Environmental Pollution 219 (2016) 323–328

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Health implications of improved air quality from Beijing's driving restriction policy☆

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ARTICLE INFO

Article history:
Received 11 July 2016
Received in revised form
13 October 2016
Accepted 17 October 2016

Keywords:
Driving restriction
Air quality
Outpatient visit
Emergency room visit
Hospital admission
Respiratory disease

ABSTRACT

Driving restrictions is one policy that Beijing enforces to alleviate traffic congestion and air pollution. Based on a before-after comparative research design with general additive models (GAM), we evaluated the effects of Beijing's driving restriction policy on air pollution and public health. The results showed that driving restrictions significantly lowered the risk of hazardous pollution and brought valuable health benefits. Moreover, the health effects of the driving restriction policy were stronger in the cold season, for females and for residents above 65 years old. The findings imply that driving restrictions in Beijing offer substantial environmental and health benefits.

1. Introduction

Unprecedented economic growth and urbanization in China have been accompanied by an explosive increase in vehicle ownership, which is climbing particularly sharply in metropolises such as China's capital city of Beijing. From 2000 to 2014, the number of vehicles grew from 1.69 million to 5.59 million, with the number of private cars increasing from 0.49 million to 4.37 million in Beijing (BMBS, 2015). Although vehicles offer great convenience, the rapid motorization also comes with great costs, including congested traffic and – particularly – declining air quality. Vehicle emissions have been identified as one of the major contributors of air pollution in China (Wu et al., 2016). At the same time, air pollutants are linked to tremendous health burdens (Lim et al., 2013). Epidemiological studies have produced strong evidence that higher concentrations of different pollutants are significantly associated with higher mortality, increased hospital admissions and outpatient visits for different diseases (Halonen et al., 2016; Kim et al., 2015; Madaniyazi et al., 2016; Zhao et al., 2014). Clearly, air pollution, particularly vehicular pollution, and its hazardous health effects, are serious public concerns in Beijing at present.

To alleviate this continuing and aggravating air pollution, the municipal government of Beijing implemented a driving restriction policy, following the lead of many megacities such as Santiago in Chile, Mexico City in Mexico, Bogota and Medellin in Colombia and Sao Paul in Brazil. A typical driving restriction policy prohibits vehicles from circulating on a specific day based on the last digit of their license plates. Beijing has two versions of this policy. The first version, known as the “Odd-Even” policy, was adopted from July 20, 2008 to September 20, 2008 to support the 2008 Olympic Games. Vehicles with odd numbers as the last digits of their license plates are allowed to drive on odd days while those with even plates drive only on even days. Evidence of reduction in both traffic congestion and air pollution during this period was confirmed (Cai and Xie, 2011; Wang et al., 2009), resulting in the implementation of a less stringent version, called the one-day-per-week (hereafter referred to as One-Day) policy, after October 11, 2008. Under this version, ten numbers were divided into five groups (0 and 5, 1 and 6, 2 and 7, 3 and 8 and 4 and 9), and vehicles with their final license plate numbers in each group were restricted from driving on a designated weekday. The One-Day policy was applicable on weekdays and within the Fifth Ring Road. Taxis, buses, public

☆ This paper has been recommended for acceptance by Dr. Hageman Kimberly Jill.

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http://dx.doi.org/10.1016/j.envpol.2016.10.049
0269-7491/

service vehicles (e.g., fire trucks, police cars) and mass transit vehicles were exempt.

The effectiveness of driving restrictions that focus primarily on improving air quality has been controversial in previous studies (Davis, 2008; Lin et al., 2011; Viard and Fu, 2015) (A detailed literature review can be found in the online supplement). Discrepancies may be caused by the different geographical research areas, periods, methods and air pollutants focused on, which suggests that the specific experience of similar policies may differ across different contexts. Long term exposure to air pollution beyond a certain level has even larger adverse impact on health. China's Ministry of Environmental Protection has established maximum exposure limits related to the health concerns of the Chinese population (CSEPA, 2012). It is therefore also important to assess the potential benefits of the policy on hazardous air pollution (HAP) (Davis, 2008; Lin et al., 2011), which has been ignored in Beijing. Furthermore, although air pollution has notable adverse effects on human health, empirical research on the impact of driving restrictions on public health is lacking. Based on a regression discontinuity (RD) design with GAM frameworks and daily data from 2007 to 2009, we first examined the impacts of driving restrictions in Beijing on hazardous air pollution, which was defined as pollution level exceeding China's national standards. Then, the impacts of the driving restrictions on different health outcomes were evaluated, and finally, we performed stratified analyses to examine the heterogeneous effects of the policy in different seasons and to identify who would derive the greatest benefits from this environmental policy. Our research offers an improved understanding of the health effects of air quality changes related to this environmental intervention. The results can also help policy makers to better and more comprehensively estimate the effectiveness and social implications of driving restrictions.

2. Materials and methods

2.1. Study area

Our study area is Beijing, the capital of China, which has experienced rapid urbanization and industrialization in recent decades. Located in 39°56′N, 116°20′E, Beijing covers an area of approximately 16,808 km^2 and consists of six urban and ten suburban districts with a population of approximately 22 million in 2015. It is on the North China Plain surrounded by mountains of 1000–1500 m in altitude to the west, north, and northeast and the Bohai Sea on the southeast side. The typical northern warm temperate semi-humid continental monsoon climate in Beijing results in hot-humid summers and cold-dry winters while springs and autumns are both of relatively short duration.

2.2. Data and variables

Our analysis includes a daily sample of 1096 days from January 1, 2007 to December 31, 2009. The data mainly focuses on three components: air pollution, health outcomes, and weather condition.

We gathered the official daily Air Pollution Index (API) from the State Environmental Protection Agency of China. API is an integrated index for reporting daily air quality, which is calculated based on three major pollutants: particulate matter (PM_{10}), Sulfur dioxide (SO_2) and Nitrogen dioxide (NO_2). API is calculated for each pollutant according to specific conversion methods but only the API of the highest pollutant is reported. The prominent air pollutant is identified and reported when the API is above 50. Ranging from 0 to 500, the API is categorized into five levels, and a higher level means worse air pollution as well as greater health concerns. The API is also regarded as a yardstick for public health concerns, and the safety cutoff is 100 according to China's National Standards of Ambient Air Pollution. When the API is less than 100, the air quality can be regarded as acceptable and only a moderate health concern to some people. We therefore focused on a relative higher air pollution level (API >100 which is referred as "hazardous air pollution" hereafter) by using an indicator of hazardous API (HAPI). We also retrieved daily PM_{10} concentrations from the API when PM_{10} was the prominent pollutant, using the conversion method used in Andrews (2008). Days with other pollutants as the prominent pollutant are treated as missing observations. Hazardous PM_{10} (HPM_{10}) is used in the analysis to denote that the PM_{10} of that day is beyond 150 μg/m^3.

Four health outcomes, including daily hospital outpatient visits (OP), emergency room visits (ER), hospital outpatient visits for respiratory diseases (RDOP) and hospital admissions for respiratory disease (RDHA) were used to measure public health. The health data was obtained from three large-scale comprehensive hospitals evaluated as tertiary first-class in Beijing during the research period. Patients from outside Beijing were excluded according to the computed individual information to assure that our measurement of health outcomes represents the general health condition of local residents. Health data was coded according to the International Classification of Diseases, Revision 10 (ICD-10).

Meteorological factors including daily mean temperature, maximum temperature, relative humidity, wind speed, wind direction, rain, duration of sunlight and average pressure were estimated as important influential factors that are significantly associated with air pollution and public health (Guo et al., 2013; Sun et al., 2014; Viard and Fu, 2015). We thus also included these variables in our models. Meteorological data was obtained from a meteorological monitoring station (named Beijing Station) located in 39°48′N, 116°28′E, which were gathered by the China Meteorological Data Sharing Service System (http://data.cma.cn/).

3. Methods

A RD design with a semi-parametric estimation framework of GAM was employed in our analysis to evaluate the effects of driving restrictions on hazardous pollution and health outcomes. This method uses pollution and health outcome data before the implementation of driving restrictions as comparisons. We first specified a GAM with a binomial link to evaluate the effects of two types of driving restrictions on hazardous air pollution in Beijing. A natural spline (ns) function with flexible degree of freedom (df) of time trend was used to control the nonlinear time-varying unobserved confounding factors in time series analysis (Peng et al., 2009). To accommodate underlying non-linear relationships between weather variables and hazardous pollution, we also adjusted for weather variables including daily average temperature, maximum temperature, relative humidity, wind speed, duration of sunshine and average pressure with *ns* smoothers. *Dfs* of the *ns* functions were chosen according to the Akaike's information criterion (AIC) (Akaike, 1987). Other covariates, including dummy variables indicating day of the week, holidays, rain and wind direction were also incorporated in the model. The model was specified as follows:

$$\ln\left(\frac{P(HAPt=1)}{1-P(HAPt=1)}\right) = \alpha0 + \alpha1 OneDay_t + \alpha2 OddEven_t + \alpha3 BreakPeriod_t + \alpha4 HAPt - 1 + \alpha5 CVt + ns(W_t, df) + ns(time, df) + \varepsilon t \quad (1)$$