams et al., 2000), smoking (Wigzell et al., 2000; Koistinen et al., 2001; Götschi et al., 2002), the use of air-conditioning (Leaderer et al., 1999), indoor fuel burning (Leaderer et al., 1999; Götschi et al., 2002) and high regional traffic intensity (Fischer et al., 2000) are associated with elevated indoor $PM_{2.5}$ levels. Housing location (Götschi et al., 2002) and seasonal variation (Mukerjee et al., 1997; Brauer et al., 2000; Adgate et al., 2002; Kinney et al., 2002) were also shown to be related to the variation of indoor $PM_{2.5}$ levels. An experimental study also showed that the quality of vacuum cleaning filter is also related to indoor $PM_{2.5}$ emissions from the vacuum cleaner (Lioy et al., 1999). For BS, it was shown that increasing outdoor concentrations, smoking, and indoor fuel burning (Götschi et al., 2002), and high regional traffic intensity (Roorda-Knape et al., 1998; Janssen et al., 2001) are associated with elevated indoor BS levels. Moreover, housing location (Götschi et al., 2002) and wind effect (Roorda-Knape et al., 1998; Janssen et al., 2001) are also related to the variation of indoor BS levels. For NO_2, increasing outdoor concentration (Baek et al., 1997; Cyrys et al., 2000), indoor fuel burning (Lee et al., 1995; Monn et al., 1998; Cyrys et al., 2000), high regional traffic intensity (Roorda-Knape et al., 1998; Janssen et al., 2001), smoking and frequent natural ventilation (Cyrys et al., 2000), and the use of unclean heaters (Sakai et al., 2004) are associated with elevation of indoor NO_2 levels. Wind (Roorda-Knape et al., 1998; Janssen et al., 2001) and seasonal variation (Cyrys et al., 2000; Kodama et al., 2002) were also shown to be related to the variation of indoor NO_2 levels.

In this paper a more sophisticated modelling methodology is used to develop regression models with interaction that could address the multi-population differences for the determinants of indoor $PM_{2.5}$, BS, and NO_2. In this paper, we include interaction terms to address the city-specific effects of the determinants and the application of all-possible subset search for the 'best' regression model with interactions for six cities and three pollutants (Lai, 2004). This has allowed us to identify what potential determinants of indoor pollutant levels are common to many cities, and which are specific to individual cities depending on local conditions, culture, and behaviour. The extent to which our empirical model might have predictive capability is also discussed.

2. Methodology

Two consecutive days of home indoor and home outdoor measurements of $PM_{2.5}$, BS, and NO_2 were carried out at the homes of adult participants on different dates and seasons during the sampling period in six European cities: Athens (Greece), Basel (Switzerland), Helsinki (Finland), Milan (Italy), Oxford (UK) and Prague (Czech Repubic). Sampling of $PM_{2.5}$ were taken inside and outside the homes for the expected non-working hours of the participants over the two consecutive sampling days, whereas the sampling of NO_2 were taken inside and outside the homes continuously over the two consecutive sampling days. The indoor sampling using diffusion tubes with these sampling durations is made easier by the lack of high levels of atmospheric turbulence and photolysis that can