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The health impacts of two policies regulating SO_2 air pollution: Evidence from China

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ABSTRACT

In developing countries widespread air pollution poses a major threat to public health calling for effective environmental regulation. This paper adds to the limited literature on the health impact of different environmental regulations. Using data from eight waves of the China Health and Nutrition Survey (1993–2015), we employ a difference-in-differences model to investigate the health impact of two policies combatting SO_2 air pollution: the command-and-control environmental regulation represented by the Two Control Zones (TCZ) and the market-oriented environmental regulation represented by the SO_2 Emissions Trading Scheme (ETS). The main findings are that the TCZ policy resulted in a 39% reduction in the 4-week prevalence of air pollution-related diseases through channels such as reducing industrial SO_2 emissions and industrial fumes emissions, and increasing individuals' amounts of physical exercise. In contrast, the ETS had no positive health effects, likely due to imperfect market mechanisms and environmental policy uncertainties. The health impact of the TCZ was most pronounced for respiratory illnesses, and was increasing over the period during which the policy was implemented. The positive health impact is stronger for outdoor, less educated, and lower income workers. Residents in Eastern regions and urban areas (especially the rural hukou holders living there) benefitted more from the environmental regulation.

1. Introduction

China has achieved rapid economic development in the past 40 years of reforms and opening up to foreign markets, but the country's high economic growth rate has also brought about increasing environmental pollution and ecological crises, which have triggered policies to mitigate them. This paper is concerned with air pollution-related environmental regulation and its environmental and health consequences. The primary source of pollution in China is coal consumption in both manufacturing and in heating. Coal consumption took off especially after China's entry to the WTO at the end of 2001. Coal production is clustered geographically, as is manufacturing using coal, and hence there are also large differences in air pollution; see Zheng and Kahn (2017) for a recent review. Today, China is the largest coal consumer in the world, accounting for nearly 50% of global coal consumption.[1] The burning of coal produces large amounts of pollutants such as SO_2, and China has consequently become one of the countries with the most severe SO_2

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[1] See https://www.eia.gov/international/data/world#/

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pollution rates. Air pollution hampers the sustainable development of society and economy as it increases the risk of respiratory diseases, heart disease, and lung cancer (Chen & Chen, 2014; Chen, Li, & Yao, 2018; Chen, Shao, Tian, Xie, & Yin, 2017; Schlenker & Walker, 2016), increases mortality for all age groups: infants and adults, as well as the elderly (Chay & Greenstone, 2003a ; Deryugina, Heutel, Miller, Molitor, & Reif, 2019; Sun & Cheng, 2021) and leads to a marked reduction in life expectancy (Chen, Ebenstein, Greenstone, & Li, 2013; Ebenstein, Fan, Greenstone, He, & Zhou, 2017). Air pollution also been shown to cause lower worker productivity (Chang, Graff Zivin, Gross, & Neidell, 2019).

In order to reduce SO_2 emissions and improve air quality, the Chinese government has successively implemented command-and-control environmental regulations as well as market-oriented environmental regulations. The command-and-control environmental regulation sets emission standards that enterprises must abide or emission reduction goals that regions must achieve. The most important regulation is the Two Control Zones (TCZ) policy that was pursued from 1998 to 2010. The government classified certain regions where acid rain or SO_2 pollution is serious into Acid Rain Control and SO_2 Control Zones, respectively, and regulated the SO_2 emission levels in these zones. As is well known, the mandatory nature of the policy and the one-size-fits-all requirements are associated with high compliance costs and hinder the efficient use of resources, which may lower economic growth of enterprises and regions (Li, Qiao, & Shi, 2019; Stewart, 1991).

In 2007, the Chinese Ministry of Finance and the State Environmental Protection Administration (SEPA)[2] successively approved the introduction of SO_2 Emissions Trading Schemes (ETS) in 11 provinces. This started China's large-scale trial of market-oriented environmental regulation. The ETS uses market signals and other economic tools to induce enterprises to reduce their emission of pollutants and to internalize the costs to the external environment. The aim is to achieve the goal of pollution emission control while maximizing firms' own interests. It has been argued that the ETS has not played an important role, and that market-oriented environmental regulation in many places in China only exists formally (Chang & Wang, 2010; Tu & Shen, 2014; Zhang et al., 2016), due to a lack of accurate emissions-measurement systems, and legal support in punitive mechanisms, as well as the complexity of cooperation between different departments.

Environmental regulations in developing countries are mostly relatively weak, and the research on the health effects of environmental regulations is scarce. Although studies have shown that environmental regulations have reduced infant mortality or premature mortality in India and China (Greenstone & Hanna, 2014; Tanaka, 2015; Zheng et al., 2017), the environmental regulation examined in these studies is of the command-and-control type and evidence on the health impacts of market-oriented environmental regulation is lacking. The negative effects of air pollution on people's health are not likely to manifest themselves only as dramatic outcomes such as mortality, but can also take other forms that reduce people's quality of life. As most studies focus on infant mortality, they do not capture any possible long-term impacts of environmental regulation. Studies have shown that differences in mortality closely mirror differences in SO_2 emissions (Azimi, Feng, & Zhou, 2019), and that air pollution increases health inequality between different income groups (Yang & Liu, 2018), suggesting that the impact of environmental policy may differ in the population.

In this paper, we study the health impacts of environmental regulations, with a special focus on determining which of the two forms of environmental regulation practiced in China has been more effective from a health perspective in reducing air pollution-related diseases. In addition, we look into whether the short- and long-term effects of the policies differ and whether and how the policy impacts differ between population groups and between regions?

To answer these questions, we make use of panel data from the China Health and Nutrition Survey (CHNS) collected in 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015, which are merged with data on air pollution and environmental policies implemented at the provincial or prefectural levels. We employ a difference-in-differences model to investigate the health impact of two policies combatting SO_2 air pollution. The CHNS covers nine provinces (Liaoning, Heilongjiang, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, and Guizhou) and uses a multi-stage, random cluster method to conduct a stratified sampling survey of cities and counties in each province, according to income levels (high, medium, and low). The survey data contain rich socio-economic and population health information at the individual, family, and community levels.

The results indicate that the TCZ policy reduced SO_2 emission intensity, resulting in a 39% reduction in the 4-week prevalence of air pollution-related diseases. In contrast, the ETS had no positive health effects. The health impact of the TCZ is most pronounced for respiratory illnesses and is increasing over the period during which the policy was implemented. The positive health impact was stronger for individuals who have been more exposed to pollution and for less educated and lower income workers. The Eastern region and the urban areas (especially the rural hukou holders living in urban areas) benefitted more from the environmental regulation.

Our study makes three contributions to the existing literature. Several studies have been concerned with how environmental policies impact various environmental outcomes. There are fewer studies of the impact of environmental regulations on residents' health, and even fewer studies that have compared the health effects of different types of environmental regulations. The evidence there is has examined command-and-control environmental regulations (Greenstone & Hanna, 2014; Tanaka, 2015), whereas our study also deals with the impact of market-oriented policies and aims at comparing their impacts. A second contribution is that our study provides evidence of the impact of environmental regulation on air pollution-related diseases. The richness of the CHNS longitudinal survey data and the exact timing and geographic locations of policies matched with the micro data allow us to control for many confounding factors that are not accounted for in earlier studies, which often have focused on infant mortality to avoid these problems (Chay & Greenstone, 2003b). Third, we use the longitudinal information in the data to examine differences over time (accounting for the accumulated policy impacts) as well as differences between different air pollution-related diseases, population

[2] In July 2008, the State Environmental Protection Administration (SEPA) was changed to the Ministry of Environmental Protection (MEP) and became an integral part of the State Council. In March 2018, the MEP was replaced by the Ministry of Ecology and Environment (MEE).

groups, and regions.

The remainder of the paper is structured as follows. Section 2 briefly introduces China's air pollution status and the environmental regulations that will be analyzed in this article. Section 3 describes the data and the empirical model employed in our analyses. Section 4 reports the empirical results, tests the parallel trends assumption, and analyses the influence channels. Section 5 provides some further results, including heterogeneity analyses for different periods, diseases, population groups, and regions. Section 6 concludes and offers some policy implications.

2. Environmental regulation in China

2.1. TCZ and SO_2 ETS

As a result of the country's rapid economic development and urbanization, China's energy demand has increased substantially and is expected to continue to grow in the future. Under the coal-based energy structure, air pollution, especially SO_2 emissions, has increased rapidly. Thus, already early during the economic reform period, total SO_2 emissions nearly doubled from 13.25 million tons in 1985 to 23.7 million tons in 1995, posing a serious threat to quality of people's life and public health. Then, China joined the WTO in December 2001, and the subsequent export boom brought about more production and increased air pollution. As can be seen from Fig. 1 below, a large increase in emissions took place after 2002. As from 2008 to 2009, there has been a clear decline in SO_2 emissions, due to the wider application of desulfurization devices in power plants, but levels remain high.

As a first attempt to control pollution emissions, the Chinese government introduced the Air Pollution Prevention and Control Law (APPCL) in 1987. This law provided general guidelines for air pollution control, but lacked practical guidance for local governments and likely had only a limited (if any) effect.

In 1998, the State Council of China approved the implementation of the Plan for Dividing the Acid Rain Control Zone and Sulfur Dioxide Control Zone issued by the SEPA. In this plan, regions with pH values for precipitation less than or equal to 4.5 were defined as Acid Rain Control Zones, and regions with average annual concentrations of SO_2 in ambient air exceeding the national Class II standard of 60 g/m^3 in the most recent three years were defined as SO_2 Control Zones. Consequently, 175 cities in 27 provinces, autonomous regions and municipalities directly under the central government were included in the Two Control Zones (TCZ), covering 11% of the national land area, 39% of the national population and 67% of the national GDP. The implementation time and the geographical distribution of TCZ policy are shown in Figs. 2 and 3, respectively.

The goals of the TCZ were as follows: by the year 2000 (short-term goal), industrial pollution sources emitting SO_2 should reach the emission standards, that is, the emission quota allocated to the enterprises in each region by the state environmental management authority. The concentration of SO_2 in the ambient air in the municipalities directly under the central government, provincial capitals, special economic zones, coastal open cities, and key tourist cities should reach the national environmental quality standards, and the deteriorating trend of acid rain in the Acid Rain Control Zone should be broken. By the year 2010 (long-term goal), total emissions of SO_2 should be limited to the levels prevalent in the year 2000; The concentration of SO_2 in urban ambient air should reach the national environmental quality standard, and the area with precipitation pH value less than 4.5 in the Acid Rain Control Zone should be significantly lower than was the case in the year 2002. In 2002, the State Council further approved the Tenth Five-Year Plan for the Prevention and Control of Acid Rain and Sulfur Dioxide Pollution in the Two Control Zones, stating that the medium-term goal of TCZ policy is to reduce SO_2 emissions in the two control zones by 20% by 2005 compared to 2000. The long-term goal of the TCZ was set for 2010, and since then, no new goals have been set for the TCZ. The focus of air pollution prevention and control in China has gradually

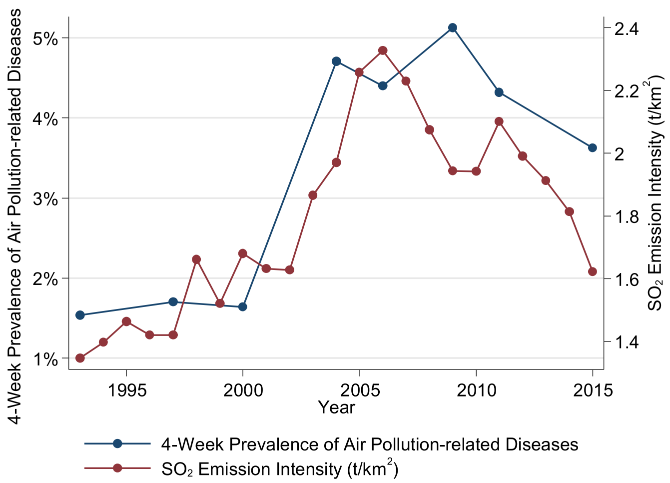

Fig. 1. Time Trends of SO_2 Emission Intensity and Air Pollution-related Diseases, 1993–2015.
Note: The SO_2 emission intensity is national-level data. The 4-week prevalence of air pollution-related diseases is calculated from the CHNS survey.
Source: Authors' compilation of data from the China Health and Nutrition Survey (CHNS) and China Statistical Yearbook.

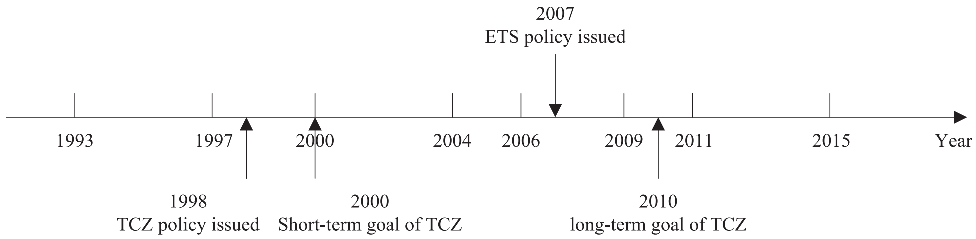

Fig. 2. The Timeline of Two Control Zones and SO_2 Emission Trading Scheme Policies.

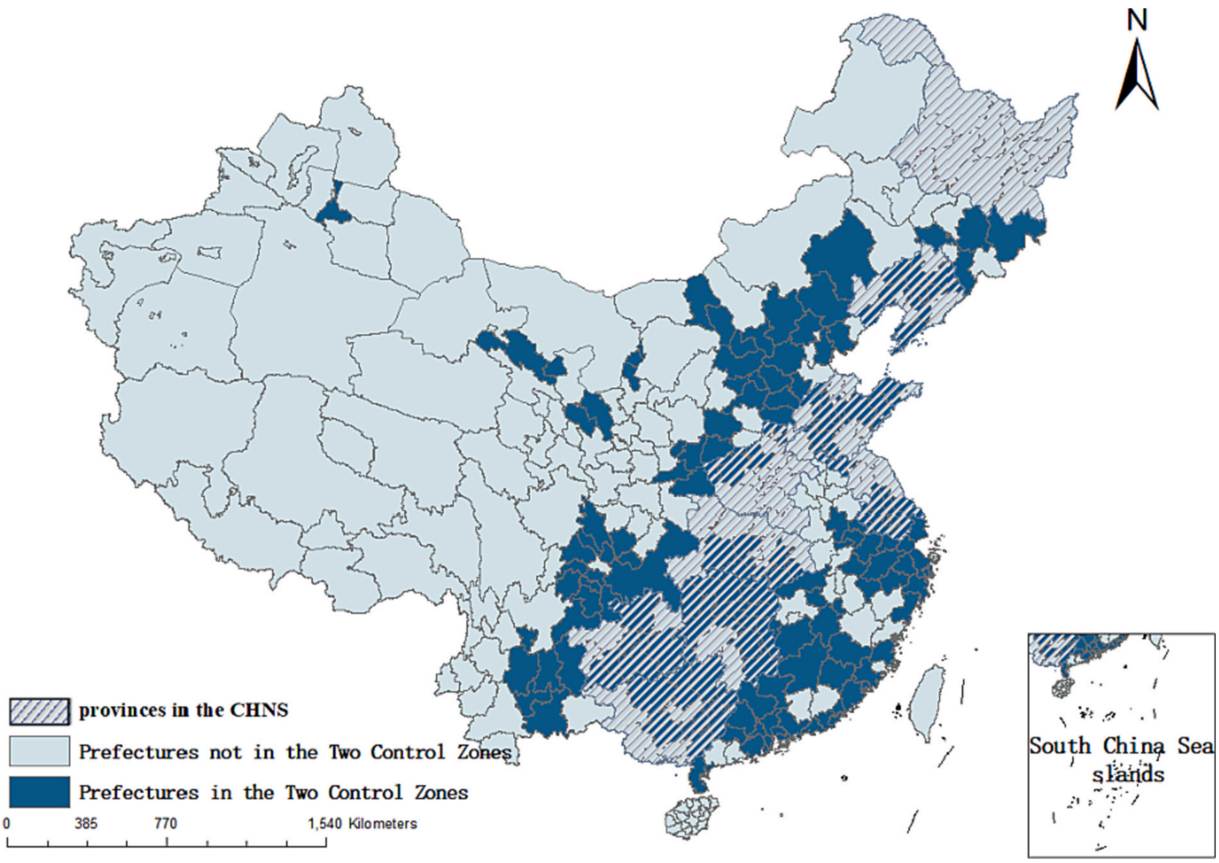

Fig. 3. Distribution of Prefectures in Two Control Zones and Provinces in CHNS.
Source: The figure is drawn using a standard map from the China National Catalogue Service for Geographic Information (Drawing Review No. GS (2016)2556), and the base map has not been modified.

shifted to $PM_{2.5}$ and CO_2; see Zheng and Kahn (2017). The TCZ policy during 1998 to 2010 controlled SO_2 emissions by prohibiting the construction and closure of mines and power plants with high sulfur content, building desulfurization and emission reduction facilities, and promoting clean technology. Notably, during this period, China joined the WTO at the end of 2001, and in particular since 2002, there has been a dramatic increase in SO_2 emissions. This is shown in Fig. 1.

At the same time, the Chinese government also considered a market-oriented environmental policy, known as the SO_2 Emissions Trading Scheme (ETS). Already in 1999, the SEPA of China and the United States Environmental Protection Agency (U.S. EPA) began a Feasibility Study in Application of Market Mechanism in Reducing SO_2 Emission in China, which had important discussions on the theories, conditions, basis and methods of emission trading. At the end of 2003, SEPA launched the so called "4 + 3 + 1" program, and selected four provinces (Shandong, Jiangsu, Shanxi, and Henan), three cities (Shanghai, Tianjin, and Liuzhou) and one company (China Huaneng Group) as pilots to study the emissions trading of SO_2. However, the pilot plants were limited to the power plant industry, no emission trading centers were established, and in most pilot provinces no SO_2 emission trading actually took place. In 2007, the Ministry of Finance and the SEPA approved 11 SO_2 emission trading pilot provinces in Jiangsu, Tianjin, Zhejiang, Hebei, Shanxi, Chongqing, Hubei, Shaanxi, Inner Mongolia, Hunan, and Henan. The implementation time and the geographical distribution of

ETS policy are shown in Figs. 2 and 4, respectively.

As shown in Fig. 4, these pilots were distributed between the Eastern, Central, and Western regions, covering 27% of the national land area and 41% of the national population, and accounted for 43% of the national GDP. Large parts of the steel, cement, glass, chemical, and mining industries were located in these provinces. In 2008, Zhejiang Province set up the first municipal emission rights reserve and trading center. The provincial government formulated the emission rights trading management measures and set up relevant supervision institutions. The SO_2 emission trading market was gradually established, and by 2012, all the other pilot provinces had also set up their emission right trading centers. At the end of 2013, emissions trading in the pilot provinces had reached the level of 4 billion yuan. In 2014, the General Office of the State Council issued the Guidance on Further Promoting the Pilot Work of Paid Use and Trading of Pollutant Emission Rights, indicating that the pilot work should be completed by 2017. The 11 pilot provinces set up by the central government in 2007 marked the official start of the cap-and-trade program, so in this paper we take 2007 as the starting time of SO_2 Emission Trading Scheme.

2.2. The effects of the TCZ and SO_2 ETS policies

Although the research on the health effects of environmental regulation in developing countries is still limited, the research on the impact of environmental regulation on air pollution and economic development has been relatively rich. This section will mainly review the effect of TCZ and SO_2 ETS policies.

The TCZ policy has been effective in reducing pollution emissions and improving air quality in terms of reaching its expected goals. According to the National Bureau of Statistics of China, In 2000, the SO_2 concentrations in the 102 TCZ cities reached the national Class II standard, and 84.3% of key polluting enterprises had complied with SO_2 emission standards.[3] In 2010, the SO_2 concentration in 94.9% of the TCZ cities had reached the national Class II standard (Cai, Lu, Wu, & Yu, 2016). The TCZ policy has had positive impacts on health, resulting in a decrease in infant mortality (Tanaka, 2015). Studies show that the TCZ policy increased the production cost of enterprises, lowered the growth of enterprise productivity (Tang, Liu, & Wu, 2020), and led to decline of enterprise production scales and the number of employees in firms affected (Sun, Yang, Ni, & Kim, 2019). Still another effect is a reduction in foreign direct investment (Cai et al., 2016). TCZ has led to the withdrawal of “dirty” industries from the market and significantly promoted the shift in industrial structure from high-pollution and high-emission secondary industries to cleaner service industries (Gao, Wang, Zhang, & Zong, 2019; Ye & Lin, 2020).

The evidence on policy effects of SO_2 ETS is more mixed. Some studies find that the SO_2 ETS in 2007 not only reduces pollution emissions, but also significantly improves the total factor productivity (TFP) of enterprises in the pilots through incentives for innovation activities and efficiency improvements, and realizes the “win-win” of economic growth and pollution reduction. This verifies Porter Hypothesis (Ren, Zhang, Liu, & Chen, 2019). Other studies demonstrate that although China’s SO_2 ETS may have decreased SO_2 emission and SO_2 intensity, it has had a negative impact on the growth of green TFP (Hou, Wang, Du, & Zhang, 2020), and the cost-saving effects of pollution prevention and control are smaller than expected (Liu, Owens, Yang, & Zhang, 2020; Zhang, Zhang, Liu, & Bi, 2013). Some studies even find that the ETS has actually have given rise to an increase in SO_2 emissions and higher average pollution prevention costs in the pilots (Li & Shen, 2008; Tu & Shen, 2014). However, no studies focus on the health effects of SO_2 ETS.

Thus, the TCZ policy has had a positive pollution reduction effect, whereas the effect of SO_2 ETS is somewhat controversial. Has the TCZ policy also led to improved residents’ health? Are there signs of SO_2 ETS policy effects on residents’ health? That is the topic of the following sections. We begin by describing the data and our empirical strategy.

3. Variables, data, and empirical strategy

3.1. Data sources

Data at the individual, household and community levels are all from the China Health and Nutrition Survey (CHNS). The CHNS is an international cooperation project jointly carried out by the Carolina Population Center (UNC) at the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Health (NINH) at the Chinese Center for Disease Control and Prevention (CCDC). It employs a multistage, random cluster process to draw the samples surveyed in each of the provinces. Counties in the nine provinces were stratified by income (low, middle, and high), and a weighted sampling scheme was used to randomly select four counties in each province. In addition, the provincial capital and a lower-income city were selected when feasible. Villages and townships within the counties and urban and suburban neighborhoods within the cities were selected randomly. The first wave of the survey was in 1989, and this has been followed by nine subsequent surveys: 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015. Thus, 26 years of health information of the respondents provides a relatively long time-period for the study of the changes in residents’ health before and after the implementation of environmental regulations.

Our research sample consists of eight surveys from 1993 to 2015 (the first two waves from 1989 and 1991 are considerably smaller than later ones, and are therefore not used), covering prefectures (including prefecture-level cities and autonomous prefectures) in

[3] See http://www.stats.gov.cn/tjsj/tjgb/ndtjgb/qgndtjgb/200203/t20020331_30014.html (in Chinese).

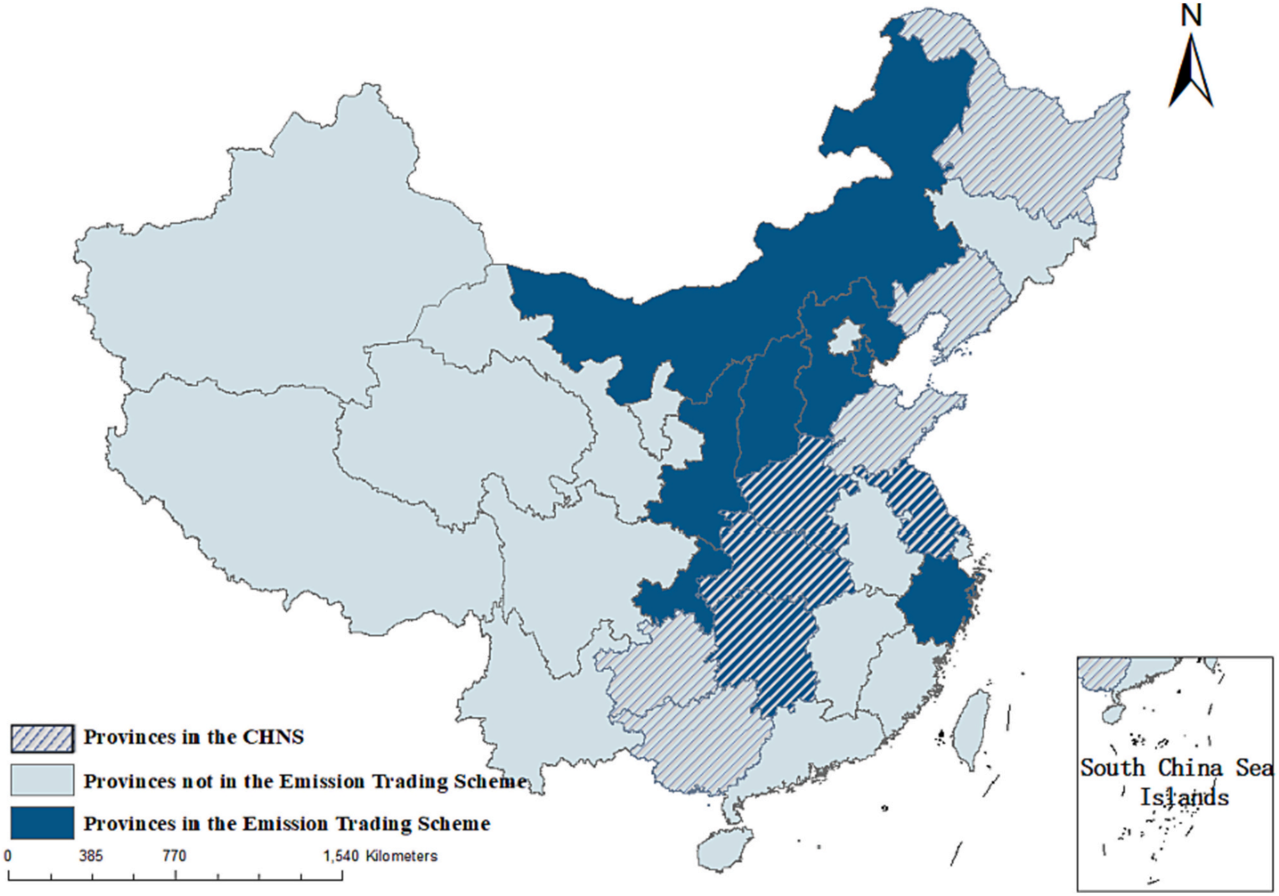

Fig. 4. Distribution of Provinces in SO_2 Emission Trading Scheme and Provinces in CHNS.
Source: The figure is drawn using a standard map from the China National Catalogue Service for Geographic Information (Drawing Review No. GS(2016)2556), and the base map has not been modified.

nine provinces: Liaoning, Heilongjiang, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, and Guizhou.[4] The nine provinces span regions from different parts of China, and differ with respect to economic development, public resources, and health services, and the provinces include regions that belong to the treatment and control groups for both TCZ and ETS. Their geographical locations are shown as the shaded regions in Figs. 2 and 3. The number of observations and dropout rates in treatment groups and control groups are shown in Table A1 in the Appendix.

The data about the prefectures have been obtained from China City Statistical Yearbook, China Statistical Yearbook for Regional Economy and statistical yearbooks of various provinces and municipalities.

3.2. Variables

The dependent variable in our regression analyses is individual health (*Disease*). Evidence from environmental science, public health, and economics shows that air pollution not only increases the morbidity and mortality of respiratory diseases, heart-related diseases (Schlenker & Walker, 2016), and cancer (especially lung cancer) (Chen et al., 2017), but also leads to a higher risk of mental or neurological diseases such as depression, anxiety (Chen, Oliva, & Zhang, 2018; Pun, Manjourides, & Suh, 2017), cognitive decline (Zhang, Chen, & Zhang, 2018), and dementia (Oudin, Forsberg, et al., 2016). In order to measure the effect of environmental regulations of SO_2 on residents' health, we select the incidence of four types of air pollution-related diseases among the individuals in our sample: respiratory diseases, heart disease, cancer, and mental / neurological diseases. Among them, mental / neurological diseases encompass mental/psychiatric disorders, mental retardation, and neurological disorders.

The data source on individuals' health is the China Health and Nutrition Survey (CHNS) questionnaire.[5] More specifically, we construct an indicator variable that takes the value of 1 if the respondent has been sick (acutely or chronically) during the four weeks preceding the interview[6] and is diagnosed by a doctor with one of the above-mentioned air pollution-related diseases; otherwise its value is 0. Fig. 1 shows the development of the 4-week prevalence of air pollution-related diseases during the period 1993 to 2015. This shows strong similarities with the SO_2 emission intensity, indicating that the "4-week prevalence of air pollution-related diseases" could well reflect changes in air quality.

Corresponding 4-week prevalence indicators, separately for respiratory diseases, heart disease, tumors, and mental/neurological diseases are shown in Fig. 5. Although there are notable differences in the prevalence of the diseases (consistently highest for respiratory diseases and lowest for tumors), they are all displaying a common increasing trend which is especially visible during years 2000–2004 when SO_2 emission intensity increased rapidly.

The key independent variable in our regressions is the regulatory status of environmental regulation of the prefecture the CHNS respondent is living in at the time of the interview denoted by $TCZ \times T_1$ and $ETS \times T_2$, respectively. If the prefecture where the respondent is located is within the TCZ specified in the plan, it is regarded as the treatment group, and the value of the *TCZ* dummy is 1, and zero otherwise. Of the sample prefectures in the sample, 56.25% are covered by the TCZ. If the interview year is before 1998, the TCZ policy has not been implemented and the dummy T_1 takes on the value 0, otherwise it is equal to unity.

As the ETS policy has been implemented in the pilot provinces beginning in 2007, the ETS dummy equals unity in four provinces (Jiangsu, Henan, Hubei, and Hunan), which make up the treatment group. The other five provinces (Liaoning, Heilongjiang, Shandong, Guangxi, and Guizhou), constitute the control group, and consequently for individuals living in them, the *ETS* dummy equals 0. If the interview year is before 2007 when the ETS was not yet implemented, T_2 takes the value of 0 and equals 1 thereafter.

In addition, based on the theory of demand for health (Grossman, 1972), demographic characteristics, living habits, local economic conditions, and medical services that may affect residents' health are included as control variables. Specifically, the individual-level controls include age, education, marital status, log individual annual net real income,[7] smoking, and medical insurance coverage. The community-level controls are the community health quality scores and sanitation scores calculated by the CHNS. The regional level controls include log GDP per capita, population density, and doctor density. Industrial SO_2, industrial fumes, and physical exercise are used in the study of the influence channels, explained below.

Definitions of the variables and summary statistics are shown in Table 1. More details about the data set are provided in Appendix Table A1 –Table A3. Table A2 shows that for both TCZ and ETS, before the implementation of the policy there was no significant difference in the 4-week prevalence of air pollution-related diseases between the control and the treatment group. That is, the parallel trends assumption is supported.

[4] The Liaoning province was absent from the 1997 survey, and was replaced by Heilongjiang province. Beijing, Shanghai, Chongqing, Yunnan, Zhejiang and Shaanxi joined the survey as from 2011. As we do not have health information of the respondents before the implementation of environmental regulations, we do not include data from these provinces in our sample.

[5] The full list of disease categories in the CHNS questionnaire is: infectious/parasitic disease, heart disease, tumor, respiratory disease, injury, alcohol poisoning, endocrine disorder, hematological disease, mental/psychiatric disorder, mental retardation, eye/ear/nose/throat/teeth disease, digestive disease, urinary disease, sexual dysfunction, obstetrical/gynecological disease, neonatal disease, dermatological disease, muscular/rheumatological disease, genetic disease, old age/mid-life syndrome, other.

[6] The CHNS asks about the prevalence of these diseases during the past 4 weeks in order to reduce the recall bias.

[7] Deflated to 2015 prices. For individuals with no income we replace it with the value of 1 in order to be able to carry out the logarithmic transformation of the income variable.

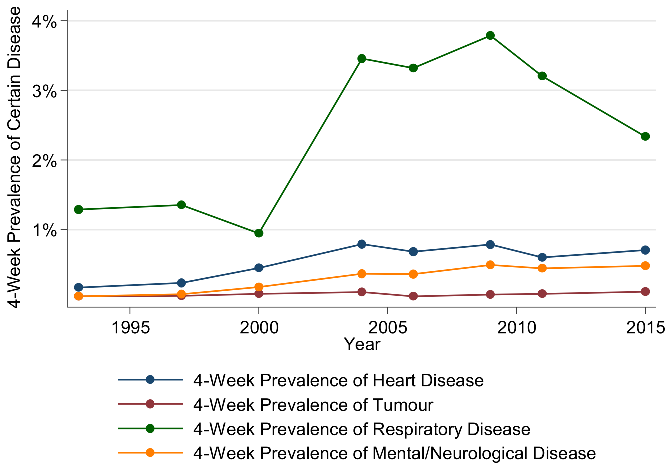

Fig. 5. Prevalence of Four Air Pollution-related Diseases, 1993–2015.
Source: Authors' compilation from the CHNS.

Table 1
Main Variables and Summary Statistics.

	Variables	Definition	Mean	SD	Min	Max
Air Pollution- related Health Problems	Diseases	4-week prevalence of air pollution-related diseases	3.162%	0.175	0	1
	Respiratory disease	4-week prevalence of respiratory	2.177%	0.146	0	1
	Heart disease	4-week prevalence of heart disease	0.606%	0.078	0	1
	Tumor	4-week prevalence of tumor	0.077%	0.028	0	1
	Mental/ Neurological disease	4-week prevalence of mental/neurological disease	0.302%	0.055	0	1
Individual Controls	Age	Age of the respondents	46.171	14.903	7	100
	Education	The highest level of education. 0= no completed education, 1 = primary school, 2 = middle school, 3 = high school, 4 = technical or vocational degree, 5 = university /college degree, 6=Master's degree or higher	1.848	1.384	0	6
	Marriage	1 = married, 0 = never married, divorced, widowed or separated	0.848	0.359	0	1
	Log income	Log of individual real annual net income	8.733	1.797	0	14.088
	Smoke	1 = smoking now, 0 = no smoking now	0.302	0.459	0	1
	Medical insurance	1 = have medical insurance, 0 = no medical insurance	0.563	0.496	0	1
Community Controls	Health	Community health quality score calculated by CHNS	5.546	2.406	0	10
	Sanitation	Sanitation score calculated by CHNS	6.237	3.122	0	10
Prefecture Controls	Log GDP per capita	Log of real GDP per capita (Ten thousand yuan)	1.326	0.646	−1.627	3.290
	Population density	Ten thousand persons per square kilometer	0.046	0.025	0.006	0.136
	Doctor density	Doctors per ten thousand residents	17.581	8.424	5.472	63.461
Channel Variables	Log Industrial SO_2	Log of industrial SO_2 emission (tons/km^2)	1.385	1.209	−2.860	5.033
	Log Industrial fumes	Log of industrial fumes emission (tons/km^2)	0.785	1.020	−2.811	4.551
	Log physical exercise	Log of physical exercise time per week (minutes)	3.074	1.843	0	8.029

3.3. *Empirical strategy*

We employ a two-way fixed-effects difference-in-differences model (DiD) to evaluate the effects of the policies on the prevalence of individuals' air pollution related illnesses. As the aim of both TCZ and ETS policies is to reduce SO_2 emissions, their impacts can be analyzed by the same empirical model. The empirical model is specified as follows:

$$Diseases_{it} = \beta_0 + \beta_1 TCZ_i \times T_1 + \beta_2 ETS_i \times T_2 + \beta_3 Var_{it} + \beta_4 Var_{ct} + \beta_5 Var_{pt} + u_i + u_t + \varepsilon_{it} \quad (1)$$

where, $Diseases_{it}$ is a dummy variable equal to unity if the respondent has suffered from an air pollution-related disease during the past four weeks, otherwise it is zero. TCZ_i (ETS_i) is an indicator variable that takes on the value of one if individual i lives in a prefecture covered by the TCZ (ETS); T_1 (T_2) is an indicator variable equal to one for years in or after 1998 (2007). The interaction $TCZ_i \times T_1$ ($ETS_i \times T_2$) is the main variable of interest. It captures the change of the residents' health in the treatment group (TCZ or ETS) before and after the implementation of the policy compared to the change of the residents' health in the control group (non-TCZ or non-ETS) before and after the implementation of the policy. Vectors Var_{it}, Var_{ct}, Var_{pt} contain controls for individual, community, and prefecture characteristics, respectively. u_i represents individual fixed effects. u_t is a time-fixed effect, and the year-month fixed effect is adopted in order to control the influence of different years and seasons (at the time of the interview) on individual health. Finally, ε_{it} is the error term. Standard errors are clustered at the prefecture level.

TCZ and ETS were implemented at different points in time (only partially overlapping), and so we chose two different time-periods in order to better identify the policy effects. As the TCZ policy began in 1998 and ended in 2010, we use the data from CHNS waves 1993, 1997, 2000, 2004, 2006, and 2009 for the estimations. As the ETS policy was implemented in 2007, in the analysis of its impact we use the waves 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015.

To examine whether TCZ and ETS influenced each other, the interaction of the two policies $(TCZ_i \times T_1) \times (ETS_i \times T_2)$ is entered into the model, as shown in Eq. (2).

$$Diseases_{it} = \beta_0 + \beta_1 TCZ_i \times T_1 + \beta_2 ETS_i \times T_2 + \beta_3 (TCZ_i \times T_1) \times (ETS_i \times T_2) + \beta_4 Var_{it} + \beta_5 Var_{ct} + \beta_6 Var_{pt} + u_i + u_t + \varepsilon_{it} \quad (2)$$

4. Empirical results

Following the empirical strategy outlined above, we first present the estimated main impacts of the two different environmental regulations on individuals' health. Then, we conduct parallel trends tests. Next, we study the underlying channels of the environmental regulation's effect on individuals' health. In addition, we discuss reasons for the lack of an impact of the environmental regulation on individuals' health.

4.1. Baseline regression results

Table 2 provides estimates of the impacts of the two different environmental regulations on individuals' health. The first three columns report the effects of the TCZ. Here, ETS is entered as a control variable, and the main focus is on the coefficient of TCZ. The last three columns of Table 2 report the effects of the ETS, and here the TCZ is entered as a control variable. The coefficient of $TCZ \times T_1$ (or $ETS \times T_2$) is the policy effect, which reflects the change in the 4-week prevalence of disease within the treatment group before and after the implementation of the policy minus the change in the 4-week prevalence of disease within the control group before and after the implementation of the policy.

The findings from Table 2 are as follows: First, it can be seen from columns (1), (3) and (5) that the TCZ policy is associated with a significant reduction in the 4-week prevalence of air pollution-related diseases, while the SO_2 ETS has no significant impact on residents' health. Moreover, the estimate is positive. Thus, China's command-and-control environmental regulation seems to have been more efficient than the market-oriented environmental regulation in reducing air pollution related illness.

Second, according to columns (2), (4) and (6), the interaction between the two environmental regulations is not significant. That is, when both are implemented, they are neither facilitating nor counteracting each other.

Third, from the results in column (1), we may note that controlling for the characteristics of individuals, communities and prefectures, the effect of the TCZ policy on the 4-week prevalence rate of disease is −0.0124, that is, after the implementation of the TCZ policy, the prevalence rate of air pollution related diseases decreased by approximately 1.24 percentage points, which is equivalent to a decrease in the prevalence rate of the magnitude of 39%.[8] Thus, this is a sizable effect.

Fourth, according to Table A4 in the Appendix, there was no significant difference in the 4-week prevalence of air pollution-related diseases between individuals who dropped out and the remaining observations, except in 2011 when the average 4-week prevalence of air pollution-related diseases was higher for the individuals who dropped out. Thus, for the ETS regions, health was poorer among the dropouts in 2011. Excluding the observations from 2011 to 2015 gives an insignificant estimate for $ETS \times T_2$, indicating that the poorer health among the drop-outs does not affect the conclusions.

In order to ensure that the improvement of residents' health in the Two Control Zones is caused by the TCZ policy, we carry out counterfactual tests (reported in Fig. A1 and Table A5 in the Appendix) and a series of robustness checks (Table A6 in the Appendix) to rule out the possibility of confounding factors influencing the baseline estimates in Table 2. The results from the baseline regressions turn out to be very robust.

4.2. Parallel trends tests

An important prerequisite for the DiD model is the parallel trends assumption. According to this idea, prior to when the policy was introduced, the trends in the prevalence of the diseases in the control and treatment groups should be parallel. However, since the TCZ policy was implemented in 1998, there are only two waves of data (1993 and 1997) prior to the introduction of the policy, it is difficult to directly observe trends. Instead, we employ an event study approach. More precisely, we include additional variables constructed as interactions of the treatment group and year dummies, see (3):

[8] The 4-week prevalence rate of air pollution-related diseases in the sample is 3.2%. 1.24%/3.16% = 39%

Table 2
Baseline Estimates of the Effect of Different Environmental Regulations on Individuals' Health.

Variables	Effect of TCZ (1993–2009)		Effect of ETS (1993–2015)		Effect of ETS (1993–2011)	
	(1)	(2)	(3)	(4)	(5)	(6)
$TCZ \times T_1$	−0.0124**	−0.0094	−0.0110**	−0.0099*	−0.0110**	−0.0101*
	(0.0057)	(0.0056)	(0.0053)	(0.0055)	(0.0052)	(0.0055)
$ETS \times T_2$	0.0058	0.0210	0.0065	0.0096	0.0030	0.0060
	(0.0095)	(0.0175)	(0.0059)	(0.0114)	(0.0067)	(0.0127)
$(TCZ \times T_1) \times (ETS \times T_2)$	No	−0.0257	No	−0.0052	No	−0.0051
		(0.0179)		(0.0118)		(0.0135)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Nb of observations	36,196	36,196	48,070	48,070	43,256	43,256
R^2	0.3125	0.3127	0.2813	0.2813	0.2940	0.2940

Note: The "controls" in this table include individual controls, community controls and prefecture controls. *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. The p value for the coefficient of $TCZ \times T_1$ in column (2) is 0.103, which is almost significant at the 10% level. Robust standard errors clustered at the prefecture level are reported in parentheses.

$$
\begin{aligned}
Diseases_{it} = \beta_0 + \beta_1 TCZ_i \times T_1^{-5} + \beta_2 TCZ_i \times T_1^{2} + \beta_3 TCZ_i \times T_1^{6} + \beta_4 TCZ_i \times T_1^{8} + \beta_5 TCZ_i \times T_1^{11} \\
+\beta_6 ETS_i \times T_2 + \beta_7 Var_{it} + \beta_8 Var_{ct} + \beta_9 Var_{pt} + u_i + u_t + \varepsilon_{it}
\end{aligned}
\tag{3}
$$

where, as before, TCZ_i is the dummy for whether resident i is in the TCZ. $T^{\pm m}$ is the year dummy. T^{-m} takes on 1 if it's m years before the implementation of the TCZ policy, and T^{+m} takes on 1 when m years have passed since TCZ was implemented, otherwise, $T^{\pm m}$ takes on a value of zero. The coefficient of $TCZ_i \times T^{\pm m}$ indicates whether the residents' health in the treatment group and the control group is significantly different in the m years before and after the TCZ policy. To visualize the estimated results, we display the effects estimates of $TCZ_i \times T^{\pm m}$ in Fig. 6.

The baseline regression only captures the average impact of environmental regulation on residents' health. The event study method helps us to further study the dynamic effects of environmental regulation, that is, whether health effects change with time and whether they are sustained.

We take the year 1997 (one year before the TCZ policy was implemented) as the reference year and standardize the effects for each year. That is, we set the effect in 1997 to 0, which is represented by a horizontal dashed line for $m = -1$. In addition, the year of implementation (1998) is represented by a vertical dashed line at $m = 0$. As can be seen in Fig. 6, when $m = -5$, the coefficient is not statistically significant at the 10% level, that is, before the TCZ policy, there is no significant difference in the prevalence of air pollution-related diseases between the treatment group and the control group. Thus, the hypothesis of parallel trends cannot be rejected. Two years after TCZ was implemented, the coefficient of $TCZ_i \times T^{+m}$ is significantly negative at the 10% level. During the next six years the size of the coefficient gradually decreases and becomes statistically insignificant. At $m = 11$, the coefficient of $TCZ_i \times T^{+m}$ is significantly negative at the 10% level, indicating that close to the year when the policy is about to end, the health improvement effect is strengthened, possibly due to pressures to reach emission reduction goals.

Similarly, we use the event study to perform a parallel trends test for the ETS. As can be seen in Fig. 7, there is no significant difference in health trends between the treatment group and the control group before nor after the implementation of ETS, indicating

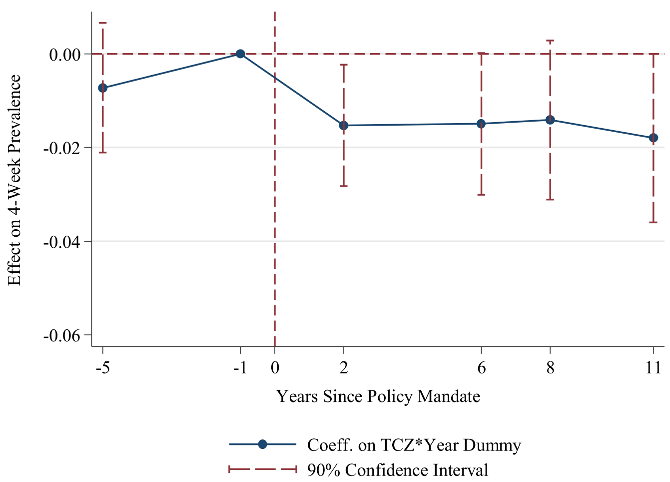

Fig. 6. Event-study Analysis of the Effect of TCZ Policy on Individuals' Health.

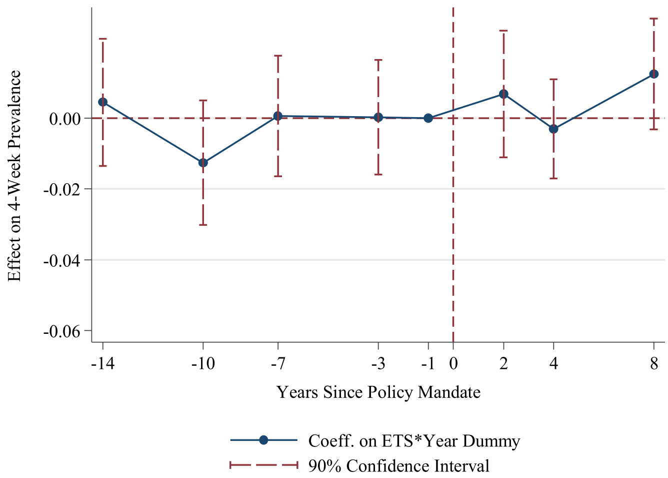

Fig. 7. Event-study Analysis of the Effect of ETS Policy on Individuals' Health.

that the hypothesis of parallel trends in ETS cannot be rejected, and moreover, that the policy effect of ETS is not significant.

We have also added the interaction terms ($TCZ_i \times t$ and $ETS_i \times t$) to the baseline model to control for pre-existing trends; see eq. (4). According to the empirical results in Table 3, the coefficients of $TCZ \times T_1$ are significantly negative, whereas the coefficients of $ETS \times T_2$ do not differ significantly from zero, lending further support to our baseline DiD model estimates.

$$Diseases_{it} = \beta_0 + \beta_1 TCZ_i \times T_1 + \beta_2 ETS_i \times T_2 + \beta_3 TCZ_i \times t + \beta_4 ETS_i \times t + \beta_5 Var_{it} + \beta_6 Var_{ct} + \beta_7 Var_{pt} + u_i + u_t + \varepsilon_{it} \quad (4)$$

4.3. The influence channels of the TCZ policy on Individuals' health

In this section, we explore three potential mediators of the TCZ policy on individuals' health: the reduction in SO_2, the reduction in other air pollutants and the increase in physical exercise.

Reduction in industrial SO_2 emissions is the most direct channel. Industrial production is often associated with many sources of air pollution, and hence the detection indicators of industrial pollutants in China include industrial SO_2, industrial fumes, industrial dust, etc. The TCZ policy may have also reduced the emissions of pollutants other than SO_2 contributing to improvements in individuals' health. Data on *Industrial Fumes* was released before 2010, whereas data on *Industrial Fumes and Dust* are available only after 2010. Consequently, we use the former.

An increase in individuals' physical exercise is another possible mediator. Air pollution significantly reduces outdoor exercise activities (Neidell, 2009). As a result, if TCZ policies improved air quality, they may have contributed to an increase in the time that individuals spend in physical exercise, which in turn may have reduced the prevalence of various diseases.

The estimates in Table 4 shows that in addition to a decrease in industrial SO_2 emissions the policy has been associated with a decrease in industrial fumes emissions and an increase in time individuals spend on physical exercise time. These are but two examples of mediators of the TCZ policy's impact on individuals' health. There could of course have been more. One hard-to-quantify channel is the awareness of the importance of protecting oneself from air pollutants.

4.4. Why is there no health impact of the SO_2 ETS policy?

The baseline regression shows that the SO_2 ETS in China has had no significant impact on public health. Some have even argued that the SO_2 ETS may be the first failed attempt to introduce experience from foreign countries into China's environmental policy (Shin, 2013). What are the possible reasons for the failure of China's SO_2 ETS?

The first is the imperfect market mechanism. Only a few pilot regions of SO_2 emissions trading in China, such as Chongqing, have adopted the enterprise-to-enterprise trading mode, while the rest of the pilots implemented a government-to-enterprise trading mode. Under this, the government intervenes in SO_2 emissions trading as a "middleman", and the price of emission permits can be fixed or auctioned. As a consequence, they often deviate from the market price (Zhang et al., 2016). Another possible reason is that emissions trading participants have not yet formed a unified and effective competitive market. Guidelines of the General Office of the State Council on Further Promoting the Pilot Work of Paid Use and Trading of Emission Permits (2014) point out that, in principle, the trading of emission allowances should be provided within each pilot province,[9] which results in insufficient supply and demand. A third reason is the absence of legislation regulating emissions trading at the national level. Although the SO_2 emissions trading pilot provinces successively promulgated their own emission rights trading management measures, these management measures lacked

[9] See http://www.gov.cn/zhengce/content/2014-08/25/content_9050.htm (in Chinese).

Table 3
Control for the Prior Trends.

Variables	Effect of TCZ (1993–2009)	Effect of ETS (1993–2015)
	(1)	(2)
$TCZ \times T_1$	−0.0128*	−0.0148*
	(0.0074)	(0.0077)
$ETS \times T_2$	0.0039	0.0034
	(0.0079)	(0.0093)
$TCZ \times t$	Yes	Yes
$ETS \times t$	Yes	Yes
Controls	Yes	Yes
Individual FE	Yes	Yes
Year-by-month FE	Yes	Yes
Observations	36,196	48,070
R^2	0.3125	0.2813

Note: The "controls" in this table include individual controls, community controls and prefecture controls. "*t*" represents time trends. *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. Robust standard errors clustered at the prefecture level are reported in parentheses.

Table 4
Influence Channels of Environmental Regulation on Individuals' Health.

Variables	Log Industrial SO_2 (Prefecture Level)	Log Industrial Fumes (Prefecture Level)	Log Physical Exercise (Individual Level)
	(1)	(2)	(3)
$TCZ \times T_1$	−0.2252*	−0.3162**	0.2415***
	(0.1307)	(0.1368)	(0.0937)
$ETS \times T_2$	YES	YES	NO
Controls	YES	YES	YES
Individual/Prefecture FE	YES	YES	YES
Year-by-month FE/Year FE	YES	YES	YES
Observations	364	248	6766
R^2	0.8466	0.8380	0.5817

Note: The time period in column (1) is 1993–2015. Since the statistics on industrial fumes changed after 2010, the time period in column (2) is 1993–2009. Due to the limited availability of data on *Physical Exercise*, the time period in column (3) is 1997–2000. The dependent variables in column (1) and (2) are at the prefecture level, so the controls are at the prefecture level, and prefecture fixed effect and year fixed effect are included. In columns (3) individual fixed effects and year-month fixed effects are included. *, **, and *** denote statistical significances at 10%, 5%, and 1% levels, respectively. Robust standard errors clustered at the prefecture level are reported in parentheses.

unified standards in the initial allocation of emission permits, pricing of emission permits and transaction supervision. Moreover, local governments often put economic interests ahead of environmental issues, leading to slow progress and poor implementation of SO_2 emissions trading (Chang & Wang, 2010). Last but not least, China's environmental policy is associated with considerable uncertainty. Research shows that when enterprises perceive uncertainty in environmental supervision and management, their willingness to reduce pollution will decrease (Zhang, Fei, Zhang, & Liu, 2015). As a response to uncertain future quotas in Five-Year Plans, enterprises with surplus emission rights reduced their sales of current emission permits and hence contributed to less liquidity in the emissions trading market.

The Chinese government has never formally announced its abandonment of the SO_2 ETS policy. Policies to reduce air pollution have increasingly shifted their focus towards fine particulate matter ($PM_{2.5}$) and greenhouse gases, mainly CO_2 (Shi, Feng, Qiu, & Ekeland, 2018; Zheng et al., 2017). Interestingly, China seems not to have given up its plan to implement emissions trade systems. In fact, there are plans for an ETS for CO_2 that would be the largest ETS in the world; see Goulder, Long, Lu, and Morgenstern (2019).

5. Further results on health effects of environmental regulation

Not all are likely to benefit (equally) from environmental regulations. Some groups' health could be more vulnerable to air pollution, for instance because they are more exposed to it, and hence gain more from a given improvement in air quality. The effects of environmental policies may also differ between the short and longer run. If the marginal effect of regulations is decreasing, we would observe large initial impacts. On the other hand, it may take time before regulations have an effect on individuals' health. The short- and long-run effects may moreover differ by type of air pollution-related disease. In order to shed light on these questions, we next carry out heterogeneity analyses for different time periods, and by different air pollution-related diseases, population groups, regions, and hukou status of urban residents.

5.1. Impact of the TCZ on different diseases and in different periods

A large amount of environmental epidemiological evidence has documented that the impact of air pollution on residents' health has an acute as well as a cumulative effect. For example, short-term exposure to air pollution is associated with an increased risk of respiratory and cardiovascular diseases, while long-term exposure can be associated with an increased risk of cognitive and mental disease, lung cancer, and chronic obstructive pulmonary disease (Cox, Liu, Shi, Zu, & Goodman, 2017; Yin, Brauer, & Cohen, 2017). To examine this, we divided the data into different time periods to study the average effect of the TCZ policy on different diseases. These time periods range from 5 years before the implementation of the policy (1993) to 2 years after the implementation of the policy (2000), 6 years after policy implementation (2004), 11 years after policy implementation (2009), 13 years after policy implementation (2011), and 17 years after policy implementation (2015). Recall that the TCZ policy was implemented from 1998 to 2010. Thus, the first three time periods are from the implementation period, while the last two periods include one year and five years when the policy was no longer pursued, respectively. Recall that the TCZ policy was implemented from 1998 to 2010. Thus, the first three time periods are from the implementation period, while the last two periods include one year and five years when the policy was no longer pursued, respectively.

We begin with an overall analysis of air pollution-related diseases for different time-periods. The first row of Table 5 shows the effects of the TCZ policy on all four air pollution-related diseases combined. The estimates are statistically significant, and their absolute values increase from column (1) to column (2), indicating that the health improvement effects of environmental regulation are cumulative. However, the estimates in last two periods are slightly smaller than that in the first three time-periods, indicating that the policy effect decreased when the policy was no longer implemented.

Next, individual diseases are analyzed. In the second row of Table 5, we see the effects of the TCZ policy on respiratory diseases. The effects in columns (1) to (3) are very significant, and their absolute values are increasing, reflecting accumulating impacts of the policy. As for the impact of TCZ on the other diseases, the estimates in rows 3 to 5 are generally smaller in magnitude and mostly do not differ significantly from zero. There are at least two explanations for this. One is that heart disease, tumors and mental/neurological disease may be influenced by many factors, such as genetics and lifestyle (e.g. dietary habits and smoking) (Alberg & Samet, 2003; Goldman & Cook, 1984), and so the impact of air quality improvement on these diseases is limited. Another is that chronic diseases such as heart disease, tumors, and mental/neurological disease take longer time to develop, and environmental regulation has a correspondingly longer time lag in the impact of these diseases that is difficult to capture by the regressions.

In addition, we examined the effect of the ETS policy on different diseases in different periods and found (in estimations not shown) only a tiny effect on tumors two years after the ETS was implemented. Other effects are also small and, moreover, insignificant.

All in all, the results point to respiratory diseases as the main driver of results of the health effects of the PCZ policy. As we saw in Fig. 5 above, this is also the air pollution-related disease with the highest prevalence rate.

5.2. The impact of the TCZ policy on different population groups

Did the TCZ policy affect the air pollution-related health of all population groups equally? To answer this question, we grouped the individuals according to occupation, gender, age, education, and income to analyze whether the impact of TCZ differed among people with different demographic and socioeconomic characteristics. As we compare groups the individuals in which may differ, a bootstrapping procedure (Cleary, 1999; Efron & Tibshirani, 1993) is employed to test the significance of observed differences in coefficient estimates ($TCZ \times T_1$) between groups. The null hypothesis is that there is no significant difference in the estimated coefficients across groups, and this procedure is repeated 1000 times; the test statistic used is the empirical P-value.

Pollution abatement is an important way for TCZ policy to improve residents' health. The exposure to air pollution varies across occupations, and the impact of the TCZ policy may therefore differ as well. In general, outdoor workers have higher pollution exposure and indoor workers have lower. We take a sample of working respondents aged 16 and over and divide them into workers in outdoor workplaces (farmers, fishermen, hunters, army officers, police officers, ordinary soldiers, policemen and drivers) and indoor workplaces (administrators/executives/managers, office staff, and service workers), respectively.[10] From the estimates set out in columns (1) and (2) of Table 6, it can be seen that the coefficient of $TCZ \times T_1$ is significantly negative and larger in magnitude for outdoor workers, while it does not differ from zero for the indoor workers. The empirical P-value test rejects the null hypothesis that there is no significant difference in the estimated coefficients between two groups at 1% level.

Turning to look at gender differences in the impact of the TCZ on air pollution-related illnesses, we may first note that the difference between men and women with respect to exposure is not large; in our sample the proportions are 73.5% for men and 70.8% for women, respectively. Columns (3) and (4) of Table 6 give the estimates by gender. The coefficient of $TCZ \times T_1$ is negative, significant, and larger in magnitude for men than for women, for whom it is smaller and not statistically significant. The empirical p-value shows that the coefficient of $TCZ \times T_1$ between two groups is significantly different at the 1% level.

We employ a division into four age groups according to the respondent's age when the policy was implemented: juveniles (0–17 years old), young people (18–44 years old), middle-aged people (45–59 years old), and elder adults (60 years old and above). The estimates in columns (5)–(8) show that the TCZ policy has had a significant health improving effect for people aged 18–44 and 45–59, but has had no significant effect for the two other age groups. To further test whether there is a significant difference in the coefficient

[10] Athletes, actors, musicians, factory workers, professional and technical workers, and other professions are removed from the sample because their occupational environments are both indoor and outdoor and it is difficult to determine the level of pollution exposure.

Table 5
The Effect of the TCZ Policy on Different Diseases in Different Periods.

Periods	2 Years After the TCZ	6 Years After the TCZ	11 Years After the TCZ	13 Years After the TCZ	17 Years After the TCZ
	1993–2000	1993–2004	1993–2009	1993–2011	1993–2015
	(1)	(2)	(3)	(4)	(5)
	Air Pollution-Related Diseases				
$TCZ\times T_1$	−0.0126*	−0.0138**	−0.0124**	−0.0110**	−0.0110**
	(0.0067)	(0.0058)	(0.0057)	(0.0052)	(0.0053)
	Disease 1: Respiratory Disease				
$TCZ\times T_1$	−0.0099*	−0.0101*	−0.0110*	−0.0099*	−0.0093*
	(0.0057)	(0.0054)	(0.0057)	(0.0050)	(0.0048)
	Disease 2: Heart Disease				
$TCZ\times T_1$	0.0031	0.0017	0.0016	0.0014	0.0011
	(0.0021)	(0.0017)	(0.0019)	(0.0019)	(0.0019)
	Disease 3:Tumors				
$TCZ\times T_1$	−0.0004	−0.0004	−0.0002	0.0000	0.0001
	(0.0007)	(0.0006)	(0.0008)	(0.0007)	(0.0006)
	Disease 4:Mental/Neurological Disease				
$TCZ\times T_1$	0.0004	−0.0009	−0.0003	−0.0001	−0.0002
	(0.0013)	(0.0012)	(0.0010)	(0.0011)	(0.0011)

Note: *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. Robust standard errors clustered at the prefecture level are reported in parentheses.

of $TCZ\times T_1$ between "18-59 years old" and "other ages", we divided the individuals into two groups: "18–59 years old" and "0-17 or over 60 years old", respectively. The empirical P-value shows that the coefficient of $TCZ\times T_1$ between 18 and 59 and other ages is significantly different. People aged 18 to 59, who make up the primary labor force, have higher pollution exposure and therefore benefit more from the improvement in air quality. As they are not old, the positive effects last into the future. Most of the juveniles aged 0–17 are not working, and when they are, special labor protection is required according to the Labor Law. Therefore, juveniles are likely less exposed to air pollution and less affected by it. There can be many reasons for why the TCZ policy had no significant impact on people over 60 years old. People over 60 have more underlying diseases which reduces the positive impact of improved air quality. At the same time, people over 60 have retired,[11] and for them the reduction in air pollution came too late (and to a too little extent) to mitigate the accumulated harmful effects of earlier exposure to air pollutants.

The next characteristics we look at are the level of education and economic conditions (household income), respectively. Both have been considered as important determinants of health (Ross & Wu, 1995; Smith, 1998). We group individuals by their highest level of education and define education below high school as lower-level education. Only respondents who are employed and aged at least 18 are included in the estimation sample. The estimates are displayed in columns (11) and (12). Columns (13) and (14) distinguish between persons in households where the per capita income is below or above the sample average in each year. The estimates imply that the TCZ policy improved the health of individuals with lower education and lower incomes. For persons with higher education and higher incomes the estimated impact is not significantly different from zero. This is not surprising, as persons with a higher level of education and higher incomes are less exposed to air pollution, are more likely to be aware of how to protect themselves from it, and also have more resources to invest in their health.

As can be seen from the second row in the table, the estimates for ETS are insignificant throughout. Thus, only the TCZ had a certain health compensation effect for some population groups, that is, the populations which are exposed to higher pollution or more vulnerable to air pollution benefitted more from the TCZ policy.

5.3. *The impact of the TCZ policy across regions*

We have seen that the impact of the TCZ policy on individuals' health differed markedly across population groups. However, residential location may also play a role. In this section, different economic geographical regions and urban / rural conditions are grouped to study the regional differences of TCZ and their potential causes.

The National Bureau of Statistics of China groups provinces into four broad regions: the Eastern, Central, Western, and Northeast Regions. The Eastern Region was at the forefront of China's economic reforms and opening-up policy, especially in the coastal areas where Special Economic Zones, Coastal Open Cities and Coastal Economic Open Zones were located. The Eastern Region is the most economically developed region in China, and it is also the most polluted (Liang, Wang, Wang, & Ma, 2019; Zheng & Kahn, 2017). Therefore, we combine the other three regions into a single second group alongside the Eastern Region. The coverage of TCZ differs among regions; the share of prefectures covered by the TCZ in the Eastern Region and the other Region is 54.8% and 38.6%, respectively.

According to the estimates in columns (1) and (2) of Table 7, the TCZ policy significantly reduced the prevalence of air pollution-related diseases in both regions. The estimate for Eastern China is larger, and according to the empirical P-value test, significantly so.

[11] The legal retirement age in China is 60 for men and 50 for women, or 55 for men and 45 for women who are engaged in particularly strenuous physical work or work harmful to health.

Table 6
Health Effects of the Environmental Regulations on Different Population Groups.

Variables	Occupation		Gender		Age						Education		Household Income Per Capita	
	Indoor Workers	Outdoor Workers	Female	Male	0–17	18–44	45–59	Over 60	18–59	0–17, over 60	Lower	Higher	Lower	Higher
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
$TCZ \times T_1$	0.0120	−0.0198***	−0.0109	−0.0131*	0.0153	−0.0128*	−0.0143*	−0.0075	−0.0133**	−0.0068	−0.0131**	−0.0004	−0.0194*	−0.0063
	(0.0123)	(0.0064)	(0.0083)	(0.0071)	(0.0314)	(0.0072)	(0.0072)	(0.0206)	(0.0060)	(0.0194)	(0.0064)	(0.0086)	(0.0098)	(0.0135)
$ETS \times T_2$	−0.0014	0.0114	0.0185	−0.0059	−0.0494	−0.0036	0.0180	0.0309	0.0041	0.0209	0.0088	−0.0025	0.0081	0.0316
	(0.0128)	(0.0191)	(0.0148)	(0.0079)	(0.0309)	(0.0120)	(0.0148)	(0.0289)	(0.0106)	(0.0242)	(0.0108)	(0.0121)	(0.0175)	(0.0206)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5518	14,889	17,708	18,482	583	20,473	10,337	4695	30,840	5283	27,547	7793	11,730	6062
R^2	0.3906	0.3281	0.3103	0.3173	0.5649	0.2948	0.2971	0.3632	0.2928	0.3720	0.3137	0.3363	0.3470	0.4101
Empirical P-value	0.000		0.000		No				0.000		0.000		0.000	

Note: The "controls" include individual, community and prefecture level controls. The time-period is 1993–2009. *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. Robust standard errors clustered at the prefecture level are reported in parentheses. Empirical *P*-value is the test statistic employed to test the significance of observed differences in coefficient estimates ($TCZ \times T_1$) across groups.

Table 7
Health Effects of the Environmental Regulations across Different Regions.

Variables	Regions		Urban or Rural Areas		Regions		Hukou Type in Urban Areas	
	East	Central, West and Northeast	Rural	Urban	Rural	Urban	Rural Hukou	Urban Hukou
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$TCZ \times T_1$	−0.0262**	−0.0121**	−0.0103	−0.0317**	−0.0090	−0.0355**	−0.0547**	−0.0032
	(0.0100)	(0.0055)	(0.0066)	(0.0145)	(0.0069)	(0.0156)	(0.0182)	(0.0321)
$TCZ \times T_1 \times East$	No	No	No	No	−0.0045	0.0308	No	No
					(0.0113)	(0.0358)		
$ETS \times T_2$	0.0162	−0.0089	0.0180	−0.0515**	0.0180	−0.0521**	−0.0270	0.0652
	(0.0158)	(0.0075)	(0.0167)	(0.0211)	(0.0166)	(0.0207)	(0.0270)	(0.0621)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9032	27,162	18,178	2840	18,178	2840	2002	454
R^2	0.3321	0.3074	0.3054	0.3777	0.3054	0.3779	0.3702	0.5534
Empirical P-value	0.000		0.000		0.000		0.000	

Note: The "controls" in this table include individual controls, community controls and prefecture controls. The time period is 1993–2009. Robust standard errors clustered at the prefecture level are reported in parentheses. *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. Empirical *P*-value is the test statistic employed to test the significance of observed differences in coefficient estimates ($TCZ \times T_1$) across groups.

Thus, the TCZ policy had a greater health improvement effect in the Eastern Region.

Next, we divide the sample into urban and rural residents (according to where they live at the time of the interviews, not their hukou). From the estimates in columns (3) and (4) of Table 7, we can see that the TCZ policy significantly reduced the 4-week prevalence of disease among residents in urban areas, but had no significant impact on residents in rural areas. Notably, we find that ETS significantly reduced the 4-week prevalence of air pollution-related diseases in urban areas.

What are the reasons for the regional differences in the health impacts of the environmental regulation? The difference in air pollution levels across regions is a potentially important factor. In the raw data, the SO_2 emission intensity is observed to be higher in the Eastern regions; that is, 9.85 tons/km^2 compared to 6.06 tons/km^2 in the Central, Western, and Northeast regions. The emission intensity in urban (rural) areas is 8.52 (6.01) tons/km^2.

Which is the more important locational factor affecting the health effect of environmental regulation, the geographical region or living in an urban or rural area? To answer this question, we add an interaction term between $TCZ \times T_1$ and the Eastern region dummy and run separate regressions for urban and rural residents. The estimates of $TCZ \times T_1$ in urban areas (column (6)) are significantly negative, whereas the estimate of $TCZ \times T_1 \times Eastern$ is not. This indicates that whether one is an urban or rural resident is more important for the impact of environmental regulation on an individual's health.

Moreover, in the context of China, the hukou type plays an important role in determining individuals' education, working, and living conditions, and access to medical services, especially for rural hukou holders living in urban areas. We divide the sample of persons living in urban areas into two sub-samples: rural hukou holders and urban hukou holders, respectively. From columns (7) and (8) in Table 7 we may note that the TCZ policy significantly reduced the 4-week prevalence of air pollution related diseases for the rural hukou holders, while it had no significant impact on those with an urban hukou. Thus, only the rural hukou holders, whose health was likely more vulnerable to air pollution, benefitted from the TCZ policy.

Consequently, as for the health compensation effect of the environmental regulation our study finds that people in regions with higher SO_2 emission intensity, such as the Eastern region and the urban areas (especially the rural hukou holders living in urban areas), are more vulnerable to the harmful effects of air pollution, and hence benefitted more from the policy.

6. Conclusions

Employing a Difference-in-Differences model, this paper studies the impact of environmental regulation on individuals' health using data from eight waves of CHNS (1993–2015). The empirical analysis shows that the command-and-control environmental regulation represented by the TCZ significantly reduced the 4-week prevalence of air pollution-related diseases by 39% (1.24 percentage points), whereas the market-oriented environmental regulation represented by the ETS had no significant impact on individuals' health. Nor did we find a positive interaction between the two regulations. The TCZ policy promoted individuals' health by reducing industrial SO_2, reducing industrial fumes and increasing individuals' time spent on physical exercise. However, the health effect of ETS is not significant. Furthermore, we find that the effect of TCZ is most pronounced for respiratory illnesses, and the impact is increasing in the length of the period the policy has been implemented. The environmental regulation had a health compensation effect, that is, the populations and regions which are exposed to higher pollution or more vulnerable to air pollution benefitted more from the TCZ policy.

A lesson from the TCZ policy regarding health effects is that it is important to set long-term goals for environmental regulations, as it takes time before the full impact of a policy is in place. The key result of this study is that the command-and-control regulation performed better than more market-based regulation system. From this it does not necessarily follow that more command-and-control policies should be implemented. Their weakness is that they can be strongly influenced by the political system, and thus may not lead to efficient outcomes. The strength of ETS policies, if properly implemented, is that they make use of market forces and therefore are likely to be efficient. Future research should provide more answers as to why the market-oriented ETS was not successful in reducing SO_2 as it has been in, for instance, the United States.

Is this, as has been suggested in the discussion, due to imperfect market structures and/or uncertainties characterizing environmental policies? Or is it due to something less, such as a powerful regulator? If so, are these obstacles less important today and in the future?

It would also be valuable to have more research-based information regarding the implications for the environment and the public health of the switch in the focus of environmental policy to CO_2 and particulate matter emissions.

Declaration of Competing Interest

None.

Data availability

The authors do not have permission to share data.

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Appendix A

As can be seen from data in Table A1, the dropout rate and the proportion of new observations in the treatment and the control groups are very similar across years, and this holds for the TCZ as well as the ETS policy.

Table A1
The number of observation and dropout rate in treatment group and control group.

	Treatment Group (TCZ)					Control Group (Non-TCZ)				
Year	N	Number of Samples Dropped Out	Dropout Rate	Number of New Samples	Proportion of New Samples	N	Number of Samples Dropped Out	Dropout Rate	Number of New Samples	Proportion of New Samples
1993	4447	–	–	–	–	2275	–	–	–	–
1997	4465	1931	43.42%	1949	43.83%	3505	781	34.33%	2011	88.40%
2000	3872	1977	44.28%	1384	31.00%	2966	1399	39.91%	860	24.54%
2004	3950	1575	40.68%	1653	42.69%	2910	1121	37.80%	1065	35.91%
2006	3783	1364	34.53%	1197	30.30%	2858	911	31.31%	859	29.52%
2009	4173	1308	34.58%	1698	44.89%	2911	1070	37.44%	1123	39.29%
2011	4105	1275	30.55%	1207	28.92%	2793	839	28.82%	721	24.77%
2015	3378	2114	51.50%	1387	33.79%	2218	1585	56.75%	1010	36.16%

	Treatment Group (ETS)					Control Group (Non-ETS)				
Year	N	Number of Samples Dropped Out	Dropout Rate	Number of New Samples	Proportion of New Samples	N	Number of Samples Dropped Out	Dropout Rate	Number of New Samples	Proportion of New Samples
1993	3463	–	–	–	–	3259	–	–	–	–
1997	4115	1028	29.69%	1680	48.51%	3855	1684	51.67%	2280	69.96%
2000	3097	1692	41.12%	674	16.38%	3741	1684	43.68%	1570	40.73%
2004	3081	1238	39.97%	1222	39.46%	3779	1458	38.97%	1496	39.99%
2006	2963	1050	34.08%	932	30.25%	3678	1225	32.42%	1124	29.74%
2009	3197	1087	36.69%	1321	44.58%	3887	1291	35.10%	1500	40.78%
2011	3090	1062	33.22%	955	29.87%	3808	1052	27.06%	973	25.03%
2015	2499	1739	56.28%	1148	37.15%	3097	1960	51.47%	1249	32.80%

Note: Dropout Rate refers to the proportion of the sample that dropped out compared with the previous survey. Proportion of New Samples refers to the proportion of new samples in the previous survey.

Table A2 shows that for both TCZ and ETS, before the implementation of the policy, the 4-week prevalence of air pollution-related diseases in the control group and the treatment group did not differ, supporting the parallel trends assumption.

Table A2
The Air Pollution-Related Diseases in Treatment and Control Groups before and after Policy Change.

Policy and Time	Variables	Control Group		Treatment Group		Difference
		N	Mean	N	Mean	Mean
Before TCZ	Respiratory disease	5780	0.011	8912	0.012	−0.001
	Heart disease	5780	0.003	8912	0.002	0.000
	Tumor	5780	0.000	8912	0.001	−0.001
	Mental/Neurological disease	5780	0.001	8912	0.001	0.000
After TCZ	Respiratory disease	16,656	0.024	28,201	0.028	−0.004**
	Heart disease	16,656	0.007	28,201	0.009	−0.001
	Tumor	16,656	0.000	28,201	0.001	−0.001***
	Mental/Neurological disease	16,656	0.004	28,201	0.004	−0.001
Before ETS	Respiratory disease	18,312	0.018	16,719	0.020	−0.002
	Heart disease	18,312	0.005	16,719	0.006	−0.001
	Tumor	18,312	0.001	16,719	0.001	0.000
	Mental/Neurological disease	18,312	0.002	16,719	0.002	0.000
After ETS	Respiratory disease	14,509	0.026	10,009	0.033	−0.007***
	Heart disease	14,509	0.010	10,009	0.007	0.004***
	Tumor	14,509	0.001	10,009	0.001	0.000
	Mental/Neurological disease	14,509	0.005	10,009	0.005	0.000

Note: *, **, and *** denote 10%, 5%, and 1% significance levels, respectively.

In order to show the representativeness of the studied prefectures in this paper, we computed summary statistics for the variables for the prefectures in the population and in the sample. It can be seen in Table A3 that the mean and standard deviation of each variable in the sample are very close to that in the population, indicating that the CHNS samples are very representative.

Table A3
Summary Statistics: The Representativeness of the Studied Prefectures.

Population or Sample	Variables	Definition	Mean	SD	Min	Max
Population	log GDP per capita	Log of real GDP per capita (Ten thousand yuan)	1.359	0.681	−0.728	4.250
	Population density	Ten thousand persons square kilometer	0.041	0.030	0.000	0.313
	Doctor density	Doctors per ten thousand residents	18.440	9.950	3.427	98.332
	SO_2 emission intensity	Industrial SO_2 emission (tons/km^2)	6.584	8.004	0.005	80.122
	TCZ	An indicator variable that takes on the value of one if the prefecture covered by the TCZ	0.503	0.501	0	1
	ETS	An indicator variable that takes on the value of one if the prefecture covered by the ETS	0.355	0.486	0	1
Sample	log GDP per capita	Log of real GDP per capita (Ten thousand yuan)	1.326	0.646	−1.627	3.290
	Population density	Ten thousand persons square kilometer	0.046	0.025	0.006	0.136
	Doctor density	Doctors per ten thousand residents	17.581	8.424	5.472	63.461
	SO_2 emission intensity	Industrial SO_2 emission (tons/km^2)	6.997	7.592	0.132	43.704
	TCZ	An indicator variable that takes on the value of one if the prefecture covered by the TCZ	0.589	0.492	0	1
	ETS	An indicator variable that takes on the value of one if the prefecture covered by the ETS	0.467	0.499	0	1

According to Table A4, there was no significant difference in 4-week prevalence of air pollution-related diseases between individuals who dropped out and the remaining observations, except in 2011.

Table A4
4-Week Prevalence of Air Pollution Related Diseases among Dropped out and Remaining Individuals in the Estimation Sample.

Year	Dropped out of sample		Remain in sample		Difference
	N	Mean of Disease	N	Mean of Disease	Mean of Disease
1993	2712	0.0173	4010	0.0132	0.0041
1997	3376	0.0187	4594	0.0168	0.0019
2000	2696	0.0174	4142	0.0215	−0.0041

(continued on next page)

Table A4 (*continued*)

Year	Dropped out of sample		Remain in sample		Difference
	N	Mean of Disease	N	Mean of Disease	Mean of Disease
2004	2275	0.0492	4585	0.0454	0.0039
2006	2378	0.0412	4263	0.0385	0.0027
2009	2114	0.0430	4970	0.0499	−0.0069
2011	4948	0.0485	4652	0.0402	0.0083**
2015	–	–	–	–	–

Note: *, **, and *** denote 10%, 5%, and 1% significance levels, respectively.

We have performed counterfactual tests by randomly selecting the treatment group and constructing a false policy implementation time. In Fig. A1, the results from 500 runs of random sampling regressions are reported. They show that the coefficient of $TCZ \times T_1$ is very small, and close to 0, and at the same time, most of the *P*-values are greater than 0.1. The coefficients of $TCZ \times T_1$ in Table A5 are insignificant, lending further support that the decline in 4-week prevalence of air pollution-related diseases is indeed the result of the environmental regulation.

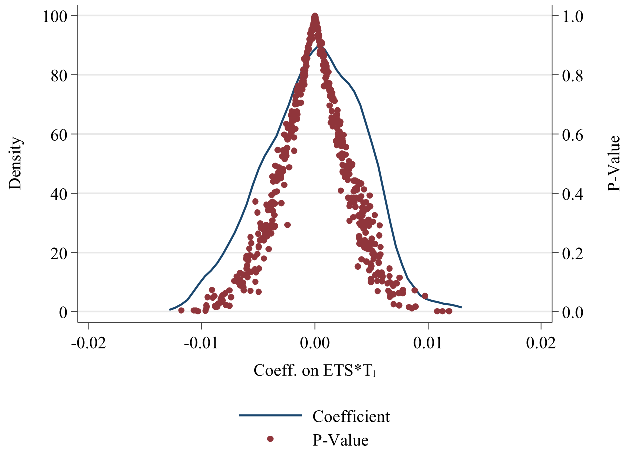

Fig. A1. Kernel Density of Coefficient in 500 Random Samples.

Table A5
Counterfactual Test.

Variables	Effect of TCZ (1993–2009)		Effect of TCZ (1993–2015)	
$TCZ \times T_1$	−0.0036	−0.0041	−0.0030	−0.0031
	(0.0071)	(0.0070)	(0.0063)	(0.0062)
$ETS \times T_2$	0.0025	0.0042	0.0048	0.0058
	(0.0086)	(0.0084)	(0.0065)	(0.0066)
Controls	No	Yes	No	Yes
Individual FE	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes
Observations	36,196	36,196	48,070	48,070
R^2	0.3114	0.3123	0.2806	0.2811

Note: Assuming that the year prior to the TCZ policy (1997) is the year of implementation, a false policy time is constructed for counterfactual test. The time-period is 1993–2009. The “controls” in this table include individual controls, community controls and prefecture controls. *, **, and *** represent the significances at 10%, 5%, and 1% levels, respectively. Robust standard errors clustered at the prefecture level are reported in parentheses.

We carried out a series of robustness checks, testing for possible confounding factors. First, different indicators or samples are used to measure the residents’ health. In the first row of Table A6, we use self-reported symptoms of air pollution-related diseases as the dependent variable. Specifically, for respondents who report having symptoms of fever, sore throat, or cough during the past four weeks, the value is 1; otherwise, zero. In the second row the sample is restricted to the respondents with a doctor’s diagnosis of air pollution-related diseases during the previous four weeks.

Persons who are more vulnerable to air pollution may move to areas with better air quality. As a robustness check for the impact of movers, we have run the regressions on a balanced panel that exclude movers, who would be recorded as missing.

The implementation time and area of the two policies overlap. In order to disentangle their effects, we limit TCZ analysis to data from 1993 to 2006 and limit ETS analysis to locations outside TCZ, respectively.

Environmental policy in the real world is often not random. Thus, there may be systemic differences between the policy treatment and control groups. In order to mitigate the impact of systemic differences on empirical results, the impacts of environmental regulations on individuals’ health are identified based on the entropy-balanced data created by the method proposed by Hainmueller (2012). The results are shown in Table A6 and the balancing tests performed on the entropy balanced data are found in Table A7.

Finally, climatic conditions may affect the incidence rate of some diseases. The last row in Table A6 includes controls for the average temperature and precipitation in the prefecture.

In all the above robustness tests, the coefficients of $TCZ \times T_1$ remain significantly negative. The coefficients of $ETS \times T_2$ do not differ significantly from zero.

Table A6
Robustness Checks.

Specifications	Coefficients of $TCZ \times T_1$(1993–2009)	Coefficients of $ETS \times T_2$(1993–2015)
Use symptoms	−0.0672*	−0.0066
	(0.0388)	(0.0156)
Use residents visiting doctors as samples	−0.2271**	−0.0816
	(0.0954)	(0.0836)
Study based on balanced panel	−0.0153*	0.0291
	(0.0088)	(0.0292)
Disentangling the effects of two policies	−0.0099*	0.0165
	(0.0059)	(0.0112)
Estimates based on the entropy balanced data	−0.0145**	0.0070
	(0.0058)	(0.0063)
Control for climatic factors	−0.0129**	0.0065
	(0.0058)	(0.0098)

Note: The "controls" in this table include individual controls, community controls and prefecture controls. *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. Robust standard errors clustered at the prefecture level are reported in parentheses.

As shown in Table A7, the balancing test performed on the entropy balanced data does not suggest there are large differences in mean, variance, and skewness between the treatment and the control group.

Table A7
The Balancing Test Performed on the Entropy Balanced Data.

Policy	Variables	Treatment Group			Control Group		
		Mean	Variance	Skewness	Mean	Variance	Skewness
TCZ	log GDP per capita	1.6460	0.4698	0.4570	1.6460	0.5139	0.8525
	Population density	0.0629	0.0020	2.4370	0.0629	0.0008	0.4259
	Doctor density	21.2200	151.9000	2.0950	21.2200	182.9000	1.3920
	SO^2 emission intensity	9.2560	78.8200	1.9350	9.2550	57.3100	0.9256
ETS	log GDP per capita	1.3620	0.3712	1.1470	1.3620	0.5442	0.6231
	Population density	0.0574	0.0006	0.2571	0.0574	0.0035	2.1960
	Doctor density	15.9000	50.9500	2.2670	15.9200	65.6900	1.2020
	SO^2 emission intensity	6.4900	40.1200	1.6310	6.4880	45.1100	1.7500

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