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Diesel vehicle emission and death rates in Tokyo, Japan: A natural experiment

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ABSTRACT

Evidence linking air pollution with adverse cardiopulmonary outcomes is accumulating. However, few studies have been conducted to evaluate whether vehicle emission control improves public health. We thus evaluated the effect of a diesel emission control law on mortality rates in 23 wards of Tokyo metropolitan area, Japan. We obtained daily counts of mortality and concentrations of nitrogen dioxide (NO_2) and particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) from April 2003 to December 2008. Time-series and interrupted time-series analysis were employed to analyze the data in two periods: prior to the introduction of tighter restrictions (April 2003 to March 2006) and after the enforcement (April 2006 to December 2008). Concentrations of air pollutants gradually decreased during the study period: from 36.3 ppb (NO_2) and 22.8 μg/m^3 ($PM_{2.5}$) to 32.1 ppb and 20.3 μg/m^3, respectively. Air pollutants were positively associated with circulatory and pulmonary disease mortality, especially cerebrovascular disease. Each same-day $PM_{2.5}$ increase of 10 μg/m^3 was associated with a 1.3% increase in cerebrovascular mortality rate (95% confidence interval: 0.2–2.4). Rate ratios were attenuated after the enforcement in most of the outcomes, probably due to reduced toxicity of the pollutants. In the crude interrupted time-series analysis, reductions of standardized mortality rates after the enforcement were the greatest in high traffic areas. Even after adjustment of longer-time trend, mortality rate from cerebrovascular disease was reduced by 8.50% ($p<.001$) with dose–response relationship. However, the declines in other cause-specific mortality became equivocal. This natural experiment in Tokyo suggests that emission controls improved air quality. Although suggestive, further data are needed to conclusively demonstrate an impact on mortality rates.

1. Introduction

Previous studies have demonstrated an association between short- and long-term exposure to air pollution and adverse health outcomes, especially cardiopulmonary outcomes (Brook et al., 2010; Pope and Dockery, 2006). Many countries have initiated regulatory efforts to control levels of air pollution; however few formal attempts have been made to evaluate the impacts of such regulation.

Until now, three types of air pollution accountability studies have been conducted. The first type examined the effects of planned actions designed to reduce air pollution by controlling the source of emissions (Clancy et al., 2002; Hedley et al., 2002). The second type evaluated the effects of air quality change due to unplanned events (e.g., plant closure or political change like reunification) resulting in air quality improvement (Parker et al., 2008; Pope et al., 2007; Sugiri et al., 2006). The third type of study examined the impacts of air quality improvement regardless of cause (Breitner et al., 2009; Dominici et al., 2007; Pope et al., 2009). From the point of view of public health action, the first type of accountability study may be the most relevant, although the number of such studies is still quite limited (Van Erp and Cohen, 2009). Examples of the first type of study include two from Dublin (Ireland) and Hong Kong which assessed the impacts of rapid regulations (a ban on the sale of coal and restricting sulfur in fuel) (Clancy et al., 2002; Hedley et al., 2002).

Abbreviations: C.I., Confidence Interval; COPD, chronic obstructive pulmonary disease; df, degrees of freedom; EC, elemental carbon; GIS, Geographic Information System; NS, natural spline; NO_2, nitrogen dioxide; PM, particulate matter; $PM_{2.5}$, particulate matter less than 2.5 μm in diameter; TMG, Tokyo Metropolitan Government.

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Automobile traffic as a source of air pollution is likely to grow in prominence as a result of the rising global demand for motor vehicles as the preferred mode of transport (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010). However, assessing the impact of traffic regulation remains challenging due to confounding influences such as changes in background levels of air pollutants (Van Erp and Cohen, 2009). For example, a study in Atlanta, Georgia, examined the impacts of a traffic control measure introduced during the 1996 Olympic Games and showed a decrease in peak ozone concentrations and children's acute care visits (Friedman et al., 2001). However, a recent report cast doubt on the ozone finding, attributing the reduction to a background regional phenomenon unrelated to the traffic control measures (Peel et al., 2010).

In recent years, the Japanese Government, the Tokyo Metropolitan Government (TMG), and neighboring three prefectures (Saitama, Chiba, and Kanagawa) have strengthened diesel vehicle emission controls (online Table 1). Particularly in Tokyo, about 60% of trucks use diesel engines, and diesel vehicles are among the largest contributors to emission of nitrogen dioxide (NO_2) and particulate matter (PM) (Tokyo Metropolitan Government, 2009). Since 1994, the Japanese Government has mandated a series of standards for **new** diesel vehicles regarding levels of emission of NO_2 and PM, including Automobile NOx/PM Control Law in 2002 which prohibits registration of noncompliant vehicles in metropolitan areas. Meanwhile, the TMG and neighboring three prefectures introduced a much stronger ordinance in October 2003 requiring any diesel vehicles traveling in their area to conform to their standards for PM. TMG and Saitama Prefecture further tightened these standards in April 2006 to the level of the 2003 national requirement for new vehicles. To meet these new standards, parallel restrictions on sulfurs in fuel have also been tightened all over Japan over time (from 500 ppm to 50 ppm in April 2003, and from 50 ppm to 10 ppm in January 2005) (Petroleum Association of Japan, 2010).

According to TMG regulations, diesel vehicles which did not meet the standards were required to be replaced by new compliant vehicles or required to fit a device to reduce the emission of PM (Tokyo Metropolitan Government, 2009). Following the introduction of the regulation, all non-compliant vehicles were prohibited from traveling in the Tokyo area. TMG regularly inspects diesel vehicles on the roads as well as at transportation companies to monitor compliance. Non compliant vehicle operators can be fined up to 500 thousand yen (about $6000). In part due to these efforts, it has been reported that the concentrations of fine particles less than 2.5 μm in diameter ($PM_{2.5}$) and elemental carbon (EC), which is often used a surrogate for diesel emission (Smith et al., 2006), have been decreasing recently in Tokyo (Bureau of Environment of TMG, 2010a). Indeed, EC accounted for as much as 35% of fine particles in 2000 but only 10% in 2008.

In short, the regulatory actions of the TMG and neighboring prefectures provide a “policy experiment” to evaluate the impacts of vehicular emission control on public health. In the present study, we focused on the Tokyo metropolitan area (and specifically, on the 23 central wards) based on data availability. We also focused on the new standards introduced in April 2006 because these regulations were limited to the Tokyo metropolitan areas (as well as neighboring Saitama Prefecture), and no further diesel emission control was introduced for several years after 2006.

We focused on the period from April 2003 to December 2008 based on data availability. Our data were able to leverage two sources of variation: time and place. In the dimension of time, we evaluated two potential effects of the emission control intervention. The first is the pre/post change in the standardized mortality rates among Tokyo residents in relation to the introduction of the tighter restrictions on diesel emissions. The second potential effect of interest is the change in the slope of the mortality rate ratios for air pollution. This could be expected as a result of changes in the composition and toxicity of the air pollutants (such as $PM_{2.5}$) due to the regulations. Previous studies have demonstrated that chemical components of air pollutants can modify the association between air pollutants and mortality (Franklin et al., 2008) and relative risks for short-term associations actually declined as pollution control measures were implemented (Breitner et al., 2009; Dominici et al., 2007). Our second source of natural variation (in the dimension of space) was to examine the impact according to the differences in traffic volume across the 23 wards of Tokyo, thereby providing us with a measure of “dose response”.

2. Methods

2.1. Participants

The Ministry of Health, Labour, and Welfare in Japan provided electronic data on all deaths during the study period, stripped of names and addresses. TMG is divided into three areas: the urbanized 23 wards, surrounding cities, and islands, and we targeted residents in the Tokyo's 23 wards (population 8,310,572 according to the 2005 census) who died between April 2003 to December 2008 (N = 371,921). The Tokyo's 23 wards is one of the world's most densely populous areas with an area of 621.97 km^2 (data from Bureau of General Affairs of TMG), and a population density of 13,362 persons per km^2.

2.2. Air pollutants and meteorological data

In the present study, we used concentrations of NO_2 and $PM_{2.5}$ as the main air pollution exposures. In Japan, air pollutants are measured at two types of monitoring stations: roadside stations and general stations (located at schools, community centers, or municipal offices). In the 23 Tokyo wards, there are 28 general and 26 roadside stations, which include one general station (No. 143) and one roadside station (No. 226) that monitors $PM_{2.5}$ levels. We used data on $PM_{2.5}$ from these two monitoring stations. We also obtained daily mean concentrations of NO_2 during the study period measured at these two stations (online Fig. 1— data from the Bureau of Environment of TMG). The stations are located about 12 km from the centroid of the 23 wards, and a 28 km buffer from the stations covers the entire area of the wards. On any day, when a measurement from one station was missing, the measurement from the other station was used instead. There was no missing in daily mean concentrations of both pollutants during the study period.

In addition, we obtained concentrations of other pollutants including NO_2, sulfur dioxide, carbon monoxide, ozone, and suspended particulate matter (SPM) from four general stations (no. 109, 110, 114, and 125), which were only stations measuring all of the five pollutants in the 23 Tokyo wards. SPM consists of larger particulate matter with an aerodynamic diameter of less than 8 μm (PM_8) (Yorifuji et al., 2005). We obtained daily mean concentrations at these four stations. These four stations are considered to represent Tokyo's 23 wards better than the above two stations because the 15 km buffers surrounding the stations cover the entire area of the wards (online Fig. 1).

We additionally obtained two meteorological variables (average temperature and relative humidity) from the same two stations which measured $PM_{2.5}$, and also calculated their daily means. There were no missing data of daily temperature and humidity.

2.3. Traffic data

To evaluate how the effect of emission control varied according to the traffic volume in the area, we obtained traffic volume information and categorized the 23 wards into levels: high, medium, or low traffic area. To do this, we obtained road type and traffic volume data of trucks and buses in the Tokyo's 23 wards from the 2005 Road Traffic Census conducted by the Road Bureau of the Ministry of Land,