HEALTH EFFECTS INSTITUTE

STATEMENT

Synopsis of Research Report 155

The Congestion Charging Scheme and Air Quality in London

INTRODUCTION

The study of the London Congestion Charging Scheme (CCS), conducted by Professor Frank Kelly and colleagues, was funded under HEI's research program aimed at measuring the possible health impacts associated with actions taken to improve air quality. With this research program, HEI has sought to (1) fund studies to assess the health outcomes associated with regulatory and incentive-based actions to improve air quality at local or national levels, and (2) develop methods required for, and specifically suited to, conducting such research.

The CCS offered an unusual opportunity to investigate the potential impact on air quality of a discrete and well-defined intervention to reduce traffic congestion in the middle of a major city. The CCS was implemented in London in February 2003 with the primary aim of reducing traffic congestion by charging vehicles to enter the central part of London, defined as the congestion charging zone (CCZ). In an earlier study based on data from the first year of the scheme, members of the investigative team had reported early findings of modest reductions in the number of vehicles entering the zone and had projected declines of about 12% in emissions of both PM_{10} (particulate matter with an aerodynamic diameter of ≤10 µm) and nitrogen oxides (NO_x) within the CCZ. Recognizing that these projected reductions, coupled with the small area represented by the CCZ within Greater London, could lead to relatively small changes in air quality, the HEI Health Research Committee recommended that the investigators first assess the actual changes in air quality and postpone their proposal to study health impacts until the air quality studies were completed. The investigators proposed a multifaceted approach to exploring the impact of the CCS on air quality, which involved a variety of modeling techniques, analysis of air monitoring data, and a newly developed assay for the oxidative potential of PM.

STUDY METHODS

Kelly and his colleagues undertook a stepwise approach to evaluating the impact of the CCS on air quality. In the first part of their study, they updated emission estimates that had originally been developed for the London transportation agency, Transport for London. Using the King's College London Emissions Toolkit (a set of statistical models and data), they developed detailed estimates of NO_x, nitrogen dioxide (NO_2), and PM_{10} emissions from vehicular and non-vehicular sources throughout the London area for the 4-year period encompassing 2 years before (pre-CCS) and 2 years after (post-CCS) the introduction of the scheme on February 17, 2003. Vehicular PM_{10} emissions were predicted from two primary sources — tire and brake wear and exhaust. These emission estimates were then input to a modeling system (the King's College London Air Pollution Toolkit), which the investigators used to predict annual mean ambient concentrations of NO_x, NO_2, and PM_{10} throughout London for each year of the study. They explored how various assumptions about the mix of vehicles, speed, and congestion over the study period might affect the predicted spatial patterns of changes in air quality associated with the implementation of the CCS.

The results of the modeling exercise were also used to help select the fixed, continuous air monitoring sites from the London Air Quality Network (LAQN) with which to evaluate measured changes in air quality. The investigators created a CCS Study Database consisting of validated (or ratified) measurements of

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Professor Frank Kelly at the School of Biomedical Sciences, King's College London, U.K., and colleagues. The complete report, *The Impact of the Congestion Charging Scheme on Air Quality in London* (© 2011 Health Effects Institute), can be obtained from HEI or our Web site (see last page).

carbon monoxide (CO), nitric oxide (NO), NO_2, NO_x, and PM_{10} from monitors sited to record roadside or urban or suburban background air pollutants across London. The investigators calculated and compared geometric mean concentrations of these pollutants for the 2 years before (2001–2002) and 2 years after (2003–2004) the scheme was introduced. The changes over time at monitors within the zone were compared with changes during the same period at similar classes of monitoring sites in a control area more than 8 km from the center of the zone. In addition, the investigators also explored three other analytic techniques for characterizing and evaluating both projected and measured changes in pollutant concentrations over the period of the study: ethane as an indicator of pollutant dispersion due to regional atmospheric conditions; the cumulative sum statistical technique to identify step changes in air pollution data; and specialized graphical techniques to improve the siting of pollutant monitors by characterizing the dependence of pollutant concentrations at potential monitoring sites on local emission sources.

In the second part of the study, the investigators set out to explore whether implementation of the CCS led to detectable changes in either the composition of the PM_{10} mixture or in its oxidative potential — an indicator of toxicity. As part of this analysis, they sought to establish a more comprehensive baseline of monitoring data to use in future studies of the CCS by collecting data from additional monitoring sites located within and outside a proposed expansion of the CCZ known as the Western Extension.

For these purposes, the investigators created an archive of about 730 filters from tapered element oscillating microbalances, a type of PM_{10} monitor used at 16 sites within and surrounding the CCZ, including the Western Extension; the filter archive covered the 3 years before and 3 years after the CCS was introduced. After extracting the PM from the filters, they measured the oxidative potential of the extracts using an in vitro assay that measures the ability of the extracts to deplete antioxidants in a synthetic respiratory tract lining fluid. The investigators' focus on oxidative potential, a measure of the capacity to generate oxidation reactions, arises from a leading theory about the causal role that oxidative stress may play in the health effects associated with exposure to air pollution. Their goal, in essence, was to use oxidative potential as an indicator of the potential toxicity of PM and to evaluate how it varied across London and in response to the introduction of the CCS.

To study the composition of PM, each filter extract was also analyzed using inductively coupled plasma mass spectrometry for a panel of metals that have been associated with traffic sources in studies by other investigators. Additional experiments were done to understand the relative contribution of different metal and non-metal components of PM to the oxidative potential measured in the assays.

RESULTS AND INTERPRETATION

The modeling studies predicted small changes in both emissions and ambient concentrations of NO_x, NO_2, and PM_{10} across London that could be related to the implementation of the CCS, although the effects within the CCZ were projected to be more pronounced than elsewhere. They projected somewhat larger average reductions (about 20%) in NO_x and PM_{10} emissions than the 12% reductions that had been predicted in the initial feasibility studies that preceded the CCS. However, the difference in these projections may partly be explained by the fact that the modeling in this study compared the 2 years before and 2 years after the introduction of the CCS, whereas the earlier estimates had been based on an analysis of only the first year of the scheme (2003). The investigators reported that unusual meteorologic conditions had led to periods of elevated pollution levels in London during that year.

Despite the somewhat larger projected reductions in emissions, the projected changes in concentrations of NO_x, NO_2, and PM_{10} related to the CCS were small. Within the CCZ, the investigators projected a net decline of 1.7 ppb in the annual average mean NO_x concentration and a decline of 0.8 $\mu g/m^3$ in PM_{10}. The modeling also suggested that a major proportion of PM_{10} might be accounted for by regional background levels, but that contributions from tire and brake wear might also be important. NO_2 was projected to increase slightly, by 0.3 ppb on average; the investigators attributed this increase to higher NO_2 emissions associated with the introduction of particle traps on diesel buses as part of Transport for London's improvements in the public transport system.

From their comparison of actual air pollutant measurements within the CCZ with those at control sites in Outer London, the investigators reported little evidence of CCS-related changes in pollutant levels at roadside monitoring sites, where their modeling had suggested the most pronounced effects would be seen. The effects of the CCS were more evident at urban background sites within the CCZ when compared with concentrations at sites in the control area: PM_{10} concentrations declined by 12% at the one background site in the CCZ where it was measured, and NO declined by between 10% and 25% at the three background sites where it was measured. However, levels of NO_2 increased by between 2% and 20% at the three background sites compared with levels at the control sites; these increases were consistent with the predictions from the modeling studies and with the likely effects of the parallel intervention that introduced more filter-equipped diesel buses. The investigators concluded that the small net changes in NO_x detected at both roadside and background monitoring sites — likely resulting from reductions in NO offset by increases in NO_2 — did not provide strong evidence of an impact of the CCS.

In the study of the oxidative potential of PM_{10}, the investigators were unable to identify a temporal, CCS-related change during the 6-year period that encompassed the implementation of the scheme. However, the city-wide spatial analysis of oxidative potential revealed that PM_{10} sampled from roadside locations showed greater oxidative activity than PM_{10} sampled at urban background sites.

When they coupled these spatial analyses of oxidative potential with analyses of the metal content of PM_{10} from the same filters, the investigators concluded that their results provided suggestive evidence that PM_{10} derived from tire and brake wear (indicated by the presence of the metals arsenic, barium, copper, iron, manganese, nickel, and vanadium) might contribute to the oxidative potential of PM seen in filters from roadside monitoring sites. However, the investigators noted that correlations among the concentrations of PM_{10} attributed to exhaust and to tire and brake wear made it difficult to isolate how much these individual sources might contribute to the oxidative potential of PM_{10}. Their other experimental findings suggested that the non-metal components of PM_{10} did not contribute substantially to oxidative potential in this assay, but the investigators could not rule out a role for all other non-metal components of ambient air pollution.

Overall, the investigators concluded that their primary and exploratory analyses collectively suggested that the introduction of the CCS in 2003 was associated with small temporal changes in air pollutant concentrations within the CCZ compared with those in control areas thought to be beyond the influence of the scheme. In addition, they observed that a number of limitations, including concurrent changes in transportation and emission control policies, unusual meteorologic conditions the year the scheme was introduced, and the influence of strong local sources on particular monitors, would preclude them from attributing these changes to the CCS alone. They also acknowledged that the area covered by the CCS — approximately 1.4% of Greater London — was likely too small to influence air pollutant levels substantially either within or outside the zone.

CONCLUSIONS AND IMPLICATIONS

In its independent evaluation of the study, the HEI Health Review Committee thought that Kelly and his colleagues made a laudable effort to evaluate the scheme's impact. The team undertook a creative, stepwise, multidisciplinary approach beginning with updated modeling of potential changes in emissions and air pollutant concentrations, followed by multiple approaches to the analysis of actual air monitoring data. They demonstrated the value of a careful modeling approach before decisions are made about whether and how to undertake studies of the actual impacts of air quality interventions, including insights as to where monitoring networks might best be positioned to capture the impact of a traffic-reduction scheme.

However, the investigators encountered a set of issues that have come to exemplify the general challenges posed by studies of this kind. One is simply the difficulty of detecting significant air quality improvements related to an intervention against the backdrop of broader regional and meteorologic changes in the background concentrations of pollutants. A second is that other changes occurring at the same time (e.g., the introduction of more filter-equipped diesel buses in response to a separate rule) may also affect air quality and obscure effects of the intervention being studied. A third is that institutional or behavioral changes in response to an intervention, not all of which may be fully anticipated, can also partly offset the possible gains expected. Finally, their experience highlights the challenges of using existing monitoring networks, even one as well-established as the LAQN, for the purposes of measuring small changes in air quality.

Their investigation into oxidative potential as a possible toxicologically relevant measure of exposure to the aggregate PM mixture was intriguing. However, their findings on the temporal and spatial changes in oxidative potential or in PM components related to the CCS were likely constrained by the same limitations that affected the first part of the study. The use of the oxidative potential assay in this study was largely exploratory, particularly with respect to its ability to discern the contributions of individual elements or classes of compounds in PM on archived filters. The HEI Health Review Committee thought the most interesting result was the modest suggestion that metals that have been associated with tire and brake wear might contribute to the oxidative activity levels observed. However, further work is necessary to solidify the role of oxidative potential in this assay, and in other assays of this nature, as an indicator of potential human toxicity.

Ultimately, the Review Committee concluded that the investigators, despite their considerable effort to study the impact of the London CCS, were unable to demonstrate a clear effect of the CCS either on individual air pollutant concentrations or on the oxidative potential of PM_{10}. The investigators' conclusion that the primary and exploratory analyses collectively indicate a weak effect of the CCS on air quality should be viewed cautiously. The results were not always consistent and the uncertainties surrounding them were not always clearly presented, making it difficult to reach definitive conclusions.

This study of the CCS in London adds to the growing body of evidence that confirms the need to establish the extent to which interventions have improved, or are likely to improve, ambient air quality before health studies are contemplated. These investigators, in essence, covered the first three steps in the "Outcomes Evaluation Cycle": they (1) provided evidence that the intervention or controls had in fact been put in place, (2) modeled the potential impact of the intervention on emissions, and (3) assessed whether the intervention had resulted in improved air quality. By choosing not to fund the evaluation of health outcomes that was originally proposed as part of the study, despite the projected reductions in emissions, HEI had emphasized the importance of meeting these initial requirements. The study's subsequent challenges in identifying an improvement in air quality reinforce that decision. Ultimately, although several factors affect the statistical power of studies to detect changes in health related to an intervention like the CCS, a documented expectation of a sufficient change in air quality is and will continue to be an important criterion for deciding whether to engage in a health outcomes study.

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