Evaluation of the Winter Pollution Mitigation Policy in China

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ABSTRACT

Rapid industrialization in China has come with substantial increases in local air pollution. This paper quantifies the health benefits of the Winter Pollution Mitigation Policy of 2017. We estimate that this policy caused an 18% reduction in fine particulate concentration levels, resulting in 19,400 deaths avoided in 2017 due to pollution exposure in Beijing, Tianjin, Hebei, and neighboring regions. Our findings suggest that the ratio of public expenditures to deaths avoided is much lower for the winter policy relative to the overall Air Pollution Prevention and Control Action Plan. This may be because the winter policy targeted the most polluted region in China during the season with highest pollution levels.

Keywords: China, Air Pollution, Environmental Policy

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1. INTRODUCTION

The environmental costs of the increases in local air pollution resulting from 30 years of rapid industrialization in China are substantial (Matus et al., 2012; Wong, 2013). Outdoor air pollution caused 1.2 million premature deaths in China in 2010, accounting for nearly 40 percent of the global total number of deaths from air pollution and about 12% of mortality in China (Gu et al., 2018; Wang et al., 2018b). The damages from premature mortality due to exposure to ambient air pollution in mainland China amounted to roughly 11% of GDP in 2013 (World Bank, 2016).[1] In response to this air pollution crisis, the Chinese premier declared a war on pollution in 2014.

As part of this effort, the winter pollution mitigation work plan, hereafter the "winter policy", was issued in 2017 to control pollution emissions in the winter in Beijing, Tianjin, Hebei and neighboring regions. As part of this policy, polluting firms and households were mandated to take costly actions to reduce pollution levels, but received large subsidies from the govern-

1. Matus et al. (2012) estimates that the health damages from pollution in China were roughly 5% of China's GDP in 2005. Other damages to the ecosystem due to pollution amounted to $230 billion, about 3.5 percent of the nation's GDP in 2010 (Wong, 2013).

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ment as compensation.[2] This paper calculates the environmental benefits and implementation costs of the winter policy, comparing the public expenditures per premature death avoided associated with the winter policy versus the Air Pollution Prevention and Control Action Plan (2013–2017).

Using a difference-in-differences approach, we estimate that the winter policy reduced the concentration levels of fine particulate matter by an average of 13.8 micrograms per cubic meter, or 18%, in treated regions. Results from event study regressions suggest that these estimates are not driven by pre-existing differences in trends in pollution levels across treatment and control regions or spillovers in treatment to control regions.[3] Plugging our estimate into the concentration-mortality relationship developed by Apte et al. (2015), we calculate that the winter policy resulted in 19,400 fewer premature deaths due to pollution exposure in 2017. Our central estimate of the monetized benefit of this policy-induced reduction in premature deaths is about 12 billion dollars, based on a China-specific estimate of the value of statistical life of $624,600 (Hoffmann, Krupnick and Qin, 2017).[4]

The annualized implementation cost of the winter policy in 2017 was at least 8 billion dollars.[5] Our findings suggest that the ratio of public expenditures to deaths avoided is much lower for the winter policy relative to the overall Air Pollution Prevention and Control Action Plan—of which the winter policy is a part. This may be because the winter policy targeted the most polluted region in China during the season with highest pollution levels.

Contributions to existing literature: A large body of existing work has studied the health costs of air pollution in China, including the costs associated with the "Huai River Policy" winter heating policy (Almond et al., 2009; Chen et al., 2013; Ebenstein et al., 2017) and residents' willingness-to-pay to reduce pollution levels (Ito and Zhang, 2020). This paper contributes to a small but growing literature studying the costs and benefits of air pollution policies in China (Zhang et al., 2019; Huang et al., 2018; Greenstone et al., 2021; Karplus, Zhang and Zhao, 2021). We do so by measuring the public expenditures per life saved of a particularly implementation-cost-effective component of the overall Air Pollution Prevention and Control Action Plan—the winter policy. This policy targeted the most polluted region in China during the winter, the most polluted season in China due in large part to home heating.

This paper is organized as follows. Section 2 provides further detail on the winter policy. Section 3 presents our estimates of the impact of the winter policy on local air pollution levels. In Section 4, we calculate the monetized benefit of winter-policy-induced reductions in local air pollution, and compare the public expenditure per premature death avoided of the winter policy to the Air Pollution Prevention and Control Action Plan from 2013–2017. We conclude by discussing the policy implications of our findings in Section 5.

2. The subsidies provided as part of the winter policy can be found at: https://www.chndaqi.com/news/267031.html

3. Recent work expresses concerns with the difference-in-differences approach when the timing of treatment is staggered (Callaway and Sant'Anna, 2020; Sun and Abraham, 2020; Goodman-Bacon, 2021). These concerns are not applicable in our setting because all treated regions were impacted simultaneously by the implementation of the winter policy.

4. Our estimates of the mortality benefits of the winter policy range from 8 billion dollars based on a VSL of $420,000 for lower-middle income countries to 24 billion dollars based on a VSL of $1.2 million for upper-middle income countries (Viscusi and Masterman, 2017).

5. These magnitudes are expressed in constant 2017 USD, adjusted to reflect differences in how much can be purchased with one dollar in China rather than the United States using the countries' relative purchasing power parity (Narain and Sall, 2016).

2. POLICY BACKGROUND

Geographically widespread and long-lasting air pollution incidents between 2012 and 2013 drew mounting attention both internationally and from the Chinese public (Wang et al., 2018a). As a consequence, the State Council of China issued the Air Pollution Prevention and Control Action Plan in 2013, which comprises specific measures and pollution concentration targets to achieve by 2017. The priority was to reduce pollution levels in the three Megalopolises: the Beijing-Tianjin-Hebei region, the Yangtze River Delta and the Pearl River Delta.[6] This Action Plan was the most stringent air pollution regulation in China to date, and was widely considered to be a promising strategy to control the deterioration of air quality in China (Huang et al., 2018).

Since 2017 was the last year to achieve the targets specified in this plan, China implemented the winter pollution mitigation policy in September of 2017. Initially, this policy aimed to reduce air pollution in the Beijing-Tianjin-Hebei region during the winter in 2017. The policy targeted two municipalities and 26 cities (the so-called "2+26" cities) in Beijing, Tianjin, Hebei and surrounding areas.

The policy consisted of seven main strategies:[7]

1. Reduce excessive steel production capacity and eliminate small and scattered polluting enterprises.
2. Promote clean heating in winter.
3. Strengthen the management of industrial pollution emissions.
4. Implement rotational industrial production during the heating season.
5. Strictly control motor vehicle emissions.
6. Improve management of urban pollution emissions.
7. Strengthen the response to weather conditions that facilitate poor air quality, such as lack of precipitation or low wind speed.

Under each main strategy, there are specific tasks with deadlines in 2017. For example, as part of strategy (2) to promote clean heating in winter, Beijing, Tianjin, Langfang and Baoding were required to complete the replacement of coal heating with gas or electricity heating by the end of October 2017. Other cities were required to convert 50,000–100,000 households from coal heating to gas or electricity heating, whichever is more suitable.

We estimate the impact of the winter policy on air quality using a difference-in-differences approach. Our study period is from September 2015 to August 2018 because the winter policy was expanded to include the Yangtze River Delta in the winter of 2018. The treatment region includes the "2+26" cities (the red region in Figure 1), and the control region is the Yangtze River Delta (the blue region in Figure 1). We chose this control region because it had a similar pollution reduction target under the initial Action Plan as the treatment region. Moreover, the Yangtze River Delta is geographically distant from the treatment region, so the impacts of the winter policy are less likely to spillover to this control region. In Appendix Section C, we document that the results remain similar if we instead construct the control group based on 16 prefecture cities closer to the treatment region in the provinces of Hebei, Shanxi, and Shandong.

6. The Action Plan required all urban areas to reduce $PM_{2.5}$ concentration levels by at least 10 percent. It required the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta regions to reduce concentrations by 25%, 20%, and 15% respectively by end of 2017.

7. The following link describes these strategies in more detail: https://www.mee.gov.cn/gkml/hbb/bwj/201708/W020170824378273815892.pdf

FIGURE 1
Regions in China treated versus not treated by the winter policy

Notes: This figure presents the regions in China treated versus not treated by the winter pollution mitigation policy in 2017. The region shaded in red is the treatment group, the "2+26" cities, and the blue region corresponds to the control group, the "Yangtze River Delta".

3. IMPACT OF THE WINTER POLICY ON POLLUTION LEVELS

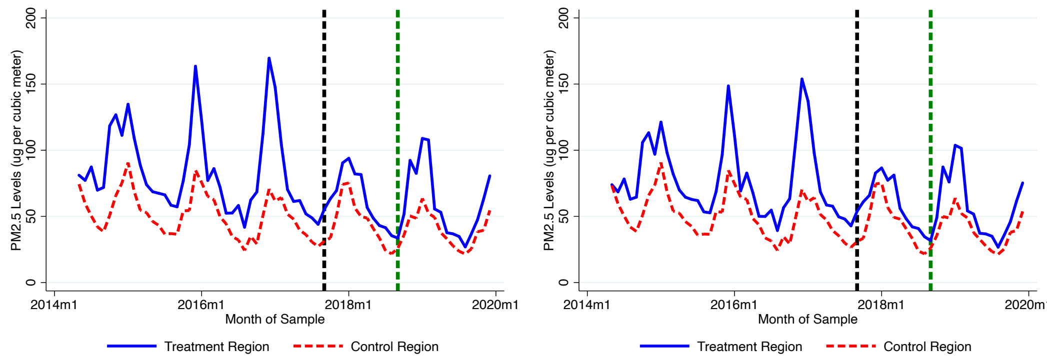
Roughly 76% of air-pollution-caused deaths in China were due to exposure to fine particulate matter (i.e., $PM_{2.5}$) (Gu et al., 2018). In this study, we estimate the impact of the winter policy on PM concentration levels. We then calculate the health benefit implied by this policy-caused reduction in pollution using existing dose-response functions relating $PM_{2.5}$ to mortality rates (Apte et al., 2015).

To measure $PM_{2.5}$ concentration levels, we use data gathered from more than one thousand monitoring stations across China. The quality of these data are checked against $PM_{2.5}$ measured at the U.S. Embassy and 4 consulates in China and released by the U.S. government. As documented in Appendix Section B.2, we find no significant difference between the readings from monitors owned by the Chinese government versus the American government during our sample period.

In 2014, there were 449 monitors installed in 161 prefecture cities, and the number quickly increased to 1,582 monitors in 2017 covering almost all prefecture cities in China. We have air quality data from 165 monitors for the treatment group and 151 monitors for the control group. Appendix Figure B.1 shows the spatial distribution of the monitoring stations in 2017.

Figure 2 presents the monthly average $PM_{2.5}$ concentration levels for the treatment and control regions from 2014 to 2019. This figure indicates that average pollution levels in the treatment region dropped dramatically after the policy was implemented in September 2017. Comfortingly, average pollution levels in the control region do not change much in response to the implementation of the winter policy. This provides evidence against the concern that polluting industry moved from the treated region to the control region in order to avoid being subject to the regulation.

FIGURE 2
Monthly averages of $PM_{2.5}$ in the "2+26" cities and Yangtze River Delta



(a) Weighted (b) Unweighted

Notes: The figure presents monthly averages of $PM_{2.5}$ concentration levels in the treatment and control regions. We weight observations by the ratio of city-level population in 2013 to the number of air quality monitors in the city for the left panel; we do not weight the sample for the right panel. The blue line denotes pollution monitor readings for the "2+26" cities (treatment region) and the red line denotes monthly averages of the readings in the "Yangtze River Delta" (control region). The black dashed vertical line denotes when the winter pollution mitigation policy was implemented (September 2017) and the green dashed vertical line denotes when the winter policy was expanded to include the control region (September 2018).

We estimate the effect of the winter policy on $PM_{2.5}$ concentration levels using the following difference-in-differences framework:

$$y_{i,t} = \alpha_i + \gamma_t + \beta\left(P_t \times T_i\right) + \varepsilon_{i,t} \quad (1)$$

where i indexes air quality monitor and i indexes day-of-sample. The indicator variable P_t is equal to one only for days-of-sample after the winter policy takes effect in September 2017. The indicator variable T_i is equal to one for the treatment regions and is equal to zero for the control regions. In our primary specifications, we weight observations by the ratio of city-level population in 2013 to the number of air quality monitors in the city. We include monitor fixed effects, day-of-sample fixed effects, and separate sets of month-of-year fixed effects for treatment regions and control regions. The separate sets of month-of-year fixed effects for the treatment and control regions control for, among other factors, persistent differences in winter heating systems across the two regions. Standard errors are clustered by city.

Table 1 presents the estimates from this difference-in-differences framework. The results in this table are quite stable across specifications. The estimate from Column 1 indicates that the winter pollution mitigation policy reduced $PM_{2.5}$ concentration levels by 13.8 $\mu g/m^3$ ($p < 0.01$) in the treated region; this constitutes an 18% reduction in pollution levels.

Figure 3 presents event study estimates of effects of the 2017 winter policy based on the model in Column (1). Prior to the policy, we see a spike in pollution levels in the treatment region in Winter 2016. Indeed, this large spike in pollution levels motivated the implementation of the winter policy in 2017. However, trends in relative pollution levels across the treatment and control regions are relatively flat and centered around zero outside of the winter months. There is not a declining trend in relative pollution levels prior to the policy that could explain the massive decrease in $PM_{2.5}$ in the treated regions in the months after the policy was implemented.

TABLE 1
Impact of the winter policy on $PM_{2.5}$ concentration levels

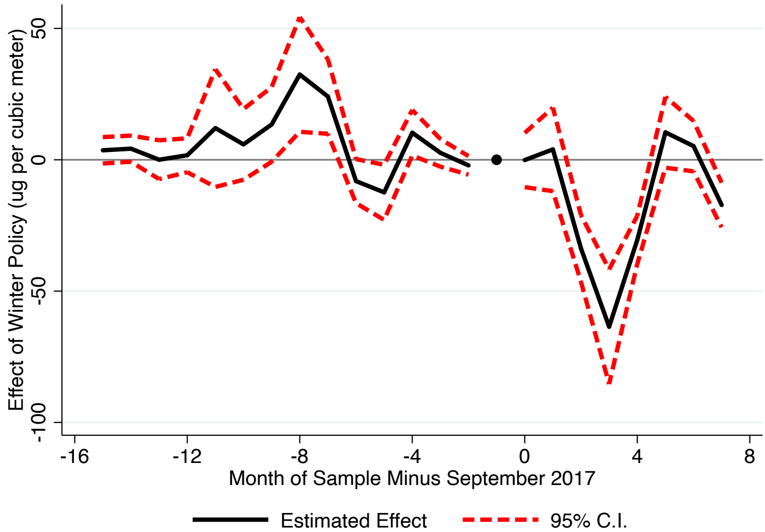
	Dep. Var.: $PM_{2.5}$ concentration levels (micrograms per cubic meter)			
	(1)	(2)	(3)	(4)
Treated Region Post Policy	–13.821***	–11.807***	–12.138***	–10.386***
	(1.717)	(1.641)	(2.971)	(1.684)
Winsorized Dep. Var.	N	Y	N	Y
AQ Monitor FE	Y	Y	Y	Y
Treatment By Month FE	Y	Y	Y	Y
Month-of-Sample FE	Y	Y	Y	Y
Day-of-Sample FE	Y	Y	Y	Y
Cluster by City	Y	Y	Y	Y
Weighted by Population	Y	Y	N	N
R^2	0.573	0.588	0.543	0.558
Mean of Dep. Var.	62.494	61.566	59.842	59.118
Number of Obs.	298,297	298,297	298,297	298,297
Number of Sites	309	309	309	309

Notes: The table presents estimates of the impact of the winter policy on $PM_{2.5}$ concentration levels. The unit of observation for all of the regressions in this table is air quality monitor/day-of-sample and the dependent variable considered is daily average $PM_{2.5}$ concentration levels. The sampling weight used when estimating these models is the ratio of city-level population in 2013 to the number of air quality monitors in the city. All regressions include monitor fixed effects, separate sets of month-of-year fixed effects for treatment and control regions, and day-of-sample fixed effects. In Column 1 and 2, we weight the observations by the ratio of city-level population in 2013 to the number of air quality monitors in the city. In Column 2 and 4, we winsorize the top 1% and bottom 1% of the dependent variable before estimating the model. Standard errors—reported in parentheses— are clustered by city for all columns. *** p<0.01, ** p<0.05, * p<0.1

After the winter policy is implemented, we see a sharp reduction in pollution levels in Winter 2017. The estimated effects for Spring 2018 are not statistically different from zero. This is intuitive: the primary aim of the winter policy was to lower pollution levels in the fall and winter. Namely, as mentioned in Section 2, some of mitigation strategies employed as part of the winter policy were short-term and reversible, such as limiting the production of steel, aluminum and chemicals during the winter. Other longer-term strategies–such as subsidies to households to replace coal heating with electric or gas heating—would also reduce pollution levels only in the winter. Our evidence suggests that the bulk of the mitigation strategies employed as part of the winter policy were effectively targeted to reduce pollution levels only during winter.[8]

8. Similarly, Linn (2008) argues that power plants utilizing methods other than installing pollution abatement technology to comply with the NO_x Budget Trading Program resulted in pollution reductions that did not spillover to seasons other than the ozone season specified as part of the program.

FIGURE 3
Event study estimates of the impact of the 2017 winter policy



Notes: The figure presents event study estimates of the effects of the winter pollution mitigation policy; we estimate a separate effect for each month before and after the policy was enacted, normalizing the effect for the month before the policy was implemented (September 2017) to be zero. The unit of observation for the regression is air quality monitor/day-of-sample, and the dependent variable is daily average $PM_{2.5}$ concentration levels (in micrograms per cubic meter). The sampling weight used when estimating this model is the ratio of city-level population in 2013 to the number of air quality monitors in the city. We include an indicator for days-of-sample after September 2017, monitor fixed effects, day-of-sample fixed effects and separate sets of month-of-year fixed effects for treatment and control regions. We present 95% confidence intervals based on standard errors clustered by city.

4. BENEFITS AND COSTS OF THE WINTER POLICY

4.1 Monetization of avoided deaths from pollution exposure

A large body of research documents that the damages from air pollution are significant in magnitude and that these damages are mostly due to the increased mortality risk from exposure to $PM_{2.5}$ (NRC and NAS, 2010; Muller, Mendelsohn and Nordhaus, 2011; Muller, 2014). Epidemiological studies have established causal estimates of the impacts of long-term exposure to $PM_{2.5}$ on premature mortality from endpoints such as heart disease, stroke, respiratory diseases, and lung cancer (Apte et al., 2015). In this subsection, we calculate the number of premature deaths avoided due to the reduction in $PM_{2.5}$ concentration levels induced by the winter policy. To do this, we apply the global concentration-mortality relationship developed by Apte et al. (2015) based on integrated exposure response curves developed for the Global Burden of Disease (Burnett et al., 2014). This concentration response curve, which maps $PM_{2.5}$ concentration levels to number of premature deaths, is plotted in Appendix Figure D.1.

Our difference-in-differences estimate indicates that the policy caused a 13.8 $\mu g/m^3$ reduction in $PM_{2.5}$ concentration levels on average in treated cities. Consequently, we shift the daily average $PM_{2.5}$ level for the treated region across the post-treatment sample period 9/2017–8/2018 (61 $\mu g/m^3$) up by 13.8 $\mu g/m^3$ to obtain the counterfactual $PM_{2.5}$ concentration level in the absence of the policy.[9] We then calculate the number of premature deaths avoided by plugging these two numbers into the relationship between $PM_{2.5}$ concentration levels and total mortality discussed above.

We calculate that the policy resulted in 19,400 less premature deaths in the treated region in 2017. We also conducted an alternative measurement of the deaths avoided using the event study results in Figure 3. Namely, we plug each of the post-treatment event study estimates into the dose response function, divide by 12 to reflect a monthly rather than annual number of avoided deaths, and then sum over months. The total number of premature deaths avoided based on this methodology is slightly lower—18,700 avoided deaths instead of 19,400. We emphasize that this dose response function approach is not well-suited to quantify the health effects of inter-temporal variations in pollution levels. For example, a reduction in $PM_{2.5}$ of 10 micrograms per cubic meter in both the summer and winter may have different health effects than a 20 micrograms per cubic meter decrease in the winter but no reduction in the summer.

We monetize this reduction in premature deaths using the value of statistical life (VSL) estimated for the Chinese population; all dollar magnitudes are reported in 2017 USD. Our central magnitude is taken from Hoffmann, Krupnick and Qin (2017), who estimate a VSL of $624,600 (2017 USD) relevant for the urban population in China. Using this VSL estimate, we calculate that the monetized value of the reduction in pollution-caused mortality due to policy in 2017 is about 12 billion dollars (=19,400×$624,600).

Using income classifications from the World Bank, Viscusi and Masterman (2017) calculates average VSLs for lower income, lower-middle income, upper-middle income, and upper income countries to be $107,000, $420,000, $1.2 million, and $6.4 million, respectively. Therefore, we also report the pollution benefits based on a range of VSL from $420,000 (for lower-middle income countries) to $1.2 million (for upper-middle income countries). Based on this range of VSL estimates, the mortality benefits of the winter policy range from 8 billion dollars to 24 billion dollars.

4.2 Public expenditures associated with the winter policy

We also calculate the direct government subsidies given to businesses and households affected by the policy. For example, to promote clean heating during the winter, the policy mandated that households replace coal-powered heating appliances with appliances powered by either gas or electricity. Affected households received government subsidies for both the equipment installation cost and the increases in heating cost. The government also subsidized businesses to eliminate or renovate their coal-fired boilers, and subsidized the owners of coal-fired power plants that were shut down before they were scheduled to retire. We provide more details on the allocation of subsidies to businesses and households in Appendix Section D.2.

We compare the monetized air pollution benefits of the policy discussed in the previous subsection to the implementation cost of the policy, which includes both the aforementioned subsidies and the direct costs of the government resources required to implement the policy. Our calculations indicate that the Chinese government spent at least 41.85 billion Yuan on air pollution mitigation in the treatment region in 2017. This includes provincial expenditure of at least 27.85 billion Yuan in the treatment region to implement the policy, and the central government's additional support of 14 billion Yuan to reduce air pollution in Beijing-Tian-

9. Appendix Table B.2 presents the daily average PM concentration levels for treatment and control groups before and after the policy.

jin-Hebei and surrounding areas in 2017.[10] Appendix Table D.1 presents a breakdown of the spending at the provincial level in the treatment region in 2017.

However, some of the subsidies went to capital investment such as new heating appliances that will bring pollution benefits for the entirety of its lifespan. We estimate the subsidies to capital investment were $2.2 billion, including the key tasks of eliminating small coal-fired boilers and converting coal heating to gas/electricity heating in households. If we amortize this value over a 15-year period assuming a discount rate of 5%, the annualized capital cost is about $0.21 billion in 2017. The overall annualized implementation cost of the winter policy in 2017 was $8 billion.

We compare the ratio of public expenditures to lives saved for the winter policy versus the overall Air Pollution Prevention and Control Action Plan from 2013–2017. The Action Plan is the most stringent air pollution regulation in China to date, and the winter policy could be viewed as the last battle fought to achieve the target set in 2013 in the Action Plan. The Energy Policy Institute at the University of Chicago estimates that the total public expenditure on the Air Pollution Prevention and Control Action Plan between 2013 and 2017 was about 1.75 trillion RMB.[11] Zhang et al. (2019) estimates that the number of premature deaths avoided between 2013–2017 due to the Action Plan was about 97,000. This implies a public expenditure of about 18 million yuan per life saved due to the Air Pollution Prevention and Control Action Plan from 2013 to 2017, compared to a public expenditure per life saved of 2 million Yuan for the winter policy.[12]

Our analysis suggests that the implementation-cost-effectiveness of the winter policy is far higher than the overall Action Plan. This is perhaps because the winter policy targeted the most polluted region in China during the season with highest pollution levels. Our evidence suggests that this targeting was more cost-effective than the national scope and relative lack of season-differentiated regulation in the overall Air Pollution Prevention and Control Action Plan.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Faced with severe environmental degradation after 30 years of rapid industrialization, China declared a war on pollution in 2014. This paper evaluates an aggressive policy implemented in 2017 to reduce pollution levels in the winter. Using a difference-in-differences approach, we estimate that the winter policy reduced the concentration levels of fine particulate matter ($PM_{2.5}$) by an average of 13.8 $\mu g/m^3$, or 18%, in Beijing-Tianjin-Hebei and neighborhood regions in the winter of 2017.

Plugging this estimate into the concentration-mortality relationship estimated by Apte et al. (2015), we calculate that the decreases in $PM_{2.5}$ concentration levels due to the policy resulted in roughly 19,400 less premature deaths from fine particulate exposure in 2017. Based on a value of statistical life of $624,600, our central estimate of the monetized mortality ben-

10. Cost information is released by the Beijing Environmental Protection Bureau: https://scjg.cnki.net/kcms/detail/detail.aspx?filename=QXZZ201806039&dbcode=CJFQ&dbname=CJFD2018&v=

11. Details on this study can be found at: https://aqli.epic.uchicago.edu/policy-impacts/china-national-air-quality-action-plan-2014/

12. Given that the EPIC study did not amortize capital costs when calculating implementation costs, we use the implementation cost of the winter policy in 2017 (without amortizing) of $10 billion when comparing the public expenditure per life saved of the Action Plan versus the winter policy.

efit of the policy is about 12 billion dollars (2017 USD). We calculate that the policy cost the government at least 8 billion dollars to implement in 2017. Combining these estimates, we find that the ratio of public expenditures to lives saved is much lower for the winter policy relative to the overall Action Plan. This may be because the winter policy targeted the most polluted region in China during the season with highest pollution levels

China is continuing to invest heavily in the winter policy.[13] Indeed, the winter policy was expanded to include other regions in 2018 and remains in effect as of 2021. Our findings suggest that the cost-effectiveness of this form of air pollution policy may be higher than other regulations since it focuses on winter—when home heating generates substantial pollution emissions—and on areas with the highest levels of pollution.

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13. The province of Hebei invested another 8.7 billion Yuan to mitigate air pollution in the winter of 2018, Beijing spent another 19 billion Yuan in 2018, and the central government continues to allocate substantial funds to this policy even as of 2021. More information on the subsidies to Beijing and Hebei can be found at: http://www.xinhuanet.com/politics/2018-01/26/c_1122322534.htm and http://czt.hebei.gov.cn/root17/zfxx/202001/t20200106_1177801.html respectively.

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