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Research article

# The effects of transboundary air pollution following major events in China on air quality in the U.S.: Evidence from Chinese New Year and sandstorms

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A B S T R A C T

Transboundary air pollution is a global environmental and public health problem including in the U.S., where pollution emissions from China, the largest emitter of anthropogenic air pollution in the world, can travel across the Pacific Ocean and reach places like California and Oregon. We examine the effects of transboundary air pollution following major events in China, specifically sandstorms, a natural-occurring source of air pollution, and Chinese New Year, a major 7-day holiday, on background air quality in the U.S. We focus on high elevation sites on the west coast between 2000 and 2013. We use regression analysis and a natural experiment to exploit the variation in the timing of these events in China, which are plausibly uncorrelated to other factors that affect air quality in China and the U.S. We find that sandstorms are associated with statistically significant increases in background coarse and fine particulate matter (PM) in the U.S., representing between 16 and 39% of average weekly PM levels. We also find Chinese New Year is associated with modest reductions in background air quality in the U.S., representing between 0.4 and 2.5% of PM levels. Findings are robust to different models and falsification tests. These results suggest that regression analysis could be a powerful tool to complement other, more widely used techniques in the environmental sciences that study this problem. This also has important implications for policymakers, who could track major sandstorms in China and prepare for possible increased foreign pollution emissions in the U.S.



## 1. Introduction

Numerous studies highlight the potential concerns transboundary air pollution (i.e., air pollution that crosses country borders) could have on air quality and public health in the U.S., particularly from East Asia (e.g., Timonen et al., 2013; Jaffe et al., 2003; Jacob et al., 1999; Ewing et al., 2010; Liu et al., 2003; McKendry et al., 2001; Yienger et al., 2000; Yu et al., 2012). For example, using a combination of various global models, Zhang et al. (2017) find that $PM_{2.5}$ from China is associated with more than 3100 premature deaths in western Europe and the U.S. However, regulations by the U.S. Environmental Protection Agency currently do not account for foreign pollution emissions, though they could possibly offset domestic pollution reductions. For example, Yu et al. (2012) find comparable emissions of PM from both domestic and foreign sources, where the latter is mostly dominated by dust. Timonen et al. (2013) show that episodes of transboundary air pollution influence background and urban air quality in the U.S. Jaffe et al. (2003) find episodes of trans-Pacific air pollution from Asia to the U.S. are common, especially during the spring, but affect air quality in the U.S. differently (more information on this literature can be found in the supplementary information).

Many of the studies examining this problem typically use a combination of methodologies, including chemical transport models, remote sensing, or in situ observations. These approaches are better suited to understanding the complex meteorological mechanisms guiding the long-range transport of air pollution across the Pacific Ocean. However, these studies are typically narrow in the time period they evaluate since episodes of transboundary air pollution can be difficult to track and predict.

We build upon this literature by using a natural experiment to examine the effects of trans-Pacific air pollution between China and

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the U.S. over a period spanning more than a decade, from 2000 to 2013. Natural experiments exploit variation caused by events that happen outside the system or the researcher's control rather than relying on the natural variation of a treatment (Dominici et al., 2014). This approach minimizes omitted variable bias from failing to control for confounding variables. In this case, a regression examining the relationship between air pollution in the U.S. and China could lead to biased results if economic factors are unaccounted for since studies show the U.S. economy, for example, can affect pollution in the U.S. and China through trade (Lin et al., 2014; Zhang et al., 2017).

In this study, we use regression analysis and exploit the variation in foreign pollution emissions induced by two major events in China: Chinese New Year (CNY), a major 7-day holiday celebrated nationally that begins on the second moon after the winter solstice, and sandstorms, a natural source of air pollution that occurs mostly in the spring (Fig. 1). Traditionally, during CNY, local pollution levels in China decrease due to reduced industrial production, while, in contrast, sandstorms cause sudden spikes in local PM levels in the spring. The timing of CNY and sandstorms could be considered plausibly exogenous to factors correlated to air quality in the U.S. and China. CNY follows the Lunar New Year, which varies every traditional calendar year, while sandstorms are mostly driven by local natural conditions unique to China. Consequently, we mitigate potential omitted variable bias in our results. In using this approach, we are less concerned with the meteorological mechanisms transporting air pollution across the Pacific Ocean, but more interested in associations between these events in China and air quality in the U.S.

We examine the impacts of these events on background air quality in the U.S. using data from high elevation monitoring sites at the Mount Bachelor Observatory (MBO) and in the Interagency Monitoring Protected Visual Environments (IMPROVE) network. We focus on monitoring sites at high elevations (≥2 km) since transboundary air pollution from East Asia is transported in the free troposphere and levels could be diluted after moving to lower elevations in the boundary layer (Jaffe et al., 2003). Our outcomes of interest are $PM_1$ (PM with an aerodynamic diameter < 1 μm), $PM_{2.5}$ (fine PM or PM with an aerodynamic diameter < 2.5 μm), and $PM_{10\text{-}2.5}$ (coarse PM or PM with an aerodynamic diameter between 10 and 2.5 μm). We also focus on the west coast of the U.S., specifically California and Oregon, because this region is more susceptible to trans-Pacific air pollution than the east coast. Our results build upon the current literature around transboundary air pollution and have important policy implications since these events could be used to predict how and when trans-Pacific air pollution could affect air quality in the U.S.

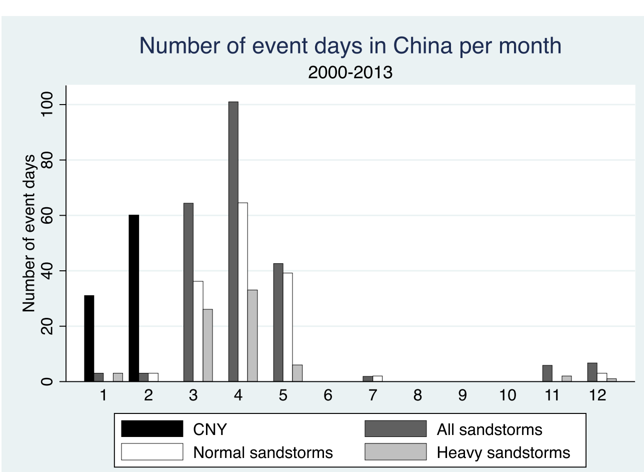


**Fig. 1.** This graph shows the number of event days (Chinese New Year (CNY), all sandstorms, normal sandstorms, and heavy sandstorms) in China per month during the study period of 2000–2013. Sandstorms peak during the spring between March and May while Chinese New Year typically occurs in January and/or February. CNY lasts 7 days while sandstorms last a couple or a few days.

## 2. Data and methodology

### *2.1. Data*

#### *2.1.1. Air quality and meteorological data in the U.S.*

We use several different data sets representing air quality in the U.S. First, we obtain daily $PM_1$ data from the MBO, which is located at the summit of Mt Bachelor (2.8 km above sea level) in the Oregon Cascade Mountains, between 2004 and 2013 (Jaffe et al., 2005). $PM_1$ is measured using aerosol scattering at different wavelengths, which correspond to various $PM_1$ mass concentrations. Very low values of $PM_1$ could be negative, so these values are replaced with half the detection limit. Although, $PM_1$ is not regulated by the U.S. EPA, previous work finds high correlations between $PM_1$ and $PM_{2.5}$, a U.S. EPA criteria pollutant (Giugliano et al., 2005).

We also obtain daily $PM_{2.5}$ and $PM_{10\text{-}2.5}$ data from the IMPROVE network, which collects 24-hr average samples every three days for various pollutants (Malm et al., 1994). We focus on sites at high elevations (≥2 km) and further narrow down monitoring stations based on sufficient weather data. Based on these criteria, we use two monitoring sites: Crater Lake National Park in Oregon (2 km) and Bliss State Park (2.1 km) near Lake Tahoe in California.

Finally, for meteorological information, we collect daily maximum temperature, relative humidity, and an indicator of possible smoke from wildfires at the MBO between 2004 and 2013. We also obtain daily maximum temperature and precipitation for Crater Lake National Park and Bliss State Park from the National Centers for Environmental Information and information on days of wildfires using data from the IMPROVE network.

#### *2.1.2. Air quality, sandstorms and CNY data in China*

We obtain daily $PM_{10}$ (PM with an aerodynamic diameter < 10 μm) data from China's Ministry of Environmental Protection (MEP) between 2000 and 2013. Our analysis focuses on the original 42 cities China's MEP started monitoring in 2000 for consistency. Additionally, we separately collect $PM_{10}$ data at the four cities closest to the Gobi desert, where most sandstorms originate from, to represent air pollution due to sandstorms in China for the same time period. These cities are Lanzhou, Xian, Xining, and Yinchuan.

We also retrieve daily information on sandstorms in China between 2000 and 2013 from the Annual Sand and Dust Weather Yearbook by China's Meteorological Administration. Sandstorms are categorized as "light," "normal," or "heavy" based on visibility. Normal sandstorms have visibility below 500 km, while heavy sandstorms have visibility below 1 km. We are interested in the effects of all sandstorms, but also examine the impacts of heavy and normal sandstorms separately. Additionally, we collect information on the official 7-day CNY holiday using publicly available government records for the same time period.

### *2.2. Statistical analysis*

We perform several statistical analyses using Stata version 11 (StataCorp, College Station, Tex). Prior to conducting these analyses, we aggregate daily air quality, weather and event data to the weekly level for a couple reasons. First, the time it takes for pollution to travel across the Pacific Ocean varies between a few