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Power stations emissions externalities from avoidance behaviors towards air pollution: Evidence from Beijing☆

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ABSTRACT

We combine a unique dataset of hourly pollutant emissions from power stations in Beijing with hourly air quality levels to demonstrate a positive feedback loop where high outdoor air pollution causes power stations' emissions to increase. The likely mechanism is increased electricity usage from measures taken to protect oneself against high outdoor air pollution. Relative to clean ('blue sky') conditions, nitrogen oxides (NO_X) emissions from power stations increased by about 14.6%, 27%, and 59.2% when outdoor air quality reaches moderate, severe, and hazardous level respectively; SO_2 emissions increased by a lower magnitude of 6.6% and 18.6% for severe and hazardous level respectively. We also find that these increases differ according to different periods of the day, signifying different patterns in avoidance behaviors. These findings potentially present a dilemma and challenge to policymakers as private actions taken to protect oneself from public harm may in fact, further exacerbate the problem.

1. Introduction

Air pollution is fast becoming a major public health, economic, and societal challenge for many developing countries. It is estimated that in 2016, about 4.2 million premature deaths globally were caused by exposure to ambient air pollution, with over 90% of these deaths occurring in low- and middle-income countries (WHO, 2018). The mortality rate is set to increase as SO_2 and NO_X emissions are projected to worsen in low- and middle-income economies until 2050 (OECD, 2012). Thus, it is not surprising that residents in cities with poor air quality adopt behavioral changes to protect themselves from harms caused by air pollution. These behavioral changes, broadly termed as 'avoidance behaviors' or 'averting behaviors', are costly to individuals in terms of their time, money, and resources. For example, the costs of using facemasks to protect oneself from exposure to air pollution include learning costs and opportunity costs of purchase. In return for these privately incurred costs, individuals and their families are protected from reduced exposure to pollution by adhering to these behaviors. For a long time, researchers have used information on the avoidance behaviors people take to infer the value one places on pollution reduction as well as to understand the drivers behind avoidance behaviors (e.g. Courant and Porter, 1981; Larson and Gnedenko, 1999; Pattanayak et al., 2005; Um et al., 2002). However, what has been missing in the literature thus far are the environmental consequences of engaging in avoidance behaviors. Towards this end, we examine a positive feedback loop of air pollution where averting behaviors taken by individuals to protect themselves from ambient air pollution in turn increase emissions from power stations due to increased electricity consumption, thus exacerbating the air pollution problem. Using data on hourly emissions of pollutants from Beijing's power stations, we show that, relative to 'blue sky' rating, nitrogen oxides (NO_X) emissions from power stations increased by about 14.6%, 27%, and 59.2% when outdoor air quality reaches moderate, severe, and hazardous level respectively. On the other hand, sulfur dioxide (SO_2) emissions increased by a lower magnitude of 6.6% and 18.6% for severe and hazardous level respectively. This non-trivial amount of increase is in-spite of very stringent emissions abatement policies in Beijing. For example, coal-fired power stations in Beijing are being phased out and this is reflected in our dataset as four of the five power stations use natural gas as the primary fuel (Chen, 2017). Moreover, Beijing's power stations are fitted with advanced scrubbing technology which reduces the NO_X and SO_2 content in emissions to very low levels (Hao et al., 2007). These policy

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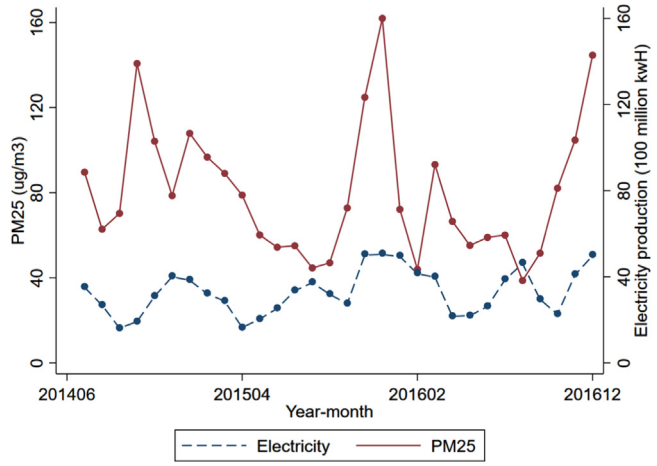

Fig. 1. Monthly electricity generation for Beijing's power stations and $PM_{2.5}$ levels (correlation = 0.35).

features are reflected in our results as we see larger increases in NO_X emissions compared to SO_2 emissions. This is likely because most of the observations in the dataset are from natural gas-fueled power plants (combustion of natural gas emits more NO_X than SO_2) and the advanced scrubbing technology has made emissions with low levels of SO_2 content more difficult to detect by measurement devices.[1]

While there are many recent studies from China highlighting how Chinese residents are protecting themselves against exposure to air pollution (e.g. Barwick et al., 2017; Ito and Zhang, 2016; Sun et al., 2017; Zhang and Mu, 2017), we extend their findings by investigating how avoidance behaviors may induce even more air pollution. In this regard, this study makes the following contributions to the literature. First, this is one of the first studies to demonstrate that avoidance behaviors taken to protect oneself from air pollution will exacerbate the problem. Second, while this study is conducted using data from Beijing, we argue that our results is applicable to other cities in the developing world with similar characteristics as Beijing, i.e. poor air quality and residents with rising income able to afford avoidance behaviors. Third, our empirical analyses are strengthened by having observations at detailed-level. This allows inclusion of fixed effects at the smokestack and hourly level to control for many unobserved factors. Additionally, we uncover heterogenous responses to air pollution at different time periods of the day. Lastly, we conducted a battery of robustness checks to rule out confounding explanations for our results.

2. Background

Avoidance behaviors have been widely studied in the field of environmental economics as researchers use this method to value non-marketed and yet, valuable public goods such as clean air and water. In its first application to air pollution, Bresnahan et al. (1997) found that avoidance behaviors (measured by time spent indoors, running air conditioning, and changes in planned outdoor leisure activities) are much more likely to take place during smoggy conditions in Los Angeles. They also found that individuals with poor respiratory health are more likely to employ avoidance behaviors. In another study, Mansfield et al. (2006) also found that children in American cities are more likely to stay indoors when outdoor air quality is bad. Up until recently though, there were no corresponding studies of avoidance behaviors with respect to air pollution in developing economies. Other than the lack of data, it is likely that population in developing countries are not sufficiently aware of the dangers of air pollution and/or have insufficient resources to undertake these costly behaviors. However, the trend has shifted in recent years, especially for China, as seen from the increasing number of studies that focus on avoidance behaviors with respect to air pollution. Zhang and Mu (2017) used Internet sales data to show that purchase of facemasks increased by more than 50% when air quality index increased by 100-point in China. In a similar application, Sun et al. (2017) also showed that sales of facemasks and air purifiers increased during heavily polluted days using Internet sales data from China. In addition, they found that wealthier households are more likely to purchase air purifiers, suggesting an inequality issue as air purifiers are much more effective than facemasks in offering protection. Lastly, Ito and Zhang (2016) used air purifiers point-of-sales (i.e. non-Internet sales) data from Chinese cities to recover willingness-to-pay for improved air quality. In all, these recent studies demonstrate that Chinese residents are particularly acute towards the harms of air pollution and will take measures to protect themselves when outdoor air quality is bad.

2.1. Avoidance behaviors and electricity usage

In a recent survey conducted on over 1000 Beijing residents, the top five behaviors respondents take to protect themselves from air pollution are (in order of): usage of air purifiers at home, growing green plants indoors, staying indoors when pollution is high, using air purifiers at workplace, and avoiding outdoor exercises (Johnson et al., 2017). Studies of avoidance behaviors from other locations have consistently placed 'staying indoors' as the top choice of strategies to avoid exposure to air pollution (Bresnahan et al., 1997; Mansfield et al., 2006). Towards this end, for the following reasons, we argue that electricity consumption will increase as more avoidance behaviors are undertaken. First, we observe statistical evidence that monthly electricity production and $PM_{2.5}$ levels in Beijing appear to move in tandem (Fig. 1).[2] Second, two most popular avoidance strategies in Beijing are usage of air purifiers at home and at the workplace (Johnson et al., 2017). A cursory check of the most popular air purifiers in the Chinese market shows that power consumption is around 80 W for an air purifier rated for use in one bedroom.[3] All else being equal, energy consumption will obviously increase if air purifiers are operated at residences or workplaces during periods of poor air quality. Third, another common strategy is to stay indoors. Even without usage of air purifier, total electricity consumption will likely increase from using other electrical appliances such as air conditioning, heating, and television as people remain indoors. Fourth, it is important to note that not only would residential electricity consumption increase, electricity usage in offices, schools, or hospitals will also likely increase during period of high air pollution as air purifiers are frequently used at these establishments too (Guo, 2017; Heng, 2013).

2.2. Choice of Beijing as a study site

We chose to study Beijing for the following reasons.

First, just as Beijing is known and seen as the center of power for the Chinese government, her chronic air pollution issues are also well-known nationally and internationally. Since the early 2000s, Beijing government has introduced many novel and strict regulations to improve air quality. While success has been limited, these efforts have highlighted the severity of air pollution to the 20 million residents in the city. As such, knowledge on the harms of air pollution is high and Beijing residents have employed a host of behaviors to combat air

[1] We thank an anonymous reviewer for raising this point.

[2] Data on electricity consumption retrieved from National Bureau of Statistics of China: http://data.stats.gov.cn/english/easyquery.htm?cn=E0101 (use the menu on the left-frame to navigate to the statistics on electricity production). Data on $PM_{2.5}$ is retrieved from United States Department of State website (http://www.stateair.net/web/historical/1/1.html).

[3] For reference, a refrigerator runs at around 120 W for a typical Chinese household (Niu et al., 2016).