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Environmental Regulation and Chronic Condition:
Evidence from China's Air Pollution Prevention and Control Action Plan

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Abstracts

The Chinese government passed the Air Pollution Prevention and Control Action Plan (APPCAP) in 2013 to improve air quality. Subsequently, local governments implemented their own action plans following APPCAP in different time. We use difference-in-differences model to evaluate the impact of the APPCAP on health outcomes. Unlike the literature focusing on mortality, we measure health outcomes based on air-pollution-related chronic conditions, respiratory diseases, and circulatory system diseases based on the medical literature. The China Family Panel Studies (CFPS 2012, 2014, 2016), a representative survey of China, collects detailed information on doctor-diagnosed chronic diseases over the last 6 months. We found that the APPCAP reduced respiratory diseases and circulatory system diseases by 23 percent and 20 percent respectively for all adults. The effects vary across subsets of the population. The low-income strata and old people benefitted most from the APPCAP regarding respiratory diseases. Furthermore, females and old people received large benefits from the APPCAP for circulatory system diseases.

1. INTRODUCTION

Ambient air pollution is a major environmental problem affecting everyone worldwide. According to the World Health Organization (WHO), the health effect of air pollution is serious, about one-third of deaths from respiratory diseases or circulatory system diseases are due to air pollution. In 2016, 91 percent of the world's population did not breathe clean air (WHO, 2018), and more than half of the urban populace was exposed to outdoor air pollution levels at least 2.5 times above the WHO's safety standard[1](WHO, 2014).

As the largest developing country in the world, China has experienced rapid advancement of the economy in the last five decades, which also brought unprecedented environmental problems. Excessive coal and fossil fuel combustion, vehicle exhaust, and industrial emissions make China one of the most polluted countries in the world.

By 2013, the highest daily concentration of fine particulate matter ($PM_{2.5}$) in some northern cities where coal-power industry concentrated, and southern cities exceeded $300\mu g/m^3$ and $200\mu g/m^3$ respectively, which is about 10 times higher than the WHO air quality guidelines of 2005. According to China's Ministry of Environmental Protection, only three out of 74 key cities in China met the official minimum standards for air quality.

The president of the China Medical Association, Nanshan Zhong, mentioned in an interview with *The Guardian* in 2012 that "air pollution will become the biggest health threat in China unless the government implements effective policies and takes

[1] According to WHO's (2006) air quality guidelines, the limit for $PM_{2.5}$ is $25\mu g/m^3$ 24-hour mean, for PM_{10} is $50\mu g/m^3$ 24-hour mean, for ozone is $100\mu g/m^3$ 8-hour mean, for nitrogen dioxide is $200\mu g/m^3$ 1-hour mean, and for sulfur dioxide is $20\mu g/m^3$ 24-hour mean.

immediate action." Outpatient cases at his clinic in Guangdong province increase by 10 percent on hazy days (The Guardian), when the concentration of PM is higher than usual (Zhao et al., 2017). As such, he concludes that there is a strong correlation between air pollution and certain illnesses, such as lung cancer and cardiovascular disease.

The Chinese government responded to these concerns by implementing the Air Pollution Prevention and Control Action Plan[2] (APPCAP) in 2013, with the objective of protecting public health by reducing the concentration of PM. By the end of 2017, the policy was a priority for the Chinese government. With this overarching initiative from the Chinese government, each administrative division implemented its own environmental preservation policies at various times between 2013 and 2017.[3] As a result of the APPCAP, air quality has improved significantly.

This study aims to evaluate the impact of the APPCAP on health outcomes in China. We examine changes in the probability of suffering from respiratory disease and circulatory system disease after the implementation of the APPCAP.[4]

How environmental policy affected health outcomes is an important question, but few studies examine the matter. The representative research in developed countries is Chay et al. (2003), who assessed the effect of the US' Clean Air Act (1970) on adult mortality. The results show that the Clean Air Act is associated with a large reduction in particulates but has no significant effect on adult mortality rates. Although developed countries provide quality data, their air pollution levels are lower than

[2] Specific terms of the APPCAP are listed in Huang et al. (2018).
[3] We compiled implementation times of the APPCAP at the administrative division level in Appendix Figure A1.
[4] The Chinese government proposed the APPCAP in 2013, which set air pollutant reduction targets for each region. Subsequently, each administrative division implemented its own environmental regulations at different times. We measure the effect of the APPCAP by taking the implementation time of the environmental regulation published on each administrative division's official website as the official implementation time of the APPCAP.

those of developing countries. Air pollution might impact health nonlinearly depending on the pollution level. In addition, composition of pollution mix and sociodemographic conditions differ between developed and developing countries. This means that the findings of studies conducted in developed countries cannot be transposed to developing countries.

Several studies have examined the effects of environmental regulation in developing countries such as China and India. Greenstone and Hana (2014) did not find a statistically significant decline in infant mortality as a result of air pollution regulation in India. On the other hand, Huang et al. (2018) found the APPCAP significantly improved the air quality and determined its long-term effect from the mortality and years of life lost perspectives.

This study focuses on the chronic health conditions associated to the APPCAP. Previous epidemiologic studies indicated that exposure to air pollution can increase the risk of respiratory and circulatory system diseases (Atkinson et al., 2001; Wong et al., 1999; Rodríguez-Villamizar et al., 2018). Our study was designed to assess changes in the probability of suffering from respiratory diseases and circulatory system diseases after the implementation of the APPCAP. Such chronic health conditions might keep deteriorating and even become fatal. Our study fills the research gap on environmental regulations and their link to mortality.

The remainder of the paper is structured as follows. In section 2, we explain the policy in detail. In sections 3 and 4, we present our data and econometric model. In section 5, we conclude.

2. AIR POLLUTION PREVENTION AND CONTROL ACTION PLAN (2013–2017)

In 2013, the Chinese government announced the APPCAP. Afterwards, each administrative division implemented their own environmental protection policy. The timing and duration of implementation in administrative division varies substantially. For example, Beijing and Shanghai implemented the APPCAP in September and November 2013, respectively, with a policy duration of four years；Sichuan and Guangdong commenced in February 2014, with a three-year policy duration; Liaoning and Guangxi implemented the policy in 2017 with a three-year policy duration. We summarized the APPCAP implementation times and its duration at the administrative division level in Table 1. Adopting administrative division level policy is close to random since we could not find much of a geographic pattern (see the map in Appendix Figure 1).

The APPCAP improved the air quality in China drastically. Figure 1 shows the average annual concentration of the six criteria air pollutants in the key cities of 24[5] administrative divisions from 2013 to 2017. The concentrations of $PM_{2.5}$, PM_{10}, sulfur dioxide, nitrogen dioxide, and carbon monoxide decreased overall during the policy implementation period. The concentration of PM decreased the most, with a slow reduction at first, followed by a rapid fall. By 2017, the concentration of $PM_{2.5}$ decreased from 68μg/m^3 to 50μg/m^3 and that of PM_{10} decreased from 108μg/m^3 to 84μg/m^3, a 26 percent and 22 percent reduction respectively, compared with 2013.

[5] The survey data we used cover 25 administrative divisions. Among these, we excluded Tianjin because Tianjin implemented environmental regulations prior to APPCAP policy. Therefore, 24 administrative divisions are used in our analysis. For consistency we also calculated air pollution using 24 administrative divisions here.

3. DATA: CHINA FAMILY PANEL STUDIES

We examine the impact of the APPCAP on health. The China Family Panel Studies (CFPS), a nationally representative study covering 25 administrative divisions, collect detailed information on individuals' health. The CFPS was first conducted in 2010, with follow-up surveys in 2012, 2014, and 2016 (CFPS2010, CFPS2012, CFPS2014, CFPS2016). We focus on the respondents who were tracked through follow-up surveys from CFPS2010 to CFPS2016. The CFPS collects self-reported health conditions. The survey considers whether an individual had been diagnosed with any disease over the last 6 months. Thus, detailed information regarding diseases was elicited, except in the 2010 survey[6].

3.1 Dependent Variables

We want to identify air pollution related chronic disease in CFPS. Based on the literature, we identified two categories of air pollution related chronic disease (see Appendix Table A1 for detail references): respiratory diseases (asthma, pneumonia, etc.) and circulatory system diseases (hypertension, stroke, etc.).

We constructed two binary variables based on the details of diseases in CFPS2012, CFPS2014, and CFPS2016: the respiratory disease variable and the circulatory system disease variable. Variables take the value of 1 if the respondent was diagnosed with a respiratory disease or circulatory system disease, and 0 otherwise.

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[6] Detailed information regarding diseases has been collected since CFPS2012. CFPS2010 was only used to control respondent's base-level health conditions, which is explained in detail in section 3.2.

3.2 Base-level Health Conditions

We controlled for base-level health conditions at the individual level to minimize possible bias (Sacks et al., 2011; Bateson and Schwartz, 2004; Goldberg et al., 2001). We used CFPS2010 questions, asking about respondents' health status using 5 categories: very unhealthy, unhealthy, relatively unhealthy, fair, and healthy. We include this information as a categorical variable for each category.

3.3 Weather Conditions

We also controlled for rich weather conditions, including mean temperature, humidity, sunshine, and precipitation over the month that we held interviews in each administrative division to isolate the impact of seasonal patterns on health (Kan et al., 2008; Peng et al., 2005; Chen et al., 2013; Katsouyanni et al., 2001). Monthly observations of weather conditions are obtained from resources such as the environmental section of China's Statistical Yearbook from 2013 to 2018.[7]

4. ECONOMETRIC MODEL

We used a linear probability model to estimate the health benefits of the APPCAP.[8] Our baseline econometric model is as follows:

$$Y_{ijt} = \beta_0 + \beta_1 APPCAP_{jt} + \delta_j + \gamma_t + \beta_2 X_{ijt} + \beta_3 Weather_{jt} + \beta_4 H_{ij} + \varepsilon_{ijt}.$$

[7] We rely on the CFPS survey conducted in 2012, 2014, and 2016. It takes two years for each survey. For example, for CFPS2016, those who failed to complete the interview conducted in 2016 were interviewed in 2017; therefore, the CFPS survey spans from 2012 to 2017. The China Statistical Yearbooks report the statistics of the previous year, that is, the 2013 yearbook includes the statistical data of 2012, and thus, we use the yearbooks from 2013 to 2018.

[8] Although the dependent variable is binary, Ai and Norton (2003) pointed out that the logit or probit model needs to be interpreted with caution for interaction terms, like in the difference-in-differences model case.

Here, the dependent variable Y_{ijt} indicates whether respondent i had respiratory diseases or circulatory system disease in the previous six months in region j at time t[9], by month; $APPCAP_{jt}$ represents whether region j implemented the APPCAP at time t[10], taking the value one if region j implemented the APPCAP at time t.[11] δ_j represents region fixed effects; γ_t denotes $\text{year} \times \text{month}$ fixed effects.[12] It is a difference-in-differences model with cross-sectional variation by region and over-time variation by month. APPCAP is the interaction term between cross-sectional and over-time variation.

We control for a set of demographic variables of health X_{ijt}, including age, gender, marital status (never married, married, cohabitation, divorced and windowed; never married as the reference group), education level (primary school, middle or high school, and university graduates or above; primary as the reference group), employment status, and annual household income (Kan et al., 2008; Gouveia and Fletcher, 2000; Atkinson et al., 2001; Bateson and Schwartz, 2004; Cakmak et al., 2006; O'Neill et al., 2003).

We controlled for rich weather conditions $Weather_{jt}$, involving mean temperature, humidity, precipitation, and sunshine to ensure the weather is seasonally representative since Chen et al. (2013) found that the health effect of particulate air

[9] The CFPS specified the date of the survey to the month.

[10] The CFPS asked respondent "whether (they) had doctor-diagnosed chronic diseases over the past 6 months." If the 6-month prior to survey time t spans pre- and post- implementation of the APPCAP, we treat it as a missing value. For example, Sichuan implemented the APPCAP in February 2014, so we treat the survey time from February to September 2014 as missing values. Missing values due to this situation accounted for 6 percent of the sample.

[11] For example, Beijing implemented the APPCAP in September 2013. If the CFPS survey time of a respondent in Beijing falls after the policy implementation, then APPCAP is equal to 1.

[12] It takes two years for each CFPS survey, so the time span of CFPS2012, CFPS2014 and CFPS2016 covers 2012 to 2017. The CFPS survey is not conducted every month of each year; therefore, we have 32 dummies.

pollution varies by season, with the largest effect in winter and summer in China. We also controlled for a set of self-rated base-level health status H_{ij}, ranging from 1 (very unhealthy) to 5 (healthy). ε_{ijt} is an error term.

The coefficient β_1 measures the effect of the APPCAP on the probability of suffering from respiratory diseases or circulatory system diseases, keeping other variables constant.

Table 2 describes the variables used in the analysis. Of our 64,663 observations, 1.45 and 2.85 percent respectively were diagnosed with respiratory and circulatory system diseases in the last 6 months. Forty eight percent of the sample was male and 47 percent lived in an urban area. The average age was 50 years.

5. RESULTS

First, we analyzed whether the entire adult sample was affected by the APPCAP. We multiplied the dependent variable by 100 in regression analysis so that the effect of the APPCAP is easy to interpret.

5.1 All Adults

Table 3 presents the regression results by estimating the equation in section 4. Columns 1 and 2 identify the effect of the APPCAP while controlling for observable individual characteristics, weather conditions, base-level health conditions, and time and region fixed effects. We find a significant reduction in the probability of suffering from respiratory diseases and circulatory system diseases after the APPCAP implementation.

Table 3 shows that the APPCAP results in a significant decrease in the average probability of being diagnosed with respiratory diseases and circulatory system diseases by 0.33 percentage point and 0.58 percentage point, respectively. The average treatment effect of the APPCAP was a 23 percent (=0.33/1.45) and 20 percent (=0.58/2.85) reduction of the sample mean in respiratory diseases and circulatory system diseases, respectively. The results suggest that the APPCAP resulted in a substantial improvement in adult health.

Based on the results of covariates, older adults, people who are in poor health status or are unemployed, are more likely to suffer from respiratory diseases or circulatory system diseases. Employed people are less likely to suffer from respiratory diseases or circulatory system diseases than unemployed people, possibly owing to the superior health of those employed.

5.2 Results by Subsample

5.2.1 Gender and Age

Specific demographics, particularly older adults, are identified as potentially more susceptible to air pollution effects compared with the general population (Sacks et al., 2011; Gouveia and Fletcher, 2000), because their physiological processes decline over time and the ability of the respiratory track to clean up PM is reduced with increasing age (Sacks et al., 2011).

From the gender perspective, there might be differences physically (Sacks et al., 2011). We divide respondents into two groups by gender and into three groups by age: young (aged between 16 and 45), middle-aged (aged between 45 and 60), and elderly (aged 60 or more). As above, a linear probability regression approach is employed.

Table 4 presents the effect of the APPCAP on the probability of suffering from respiratory diseases (first panel) and circulatory system diseases (second panel) by gender and age. The results show that after the APPCAP implementation, though there is a decrease in the risk of respiratory diseases for both males and females, the reduction is insignificant at the 90 percent confidence level. The risk for circulatory system diseases is significantly decreased by 1.23 percentage points among females, which is 36 percent of the sample mean; the risk for respiratory diseases and circulatory system diseases are significantly decreased by 0.90 percentage point and 1.87 percentage points among older adults (>60-year-old) respectively, which are 36.9 percent and 28.9 percent of the sample mean.

These results align with our initial speculation that both males and females, and older adults (>60-year-old) might be the groups that benefit most from the APPCAP.

5.2.2 Socioeconomic Status

Socioeconomic status can be defined from numerous perspectives, including income, education, and occupation perspectives, and these factors can influence a population's susceptibility to air pollution (Sacks et al., 2011; Kan et al., 2008; O'Neill et al., 2003; Finkelstein et al., 2003; Cakmak et al., 2006). The low socioeconomic population bracket is more likely to work outdoors (for example, in the construction, transportation, and road services industries), live in polluted areas; have more limited access to medical care, and fresh food and water; information related to air quality via the Internet, newspapers, or smartphones is not easily accessible, all of which may contribute to their increased susceptibility to air pollution (Greenstone and Hanna, 2014; Sacks et al., 2011). We expect the group with low socioeconomic status to benefit most from the APPCAP.

In this study, socioeconomic status is defined through the educational attainment and household annual income levels to identify low, medium, and high socioeconomic status. We divide the respondents into three groups by education level: primary school, middle or high school, and university graduates or above; and into four groups by quantile of annual household income. To mitigate the potential influence of variations in time and location, these four groups are then segmented by region and year of survey.

Thirty percent of the sample had a primary school education or less, 31 percent had a middle or high school diploma, and 39 percent had a university diploma or above. The results in Table 5 show that after the APPCAP implementation, the probability of being diagnosed with circulatory system diseases among those who received middle or high school education was reduced by 0.8 percentage point, which is about 42.6 percent of the sample mean. The results in Table 6 show that the effect of the APPCAP was significantly associated with a reduction in respiratory diseases and circulatory system diseases in the lower family income group. There is a 0.63 percentage point reduction in respiratory diseases, which is 47.4 percent of the sample mean; a 1.29 percentage point reduction in circulatory system diseases, which is 36 percent of the sample mean in the lower quartile of the income. The results confirm that those with lower socioeconomic status benefited the most from the APPCAP.

5.3. Robustness Checks

In this section, we did a robustness check for our results. First, we experimented with different implementation times of the APPCAP for each region. Second, we test if the APPCAP has an effect on all-cause diseases and on diseases besides respiratory diseases and circulatory system diseases.

5.3.1 Choices of APPCAP Implementation Times

CFPS survey data from 2012, 2014, and 2016 are used in our study. Most regions implemented the APPCAP in 2013 and 2014, and thus, we considered only two different implementation times: advanced implementation time by half a year and advanced implementation time by one year. Table 7 summarizes the estimates. All the coefficients were statistically insignificant.

5.3.2 All-cause Diseases and Non-respiratory, Non-circulatory System Diseases

We consider all-cause diseases. Variables take the value of 1 if the respondent was diagnosed with any type of disease in the last 6 months, and 0 otherwise. The regression results in column 1 of Table 8 show that the APPCAP led to an insignificant reduction in all-cause diseases. Second, we consider all-cause diseases besides respiratory diseases and circulatory system diseases. The regression results in column 2 of Table 8 indicate that environmental policies had no significant effect on diseases other than those related to the respiratory and circulatory systems.

6. CONCLUSION

This study evaluates the impacts of environmental regulation on chronic health conditions by using the most powerful and effective environmental regulation in China—the APPCAP.

We attempt to investigate the causal effect of environmental regulation on air pollution-related diseases by taking advantage of the fact that the APPCAP was implemented at different times by different administrative divisions. We applied difference-in-differences model and found that the APPCAP significantly improved air quality and led to a significant decline in the risk of respiratory diseases and circulatory system diseases. When we analyze by subset of populations, we found that its effects vary across subsets of the population defined by gender, age, education, and annual household income. This provides strong evidence that the APPCAP has greatly improved the health of people with lower socioeconomic status.

There are limited quantitative epidemiological studies on the causal relationship between environmental regulations and their impacts on health.

Although the APPCAP has successfully improved air quality, particulate air pollution has still not reached the official minimum air quality standards, and thus, it still demands attention from the government. For example, efforts can be made to increase the awareness of the public by issuing air quality alerts (Henry and Gordon, 2003). Our study provides a reference for developing countries, that are experiencing serious air pollution problems, when formulating environmental preservation policies.

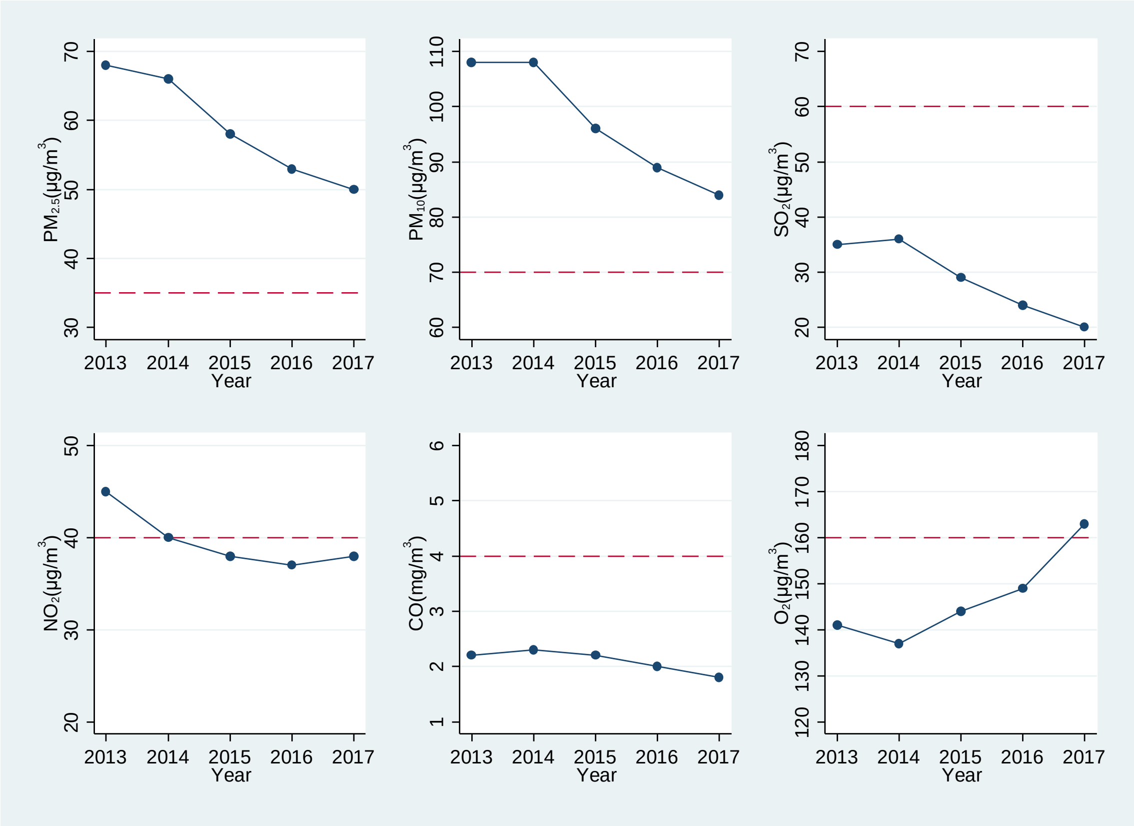

Figure 1.
Annual Average Concentration of the Six Criteria Air Pollutants in the Key Cities of 25 Administrative Divisions, 2013–2017.

Data Source: Resources and environmental part of China Statistical Yearbook 2013–2018.
Notes: The red dashed lines indicate the Grade-2 air pollutant concentration limit in China's ambient air quality standards. The Grade-2 air pollution concentration standard applies to residential areas, industrial areas, and rural areas.

Table 1. Environmental preservation policy by administrative division

Administrative Division	APPCAP Enacted Time	Duration
Shandong	July 2013	~2020
Beijing	September 2013	~2017
Hebei	September 2013	~2017
Shanxi	October 2013	~2017
Shanghai	November 2013	~2017
Anhui	December 2013	~2017
Chongqing	December 2013	~2017
Shannxi	December 2013	~2017
Jilin	December 2013	~2017
Zhejiang	December 2013	~2017
Jiangxi	December 2013	~2017
Hunan	December 2013	~2017
Gansu	December 2013	~2017
Hubei	January 2014	~2017
Jiangsu	January 2014	~2017
Guangdong	February 2014	~2017
Sichuan	February 2014	~2017
Yunnan	March 2014	~2017
Guizhou	May 2014	~2017
Fujian	June 2014	~2017
Heilongjiang	March 2016	~2018
Henan	July 2016	~2017
Liaoning	April 2017	~2020
Guangxi	June 2017	~2020

Source: Official website of each administrative division.
Notes: Thirty-one administrative divisions have implemented their own environmental protection policies. The survey data at the individual level covered 25 administrative divisions. From these 25, we excluded Tianjin because it had implemented environmental regulations prior to the APPCAP. Therefore, 24 administrative divisions are used in our analysis.

Table 2. Descriptive statistics: CFPS2012, 2014, 2016

Variables	Mean	Standard Deviation
<u>Dependent Variables</u>		
Respiratory diseases (percent)	1.45	0.12
Circulatory system diseases (percent)	2.85	0.17
<u>Independent Variables</u>		
<u>*Weather*</u>		
Mean Temperature (°C)	21.37	9.62
Humidity (percent)	72.05	8.76
Precipitation (mm)	124.33	106.90
Sunshine (hour)	180.60	53.57
<u>*Demographic characteristics of CFPS surveys*</u>		
Age (year)	49.92	14.94
Primary school or less	30.11	0.46
Middle/high school	30.76	0.46
University or above	39.13	0.49
Mean annual household income[a] (log form)	7.28	4.50
<u>*Unit: percent*</u>		
Male	48.09	0.50
Urban	46.63	0.50
Labor force participation	72.80	0.44
Married	85.69	0.35
<u>*Base-level health condition (CFPS 2010)*</u>		
Self-rated health status[b]	4.17	1.01
Observations	*64,663*	

Notes: [a]Logarithm form of annual household income (CNY). Standard deviation is reported in parentheses.
[b]Self-rated health status in CFPS 2010 survey, ranging from 1 to 5. The higher the score, the better the health status.

Table 3. Linear probability estimates of the effects of the APPCAP on respiratory diseases and circulatory system diseases

	Air Pollution-related Diseases (× 100)	
Variables	Respiratory	Circulatory
APPCAP	-0.33*	-0.58**
	(0.20)	(0.27)
Age	0.03***	0.11***
	(0.00)	(0.01)
Male	0.35***	-0.67***
	(0.11)	(0.13)
Urban	0.13	0.28**
	(0.11)	(0.14)
Married	-0.20	-1.02***
	(0.18)	(0.17)
Cohabitation	-0.07	-0.76
	(0.85)	(1.16)
Divorced	-0.05	-1.20**
	(0.43)	(0.52)
Widowed	-0.58*	-0.78*
	(0.30)	(0.45)
Employed	-0.25**	-1.83***
	(0.13)	(0.18)
Ln(Annual household income)	0.01	0.07***
	(0.01)	(0.01)
Middle/high school	-0.16	0.39**
	(0.13)	(0.17)
University or above	-0.03	0.24
	(0.20)	(0.26)
Self-rated health status (unhealthy)	0.04	-2.29**
	(0.56)	(0.91)
Self-rated health status (relative unhealthy)	-1.33**	-3.37***
	(0.56)	(0.92)
Self-rated health status (fair)	-1.62***	-5.43***
	(0.52)	(0.85)
Self-rated health status (healthy)	-2.08***	-6.47***
	(0.52)	(0.85)
Constant	2.29*	-1.32
	(1.32)	(1.82)
R-squared	0.01	0.04
Observations	64,663	64,663
Weather controls	Y	Y
Region Fixed Effects	Y	Y
Year×Month Fixed Effects	Y	Y

Notes: The sample includes all respondents in CFPS 2012, 2014, and 2016 in Table 1. The dependent variable is respiratory diseases and circulatory system diseases, which are multiplied by 100; if the respondent had suffered from respiratory diseases or circulatory system diseases in the previous six months, then the variable is coded as a dummy, *respiratory diseases* or *circulatory system diseases* (=1).
Robust standard errors are presented in parentheses.
*, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels, respectively.

Table 4. The effects of the APPCAP on respiratory diseases and circulatory system diseases by gender and age

	Respiratory Diseases ($\times 100$)					
	Total	Female	Male	15<age≤45	45<age≤60	age>60
APPCAP	-0.33*	-0.26	-0.41	-0.07	-0.26	-0.90*
	(0.20)	(0.27)	(0.28)	(0.23)	(0.34)	(0.48)
Dependent variable mean ($\times 100$)	1.45	1.34	1.58	0.91	1.25	2.44
R-squared	0.01	0.01	0.01	0.01	0.01	0.01
	Circulatory System Disease ($\times 100$)					
	Total	Female	Male	15<age≤45	45<age≤60	age>60
APPCAP	-0.58**	-1.23***	0.13	0.02	-0.28	-1.87**
	(0.27)	(0.40)	(0.35)	(0.24)	(0.48)	(0.75)
Dependent variable mean ($\times 100$)	2.85	3.37	2.30	0.57	2.45	6.47
R-squared	0.17	0.05	0.04	0.01	0.02	0.04
Individual characteristics	Y	Y	Y	Y	Y	Y
Base-level health condition	Y	Y	Y	Y	Y	Y
Weather controls	Y	Y	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y	Y	Y
Year×Month Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	64,663	33,567	31,096	25,332	20,988	18,343

Notes: The sample includes all respondents in CFPS 2012, 2014, and 2016 in Table 1. Gender, age, urban, marital status (married, cohabitation, divorced, widowed), employed, logarithm form of annual family income, weather information, and base-level health conditions are included as independent variables.

Robust standard errors are presented in parentheses.

*, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels, respectively.

Table 5. The effects of the APPCAP on respiratory diseases and circulatory system diseases by education level

	Respiratory Diseases ($\times 100$)			
	Total	≤primary school	Middle/High school	College graduate and above
APPCAP	-0.33*	-0.71	-0.22	0.18
	(0.20)	(0.44)	(0.32)	(0.46)
Dependent variable mean ($\times 100$)	1.45	1.62	1.10	1.60
R-squared	0.01	0.01	0.01	0.01
	Circulatory System Diseases ($\times 100$)			
	Total	≤primary school	Middle/High school	College graduate and above
APPCAP	-0.58**	-0.43	-0.81*	-0.13
	(0.27)	(0.62)	(0.45)	(0.63)
Dependent variable mean ($\times 100$)	2.85	3.19	1.90	3.34
R-squared	0.04	0.04	0.04	0.05
Individual characteristics	Y	Y	Y	Y
Base-level health condition	Y	Y	Y	Y
Weather controls	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
Year×Month Fixed Effects	Y	Y	Y	Y
Observations	64,663	19,469	19,891	25,303

Notes: See notes in Table 3.

Table 6. The effects of the APPCAP on respiratory diseases and circulatory system diseases by annual family income

	Respiratory Diseases ($\times 100$)				
	Total	First quartile	Second quartile	Third quartile	Fourth quartile
APPCAP	-0.33*	-0.63*	-0.06	-0.19	-0.56
	(0.20)	(0.34)	(0.47)	(0.37)	(0.39)
Dependent variable mean ($\times 100$)	1.45	1.33	1.85	1.32	1.39
R-squared	0.01	0.01	0.01	0.01	0.01
	Circulatory System Diseases ($\times 100$)				
	Total	First quartile	Second quartile	Third quartile	Fourth quartile
APPCAP	-0.58**	-0.11	-1.29**	-0.44	-0.29
	(0.27)	(0.46)	(0.64)	(0.53)	(0.56)
Dependent variable mean ($\times 100$)	2.85	2.24	3.59	2.69	3.08
R-squared	0.04	0.03	0.04	0.04	0.06
Individual fixed effects	Y	Y	Y	Y	Y
Base-level health condition	Y	Y	Y	Y	Y
Weather controls	Y	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y	Y
Year×Month Fixed Effects	Y	Y	Y	Y	Y
Observations	64,663	18,445	13,914	16,111	16,193

Notes: See notes in Table 3.

Table 7. Robustness check 1

	Air Pollution-related Diseases (× 100)	
Variables	Respiratory	Circulatory
APPCAP (6-month in advance)	-0.05	-0.28
	(0.20)	(0.27)
R-squared	0.01	0.04
Observations	61,751	61,751
APPCAP (1-year in advance)	-0.10	-0.39
	(0.21)	(0.28)
R-squared	0.01	0.04
Observations	58,431	58,431
Individual characteristics	Y	Y
Base-level health conditions	Y	Y
Weather controls	Y	Y
Region fixed effect	Y	Y
Year×Month Fixed Effects	Y	Y

Notes: See notes in Table 3.

Table 8. Robustness check 2

Variables	All-cause diseases (× 100)	Non-air pollution-related disease (× 100)
APPCAP	-0.67	0.19
	(0.60)	(0.55)
R-squared	0.10	0.06
Individual characteristics	Y	Y
Base-level health conditions	Y	Y
Weather controls	Y	Y
Region Fixed Effect	Y	Y
Year×Month Fixed Effects	Y	Y
Observations	64,663	64,663

Notes: See notes in Table 3.

References

Ai, C., & Norton, E. C. (2003). Interaction terms in logit and probit models. Economics Letters, 80(1), 123–129.

Atkinson, R. W., Anderson, H. R., Sunyer, J., Ayres, J., Baccini, M., Vonk, J. M., … Katsouyanni, K. (2001). Acute effects of particulate air pollution on respiratory admissions: Results from APHEA 2 project. American Journal of Respiratory and Critical Care Medicine, 164(10 I), 1860–1866.

Bateson, T. F., & Schwartz, J. (2004). Who is sensitive to the effects of particulate air pollution on mortality? A case-crossover analysis of effect modifiers. Epidemiology, 15(2), 143–149.

Cakmak, S., Dales, R. E., & Judek, S. (2006). Do gender, education, and income modify the effect of air pollution gases on cardiac disease? Journal of Occupational and Environmental Medicine, 48(1), 89–94.

Chay, K., Dobkin, C., & Greenstone, M. (2003). The Clean Air Act of 1970 and Adult Mortality. Journal of Risk and Uncertainty, 27(3), 279–300.

Chen, R., Peng, R. D., Meng, X., Zhou, Z., Chen, B., & Kan, H. (2013). Seasonal variation in the acute effect of particulate air pollution on mortality in the China Air Pollution and Health Effects Study (CAPES). Science of the Total Environment, 450–451, 259–265.

Finkelstein, M. M., Jerrett, M., DeLuca, P., Finkelstein, N., Verma, D. K., Chapman, K., & Sears, M. R. (2003). Relation between income, air pollution and mortality: A cohort study. Canadian Medical Association Journal, 169(5), 397–402.

Goldberg, M. S., Burnett, R. T., Bailar, J. C., Tamblyn, R., Ernst, P., Flegel, K., … Vincent, R. (2001). Identification of persons with cardiorespiratory conditions who are at risk of dying from the acute effects of ambient air particles. Environmental Health Perspectives, 109(SUPPL. 4), 487–494.

Gouveia, N., & Fletcher, T. (2000). Time series analysis of air pollution and mortality: Effects by cause, age and socioeconomic status. Journal of Epidemiology and Community Health, 54(10), 750–755.

Greenstone, B. M., & Hanna, R. (2014). Environmental regulations , air and water pollution, and infant mortality. The American Economic Review , 104(10), 3038–3072.

Henry, G. T., & Gordon, C. S. (2003). Driving less for better air : Impacts of a public informotion campaign. Journal of Policy Analysis and Management, 22(1), 45–63.

Huang, J., Pan, X., Guo, X., & Li, G. (2018). Health impact of China’s Air Pollution Prevention and Control Action Plan: An analysis of national air quality monitoring and mortality data. The Lancet Planetary Health, 2(7), e313–e323.

Kan, H., London, S. J., Chen, G., Zhang, Y., Song, G., Zhao, N., … Chen, B. (2008). Season, sex, age, and education as modifiers of the effects of outdoor air pollution on daily mortality in Shanghai, China: The Public Health and Air Pollution in Asia (PAPA) study. Environmental Health Perspectives, 116(9), 1183–1188.

Katsouyanni, K., Touloumi, G., Samoli, E., Gryparis, A., Le Tertre, A., Monopolis, Y., … Schwartz, J. (2001). Confounding and effect modification in the short-term effects of ambient particles on total mortality: Results from 29 European cities within the APHEA2 project. Epidemiology, 12(5), 521–531.

National Bureau of Statistics of China. 2013-2018. "China Statistical Yearbook." Available at http://www.stats.gov.cn/english/statisticaldata/annualdata/.

O'Neill, M. S., Jerrett, M., Kawachi, I., Levy, J. I., Cohen, A. J., Gouveia, N., … Zanobetti, A. (2003). Health, wealth, and air pollution: Advancing theory and methods. Environmental Health Perspectives, 111(16), 1861–1870.

Peng, R. D., Dominici, F., Pastor-Barriuso, R., Zeger, S. L., & Samet, J. M. (2005). Seasonal analyses of air pollution and mortality in 100 US cities. American Journal of Epidemiology, 161(6), 585–594.

Rodríguez-Villamizar, L. A., Rojas-Roa, N. Y., Blanco-Becerra, L. C., Herrera-Galindo, V. M., & Fernández-Niño, J. A. (2018). Short-term effects of air pollution on respiratory and circulatory morbidity in Colombia 2011–2014: A multi-city, time-series analysis. International Journal of Environmental Research and Public Health, 15(8).

Sacks, J. D., Stanek, L. W., Luben, T. J., Johns, D. O., Buckley, B. J., Brown, J. S., & Ross, M. (2011). Particulate matter-induced health effects: Who is susceptible? Environmental Health Perspectives, 119(4), 446–454.

Sun, X. 2014. "China's Ministry of Environmental Protection announced that in 2013, only 3 cities in 74 cities met the air quality standard." People's Daily Online, March 26, 2014. Available at http://env.people.com.cn/n/2014/0326/c1010-24735839.html.

Watts, J. 2012. "Air pollution could become China's biggest health threat, expert warns." The Guardian, March 16, 2012. Available at http://www.theguardian.com/environment/2012/mar/16/air-pollution-biggest-threat-china.

Wong, T., Lau, T., Yu, T., Neller, A., Wong, S., Tam, W.,& Pang, S. (1999). Air pollution and hospital admissions for respiratory and cardiovascular diseases in HongKong. Occupational and Environmental Medicine, 56(10), 679–683.

World Health Organization. 2014. "Air quality deteriorating in many of the world's cities." Media Center. Accessed May 20, 2019. Available at http://www.who.int/mediacentre/news/releases/2014/air-quality/en/.

World Health Organization. 2016. "Ambient air pollution: A global assessment of exposure and burden of disease." Accessed December 11, 2019. Available at https://apps.who.int/iris/handle/10665/250141.

World Health Organization. 2018. "Ambient (outdoor) air quality and health." Accessed May 20, 2019. Available at http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

World Health Organization Occupation and Environmental Health Team. 2006. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005: Summary of risk assessment. WHO Press. Available at https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf?sequence=1&isAllowed=y.

Zhao, H., Che, H., Ma, Y., Wang, Y., Yang, H., Liu, Y., … Zhang, X. (2017). The relationship of PM variation with visibility and mixing-layer height under hazy/foggy conditions in the multi-cities of northeast China. International Journal of Environmental Research and Public Health, 14(5), 471.

APPENDIX

Table A1. Air pollution-related diseases (ICD-10 Version: 2010)

Disease Type	References
<u>Respiratory Disease</u>	
All respiratory diseases	Atkinson et al., 1999; Zanobetti et al., 2009; Villamizar et al., 2018; WHO, 2016; Wong et al., 1999
Upper Respiratory Tract Infections	Joo et al., 2015; Li et al., 2017; Teng et al., 2017; Trevino, 1996; Zheng et al., 2017
Influenza	Pan et al., 2016
Pneumonia	Sahuquillo-Arce et al., 2017
Lower respiratory diseases	Zheng et al., 2017; Horne et al., 2018
Emphysema	Wang et al., 2019
Chronic Obstructive Pulmonary Disease	Bloemsma et al., 2016; DeVries et al., 2017; Li et al., 2017; Sinmoni et al., 2015
Asthma	Fan et al., 2016; Guarnieri et al., 2014; Sinmoni et al., 2015
<u>Circulatory System Disease</u>	
All circulatory system diseases	Barnett, 2006; Brook et al., 2004; Kaufman et al., 2016; Zanobetti et al., 2009; Villamizar et al., 2018; WHO, 2016; Wong et al., 1999
Hypertension	Dong et al., 2013; Sanidas et al., 2017
Angina Pectoris	Cesaroni, 2014; Sanidas et al., 2017
Acute Myocardial Infarction	Cesaroni, 2014; Liu et al., 2017; Liu et al., 2018; Sanidas et al., 2017
Heart Diseases	Morris, 2001; Shah et al., 2013
Stroke	Shah et al., 2015; Tsai, 2003

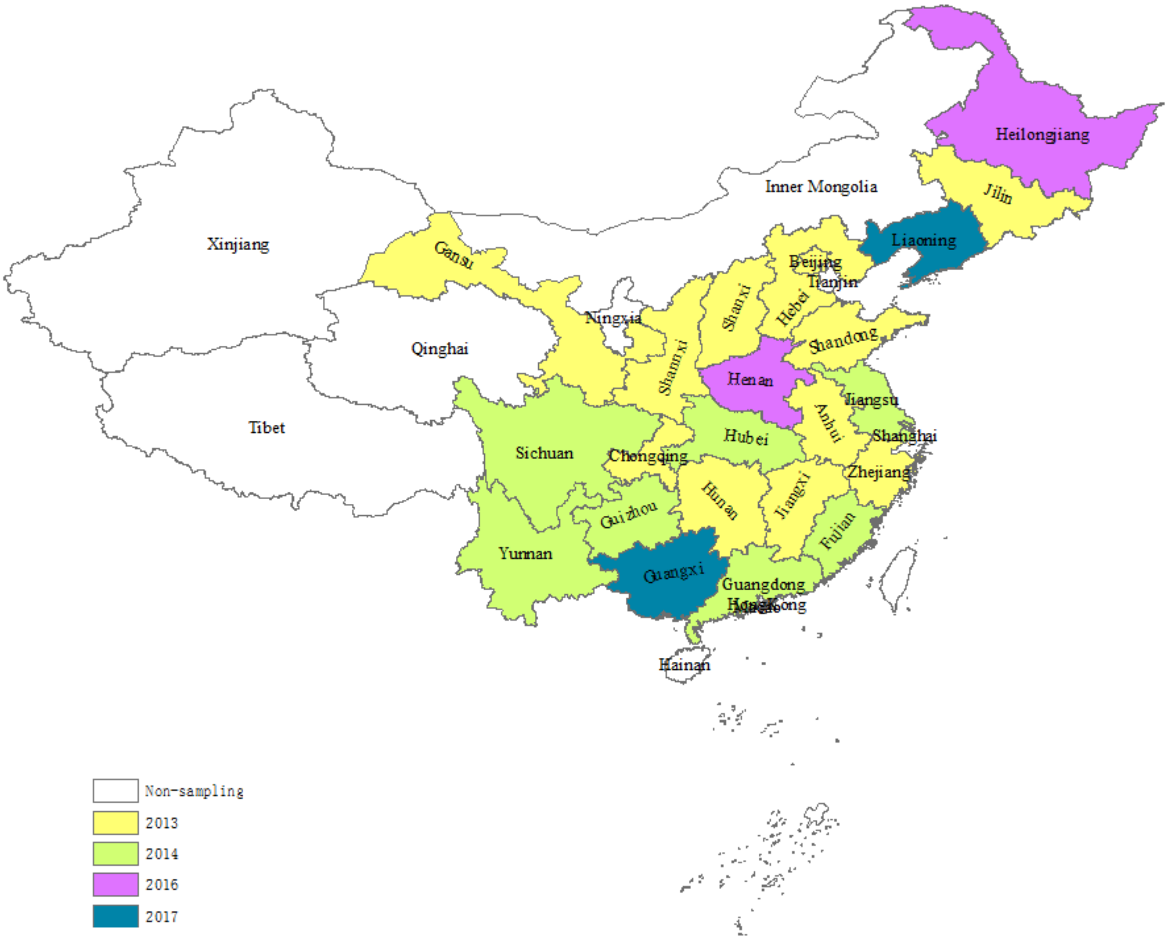

Figure A1. Provincial APPCAP Policy Implementation Time

Data Source: Official website of each administrative division

Notes: Thirty-one administrative divisions have implemented their own environmental protection policies at different times. The survey data at the individual level covered 25 administrative divisions. From these 25, we excluded Tianjin because it implemented environmental regulations before the APPCAP. Therefore, 24 administrative divisions (shown in color) are used in our analysis.

Reference

Atkinson, R. W., Anderson, H. R., Sunyer, J., Ayres, J., Baccini, M., Vonk, J. M., … Katsouyanni, K. (2001). Acute effects of particulate air pollution on respiratory admissions: Results from APHEA 2 project. *American Journal of Respiratory and Critical Care Medicine*, *164*(10 I), 1860–1866.

Barnett, A. G., Williams, G. M., Schwartz, J., Best, T. L., Neller, A. H., Petroeschevsky, A. L., & Simpson, R. W. (2006). The effects of air pollution on hospitalizations for cardiovascular disease in elderly people in Australian and New Zealand cities. *Environmental Health Perspectives*, *114*(7), 1018–1023.

Bloemsma, L. D., Hoek, G., & Smit, L. A. M. (2016). Panel studies of air pollution in patients with COPD: Systematic review and meta-analysis. *Environmental Research*, *151*, 458–468.

Brook, R. D., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., … Tager, I. (2004). Air pollution and cardiovascular disease: A statement for healthcare professionals from the expert panel on population and prevention science of the American Heart Association. *Circulation*, *109*(21), 2655–2671.

Cesaroni, G., Forastiere, F., Stafoggia, M., Andersen, Z. J., Badaloni, C., Beelen, R., … Peters, A. (2014). Long term exposure to ambient air pollution and incidence of acute coronary events: Prospective cohort study and meta-analysis in 11 european cohorts from the escape project. *BMJ (Online)*, *348*(January), 1–16.

DeVries, R., Kriebel, D., & Sama, S. (2017). Outdoor Air Pollution and

COPD-Related Emergency Department Visits, Hospital Admissions, and Mortality: A Meta-Analysis. *COPD: Journal of Chronic Obstructive Pulmonary Disease*, *14*(1), 113–121.

Dong, G. H., Qian, Z. M., Xaverius, P. K., Trevathan, E., Maalouf, S., Parker, J., … Simckes, M. (2013). Association between long-term air pollution and increased blood pressure and hypertension in China. *Hypertension*, *61*(3), 578–584.

Fan, J., Li, S., Fan, C., Bai, Z., & Yang, K. (2016). The impact of PM2.5 on asthma emergency department visits: a systematic review and meta-analysis. *Environmental Science and Pollution Research*, *23*(1), 843–850.

Guarnieri, M., & Balmes, J. R. (2014). Outdoor air pollution and asthma. *The Lancet*, *383*(9928), 1581–1592.

Horne, B. D., Joy, E. A., Hofmann, M. G., Gesteland, P. H., Cannon, J. B., Lefler, J. S., … Arden Pope, C. (2018). Short-term elevation of fine particulate matter air pollution and acute lower respiratory infection. *American Journal of Respiratory and Critical Care Medicine*, *198*(6), 759–766.

Joo, Y. H., Lee, S. S., Han, K. Do, & Park, K. H. (2015). Association between chronic laryngitis and particulate matter based on the korea national health and nutrition examination survey 2008-2012. *PLoS ONE*, *10*(7), 1–10.

Kaufman, J. D., Adar, S. D., Barr, R. G., Budoff, M., Burke, G. L., Curl, C. L., … Watson, K. E. (2016). Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. *The Lancet*, *388*(10045), 696–704.

Li, R., Jiang, N., liu, Q., Huang, J., Guo, X., Liu, F., & Gao, Z. (2017). Impact of air pollutants on outpatient visits for acute respiratory outcomes. *International Journal of Environmental Research and Public Health*, *14*(1), 47.

Liu, H., Tian, Y., Cao, Y., Song, J., Huang, C., Xiang, X., … Hu, Y. (2018). Fine particulate air pollution and hospital admissions and readmissions for acute myocardial infarction in 26 Chinese cities. *Chemosphere*, *192*, 282–288.

Liu, H., Tian, Y., Xiang, X., Sun, K., Juan, J., Song, J., … Hu, Y. (2017). Air Pollution and Hospitalization for Acute Myocardial Infarction in China. *American Journal of Cardiology*, *120*(5), 753–758.

Morris, R. D. (2001). Airborne particulates and hospital admissions for cardiovascular disease: A quantitative review of the evidence. *Environmental Health Perspectives*, *109*(SUPPL. 4), 495–500.

Pan, Q., Tang, Z., Yu, Y., Xi, M., & Zang, G. (2016). Haze and influenza A virus: Coincidence or causation? *American Journal of Infection Control*, *44*(8), 959–960.

Rodríguez-Villamizar, L. A., Rojas-Roa, N. Y., Blanco-Becerra, L. C., Herrera-Galindo, V. M., & Fernández-Niño, J. A. (2018). Short-term effects of air pollution on respiratory and circulatory morbidity in colombia 2011–2014: A multi-city, time-series analysis. *International Journal of Environmental Research and Public Health*, *15*(8).

Sahuquillo-Arce, J. M., Ibáñez-Martínez, E., Hernández-Cabezas, A., Ruiz-Gaitán, A., Falomir-Salcedo, P., Menéndez, R., & López-Hontangas, J. L. (2017). Influence of environmental conditions and pollution on the incidence of Streptococcus pneumoniae infections. *ERS Monograph*, *3*(4), 0–2.

Sanidas, E., Papadopoulos, D. P., Grassos, H., Velliou, M., Tsioufis, K., Barbetseas, J., & Papademetriou, V. (2017). Air pollution and arterial hypertension. A new risk factor is in the air. *Journal of the American Society of Hypertension*, *11*(11), 709–715.

Shah, A. S. V., Langrish, J. P., Nair, H., McAllister, D. A., Hunter, A. L., Donaldson, K., … Mills, N. L. (2013). Global association of air pollution and heart failure: A systematic review and meta-analysis. *The Lancet*, *382*(9897), 1039–1048.

Shah, A. S. V., Lee, K. K., McAllister, D. A., Hunter, A., Nair, H., Whiteley, W., … Mills, N. L. (2015). Short term exposure to air pollution and stroke: Systematic review and meta-analysis. *BMJ (Online)*, *350*(January).

Simoni, M., Baldacci, S., Maio, S., Cerrai, S., Sarno, G., & Viegi, G. (2015). Adverse effects of outdoor pollution in the elderly. *Journal of Thoracic Disease*, *7*(1), 34–45.

Teng, B., Zhang, X., Yi, C., Zhang, Y., Ye, S., & Wang, Y. (2017). The Association between Ambient Air Pollution and Allergic Rhinitis : Further Epidemiological Evidence from Changchun , Northeastern China. *International Journal of Environmental Research and Public Health*, *14*(3), 226.

Trevino, R. J. (1996). Air pollution and its effect on the upper respiratory tract and on allergic rhinosinusitis. *Otolaryngology - Head and Neck Surgery*, *114*(2), 239–

241.

Tsai, S. S., Goggins, W. B., Chiu, H. F., & Yang, C. Y. (2003). Evidence for an Association Between Air Pollution and Daily Stroke Admissions in Kaohsiung, Taiwan. *Stroke*, *34*(11), 2612–2616.

Wang, M., Aaron, C. P., Madrigano, J., Hoffman, E. A., Angelini, E., Yang, J., … Barr, R. G. (2019). Association between long-term exposure to ambient air pollution and change in quantitatively assessed emphysema and lung function. *JAMA - Journal of the American Medical Association*, *322*(6), 546–556.

Wong, T., Lau, T., Yu, T., Neller, A., Wong, S., Tam, W., & Pang, S. 1999. Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong. *Occupational and Environmental Medicine*, *56*(10), 679–683.

Zanobetti, A., Franklin, M., Koutrakis, P., & Schwartz, J. (2009). Fine particulate air pollution and its components in association with cause-specific emergency admissions. *Environmental Health: A Global Access Science Source*, *8*(1).

Zheng, P. wen, Wang, J. bing, Zhang, Z. yu, Shen, P., Chai, P. fei, Li, D., … Chen, K. (2017). Air pollution and hospital visits for acute upper and lower respiratory infections among children in Ningbo, China: A time-series analysis. *Environmental Science and Pollution Research*, *24*(23), 18860–18869.