Is China's Pollution the Culprit for the Choking of South Korea? Evidence from the Asian Dust [*]

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Abstract

This paper assesses the impact of cross-border air pollution from China to South Korea. Since both countries share similar business cycles and hence pollution cycles, separating pollution spillover from locally generated pollution is difficult. To overcome this challenge, we exploit within-South Korea variations in the incidence of Asian dust – a meteorological phenomenon in which yellow dust clouds passing over China are carried eastward to South Korea by strong, stable westerly winds – together with temporal variations in China's air quality. Analysis based on monthly data from South Korea and China for 2000-2011 shows that at the mean incidence of Asian dust, a one standard deviation increase in China's pollution leads to around 280 extra deaths per year in South Korea from respiratory and cardiovascular diseases, with additional effects on overall mortality for children aged below five. We also compare the role of Asian dust as a carrier of China's pollution with that of westerly winds.

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1 Introduction

This paper investigates the impact of China's air pollution on the mortality of South Koreans, a prominent example of the increasingly important global issue of pollution spillover across country borders.[1] While there exists a literature establishing the causal impact of local pollution on local health[2] as well as a separate, scientific literature simulating the movement of chemical species/pollutants across borders,[3] there is hardly any evidence on the health costs of transnational air pollution, i.e., how one country's air pollution affects health outcomes in another country. In this paper, we use observed micro data from China and South Korea for 2000-2011 and directly estimate the impact of China's ambient air quality on the mortality of South Koreans, providing concrete evidence on the health impacts of pollution spillover across country borders. Given that China is the world's largest emitter of anthropogenic air pollutants, the effects found on South Korea will not only contribute to the debates between the two countries but set a useful benchmark in understanding China's impact on other countries located further away.

There are at least three major challenges to identifying spillover effect between China and South Korea. First, the observed or measured pollution in South Korea is an outcome of local activities as well as possible spillovers from neighboring countries. Second, these countries share similar business cycles and, hence, pollution cycles, which makes it even harder than in other contexts to separate pollution spillover from locally generated pollution. Third, China's pollution is a perennial process and not a one-off shock. Therefore, plausibly exogenous variation is hard to come by in time-series data of China's pollution alone. At the same time, these very factors that make identification difficult are also what make the question policy-relevant. Unlike isolated cases of environmental disasters such as Chernobyl in 1986 or Fukushima in 2011, China's air pollution is an ongoing process and a choice variable, which the Chinese government can directly influence and control

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[1] Other examples include air pollution spillover at the Canada-U.S. border and the haze crisis in Malaysia and Singapore stemming from forest fires in Indonesia.

[2] See, e.g., Chay and Greenstone (2003), Currie and Neidell (2005), Jayachandran (2009), Lleras-Muney (2010), Chen et al. (2013), Greenstone and Hanna (2014), Schlenker and Walker (2015), Anderson (2015) and many others. Zivin and Neidell (2013) provides a thorough survey on this line of research.

[3] A recent example is Lin et al. (2014) who simulate the impact of export-related emissions in China on air quality in the U.S., using the GEOS-Chem model. Among the many atmospheric models developed by scientists, Chemical transport models such as GEOS-Chem or MOZART are typically employed to simulate the flow of chemical species over wider areas (e.g., across the globe) whereas atmospheric dispersion models such as ADMS or HYSPLIT are more commonly used to simulate the dispersion of pollution from point sources (e.g., industrial plants) to the local areas.

through its energy and environmental policies and regulations.

To overcome these empirical challenges and to quantify the impact of China's air pollution on South Korean mortality, we therefore exploit the meteorological phenomenon known variously as Asian dust, yellow dust, or yellow sand, in which yellow dust clouds passing over China are carried eastward to South Korea by strong and stable westerly winds (Duce et al., 1980). Asian dust originates in the deserts of Mongolia, northern China, and Kazakhstan. Intense dust storms in the source regions, facilitated by high surface winds and low humidity, raise dense clouds of fine, dry soil particles, which are then carried eastward by the prevailing westerlies across China, Korea, Japan, and even the United States (Chun et al., 2001; Bishop et al., 2002). First documented in 174 AD, the dust phenomena have a long history in Korea (Chun et al., 2008). Before the industrialization of China, the occurrence of Asian dust in South Korea merely signified strong westerly winds that happen to be visually salient (because of the yellow sand/dust particles blown in them). In recent decades, however, Asian dust has become an important concern with intensifying pollution problems in China because, now, a dust event can bring to South Korea China's man-made pollution as well as its byproducts (Choi et al., 2001; Li et al., 2012).

To isolate measurable variations in South Korea's air quality that can be definitively attributed to China (and not to South Korea or Japan), we exploit within-South Korea and over-time variations in the incidence of Asian dust together with temporal variations in China's air quality (measured by Air Quality Index in 120 Chinese cities) for 2000-2011. Specifically, we interact district-specific monthly incidence of Asian dust in South Korea with the intensity of China's air pollution and examine its contemporaneous and lagged effects on cause-specific monthly deaths in 232 South Korean districts.[4] Our identification strategy is motivated by three primary features of the Asian dust occurrence. First, Asian dust has a clear directional aspect in that the wind underlying it blows from west (China) to east (South Korea), meaning that it can transport Chinese pollutants to Korea but not vice versa. Second, the incidence of Asian dust in a region in South Korea is driven by wind patterns and topography rather than by local activities. That is, depending on the wind corridors that transport the dust storms, different Asian dust storm episodes can affect

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[4] We focus on the monthly information in our baseline so that we can control for the impact of locally generated pollution using local production data, which are available only at the monthly level. We also conduct analysis employing daily data for robustness checks.

different South Korean regions at different times. Third, the occurrence of Asian dust – because of its visual salience[5] – is monitored and recorded station by station in South Korea. Such monitoring makes Asian dust a useful apparatus for determining which districts within South Korea are under the influence of China's pollution.[6]

We find that conditioning on the direct effects of Asian dust and China's pollution, their interaction effect on South Korean mortality is significantly positive, in particular for deaths from respiratory and cardiovascular diseases (hereafter, respiratory and cardiovascular deaths) but not for deaths from other causes such as cancer. Specifically, at the mean incidence of Asian dust (roughly 0.8 days per month), a one standard deviation increase in China's pollution leads to about 280 extra respiratory and cardiovascular deaths per year in South Korea, around 0.6% of the yearly mean deaths from the two groups of diseases. We also find a significant effect on overall deaths from children aged below five, especially for those aged below one.

Our finding on the contemporaneous effects can be driven by both a net increase in deaths and a short-term forward shift in mortality of those individuals on the verge of dying anyway (known as the "harvesting effect" (Schwartz, 2000)). Investigating the impacts of lagged variables, we find that harvesting effect is not the main driver of our findings. In addition, our finding on children aged below five is unlikely to be explained by harvesting effect alone. We conduct extensive checks of our baseline findings including several alternative ways of measuring China's influence and examining China's pollution by quartiles. We also examine whether our finding is affected by possible spillovers within South Korea and find it not to be the case.

We next examine possible mechanisms for these outcomes. One natural explanation is that Asian dust and China's pollution elevate the pollution concentration in South Korea beyond what it would have been in the absence of spillovers from China. Although a variety of toxic materials can be carried via Asian dust (see the discussion in Section 2.1), we are limited to examining the impact on the common pollutants routinely measured by governments. We find that the interaction of Asian dust and China's pollution indeed raises the concentration of the major pollutants such

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[5] Appendix Figure A.1 presents a satellite image of Asian dust leaving China for Korea and Japan. When Asian dust arrives in an area, it is visible in the air.

[6] In contrast, based on regular winds, such quantitative information on district-specific exposure to China's pollution is difficult to obtain, as variations in wind speeds and directions are highly volatile. Later, we exploit time-series variations in winds (blowing over China) and compare the estimate with our main estimate based on Asian dust.

as sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3).

Using variation in Asian dust is advantageous to isolation of causal effect because not only is Asian dust precisely traceable, but depending on wind patterns and topography, different districts in South Korea are affected by the Asian dust phenomenon at different times. Asian dust, however, is a rare natural phenomenon that occurs only around one day per month on average. Therefore, the parameter identified, while useful for setting a lower bound on China's effect on South Korea, is specific to the variations in Asian dust. To have a sense of the overall effect of China's pollution on South Korea, we further exploit time-series variation in winds (with or without dust) that pass over China. Specifically, we examine the role of westerly winds (blowing over China) of varying strengths – defined as over the 50th, 75th, and 90th percentiles, respectively, on the distribution of wind speeds in the sample – as a carrier of China's pollution in a specification parallel to the one where Asian dust is viewed as the carrier. Notice that unlike Asian dust that gives us both spatial and temporal variation within South Korea, winds blowing over China provide time-series variation only.[7] The estimated effect of China's pollution via westerly winds ranges from 530 to 640 respiratory and cardiovascular deaths per year (for a one standard deviation increase in China's pollution), around 1.1%-1.4% of mean deaths from the two groups of diseases. This comparison suggests that our approach relying on Asian dust captures a relatively important part of the spillover effect. This finding is also consistent with the media and public attention directed towards China's air pollution spillover during Asian dust episodes.[8]

By quantifying the mortality impacts of transnational pollution spillover from China to South Korea, we contribute to several lines of literature. Using a novel method, our study provides concrete evidence on the health impacts of transnational air pollution. Our method explores *differential exposure* of district-time cells in South Korea to a given pollution condition in China.[9]

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[7] From the perspective of South Korea, time-series variation in winds (blowing over China) is much "cruder" than the within-Korea variation in the incidence of Asian dust. Nonetheless, the time-series variation we obtain from the wind data is likely informative because the surface area of China is much larger than that of South Korea. If, on the contrary, China and South Korea were of equal sizes or if South Korea were larger than China, crude wind patterns over China alone will be insufficient in determining China's influence on the air quality in South Korea.

[8] See reports including "China's killer yellow dust hits Korea, Japan" at Reuters (March 3, 2008) and "Worries in the Path of China's Air" at the New York Times (December 25, 2013) for example.

[9] Our identification strategy can be nicely contrasted with the approach in Schlenker and Walker (2015)'s innovative recent work, though cross-border spillover is not the focus of that study. The authors use the day-to-day variation in airplane taxi time in California airports to induce exogenous variation at the point source of pollution, namely each airport and link that to morbidity outcomes in local areas (within 10 km from each airport). In contrast, we are dealing with the issue of long-range spillover between countries, where the source country is very large with numerous

This approach thus addresses the major empirical challenge posed by correlated pollution cycles between the two countries. In addition, our findings add to the few existing studies on transnational spillover in other areas such as Sigman (2002) on water pollution and Almond et al. (2009) and Black et al. (2013) on radiation.

This study is also related to the public health literature on the health impacts of Asian dust *per se*, where the incidence of Asian dust itself is viewed as a shock (e.g., Wilson et al., 2012a, 2012b; Lee et al., 2013; Baek et al., 2015). It is worthwhile clarifying that our focus is different from this line of research. We are interested in the effect of China's air pollution on South Korea rather than that of Asian dust itself. Since Asian dust is a meteorological phenomenon (which is not caused by China), any direct effects found of Asian dust cannot be attributed to China. Our approach focuses on the interaction between China's pollution and the Asian dust phenomenon and identifies the effects of China's pollution operating via Asian dust. To the best of our knowledge, this is the first study that combines data from both countries to understand the health impacts of transnational air pollution spillover.

The data used and our identification strategy are described in Sections 2 and 3, respectively, after which Section 4 reports the main empirical results and robustness checks. Section 5 compares Asian dust a carrier with that of winds, and Section 6 concludes the paper.

2 Background and Data

As background to our analysis, we first provide a brief description of the Asian dust phenomenon and related wind patterns. Our primary dataset consists of information on the incidence of Asian dust storms, the number of deaths by cause, and pollution levels in both South Korea and China. Our baseline analysis focuses on monthly variation across all 232 Korean districts between 2000 and 2011. An average South Korean district is 432 square kilometers in size with a population of about 210,000. Summary statistics of the variables discussed below are presented in Table 1.

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point sources of pollution (with the point-specific quantities of emission unknown to the researchers). Our strategy hence relies on the variation at the receiving end of the pollution spillover, rather than variation at the source of the pollution.

2.1 Asian Dust and Wind Patterns

Asian dust as a carrier of pollutants Scientific studies have documented that China's pollution can affect South Korea during Asian dust periods in two ways. First, the dust particles and the strong winds underlying the Asian dust phenomenon can directly transport pollutants. For instance, Lee et al. (2013)'s time-series analysis documents that in South Korea, the levels of major pollutants, such as PM_{10}, SO_2 and NO_2, are significantly elevated during the Asian dust periods. Besides these pollutants, which governments routinely monitor, increased levels of elements such as Ni, Cu, Zn, Cd and Pb are also found in South Korea during the dust events. As Choi et al. (2001) explain, since dust particles (without picking up any man-made pollutants before reaching Korea) should consist primarily of crustal elements such as Na, Mg, Al, Ca, Fe and Mn, the observed increase in non-crustal elements (e.g., Ni, Cu, Zn, Cd and Pb) reveals that the Asian dust must have picked up pollutants from the industrialized regions of China. Second, in traveling long distances, dust particles can also react with pollutants and generate other compounds that may have adverse effects on health (Choi et al., 2001; Li et al., 2012). In particular, Nishikawa et al. (1991) and Carmichael et al. (1996), based on aerosol samples taken in Japan and Korea, respectively, show that, during the long-range transport of the wind-blown dust particles, significant amounts of sulfates and nitrates are introduced through reaction with SOx and NOx gases.

By focusing on the interaction between China's pollution and the Asian dust phenomenon, we aim to isolate the effect of pollution spillover that operates via the two pathways discussed above. In our approach, Asian dust is viewed as a medium by which China's pollution can exercise influence on South Koreans, and our main objective is to identify the reduced-form effect of the Asian dust-China pollution interaction on cause-specific mortality in South Korea. While the identification of pollution spillover on each and every possible pollutant and toxic element is beyond the scope of this study, we examine the effect on the common pollutants such as SO_2 and NO_2 that governments routinely measure.

Incidence of Asian dust The data on the incidence of Asian dust come from the Korean Meteorological Administration (KMA), which compiled incidence records for the 2000-2011 period from 28 stations across South Korea (designated by stars in panel (a) of Figure 1). To designate an Asian dust day, the KMA first verifies that dust storms have occurred in the desert regions of Mongolia and China and then uses weather maps and satellite images to track their movements toward and across Korea. The KMA confirms the storms' presence through visual observation and issues a dust storm warning when necessary (Lee et al., 2013).[10] The main component of aerosols during the Asian dust events are dust particles ranging in size from one micrometer and ten micrometers, i.e., between the size of PM_1 and that of PM_{10} (Chun et al., 2001). When Asian dust occurs, it is visible in the air.

Our analysis covers 232 South Korean districts, each assigned Asian dust records from the nearest station, based on distance from the district centroid. For robustness, we also conduct analysis for different subgroups within varying distances from the monitoring stations.

Variation in Asian dust As panel (b) of Figure 1 illustrates, districts in South Korea vary greatly in topography. The wind patterns and topography of South Korea generate rich spatial and temporal variations in the incidence of Asian dust. As an example, Figure 2 maps the incidence of Asian Dust in March across three years. Clearly, the overall frequency of dust events varies significantly across years, even for the same month. Moreover, there are rich spatial variations within years. For instance, in March 2000, the western regions experienced more than five Asian dust days, whereas the eastern regions experienced around three. In March 2010, with stronger winds, the pattern was the opposite. In March 2003, all the regions were affected evenly, with an average region having one Asian dust day.

Besides varying across years, Asian dust storms also show strong (within-year) seasonality based on seasonal meteorological conditions. Panel (a) of Figure 3 illustrates this seasonality by displaying the mean number of Asian dust days per month between June 2000 and December 2011. Because of the humidity associated with monsoon season, Asian dust never occurs in summer (June through August); thus, these months are omitted from the figure. Dust events are most frequent in spring (March through May), and the occurrence outside spring is less frequent. Given this seasonality, our analysis always control for month fixed effects.

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[10] KMA issues dust storm warnings based on PM_{10} concentrations: severe dust storms have over 400 $\mu g/m^3$ and more-severe dust storms over 800 $\mu g/m^3$ for two continuous hours in a day. The warning can lead to some avoidance behavior (Baek et al., 2015). Our estimate should be thought of as the net effect on mortality after taking into account possible reduction in mortality, if any, due to such avoidance behavior.

Asian dust and wind patterns To illustrate the relation between Asian dust and wind patterns, we draw on data from the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, which cover information on daily wind speed and direction collected by 499 stations located across China. Wind speed is reported in m/s and wind direction in cardinal directions, where a wind blowing from the south, for example, is given as 180 degrees (for a wind directional map and an example of winds on an Asian dust day, see Appendix Figure A.2).

We aggregate these daily observations from the 499 stations up to a measure that can approximate – albeit very crudely – the daily wind pattern over China as a whole. Specifically, if the mean of station-daily data on wind direction is between 180 and 360 degrees, we treat the prevailing wind pattern over China on that day as being westerly. Similarly, we approximate the daily wind speed over China by taking the mean of station-daily data on wind speed.

In Figure 4, the distributions of daily wind speed and wind direction over China in the presence and absence of Asian dust are plotted. Two patterns are apparent: (i) wind speed is significantly higher on dust days: the mean speed on dust days is 6.2 m/s, above the 75th percentile (5.8) on the overall wind speed distribution; (ii) the wind direction over China is almost always from west to east on Asian dust days (i.e., above 180 degrees), confirming that westerly winds are necessary for Asian dust.

Therefore, dust days can be considered as a subset of westerly wind days. Our baseline analysis centers on Asian dust that gives us rich regional variation to explore. Then, we expand our study to time-series variation in westerly winds.

2.2 Deaths in South Korea

The impacts of pollution on mortality are well documented, in particular, the sensitivity to air pollution of those with respiratory and cardiovascular diseases (Dockery et al., 1993; Samet et al., 2000; Dominici et al., 2006; Chen et al., 2013) and infant mortality (Chay and Greenstone, 2003; Currie and Neidell, 2005). Here, we draw on the useful overview of the medical literature in Zanobetti et al. (2003) to describe the different causes on which we focus.

Cause-specific deaths Our individual-level data on cause-specific mortality, compiled by Statistics Korea, show all deaths in South Korea on all days between 2000 and 2011. This information covers the date, place, and cause of deaths classified according to the World Health Organization's 10th revision of the International Classification of Diseases (ICD-10) – as well as selective information on such characteristics as age, gender, and education. Following the literature, we focus on mortality from all internal causes. Using these individual-level data, we construct a district-month level dataset on deaths by major causes, with a focus on respiratory (ICD-10 codes J00-J99) and cardiovascular deaths (ICD-10 codes I00-I52). As a placebo test, we also explore deaths from cancers (ICD-10 codes C00-C97), which are unlikely to be affected in the short run by China's pollution. We also examine major causes of deaths individually as well as investigate subgroups within respiratory and cardiovascular deaths.

As might be expected, deaths also exhibit seasonality, illustrated by the monthly distributions of mortality by cause plotted in Figure 3. However, the seasonality of deaths and that of Asian dust do not appear related in any systematic way.

Migration concerns In our baseline we use the district-month level number of deaths from different causes as the dependent variable and always control for district-year fixed effects. Because the population size of each district is unlikely to change dramatically within a year, the change in the number of deaths can be interpreted as a mortality rate (when denominated by the population size for the district-year).

However, even though we account for the longer-term movement of individuals by controlling for district-year fixed effects, our estimates may be biased upward or downward if systematic within-year migration occurs. For instance, individuals may migrate out from own districts during polluting dust days. On the contrary, frail individuals from less affected – by Asian dust-induced Chinese pollution – districts may seek care in large hospitals located in more affected districts and die there. To make sure that our district-by-district analysis is not driven by short-term migration scenarios of either type, we also estimate a specification in which the entire South Korea is treated as a single district.

Deaths by Social-economic Status In part of our analysis, we consider differential impacts of Asian-dust induced Chinese pollution by subgroups of South Koreans. Specifically, we examine possible heterogeneity along two dimensions: age groups and levels of schooling (for those aged 15 and above). In examining the effect by age groups, we will evaluate the impact on young children separately in light of a literature documenting the health impacts on them (e.g., Currie and Neidell, 2005).

2.3 Air Pollution in China

China's pollution For pollution values, we draw on daily information on air pollution in 120 cities across China (provided by the Ministry of Environmental Protection of China), the distribution of which is mapped in Figure 5. The size of the circles indicates the number of daily observations available between June 2000 and December 2011. The dark circles are the 31 provincial capitals; their daily data can be traced back to June 2000, but for some cities, daily records are available only for very recent years. We include information from all 120 cities in our baseline estimation and then use data from the provincial capitals only as a robustness check.[11]

The reported pollution information is based on the Air Quality Index (AQI), which runs from 0 to 500. The mean and median of city-day level observations of AQI between June 2000 and December 2011 are 66 and 72, respectively. The interpretation of the AQI is such that the higher the value, the greater the air pollution and concern for health. It is worth noting, however, that the AQI is not a linear measure; that is, an AQI of 100 does not mean twice the pollution concentration of an AQI of 50 or a pollution condition that is twice as harmful. Thus, we consider this nonlinearity in measuring China's influence.

Researchers who use pollution data from China are often worried about underreporting by the Chinese government. Given our research question of interest – whether or not the pollution situation in China matters for South Koreans' health – all we require for our sample is an internally consistent classification of the pollution situation. Hence, these pollution data would still be informative even if all the cities were to underreport. We also verify that our measures of China's pollution and industrial production are highly correlated, suggesting that the pollution data do, indeed,

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[11] Cities added to the sample more recently are not significantly more (or less) polluting than other cities.

capture meaningful variations in China's air quality (see the discussion after the description of our measures).

Measuring China's Influence An important concern for this study is whether our findings are robust to different ways of measuring China's influence. To ensure that our analysis is robust to this concern, we consider six alternative ways of aggregating the AQI information with an additional measure based on China's industrial output.

(i) Simple mean of AQI. The most straightforward way to measure China's influence would be to take the arithmetic mean of the raw AQI across Chinese cities. However, because of the AQI's nonlinearity in pollutants, such an aggregation is not ideal, although we use this measure for robustness.

(ii) Share of city-daily observations above a pollution threshold. For each month, we calculate the share of cities (out of 120) with an AQI larger than a fixed threshold. We start by using the mean AQI during the sample period as the threshold. Because changes or differences in this measure can always be interpreted consistently – for a given threshold – we prefer this measure to measure (i) and use this as our baseline. It varies from 22% to 78%, with a standard deviation of 14%. Panel (b) of Figure 3 plots our baseline measure across different months, China is more polluting in winter and spring, which is consistent with increased wintertime pollution from coal heating (Chen et al., 2013). For robustness, we also vary the threshold (e.g., median instead of mean) to calculate the daily share of "polluted" cities.

(iii) Measure (ii) weighted by distance to South Korea. We use the weighted measure as a robustness check. Specially, for each of the 120 Chinese cities with AQI information, we calculate its nearest distance to South Korea and weight the "polluted" dummy (i.e., indicator for whether AQI is above the mean) by the inverse distance.

(iv) Information on province capitals only. Instead of using information from all 120 cities, we restrict our attention to provincial capitals, not only because the data for these cities have been available for longer periods, but also because each of them represents one province, enabling verification that our findings are not driven by the geographic variation in information availability.

(v) Southwest region vs. the other regions. As illustrated in Appendix Figure A.2, on an Asian dust day (in this case, March 21, 2012), the wind can carry pollutants from both northern and southern China. As a result, it is not entirely obvious which region of China matters most for pollution spillover to South Korea.[12] To further understand possible heterogeneous influence of Chinese regions, we hypothesize that the impact of the southwestern region (the shaded area in Figure 5) should be less important because this region is further from the trajectories of Asian dust, and because the correlation of pollution conditions in this region with that of other Chinese regions is weaker (albeit still positive).

(vi) Measurement by quartiles. It is conceivable that the effect of pollution on health is not linear: the effect can be much worse when China is very dirty than when China is modestly polluting. To take this into consideration, we also divide measure (ii) into quartiles and examine the results by quartiles.

Correlation between China's pollution and industrial production To verify whether our measure is informative and, in particular, whether it captures China's industrial production, we examine the correlation between the level of such production and our baseline pollution measure. The data on *monthly* production are very limited. We draw on the best available – the Statistical Bureau of China's figures on year-on-year growth in industrial value-added available between 2000 and 2006. Using these data, we calculate the year-on-year change in our baseline measure of China's pollution and then examine its correlation with the year-on-year growth in industrial production. As Figure 6 shows, these two measures are significantly correlated (with a slope of 1.02 and a p-value of 0.005), suggesting that our measure does capture meaningful variations in China's air quality. In part of our analysis, we also use the (year-on-year growth in) industrial value-added itself as a measure of China's pollution, with the caveat that the data are available for 2000-2006 only and all the relevant variables have to be expressed in year-on-year growth terms, introducing further noise in estimation. Nonetheless, we see the exercise as a useful robustness check.

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[12] In fact, Li et al. (2014) show that there is substantial within-China spillover in air pollution.

2.4 Local Pollution, Production, and Weather in South Korea

Local pollution The data on observed (i.e., measured) pollution – which is the combination of South Korea's locally generated pollution and pollution spillover from China – in South Korea are available for 2001-2011 from the National Institute of Environmental Research (NIER), which provides hourly information on the density of five major pollutants (SO_2, CO, NO_2, O_3, and PM_{10}) for 147 monitoring sites. We aggregate the hourly information into monthly statistics such as the monthly mean or monthly maximum concentration and assign the values from the nearest site to each district, based on the distance to the district centroid. The units of measurement are *ppm* for SO_2, CO, NO_2, O_3, and $\mu g/m^3$ for PM_{10}. Using this month-level information, we examine how the interaction of Asian dust and China's pollution affects the mean or maximum concentration of SO_2, CO, NO_2, O_3 in a district-month.[13] Moreover, we link the observed levels of each pollutant to the thresholds of health-harmful levels and examine whether the interaction effect of China's pollution and dust affects the likelihood of exceeding such thresholds.[14]

Local production Similar to most industrialized countries, South Korea's most important emission sources are energy production and vehicle transportation, although their relative importance differs by type of pollutant. Whereas energy production accounts for 40% of sulfur oxides (SO_X) and 30% of nitrogen oxides (NO_X) emitted, vehicle transportation accounts for 85% of PM_{10}.[15] While no region-specific monthly information is available on vehicle transportation, Statistics Korea's Mining and Manufacturing Production Index provides monthly information on industrial production across all of South Korea's 16 provinces. This index, which is available both for industry overall and for the energy industry specifically, measures the relative production level across months for each province (using the 12-month average from 2010 for that province as the benchmark = 1). The mean of the local energy production measure is 0.74 (with a standard deviation of 0.37), which means that the monthly average energy production level between 2000 and 2011 is

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[13] Because the density of PM_{10} is a criterion in the definition of Asian dust and is highly correlated with its incidence, it is not reasonable to examine the interaction effect of China's pollution and dust on PM_{10}. Therefore, for PM_{10}, we only check the direct effect of dust incidence without interacting with China's pollution.

[14] The thresholds are based on the regulation of South Korean Ministry of Environment. Source: http://www.me.go.kr/mamo/web/index.do?menuId=586. The values above these thresholds are significantly harmful to health.

[15] Source: *National Air Pollutants Emission 2001*, National Institute of Environmental Research, South Korea.

74% of the 12-month average in 2010.

Local weather conditions To control for the impact of local climate conditions, we use the KMA data on monthly average temperature and precipitation for 59 weather stations.[16] Districts are assigned the weather data from the nearest station, based on the distance from the district centroid. To allow for a flexible effect of weather on deaths, we include the levels of both precipitation and temperature and their squared terms.

3 Estimation Strategy

To identify the presence of pollution spillover from China to South Korea, we exploit the incidence of Asian dust across South Korean districts over time and the time-series variation in China's air quality. We capture the delivery of air pollution from China via Asian dust in the following specification:

$$\begin{aligned}
(\ln)Death_{k,y,m} \;=\;& \gamma_0 + \gamma_1(Dust_{k,y,m} \times CP_{y,m}) + \gamma_2 Dust_{k,y,m} + \gamma_3 CP_{y,m} \qquad (1) \\
& + \delta_1 Energy_{p(k),y,m} + \delta_2(Dust_{k,y,m} \times Energy_{p(k),y,m}) \\
& + \delta_3 WT_{k,y,m} + \delta_4(CP_{y,m} \times WT_{k,y,m}) \\
& + \lambda_{1i}(Dust_{k,y,m-i} \times CP_{y,m-i}) + \lambda_{2i} Dust_{k,y,m-i} + \lambda_{3i} CP_{y,m-i} \\
& + \rho_i (\ln)Death_{k,y,m-i} + \phi_{k,y} + \psi_{R(k),m} + u_{k,y,m}
\end{aligned}$$

where $Death_{k,y,m}$ is the number of cause-specific deaths in South Korean district k in year y and month m. We also use the logged number of deaths as an alternative dependent variable.

On the right side of the equation, $Dust_{k,y,m}$ is the number of Asian dust days observed in South Korean district k in year y and month m, and $CP_{y,m}$ shows the extent of pollution in China in year y and month m. Our main coefficient of interest is γ_1, that is, how $Dust_{k,y,m} \times CP_{y,m}$ in month m affects death outcomes in that same month.

To absorb variation in locally generated pollution and to account for other unobserved hetero-

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[16] Of these 59 weather stations, 28 are operated by the national government and the rest by the regional governments. Asian dust data come from the 28 stations operated by the national government.

geneity across districts and time, we include, throughout the analysis, district-year fixed effects $\phi_{k,y}$ and ring-month fixed effects $\psi_{R(k),m}$ (where $R(k)$ indicates the "ring" to which district k belongs, with the rings defined by the distance to Beijing, as described below). The former accounts for year-specific district characteristics such as year-average air quality and yearly population changes, whereas the latter takes into consideration the seasonality of deaths and other season-specific shocks. As for monthly fixed effects, rather than inflexibly imposing common month effects on all districts, we divide South Korea into six rings, based on distances from Beijing (see panel (a) of Figure 1) and allow ring-specific monthly fixed effects $\psi_{R(k),m}$ for districts inside ring R. These effects capture the monthly seasonality in economic activities across different regions. For instance, the region closest to China is also the most industrialized region in South Korea, so the month-to-month variation in its activities might differ from that of other regions. Including these effects also isolates the direct month-specific effect of distances from China that might confound the effect of Asian dust.

Our results are also robust to including district-month fixed effects (instead of ring-month fixed effects). We present the ring-month fixed effects because they speak to distance in an intuitive way and we will also explore the rings when discussing spillovers within South Korea in Section 4.4.

To ensure that γ_1 will only pick up the spillover effects from Chinese pollution without convolution with the effects of unobserved local conditions, we additionally control for a series of district-time level covariates. In particular, we control for $Energy_{p(k),y,m}$, a variable representing the year-month index of energy production in the 16 South Korean provinces, to account for the effect of locally generated pollution. In addition, we also allow for its interaction effect with Asian dust. Moreover, we control for $WT_{k,y,m}$, a vector of local climatic conditions, including district-specific monthly averages of temperature and precipitation, as well as their squared terms. Furthermore, we allow for the interaction effects of China's pollution and local weather conditions. Throughout, we demean the variables ($CP_{y,m}$, $Energy_{p(k),y,m}$, $WT_{k,y,m}$) to facilitate reading of the coefficients.

In addition, to account for possible correlations in deaths between months, we allow for the inclusion of lagged deaths. In some specifications, we also examine whether the effect of our main explanatory variable, the interaction of Asian dust and Chinese pollution, might persist beyond the first month of an event by including this interaction in past months (designated by $m-i$ with

$i = 1, 2, ...$) in addition to the contemporaneous variables.

Conditional on the direct effects of $Dust_{k,y,m}$ and $CP_{y,m}$, the district and time fixed effects, plus the extensive district-by-time level covariates such as local energy production and its interaction with Asian dust, our identifying assumption is that the interaction $Dust_{k,y,m} \times CP_{y,m}$ will remain uncorrelated with unobserved mortality-inducing local conditions.

Discussion on Identification Assumption Although the (conditional) orthogonality of $Dust_{k,y,m} \times CP_{y,m}$ with respect to $u_{k,y,m}$ is not directly testable, we can nonetheless check whether the interaction of dust incidence and China's pollution is orthogonal to some of the observable local characteristics that can lead to pollution-related mortality. We consider two types of observable characteristics: Statistics Korea data on province-monthly production index by sectors (overall, manufacturing, and energy) and NIER data on province-yearly emission by pollutants (SO_2, NO_2, CO, PM_{10}, and volatile organic compounds (VOCs)).[17] Columns (1) through (3) in Appendix Table A.1 show the relationship between province-monthly production index and $Dust_{p(k),y,m} \times CP_{y,m}$, where $Dust_{p(k),y,m}$ measures the mean dust days in all districts within a province p for a given month m. In the heading of each column, we also present the correlation between the production index and SO_2 and NO_2 concentration for information purposes. Consistent with the discussion in Section 2.4, there is a sizable positive correlation between the energy production index and pollution concentration, which is why we include energy production in equation (1).[18] More importantly, looking at the key coefficients of interest in this table, $Dust_{p(k),y,m} \times CP_{y,m}$, we find no evidence for a positive correlation between $Dust_{p(k),y,m} \times CP_{y,m}$ and monthly local production irrespective of sectors.

Next, we turn to the data on province-yearly level emissions of key pollutants from all sources (including manufacturing, energy production, and vehicle transportation, among others). The emissions data – though available at the province-yearly level only – are a more direct measure of South Korea's local pollution generation than the sector-specific production index. As columns (4) through (8) show, the correlation between emissions (in tons) and $Dust_{p(k),y} \times CP_y$ is insignificant.

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[17] The data on province-monthly production index are described in Section 2.4. The data on annual emission (in tons) by provinces and pollutants are available at http://airemiss.nier.go.kr/.

[18] Including the other two indexes (overall production and manufacturing) in equation (1) does not vary the findings.

The two pieces of evidence, albeit merely suggestive, are clearly in line with our identification assumption.

4 Main Results

Section 4.1 presents the reduced-form estimates on deaths by cause based on equation (1). Section 4.2 discusses nonlinearity and heterogeneous effects whereas Section 4.3 presents extensive robust checks. As one mechanism for our baseline finding, Section 4.4 documents the impact on different pollutants.

4.1 The Impact on Deaths by Cause

Results on respiratory and cardiovascular deaths Table 2A reports our baseline estimates of equation (1), focusing on respiratory deaths at the district-month level (with a mean of 5.62). All regressions include district-specific year fixed effects and ring-specific month fixed effects, with standard errors clustered at the district level. According to column (1), in which Chinese pollution is not accounted for, Asian dust appears to increase respiratory mortality in South Korea, consistent with the findings in the public health literature focusing on dust per se (e.g., Wilson et al., 2012a, 2012b). Column (2) also demonstrates a positive association between respiratory deaths and China's pollution.

In column (3), the coefficient on $Dust_{k,y,m}$ now turns statistically insignificant, suggesting that when China is relatively clean – at the mean level of China's pollution – Asian dust in itself is not necessarily harmful; dust (and the strong winds underlying it) may even dilute the direct effect of local pollution. In contrast, our main coefficient of interest – the effect of $Dust_{k,y,m} \times CP_{y,m}$ – is strongly positive and statistically significant. This finding is consistent with the discussions in the background: the dust traces China's air before it reaches Korea, thus bringing China's pollutants to Korea (along with other harmful elements generated by the chemical reaction of dust particles to SOx and NOx in the transportation processes). In columns (4) through (6), we progressively add controls including South Korea's energy production index and its interaction with the dust phenomenon, flexible specifications of weather conditions, and the interactions of China's pollution and weather conditions. The estimates remain very stable across all these specifications, with a magnitude around 0.46.

The estimates of the coefficient on $Dust_{k,y,m} \times CP_{y,m}$ show that at the mean dust days (0.8 days a month), a one standard deviation increase in China's pollution (0.14) leads to 0.052 (0.8×0.46×0.14) extra deaths from respiratory disease per month and per district – or around 12 (0.052×232) extra respiratory deaths a month for South Korea. This effect size is roughly 1% of the mean respiratory deaths in an average month. The results using logged deaths from respiratory diseases as an alternative dependent variable (columns (7)-(8)) are close to the estimates using levels.

Table 2B shows similar analysis using cardiovascular deaths as the dependent variable (with a mean of 10.69). The pattern is very similar to that for respiratory deaths: at the mean dust days, a one standard deviation increase in China's pollution leads to around 12 extra cardiovascular deaths a month for South Korea, or around 0.5% of the mean cardiovascular deaths.

Taken together, the results in Tables 2A and 2B show that at the mean of Asian dust days, a one standard deviation increase in China's pollution leads to around around 280 extra respiratory and cardiovascular deaths in a year, about 0.6% of the yearly mean. These are based on contemporaneous effects of $Dust_{k,y,m} \times CP_{y,m}$ on monthly mortality. Next, we allow lagged explanatory variables and lagged deaths to affect the current period's deaths.

Impacts of lagged pollution spillover Column (1) of Table 3 reports the results for lagged pollution spillover on respiratory deaths up to three months before the current month. Column (2) also adds lagged deaths in the previous months. Columns (3)-(4) present the results for cardiovascular deaths using the same specifications. As shown, $Dust_{k,y,m-1} \times CP_{y,m-1}$ has a significantly positive impact on respiratory and cardiovascular deaths in month m but the magnitude is smaller than the concurrent impact. The other lagged results are generally positive but insignificant except for one insignificantly negative coefficient.

The estimates on the lagged variables can be driven by two factors. First, there can be some persistence effect of pollution spillover, which is positive. Second, there can be a harvesting effect, which implies a negative correlation between past pollution and current deaths – a significant decrease in deaths after an initial surge. We can only estimate a net effect of these factors. Given the generally positive coefficients, these results show that the harvesting effect is unlikely to dominate the other, even though it can also be at work together with a net increase in deaths.

Placebo tests: results on deaths from cancers and other diseases To ensure that our findings on respiratory and cardiovascular deaths above are specific to air pollution, we conduct a placebo test using cancer deaths as the dependent variable. Cancers – though a major cause of mortality in South Korea (with a mean of 23.3 in the district-month data) – are much less likely than respiratory and cardiovascular disease to result in a changed number of deaths in response to short-term variations in pollution. In fact, as Table 4 shows, contrary to the results for respiratory and cardiovascular deaths, our main variable of interest, $Dust_{k,y,m} \times CP_{y,m}$, has no impact on deaths from cancers. This finding suggests that our baseline results are unlikely to driven by omitted district-monthly characteristics that affect all types of diseases.

Another way to understand the consequences of $Dust_{k,y,m} \times CP_{y,m}$ is to examine – without having any prior on which diseases are responsive to pollution – its impacts on deaths cause by cause and let the data tell which type of deaths are affected. For such an analysis, it is reasonable to focus on major causes of deaths only; otherwise, the no-effect result might be mechanically driven by the fact that not many people die from a certain minor disease. Therefore, we focus on the top five causes of deaths in South Korea: cancers (with a mean death of 23.3), cardiovascular diseases (with a mean death of 10.69), non-cardiovascular diseases in the circulatory system (with a mean of 9.47), respiratory diseases (with a mean death of 5.62), and digestive diseases (with a mean death of 4.25). We group the other 13 minor causes together (with a mean death of 22.49).

To facilitate the comparison across groups, we focus on the results using logged deaths as the dependent variable and present them in descending order of the mean deaths. Columns (1), (2) and (4) of Appendix Table A.2 replicate the results on logged deaths in column (8) of Tables 2A–2B and Table 4. As shown in columns (3) and (5), we find no significant impact of $Dust_{k,y,m} \times CP_{y,m}$ on deaths from non-cardiovascular diseases in the circulatory system or digestive diseases. Column (6) further shows that $Dust_{k,y,m} \times CP_{y,m}$ also has a positive but insignificant impact on deaths from other diseases when examining them together.

Together, these results show that respiratory and cardiovascular deaths are more responsive than deaths from other causes. Moreover, the fact that the effects on other diseases are not negative means that the main effect on respiratory and cardiovascular deaths are unlikely to be driven by coding of deaths, in particular, substitution away from other causes to respiratory and cardiovascular deaths, in response to the salience of dust events. Hence, our focus on them as the baseline seems reasonable.

4.2 Nonlinearity and Heterogeneous Effects

Results by Quartiles It is possible that the effect can be much worse when China is very dirty than when China is moderately polluted. To examine potential nonlinearity in Asian dust-induced spillover effect from China, we divided our baseline measure of China's pollution into quartiles. The first quartile indicates the share of city-daily AQI observations below the mean is no higher than 41%. The second quartile refers to the months when the share is above 41% but no more than 51%. The third quartile indicates the months when the share is above 51% but no more than 63%. Finally, the fourth quartile refers to the months where the share is higher than 63%.

The results are presented in Table 5, where the first quartile is left as a comparison group. Columns (1)-(3) present the results for respiratory deaths and columns (4)-(6) for cardiovascular deaths. The results show that the adverse effect of a dust day is increasing in the degree of China's pollution, suggesting that our baseline finding is robust to nonlinear specifications.

Impacts across Age and Education Groups To shed light on the impacts across socioeconomic status status, we examine the impacts by age and education groups. Table 6A reports our findings on the potentially heterogeneous effects of the Asian dust-Chinese pollution interaction across age groups. Specifically, we examine the heterogeneous impacts for the elderly (aged 65 or older), individuals aged between 35 and 64, and those aged between 15 and 34. For the young people aged under 15, we examine deaths from all causes together considering the small number of deaths in each district-month cell. We divide the young people into four groups: less than 1 year old, 1-4 years old, 5-9 years old and 10-14 years old.

As columns (1)-(6) show, the adverse health impact in terms of respiratory and cardiovascular diseases falls mostly on the elderly, who account for over 73% of respiratory deaths and 70% of cardiovascular deaths. These results are partly driven by the fact that the mean deaths (from all causes) are higher for the elderly.

Moreover, columns (7)-(8) show that very young children (aged below 5) are also significantly affected, especially those aged below 1. The effect is even larger than our baseline finding on respiratory and cardiovascular deaths (compared with the mean deaths): conditional on mean dust days (0.8), a one standard deviation increase in China's pollution increases deaths (from all causes) for those aged below 1 by around 1.7%. In contrast, those aged between 5 and 14 are not significantly affected (as shown in columns (9)-(10)). Although the percentage impact on under-five mortality is large, children's deaths are rare and account for only a small part of the overall deaths in each district-month cell. Therefore, when we discuss the aggregate implications, we do not emphasize this finding on under-five mortality and instead focus on the respiratory and cardiovascular deaths for all age groups.

We also examine the impacts by four categories of education: no schooling; primary school; lower secondary school; and upper secondary school or above. A significant share of deaths are for individuals with no schooling, which is consistent with the fact that most deaths occur in elderly population and that a large share of elderly population in South Korea have no formal schooling.

Columns (1)-(4) in Table 6B present the results for respiratory deaths and columns (5)-(8) for cardiovascular deaths. As shown, the adverse effects fall disproportionately on those with lower levels of education. Individuals with low education are likely to suffer more either indirectly through their low income and low underlying health conditions or directly through their educational status itself to the extent that the tendency to engage in avoidance behavior depends on educational status.

Specific causes within respiratory and cardiovascular deaths We also examine more specific causes of respiratory and cardiovascular deaths. Similar to the logic in Appendix Table A.2, we investigate how the major subgroups within respiratory and cardiovascular diseases respond to $Dust_{k,y,m} \times CP_{y,m}$. For respiratory deaths, chronic lower respiratory diseases (e.g., COPD and asthma) and acute lower respiratory infections (e.g., acute bronchitis) are the two major subgroups that account for 75% of the deaths. For cardiovascular deaths, chronic rheumatic heart diseases (e.g., rheumatic aortic valve diseases) and ischemic heart diseases (e.g., acute myocardial infarction or "heart attack") are the two major subgroups that account for 61% of the cardiovascular deaths.

Appendix Table A.3 presents the results on deaths by these subgroups of diseases within the respiratory and cardiovascular categories. Columns (1) and (5) replicate the results in Tables 2A-2B. Columns (2)-(4) and columns (6)-(8) show the decomposition for respiratory and cardiovascular deaths, respectively. As shown, all major subgroups within respiratory and cardiovascular diseases are affected to some extent.

4.3 Further Robustness Checks

In this section, we first examine whether our findings are affected by spillover within South Korea. Then, we discuss alternative ways of measuring China's influence and matching the data. We also check whether our main findings are robust to using moving-average analysis based on daily data. A few results are presented in the Appendix.

Spillover within South Korea Although we have interpreted the coefficient on $Dust_{k,y,m} \times CP_{y,m}$ as the effect of exposure to China's pollution via Asian dust, if the latter also facilitates pollution spillover within Korea, we might be overstating the impact. For instance, Asian dust storms (which blow from west to east) are not only capable of transporting China's pollution to South Korea, but can also transport pollution from the northwest part of South Korea to other South Korean districts. We conduct two checks to examine the importance of this concern.

First, we check whether pollution spillover within South Korea matters for our finding. We focus on the pollution-generating activities of the South Korean regions closest to China (the first ring in Figure 1), which include Seoul (South Korea's capital) and Incheon (a major port), as well as the industrial complexes surrounding those cities. Table 7 shows the estimates of a variant of equation (1) that includes not only China's pollution, but also the mean energy production index among districts in Ring 1 and its interaction with Asian dust. The estimation sample contains all district-months except for the districts inside Ring 1. The results for both respiratory deaths (columns (1)-(3)) and cardiovascular deaths (columns (4)-(6)) indicate that our main effect of interest (coefficient on $Dust_{k,y,m} \times CP_{y,m}$) is robust to the inclusion of Ring 1's energy production interacted with Asian dust. They also show that, if anything, the interaction of dust and energy production in Ring 1 has a weakly negative impact on respiratory (but not cardiovascular) deaths, perhaps because the dust dilutes local pollution, as evidenced by earlier results. These results support the likelihood that our main findings are, indeed, due to pollutants from China and not to the redistribution of locally-generated pollution.

Another check we conduct is to examine the impacts on South Korea as a single region. As shown in Appendix Table A.4, the size of the effect for South Korea as a single region is comparable to the sum of the estimates from the district-level analysis. Therefore, these findings provide further evidence that spillover within South Korea is unlikely to be a critical concern. This result also shows that systematic within-year migration is unlikely to be responsible for our main findings.

Alternative ways of aggregating China's pollution The quartile results in Table 5 have shown that our finding is robust to nonlinear specifications. Appendix Table A.5 further presents the results using measures (i)-(v) for China's pollution (defined in Section 2.3). To facilitate the comparisons, we standardize these various measures so that the coefficients can be interpreted as the impact of one standard deviation increase in each measure. Column (1) reports the baseline result. Column (2) presents the result using the simple mean of AQI: one standard deviation increase in this measure has a relatively smaller impact than that using the baseline measure but the pattern is very similar. Column (3) shows an effect similar to the baseline estimate using the share of "polluted" city-days above the median (as opposed to the mean) AQI as the threshold. Column (4) confirms that the baseline findings remains robust to weighting the pollution conditions in Chinese cities by their distances from South Korea. Column (5) shows that using air quality information for provincial capitals only delivers estimates similar to those in earlier analyses. Columns (6)-(7) demonstrate that the impact of the pollution conditions in China's southwestern region is half to one third that of other regions, which is reassuring.

In sum, these results show that the baseline pattern is robust to different ways of aggregating China's influence on South Korea.

Using information on China's industrial value-added We also explore information on China's industrial value-added. As mentioned in Section 2.3, the data are only available for the period between 2000 and 2006 in the form of year-on-year growth. Thus, to keep consistency, we use the same specification as in the baseline but transform all the variables as year-on-year growth.

Appendix Table A.6 presents the results using the year-on-year growth of China's monthly industrial value-added instead of the AQI measures for 2000-2006. As shown, even though this measure introduces noise when calculating growth, the pattern is also similar to our baseline, providing further support for our analysis. Based on these results, if China's pollution grows by 10% and Asian dust days grows by 10%, respiratory and cardiovascular deaths grow by around 1.5% and 0.6% respectively.

Matching Dust Stations and Korean Districts by Distance In our baseline, we match each of the 232 districts with the nearest Asian dust monitoring station (out of 28 stations). Because this matching introduces noise into the data, as a robustness check, we restrict the sample to those with a station within 10 KM, 30 KM, or 50 KM (calculated based on the closest distance between stations and districts). The main results, given in Appendix Table A.7, are robust to varying the distances to stations. If anything, our baseline estimates based on the full sample are a slight understatement of the effects that would have been obtained had the incidence of Asian dust been measured in every district.

Moving-Average Analysis Based on Daily Data We have daily information for the main variables: China's pollution, Asian dust and deaths by cause. Our baseline analysis focuses on monthly data for two reasons. First, the monthly approach allows us to account for confounding factors for which information is available only at the monthly level, such as the impact of local energy production. Second, one month is a sufficiently wide window to internalize the possible day-to-day forward shifting of deaths, which reduces the likelihood of falsely claiming an increase in deaths when, in fact, the short-term surge in deaths within the first few days from the pollution shock may be followed only by an offsetting decrease in deaths in subsequent periods. However, we also conduct a day-level analysis as a robustness check.

Following the public health literature, we use moving averages, with the caveat that this method naturally introduces measure errors. For moving-average analysis, we use window sizes of five, 15, 30, 45, and 60 days, respectively. For example, for the five-day window at day t, we calculate the moving average over the days $t-4$, $t-3$, $t-2$, $t-1$, and t for each of the main variables (i.e., number of deaths, number of dust days, and share of Chinese cities with an above-mean AQI). The specification estimated is similar to that for the baseline, except that we also control for day fixed effects now. As shown in columns (1)-(5) of Appendix Table A.8, the effect on respiratory deaths is already apparent in the five-day window and becomes larger as the window expands, which suggests that not all deaths occur immediately (i.e., within days of exposure to pollution) and some deaths take a few weeks to materialize. Moreover, the effect from the 30-day window is very similar to that from our earlier estimates in the month-level analysis, which is reassuring. Columns (6)-(10) show similar patterns for cardiovascular deaths, except that it takes longer for the effect to become significant compared to the case of respiratory deaths, which is consistent with the findings in the public health literature (see, e.g., Zanobetti et al., 2003).

Therefore, the results from the moving-average analysis provides further support to our baseline finding based on district-monthly data.

4.4 Impact on Different Pollutants

Since our main purpose is to understand the spillover effect of China's pollution on South Korea, we have so far focused on the "reduced-form" effect of dust-induced Chinese pollution on South Korean mortality as represented by equation (1). Conceptually, one could think of using $Dust_{k,y,m} \times CP_{y,m}$ as an instrument for measured air quality in South Korea and estimating the effect of South Korea's measured air quality on South Korean outcomes. However, we do not pursue the IV approach since the exclusion restriction is likely violated in this context. The interaction of China's pollution and Asian dust affects multiple pollutants (including those we do not have data on) and it is unlikely that $Dust_{k,y,m} \times CP_{y,m}$ will affect deaths through one specific pollutant only. More importantly, given that the main contribution of this paper is to identify the spillover effect from China, the reduced-form effect is the economically relevant parameter. Therefore, instead of using $Dust_{k,y,m} \times CP_{y,m}$ as an instrument, we examine its effects on the concentration of different pollutants, viewing them as important – but not the exclusive – mechanisms through which dust-induced Chinese pollution affects South Korean mortality.

Although numerous minerals and toxic elements could be responsible, we are limited to examining the effects through common pollutants such as SO_2, CO, NO_2 and ozone, whose level of concentration is routinely monitored by governments. Based on the data on hourly concentration of pollutants, we take two approaches. First, we examine the impacts on the concentration levels. Columns (1)-(2) of Appendix Table A.9 first confirm that Asian dust occurrence is highly correlated with PM_{10} concentration, as it should be, because PM_{10} is one of the criteria for defining Asian dust. Columns (3)-(10) show that the levels of other pollutants are generally elevated by $Dust_{k,y,m} \times CP_{y,m}$, especially for the maximum values.

To better understand the link with the health consequences, we examine the impacts of Asian dust and Chinese pollution on the probability of exceeding the thresholds for health-harmful levels. We take the levels designated by the government of South Korea (explained in Section 2.4). The values above these thresholds are significantly harmful to health. As shown in Table 1, the major pollutants that exceed the health-harmful levels are PM_{10}, NO_2 and ozone while SO_2 and CO rarely exceed the thresholds.[19] This fact suggests that even though $Dust_{k,y,m} \times CP_{y,m}$ elevates the concentration of SO_2 and CO to some extent, they are less likely to be a critical threat to South Korean health than other pollutants. Table 8 reports the results using the number of pollutant-specific days exceeding the thresholds as the dependent variable. Similar to Table A.9, columns (1)-(2) first confirm that the number of dust days is highly correlated with the number of days exceeding the PM_{10}-threshold. The rest of Table 8 further shows that the frequency of days exceeding the NO_2-threshold and the ozone-threshold is also elevated by $Dust_{k,y,m} \times CP_{y,m}$. Specifically, for an extra day of Asian dust in a month, a one standard deviation increase in China's pollution (0.14) increases the number of days exceeding the NO_2-threshold and the ozone-threshold by about 13% (0.14*0.197/0.202) and 5% (0.14*0.190/0.472).

In sum, even though we cannot identify every possible pollutant carried by Asian dust, these results show that major pollutants routinely measured by governments are indeed affected by $Dust_{k,y,m} \times CP_{y,m}$. Exploring the pollutant-specific thresholds on the health-harmful levels also sheds some light on the relative importance of the major pollutants.

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[19] According to the regulation, the thresholds for SO_2, NO_2 and PM_{10} are defined by 24-hour average concentration, while CO and ozone are defined by 8-hour average concentration. Since the thresholds are defined based on scientific evidence, this way of defining threshold is not specific to South Korea. See the thresholds for the U.S. as an example: https://www3.epa.gov/ttn/naaqs/criteria.html.

5 Comparing Asian Dust with Strong Winds

To isolate the causal effect of China's pollution on South Korean mortality, we used within-South Korea variation in the incidence of Asian dust. Our estimates show that at the mean incidence of Asian dust (0.8 days per month), a one standard deviation increase in China's pollution leads to 280 extra deaths per year in South Korea from respiratory and cardiovascular diseases. While conducive to isolation of causal effect, the effect we identify shows the effect of China's pollution that operates via Asian dust. And Asian dust is a rare natural phenomenon that occurs only around one day per month on average. Therefore, the parameter identified, while useful for setting a lower bound on China's effect on South Korea, is specific to the variations in Asian dust.

In order to have a sense of the overall effect of China's pollution on South Korea – and not just the effect operating via Asian dust – we compare the effect of Asian dust as a carrier with that of strong westerly winds blowing over China toward the Korean peninsula. We define strong winds variously as winds with a speed over the 50th, 75th, or 90th percentile on the distribution of wind speed in the sample, and west winds as those with a number larger than 180 degrees in the cardinal measure of wind directions. We then count for each month the number of days with strong westerly winds and examine the impact of their interaction with China's pollution.

The results of this exercise are reported in Table 9. Column (1) presents the effect of a given level of Chinese pollution carried by a mildly strong westerly wind (wind speed over the 50th percentile). The coefficient on $Wind_{y,m} \times CP_{y,m}$ is positive but much smaller than that on $Dust_{k,y,m} \times CP_{y,m}$ (0.10 vs. 0.46). Likewise, column (2) makes the same comparison but for westerly winds over the 75th percentile and shows that, the effect of the same level of China's pollution mediated by an additional strongly windy day a month is about 40 percent (0.17/0.46) of that by an additional Asian dust day per month. When the effect of an extra dust day as a carrier of China's pollution is compared with that of an extra day of extremely strong wind (over the 90th percentile on the distribution of wind speed, column (3)), the former is similar to the latter (0.37 vs. 0.46). The results for cardiovascular deaths, reported in columns (5)-(8), exhibit the same pattern.

Thus, a strong westerly wind – albeit very crudely measured – also matters for the spillover of China's pollution. However, the effect of dust as a carrier is even stronger than that of extremely strong winds (defined as over the 90th percentile on the wind speed distribution). This finding suggests that exploiting Asian dust is effective in capturing a relatively important part of the spillover effect. On the other hand, westerly winds occur much more frequently than Asian dust, so the weaker spillover effect operating via westerly winds can add up to a larger overall effect. Our back-of-the-envelope calculation shows that conditional on westerly winds with speed above the 50th percentile (occurring 10 days per month), a one standard deviation increase in China's pollution (0.14) is associated with 640 extra respiratory and cardiovascular deaths per year in South Korea.[20] Similarly, conditional on the westerly winds with speed above the 75th percentile (occurring 5 days per month), a one standard deviation increase in China's pollution is associated with 530 extra respiratory and cardiovascular deaths per year in South Korea. These magnitudes are between 1.1% and 1.4% of the mean respiratory and cardiovascular deaths in the yearly data, about twice the magnitude estimated from variations in Asian dust only.

Although these numbers should be taken with a grain of salt since they only rely on coarse time-series variations, this comparison is nonetheless instructive as it allows us to put the estimates based on Asian dust in a broader context.

6 Conclusion

In this paper, we exploit the meteorological phenomenon of Asian dust to establish a causal link between China's air pollution and South Korean mortality. Specifically, we use the interaction of Asian dust incidence across South Korean districts over time and temporal variations in China's air pollution in order to isolate measurable variations in South Korea's air quality that can be definitively attributed to China (and not to South Korea or Japan).

Our findings, based on combined data sources from China, South Korea, and the U.S., suggest that, conditional on Asian dust, China's pollution significantly increases South Korean deaths from respiratory and cardiovascular diseases – the diseases most sensitive to air pollution – but not deaths from cancers or digestive diseases. The impact on South Korean mortality identified via Asian dust is likely to be a lower bound of the total effects of Chinese pollution on South Korea in

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[20] For respiratory deaths, 0.104*0.14*10 days/month multiplied by 12 months and 232 districts leads to 405. For cardiovascular deaths, 0.062*0.14*10*12*232 leads to 241.

that strong westerly winds (with or without dust) are also capable of carrying Chinese pollution to Korea and that mortality is only a part of the overall economic and health costs of air pollution.

Asian dust itself is a natural phenomenon which has been present all the time in this region. Thus, our analysis did not use the no-Asian dust scenario as the counterfactual. Rather, our analysis focused on comparing two situations in which China is relatively clean (mean Chinese pollution of 2000-2011) versus heavily polluted (one standard deviation above the mean), while allowing for the direct effect of Asian dust occurrence on South Korea. Therefore, the spillover effect presented in this study has clear policy implications, since China's pollution is what the government of China can directly influence through its economic policies and regulations.

At a time when transnational pollution is becoming increasingly important both economically and politically, our study provides the first concrete evidence on such spillover, thus contributing to the political debate between China and South Korea. The significant impact of China's pollution on public health in South Korea that we identify here also underscores that fighting pollution in China can have benefits that reach beyond Chinese citizens.

References

[1] Almond, Douglas, Lena Edlund, and Marten Palme (2009), "Chernobyl's Subclinical Legacy: Prenatal Exposure to Radioactive Fallout and School Outcomes in Sweden," *Quarterly Journal of Economics*, 124: 1729-1772.

[2] Anderson, Michael (2015), "As the Wind Blows: the Effects of Long-term Exposure to Air Pollution on Mortality," NBER Working Paper 21578.

[3] Baek Deokrye, Duha T. Altindag, and Naci Mocan (2015), "Chinese Yellow Dust and Korean Infant Health," NBER Working Paper 21613.

[4] Bishop, James K. B., Russ E. Davis, and Jeffrey T. Sherman (2002), "Robotic Observations of Dust Storm Enhancement of Carbon Biomass in the North Pacific," *Science*, 298: 817-821.

[5] Black, Sandra, Aline Butikofer, Paul J. Devereux, and Kjell G. Salvanes (2013). This Is Only a Test? Long-Run Impacts of Prenatal Exposure to Radioactive Fallout," NBER Working Paper 18987.

[6] Carmichael, Gregory R., Yang Zhang, Li-Ling Chen, Min-Sun Hong, and Hiromasa Ueda (1996), "Seasonal Variation of Aerosol Composition at Cheju Island, Korea," *Atmospheric Environment*, 30 (13): 2407-2416.

[7] Chay, Kenneth Y., and Michael Greenstone (2003), "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession," *Quarterly Journal of Economics*, 1121-1167.

[8] Chen, Yuyu, Avraham Ebenstein, Michael Greenstone, and Hongbin Li (2013), "Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy," *Proceedings of the National Academy of Sciences*, 110 (32): 12936-12941.

[9] Choi, Jae C., Meehye Lee, Youngsin Chun, Jiyoung Kim, and Sungnam Oh (2001), "Chemical Composition and Source Signature of Spring Aerosol in Seoul, Korea," *Journal of Geophysical Research*, 106 (D16): 18067-18074.

[10] Chun, Youngsin, Kyung-On Boo, Jiyoung Kim, Soon-Ung Park, and Meehye Lee (2001), "Synopsis, Transport, and Physical Characteristics of Asian Dust in Korea," *Journal of Geophysical Research*, 106 (D16): 18461-18469.

[11] Chun, Youngsin, Hi-Ku Cho, Hyo-sang Chung, and Meehye Lee (2008), "Historical Records of Asian Dust Events (Hwangsa) in Korea," *Bulletin of the American Meteorological Society*, 89: 823-827.

[12] Currie, Janet, and Matthew Neidell (2005), "Air Pollution and Infant Health: What Can We Learn from California's Recent Experience?," *Quarterly Journal of Economics*, 1003-1030.

[13] Dockery, Douglas W., C. Arden Pope, Xiping Xu, John D. Spengler, James H. Ware, Martha E. Fay, Benjamin G. Ferris Jr, and Frank E. Speizer (1993), "An Association between Air Pollution and Mortality in Six US Cities," *New England Journal of Medicine*, 329 (24): 1753-1759.

[14] Dominici, Francesca, Roger D. Peng, Michelle L. Bell, Luu Pham, Aidan McDermott, Scott L. Zeger, and Jonathan M. Samet (2006), "Fine Particulate Air Pollution and Hospital Admission for Cardiovascular and Respiratory Diseases," *Journal of American Medical Association*, 295 (10): 1127-1134.

[15] Duce, R. A., C. K. Unni, B. J. Ray, J. M. Prospero, and J. T. Merrill (1980), "Long-range Atmospheric Transport of Soil Dust from Asia to the Tropical North Pacific: Temporal Variability," *Science*, 209 (4464): 1522-1524.

[16] Greenstone, Michael, and Rema Hanna (2014), "Environmental Regulations, Air and Water Pollution, and Infant Mortality in India," *American Economic Review*, 104(10): 3038-72.

[17] Jayachandran, Seema (2009), "Air Quality and Early-Life Mortality Evidence from Indonesia's Wildfires," *Journal of Human Resources*, 44(4): 916-954.

[18] Lee, Hyewon, Ho Kim, Yasushi Honda, Youn-Hee Lim, and Seungmuk Yi (2013), "Effect of Asian Dust Storms on Daily Mortality in Seven Metropolitan Cities of Korea," *Atmospheric Environment*, 79: 510-517.

[19] Li, J., Z. Wang, G. Zhuang, G. Luo, Y. Sun, and Q. Wang (2012), "Mixing of Asian Mineral Dust with Anthropogenic Pollutants over East Asia: a Model Case Study of a Super-duststorm in March 2010," *Atmospheric Chemistry and Physics* 12(16): 7591-7607.

[20] Li, Zhigang, Jia Yuan, Frank Song, and Shangji Wei (2014), "Estimating Long-Range Pollution Spillover through Visibility: The Case of China," working paper.

[21] Lin, Jintai, Da Pan, Steven J. Davis, Qiang Zhang, Kebin He, Can Wang, David G. Streets, Donald J. Wuebbles, and Dabo Guan (2014), "China's International Trade and Air Pollution in the United States," *Proceedings of the National Academy of Sciences*, 111 (5): 1736-1741.

[22] Lleras-Muney, Adriana (2010), "The Needs of the Army: Using Compulsory Relocation in the Military to Estimate the Effect of Environmental Pollutants on Children's Health," *Journal of Human Resources*, 35(3): 549-590.

[23] Nishikawa, M., Kanamori, S., Kanamori, N., Mizoguchi, T. (1991), "Kosa Aerosol as Eolian Carrier of Anthropogenic Material," *Science of the Total Environment*, 107: 13-27.

[24] Samet, Jonathan M., Francesca Dominici, Frank C. Curriero, Ivan Coursac, and Scott L. Zeger (2000), "Fine Particulate Air Pollution and Mortality in 20 US Cities, 1987-1994," *New England Journal of Medicine*, 343 (24): 1742-1749.

[25] Schwartz, Joel (2000), "Harvesting and Long Term Exposure Effects in the Relation between

Air Pollution and Mortality," *American Journal of Epidemiology*, 151 (5): 440-448.

[26] Schlenker, Wolfram, and W. Reed Walker (2015), "Airports, Air Pollution, and Contemporaneous Health," *Review of Economic Studies*, forthcoming.

[27] Sigman, Hilary (2002), "International Spillovers and Water Quality in Rivers: Do Countries Free Ride?," *American Economic Review*, 92 (4): 1152-59.

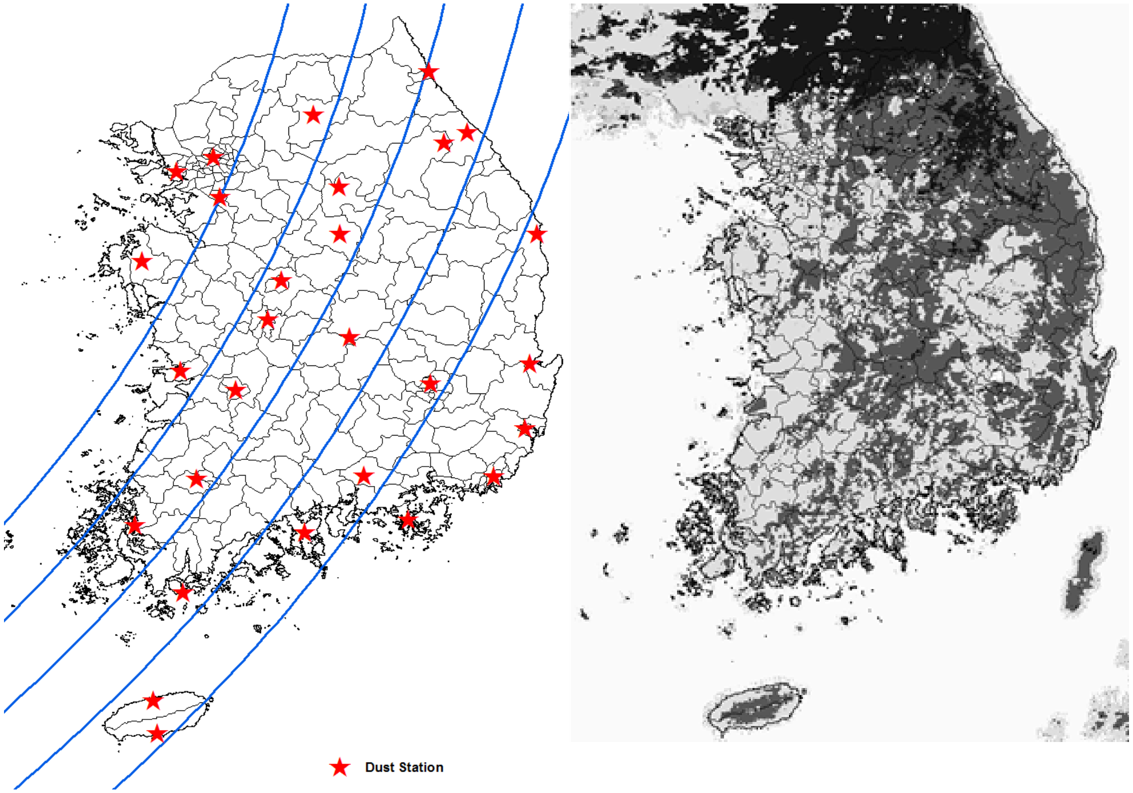
[28] Wilson W.S. Tam, Tze Wai Wong, Andromeda H.S. Wong (2012), "Effect of Dust Storm Events on Daily Emergency Admissions for Cardiovascular Diseases," *Circulation Journal*, 76 (3): 655-660.

[29] Wilson W.S. Tam, Tze Wai Wong, Andromeda H.S. Wong and David S.C. Hui (2012), "Effect of Dust Storm Events on Daily Emergency Admissions for Respiratory Diseases," *Respirology*, 17 (1): 143-148.

[30] Zanobetti A, Schwartz J, Samoli E, et al. (2003), "The Temporal Pattern of Respiratory and Cardiovascular Disease Mortality in Response to Air Pollution," *Environmental Health Perspectives*, 111(9): 1188-1193.

[31] Zivin, Joshua Graff and Matthew Neidell (2013), "Environment, Health, and Human Capital," *Journal of Economic Literature*, 689-673.

Figure 1: Topography and Asian Dust Stations in South Korea


(a) Distribution of Dust Stations

(b) Topography of South Korea

Notes: Panel (a) maps the 28 stations where there is information on the daily incidence of Asian Dust. The concentric circles indicate different “rings” that divide South Korean regions based on their distance from Beijing (1000 KM, 1050 KM, ..., 1200 KM). Panel (b) shows that South Korea has a rich topography, which, together with idiosyncratic wind patterns, produces wide variations in the incidence of Asian dust.

Figure 2: Examples of Asian Dust Incidence in South Korea

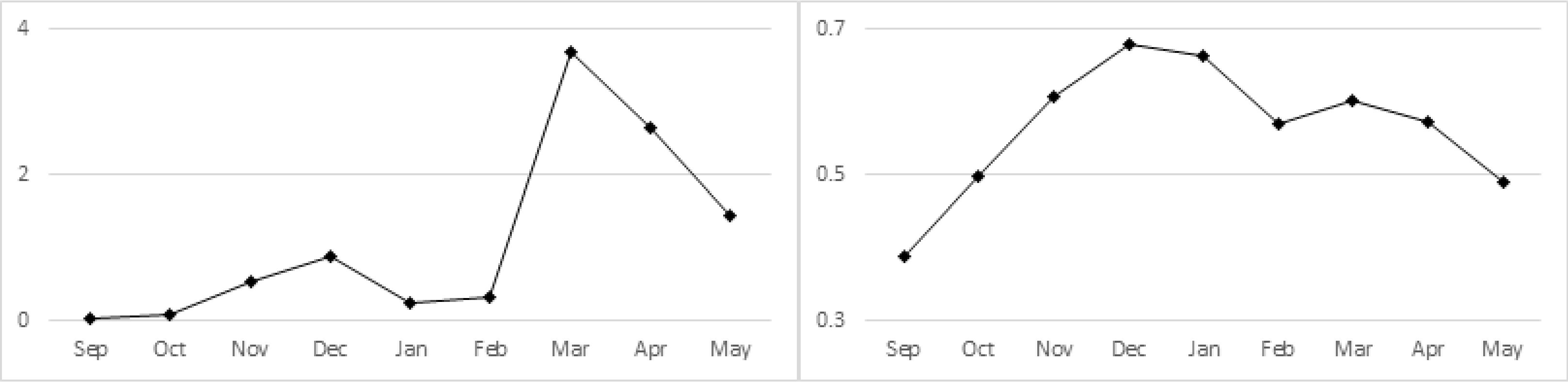

(a) March 2000

(b) March 2003

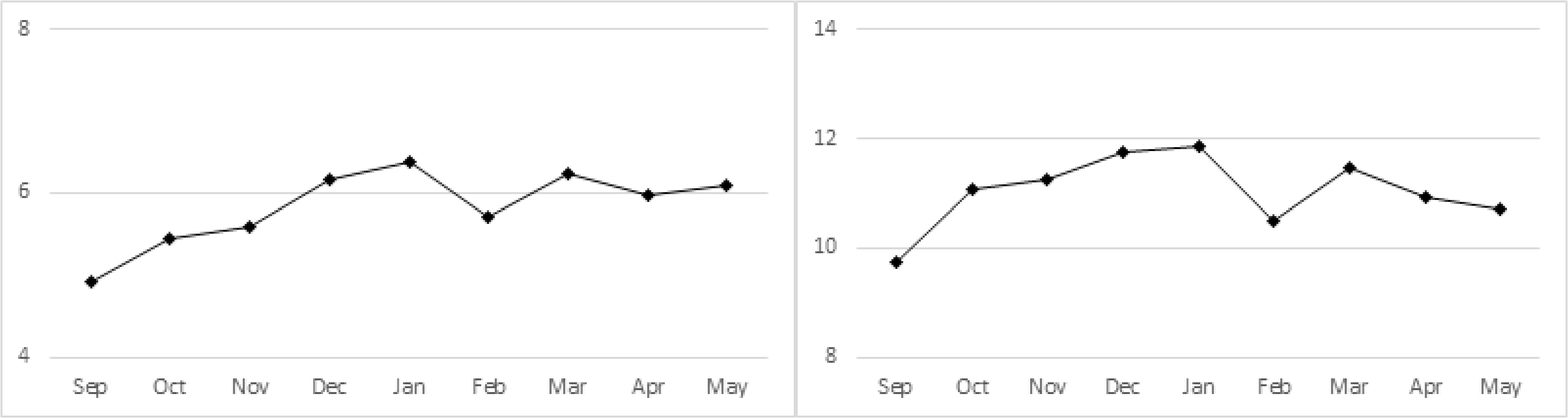
(c) March 2010

Notes: This figure plots the distribution of dust days across dust stations in March 2000, March 2003 and March 2010. It illustrates that the incidence of Asian Dust varies significantly across years, even for the same month.

Figure 3: Seasonality in the data


(a) Mean Dust Days

(b) Mean China's Pollution (share)

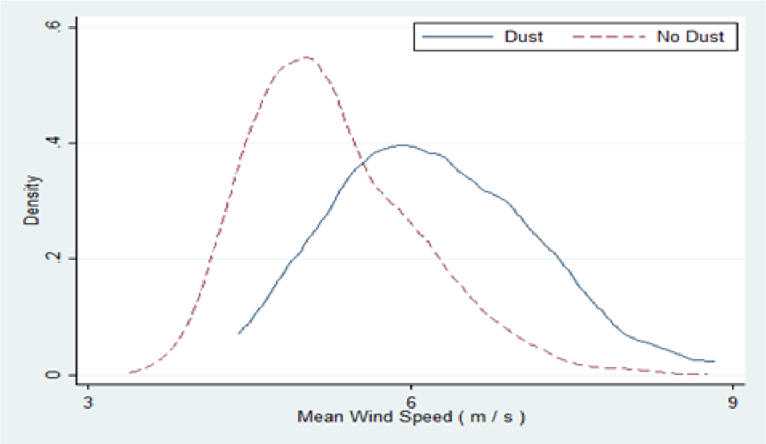

(c) Mean Respiratory Deaths

(d) March Cardiovascular Deaths

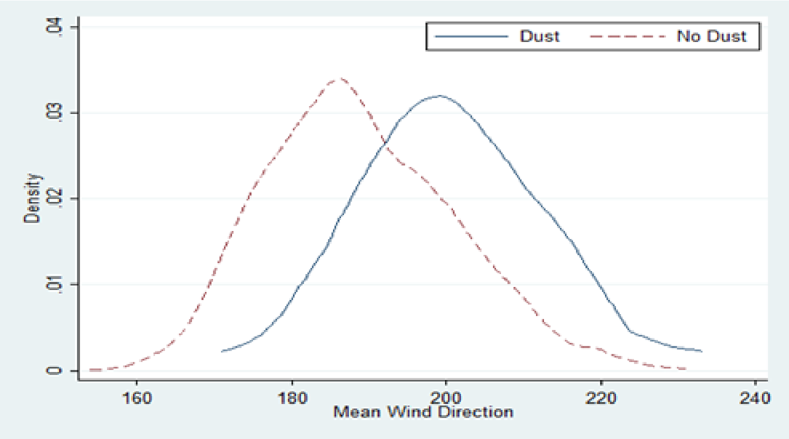
Notes: This figure illustrates the seasonality in different variables in the data. It shows that the seasonality is unlikely to explain our findings, as the each variable exhibits a different seasonality.

Figure 4: Wind Speed, Wind Direction and Asian Dust

(a) Wind speed and Asian Dust

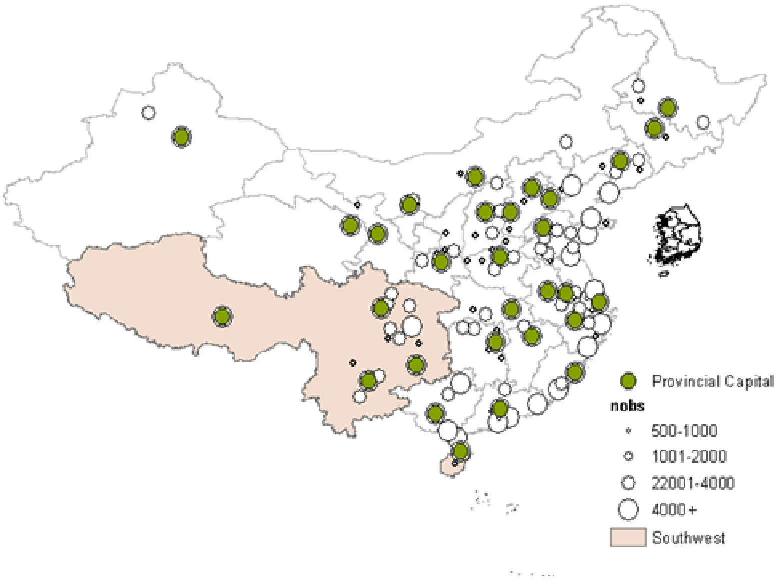


(b) Wind direction and Asian Dust



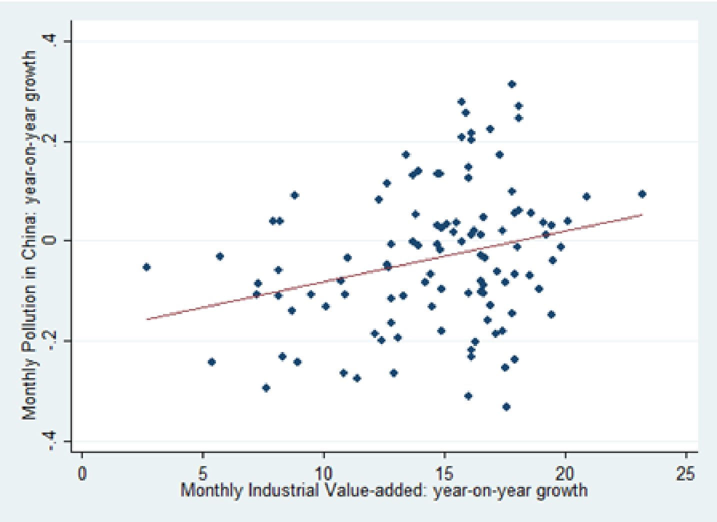
Notes: Panel (a) shows that the wind speed is higher during the dust days. Panel (b) shows that wind directly is from west to east (winds with a degree larger than 180) on the dust days.

Figure 5: 120 cities with Pollution Information in China



Notes: This figure maps the 120 cities where there is information on the daily pollution index. The size of circles indicates the number of daily observations available between June 2000 and December 2011. Those marked in green are provincial capitals. The shaded area is the southwest region, which is expected to affect South Korea less than the rest of China.

Figure 6: Checking Pollution Data in China



Notes: This figure plots the year-on-year growth of our measure of Chinaâs pollution vs. the year-on-year growth of industrial valued-added from the China Statistical Bureau. The positive correlation (with a slope of 1.02 and a p-value of 0.005) suggests that our pollution measure captures part of the industrial production in China.

Table 1: Summary Statistics of the Main Variables

Variable	Country	Sources	Obs.	Mean	Std. Dev.
Dependent Var.					
Deaths from Cancers	Korea	1,2	32248	23.30	15.80
Deaths from Cardiovascular Diseases	Korea	1,2	32248	10.69	13.24
Deaths from Non-cardio. Circulatory Diseases	Korea	1,2	32248	9.47	6.81
Deaths from Respiratory Diseases	Korea	1,2	32248	5.62	4.11
Deaths from Digestive Diseases	Korea	1,2	32248	4.25	3.30
Deaths from Other Minor Diseases	Korea	1,2	32248	22.49	15.25
#days exceeding the health-harmful thresholds					
PM10 (24-hour mean>100 μ g/m^3)	Korea	3	32256	2.176	3.247
SO2 (24-hour mean>0.05 ppm)	Korea	3	32256	0.0003	0.0176
NO2 (24-hour mean>0.06 ppm)	Korea	3	32256	0.202	0.998
CO (8-hour mean>9 ppm)	Korea	3	28566	0	0
Ozone (8-hour mean>0.06 ppm)	Korea	3	28666	0.472	1.155
Main Independent Var.					
#Asian Dust	Korea	4	32248	0.79	1.72
CN Pollution: Share of cities with AQI>66	China	5	32248	0.51	0.14
Alternative CN Pollution: Mean AQI	China	5	32448	73.6	12.3
Controls and Comparisons					
Energy Production Index	Korea	1	32138	0.74	0.37
Temperature (C)	Korea	4	31692	13.23	9.19
Rainfall (10cm)	Korea	4	31680	1.213	1.508
#West Windy Days (spd50)	China	6	32248	10.40	8.54
#West Windy Days (spd75)	China	6	32248	5.31	6.93
#West Windy Days (spd90)	China	6	32248	2.18	3.82

Notes: This table presents summary statistics for the main variables using the following data sources:
1: Statistics Korea
2: World Health Organization, the 10th revision of the International Classification of Diseases
3: National Institute of Environmental Research in South Korea
4: Korea Meteorological Administration
5: Ministry of Environmental Protection in China
6: National Oceanic and Atmospheric Administration, U.S. Department of Commerce
The thresholds for pollutants are based on environmental regulation in South Korea. The values above the thresholds are considered significantly harmful for health. See: http://www.me.go.kr/mamo/web/index.do?menuId=586.

Table 2A: The Impact on Respiratory Deaths

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	#Deaths (Mean 5.62)						Ln Deaths	
CN Pollution*#Dust			0.489***	0.466***	0.463***	0.528***	0.068***	0.074***
			(0.098)	(0.099)	(0.100)	(0.105)	(0.019)	(0.019)
CN Pollution		0.524	-0.297	-0.233	-0.125	-0.432	0.012	-0.046
		(0.318)	(0.344)	(0.345)	(0.347)	(0.465)	(0.067)	(0.084)
#Dust	0.047***		-0.025	-0.024	-0.022	-0.030	-0.004	-0.005
	(0.013)		(0.018)	(0.019)	(0.019)	(0.019)	(0.004)	(0.004)
KR Energy*#Dust				-0.028	-0.030	-0.018	-0.004	-0.003
				(0.034)	(0.035)	(0.035)	(0.007)	(0.007)
KR Energy				0.593***	0.524***	0.513***	0.097***	0.097***
				(0.139)	(0.139)	(0.139)	(0.024)	(0.024)
KR Temperature					-0.023*	-0.016	-0.002	-0.000
					(0.013)	(0.014)	(0.003)	(0.003)
KR Temperature (sq)					0.001**	0.002***	0.000**	0.000**
					(0.001)	(0.001)	(0.000)	(0.000)
KR Precipitation					0.022	-0.037	0.008	0.001
					(0.028)	(0.037)	(0.006)	(0.007)
KR Precipitation (sq)					-0.002	0.003	-0.001	-0.001
					(0.005)	(0.009)	(0.001)	(0.002)
Dist. FE*Year FE,	Y	Y	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y	Y	Y
CN Pollution*Weather						Y		Y
Observations	32,248	32,248	32,248	32,138	31,570	31,570	30,353	30,353
R-squared	0.667	0.667	0.667	0.668	0.666	0.667	0.586	0.587

Notes: CN Pollution is the (demeaned) share of polluting days above the mean index in China, #Dust is the number of dust days in a district-month in Korea, and KR Energy is the (demeaned) energy production in Korea. Temperature and Precipitation are also demeaned. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 2B: The Impact on Cardiovascular Deaths

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	#Deaths (Mean 10.69)						Ln Deaths	
CN Pollution*#Dust			0.487***	0.523***	0.521***	0.459***	0.052***	0.043***
			(0.117)	(0.126)	(0.126)	(0.129)	(0.014)	(0.014)
CN Pollution		0.609	-0.356	-0.334	-0.167	0.217	0.001	0.037
		(0.453)	(0.491)	(0.491)	(0.500)	(0.629)	(0.057)	(0.073)
#Dust	0.063***		-0.008	-0.019	-0.017	-0.019	-0.004	-0.004
	(0.018)		(0.022)	(0.024)	(0.024)	(0.024)	(0.003)	(0.003)
KR Energy*#Dust				0.045	0.025	0.050	0.002	0.004
				(0.045)	(0.046)	(0.047)	(0.005)	(0.005)
KR Energy				0.509***	0.415**	0.352*	0.025	0.019
				(0.190)	(0.191)	(0.193)	(0.020)	(0.020)
KR Temperature					-0.097***	-0.108***	-0.009***	-0.010***
					(0.018)	(0.020)	(0.002)	(0.002)
KR Temperature (sq)					-0.001	-0.001	0.000	0.000
					(0.001)	(0.001)	(0.000)	(0.000)
KR Precipitation					-0.047	-0.096**	-0.002	-0.007
					(0.034)	(0.044)	(0.004)	(0.006)
KR Precipitation (sq)					0.001	0.020*	0.000	0.001
					(0.005)	(0.012)	(0.001)	(0.001)
Dist. FE*Year FE,	Y	Y	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y	Y	Y
CN Pollution*Weather						Y		Y
Observations	32,248	32,248	32,248	32,138	31,570	31,570	31,209	31,209
R-squared	0.814	0.814	0.814	0.815	0.815	0.815	0.761	0.761

Notes: CN Pollution is the (demeaned) share of polluting days above the mean index in China, #Dust is the number of dust days in a district-month in Korea, and KR Energy is the (demeaned) energy production in Korea. Temperature and Precipitation are also demeaned. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 3: Impacts of Lagged Variables

	(1)	(2)	(3)	(4)
	#Respiratory Deaths		#Cardiovascular Deaths	
CN Pollution*#Dust	0.601***	0.579***	0.517***	0.495***
	(0.109)	(0.108)	(0.132)	(0.134)
L.CN Pollution*L.#Dust	0.317***	0.322***	0.189	0.203*
	(0.091)	(0.090)	(0.115)	(0.115)
L2.CN Pollution*L2.#Dust	-0.090	-0.046	0.181	0.222
	(0.092)	(0.090)	(0.137)	(0.135)
L3.CN Pollution*L3.#Dust	0.036	0.074	0.138	0.181
	(0.088)	(0.088)	(0.130)	(0.131)
CN Pollution	-0.435	-0.314	0.164	0.104
	(0.470)	(0.465)	(0.662)	(0.666)
#Dust	-0.056***	-0.059***	-0.029	-0.027
	(0.020)	(0.020)	(0.025)	(0.025)
L.CN Pollution	-0.350	-0.281	-0.294	-0.303
	(0.346)	(0.344)	(0.518)	(0.516)
L.#Dust	-0.008	-0.012	-0.022	-0.023
	(0.020)	(0.020)	(0.027)	(0.027)
L2.CN Pollution	0.169	0.102	0.362	0.236
	(0.340)	(0.343)	(0.534)	(0.531)
L2.#Dust	-0.006	-0.009	-0.049*	-0.051*
	(0.020)	(0.019)	(0.028)	(0.028)
L3.CN Pollution	0.931***	0.809**	-0.098	-0.288
	(0.328)	(0.327)	(0.456)	(0.464)
L3.#Dust	-0.001	0.000	0.009	0.007
	(0.019)	(0.019)	(0.025)	(0.025)
Dist. FE*Year FE,	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y
Korea Weather	Y	Y	Y	Y
CN Pollution*Weather	Y	Y	Y	Y
Lagged Deaths (l1-l3)		Y		Y
Observations	30,892	30,892	30,892	30,892
R-squared	0.668	0.670	0.816	0.817

Notes: This table confirms that the baseline finding is robust to including lagged variables. It also shows the harvesting effect alone cannot explain the baseline finding. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 4: Placebo Test I – Deaths from Cancers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	#Deaths (Mean 23.30)						Ln Deaths	
CN Pollution*#Dust			0.049	0.023	0.006	0.003	-0.008	-0.006
			(0.174)	(0.185)	(0.186)	(0.192)	(0.009)	(0.010)
CN Pollution		0.121	-0.017	0.047	0.184	0.694	0.010	0.029
		(0.587)	(0.630)	(0.637)	(0.648)	(0.846)	(0.035)	(0.049)
#Dust	0.011		0.004	0.009	0.009	0.006	-0.008	-0.006
	(0.025)		(0.035)	(0.036)	(0.037)	(0.036)	(0.009)	(0.010)
Dist. FE*Year FE,	Y	Y	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y	Y	Y
KR Energy, KR Energy*#Dust				Y	Y	Y	Y	Y
Korea Weather					Y	Y	Y	Y
CN Pollution*Weather						Y		Y
Observations	32,248	32,248	32,248	32,138	31,570	31,570	31,570	31,570
R-squared	0.969	0.969	0.969	0.969	0.969	0.969	0.960	0.960

Notes: This table shows that deaths from cancer do not respond to China's pollution spillovers. The variable definitions are the same as in Tables 2A–2B. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%. Additional placebo tests are presented in Appendix Table A.2.

Table 5: Addressing Nonlinearity – Effects by Quartiles of Chinese Pollution

	(1)	(2)	(3)	(4)	(5)	(6)
	#Respiratory Deaths			#Cardio. Deaths		
CN Pollution (p25-p50) * #Dust	0.045	0.055	0.218*	-0.027	0.003	0.092
	(0.043)	(0.043)	(0.116)	(0.058)	(0.057)	(0.127)
CN Pollution (p50-p75) * #Dust	0.188***	0.195***	0.312***	0.069	0.096*	0.141
	(0.038)	(0.039)	(0.114)	(0.051)	(0.051)	(0.126)
CN Pollution (p75+) * #Dust	0.252***	0.259***	0.387***	0.148***	0.173***	0.224*
	(0.040)	(0.040)	(0.116)	(0.046)	(0.046)	(0.121)
Dist. FE*Year FE	Y	Y	Y	Y	Y	Y
Ring FE* Month FE	Y	Y	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y	Y	Y
Weather Conditions		Y	Y		Y	Y
CN Pollution*Weather			Y			Y
Observations	33,288	32,690	31,570	33,288	32,690	31,570
R-squared	0.667	0.665	0.669	0.814	0.814	0.815

Notes: This table reports the results using categorical measures of China's pollution instead of a linear function. It shows an increasing effect of China's pollution, given the same number of dust days. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 6A: Heterogeneous Effects I – by Ages

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	#Respiratory deaths			#Cardiovascular deaths			#All internal deaths			
Age group	65+	35-64	15-34	65+	35-64	15-34	<1	1-4	5-9	10-14
Mean of D.V.	4.92	0.62	0.04	8.35	2.18	0.14	0.66	0.104	0.111	0.389
CN Pollution*#Dust	0.389***	0.134***	0.010	0.324***	0.122**	0.016	0.078**	0.033**	-0.013	-0.004
	(0.093)	(0.036)	(0.009)	(0.109)	(0.054)	(0.015)	(0.034)	(0.014)	(0.013)	(0.013)
CN Pollution	-0.196	-0.228*	0.033	0.145	0.154	-0.086	-0.009	-0.147**	-0.058	-0.049
	(0.433)	(0.136)	(0.032)	(0.552)	(0.256)	(0.062)	(0.129)	(0.070)	(0.060)	(0.053)
#Dust	-0.033*	0.003	-0.002*	-0.017	-0.003	-0.001	0.008	-0.001	0.003	0.005**
	(0.018)	(0.006)	(0.001)	(0.021)	(0.010)	(0.003)	(0.006)	(0.003)	(0.002)	(0.002)
All FEs, All Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	31,570	31,570	31,570	31,570	31,570	31,570	31,570	31,570	31,570	31,570
R-squared	0.643	0.287	0.112	0.766	0.585	0.171	0.433	0.204	0.171	0.171

Notes: This table presents the heterogeneous effects with respect to age. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 6B: Heterogeneous Effects II – by Education

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	#Respiratory deaths				#Cardiovascular deaths			
Educational category	No School	Primary	Lower Sec.	Above	No School	Primary	Lower Sec.	Above
Mean of D.V.	2.37	1.89	0.55	0.79	4.08	3.38	1.13	2.11
CN Pollution*#Dust	0.252***	0.198***	0.049*	0.045	0.185**	0.140**	0.060	0.086
	(0.066)	(0.058)	(0.029)	(0.034)	(0.075)	(0.069)	(0.040)	(0.065)
CN Pollution	-0.138	-0.532**	0.011	0.068	-0.106	0.342	-0.434**	0.427
	(0.276)	(0.244)	(0.133)	(0.152)	(0.383)	(0.313)	(0.180)	(0.304)
#Dust	-0.022*	-0.013	0.006	-0.001	0.001	-0.006	-0.008	-0.007
	(0.012)	(0.012)	(0.006)	(0.007)	(0.014)	(0.014)	(0.008)	(0.012)
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
All FEs, All Controls	Y	Y	Y	Y	Y	Y	Y	Y
Observations	31,570	31,570	31,570	31,570	31,570	31,570	31,570	31,570
R-squared	0.469	0.428	0.301	0.483	0.591	0.585	0.466	0.679

Notes: This table presents the heterogeneous effects with respect to education. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 7: China's Pollution vs. Pollution Spillover within Korea

	(1)	(2)	(3)	(4)	(5)	(6)
	Respiratory			Cardiovascular		
	#Deaths	#Deaths	Ln Deaths	#Deaths	#Deaths	Ln Deaths
CN Pollution*#Dust		0.613***	0.091***		0.465***	0.038**
		(0.124)	(0.022)		(0.140)	(0.016)
KR Energy Ring 1*#Dust	-0.074	-0.111**	-0.023**	0.109	0.081	0.007
	(0.052)	(0.054)	(0.011)	(0.071)	(0.070)	(0.009)
CN Pollution		-0.433	-0.046		0.307	0.067
		(0.502)	(0.095)		(0.686)	(0.083)
#Dust	0.055***	-0.020	-0.004	0.039*	-0.024	-0.004
	(0.020)	(0.022)	(0.004)	(0.023)	(0.027)	(0.004)
KR Energy Ring 1	1.670***	1.664***	0.351***	0.796**	0.770**	0.124***
	(0.246)	(0.247)	(0.051)	(0.308)	(0.308)	(0.040)
Dist. FE*Year FE	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y
Korea Weather	Y	Y	Y	Y	Y	Y
CN Pollution*Weather	Y	Y	Y	Y	Y	Y
Observations	23,896	23,896	22,906	23,896	23,896	23,596
R-squared	0.651	0.651	0.566	0.805	0.805	0.739

Notes: This table shows that the results in Tables 2A–2B are not driven by spillovers within Korea. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table 8: Impacts on the Number of Days Exceeding the Health-Harmful Thresholds by Pollutant

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number of days exceeding the health-harmful threshold for								
	PM10		SO2		NO2		Ozone		CO
Mean of D.V.	2.176		0.0003		0.202		0.472		0
CN Pollution*#Dust			0.0000	0.0000	0.173***	0.197***	0.190***	0.152***	NA
			(0.0002)	(0.0002)	(0.055)	(0.056)	(0.028)	(0.028)	
CN Pollution			0.0022	0.0030	0.426***	0.452***	0.696***	0.688***	
			(0.0020)	(0.0020)	(0.144)	(0.147)	(0.092)	(0.098)	
#Dust	0.558***	0.668***	-0.0000	-0.0000	-0.018***	-0.023***	-0.056***	-0.046***	
	(0.017)	(0.057)	(0.0001)	(0.0001)	(0.005)	(0.006)	(0.008)	(0.008)	
Dist. FE * Year FE	Y	Y	Y	Y	Y	Y	Y	Y	
Ring FE* Month FE	Y	Y	Y	Y	Y	Y	Y	Y	
KR Energy		Y		Y		Y		Y	
KR Energy*#Dust		Y		Y		Y		Y	
Korea Weather		Y		Y		Y		Y	
Observations	31,692	31,570	31,692	31,570	31,692	31,570	28,566	28,458	
R-squared	0.567	0.595	0.103	0.104	0.337	0.338	0.493	0.498	

Notes: This table shows the results on the monthly number of days exceeding health-harmful thresholds by pollutant. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

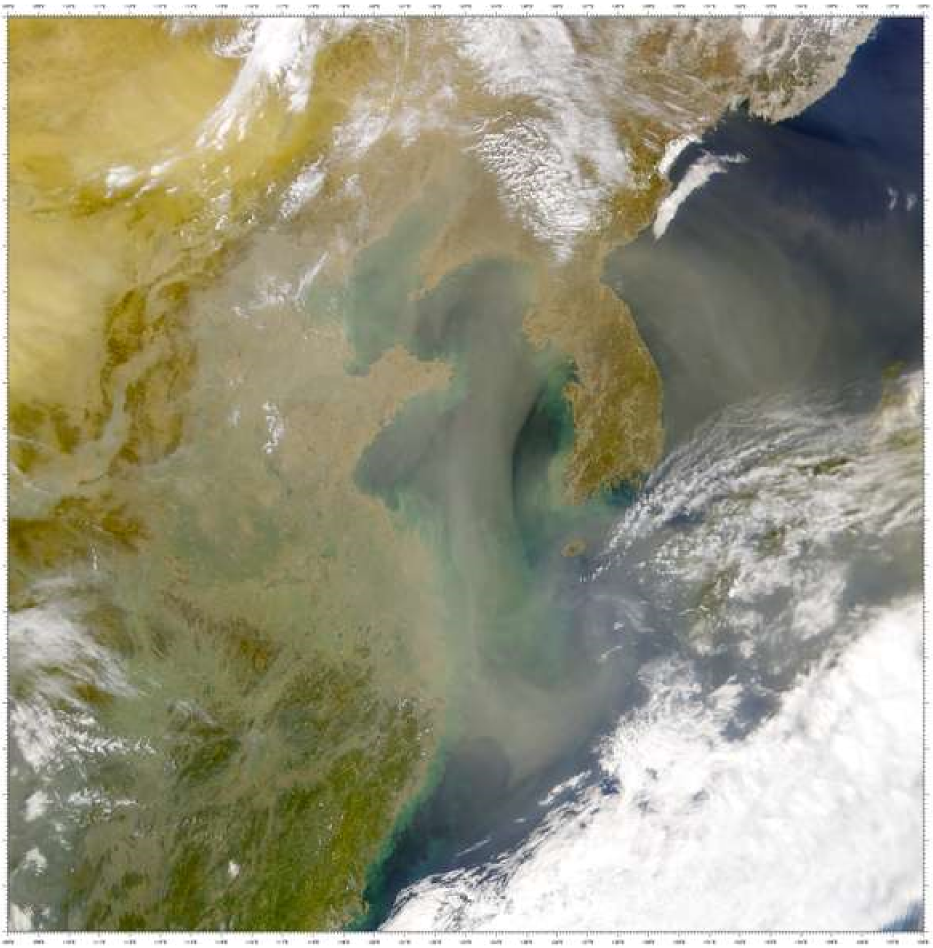
Table 9: Strong Westerly Winds as a Carrier

	(1)	(2)	(3)	(4)	(5)	(6)
	#Respiratory deaths			#Cardiovascular deaths		
Wind Speed	50	75	90	50	75	90
CN Pollution*#West Wind Days	0.104***	0.170***	0.378***	0.062**	0.100***	0.337***
	(0.022)	(0.030)	(0.055)	(0.029)	(0.038)	(0.071)
CN Pollution	-0.153	-0.433	-0.642	0.731	0.533	0.113
	(0.455)	(0.459)	(0.452)	(0.633)	(0.629)	(0.627)
#West Wind Days	-0.006	-0.006	-0.017**	0.005	0.006	-0.023*
	(0.005)	(0.005)	(0.008)	(0.006)	(0.007)	(0.012)
Dist. FE*Year FE	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y	Y	Y
Korea Weather	Y	Y	Y	Y	Y	Y
CN Pollution*Weather	Y	Y	Y	Y	Y	Y
Observations	31,680	31,680	31,680	31,680	31,680	31,680
R-squared	0.666	0.666	0.666	0.814	0.814	0.814

Notes: This table shows the impact using strong westerly winds as a carrier of China's pollution. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

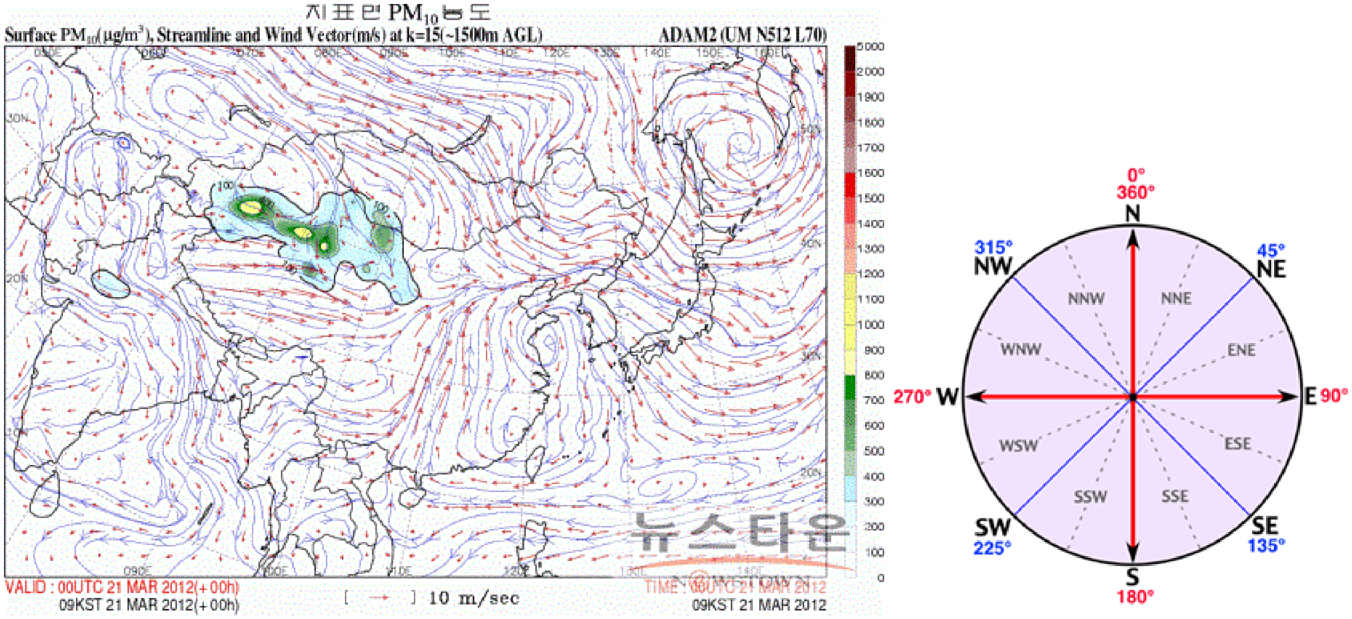
A Appendix

Figure A.1: Dust clouds leaving China and traveling toward Korea and Japan on March 21, 2001



Source: The SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE
http://visibleearth.nasa.gov/view_rec.php?id=1707

Figure A.2: Wind Directions on a Dust Day



Notes:This figure shows the wind directions on an Asian dust day, with winds able to come from various directions, making it challenging to determine pollution origins across China (Source: Korea Meteorological Administration).

Table A.1: Asian dust, Chinese Pollution, and Economic Activities in Korea

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Var.	Production Index (Province-Monthly)			Ln Emission in tons (Province-Yearly)				
	Overall	Manufac.	Energy	SOX	NOX	CO	PM10	VOCs
Mean of D.V.	0.82	0.82	0.74	9.63	10.95	10.59	8.07	10.54
Corr. with SO2 concentration	-0.04	-0.05	0.35					
Corr. with NO2 concentration	-0.07	-0.08	0.34					
CN Pollution*#Dust	-0.005	-0.007	0.012	0.902	0.908	0.792	6.360	1.739
	(0.006)	(0.006)	(0.015)	(4.663)	(1.981)	(1.195)	(4.246)	(1.261)
CN Pollution	0.105***	0.104***	0.038	3.331	1.959	4.262*	7.368	-1.339
	(0.022)	(0.022)	(0.048)	(10.623)	(5.510)	(2.349)	(11.699)	(3.522)
#Dust	0.003	0.004	-0.001	-0.549	-0.476	-0.414	-3.486	-0.894
	(0.004)	(0.004)	(0.008)	(2.488)	(1.067)	(0.629)	(2.277)	(0.670)
Province FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Month FE	Y	Y	Y					
Weather	Y	Y	Y	Y	Y	Y	Y	Y
Observations	2,169	2,169	2,169	192	192	192	192	192
R-squared	0.771	0.766	0.803	0.970	0.972	0.987	0.873	0.986

Notes: This table shows that CN Pollution*Dust is not systematically related to observable and time-varying local conditions such as local production and local emission. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.2: Placebo Test II – Results on Deaths Cause by Cause
D.V.: Ln Deaths

	(1)	(2)	(3)	(4)	(5)	(6)
	Cancers	Cardio.	Non-Cardio. Circulatory	Respir.	Digestive	Others (13 groups)
Mean of D.V.	23.30	10.69	9.47	5.62	4.25	22.49
CN Pollution*#Dust	-0.006	0.043***	0.015	0.074***	0.003	0.015
	(0.010)	(0.014)	(0.016)	(0.019)	(0.018)	(0.012)
CN Pollution	0.029	0.037	0.148**	-0.046	0.142	0.131*
	(0.049)	(0.073)	(0.069)	(0.084)	(0.096)	(0.072)
#Dust	0.002	-0.004	-0.002	-0.005	0.004	-0.001
	(0.002)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)
Dist. FE*Year FE,	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y	Y	Y
Korea Weather	Y	Y	Y	Y	Y	Y
CN Pollution*Weather	Y	Y	Y	Y	Y	Y
Observations	31,537	31,209	31,119	30,353	29,237	31,328
R-squared	0.872	0.761	0.744	0.587	0.563	0.798

Notes:This table reports the impacts for the five major groups of causes. The variable definitions are the same as in Tables 2A–2B. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.3: Heterogeneity III: Subgroups within Respiratory and Cardiovascular Deaths

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		#Respiratory deaths by subgroups				#Cardio. deaths by subgroups		
	All	Chronic. Lower	Acute Lower	Other	All	Chronic. Rheum.	Ischemic	Other
Mean of D.V.	5.62	2.64	1.60	1.39	10.69	2.10	4.64	4.13
CN Pollution*#Dust	0.528***	0.222***	0.115**	0.191***	0.459***	0.164***	0.128*	0.167**
	(0.105)	(0.070)	(0.052)	(0.048)	(0.129)	(0.055)	(0.073)	(0.084)
CN Pollution	-0.432	-0.029	0.097	-0.500**	0.217	-0.557**	0.816*	-0.042
	(0.465)	(0.296)	(0.234)	(0.225)	(0.629)	(0.255)	(0.428)	(0.349)
#Dust	-0.030	-0.033***	0.007	-0.003	-0.019	0.009	-0.024	-0.003
	(0.019)	(0.013)	(0.011)	(0.010)	(0.024)	(0.010)	(0.015)	(0.017)
Dist. FE * Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Ring FE * Month FE	Y	Y	Y	Y	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y	Y	Y	Y	Y
Weather Conditions	Y	Y	Y	Y	Y	Y	Y	Y
CN Pollution*Weather	Y	Y	Y	Y	Y	Y	Y	Y
Observations	31,570	31,570	31,570	31,570	31,570	31,570	31,570	31,570
R-squared	0.667	0.500	0.528	0.432	0.815	0.657	0.701	0.660

Notes: This table shows that major subgroups within respiratory and cardiovascular diseases are all affected. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.4: Treating South Korea as a Single Region

	(1)	(2)	(3)	(4)	(5)	(6)
	#Respiratory Deaths			#Cardiovascular Deaths		
CN Pollution*#Dust	132.343**	130.494*	134.495*	120.269**	142.223**	138.755**
	(62.133)	(69.476)	(69.874)	(51.096)	(56.510)	(55.167)
#Dust	-97.102	-88.525	-62.730	-88.380	-107.126	-52.114
	(223.574)	(225.964)	(229.599)	(183.858)	(183.791)	(181.273)
CN Pollution	-7.212	-7.970	-7.827	-2.984	-7.807	-6.700
	(13.454)	(14.438)	(14.489)	(11.064)	(11.743)	(11.439)
Year FE	Y	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y	Y
KR Energy, Energy*Dust		Y	Y		Y	Y
Weather			Y			Y
Observations	139	139	139	139	139	139
R-squared	0.765	0.771	0.778	0.871	0.877	0.888

Notes: This table reports the results treating South Korea as a single region. It implies that spillover within South Korea is unlikely to be the main driver of our baseline finding. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.5: Alternative Measures of China's Influence
(Each measure of CN Pollution is standardized)

Measure of CN Pollution	(1) Baseline	(2) Mean Index	(3) Above Median	(4) Weighted	(5) Prov. Capital	(6) Southwest	(7) Non-Southwest
	#Respiratory Deaths (Mean 5.62)						
CN Pollution*#Dust	0.065***	0.032***	0.058***	0.059***	0.069***	0.037***	0.068***
	(0.014)	(0.010)	(0.013)	(0.014)	(0.015)	(0.013)	(0.015)
CN Pollution	-0.017	0.013	-0.081	-0.051	0.002	-0.128***	-0.090**
	(0.049)	(0.052)	(0.054)	(0.047)	(0.046)	(0.036)	(0.035)
#Dust	-0.022	-0.004	-0.008	-0.019	-0.022	0.027	-0.016
	(0.019)	(0.019)	(0.019)	(0.020)	(0.019)	(0.017)	(0.019)
	#Cardiovascular Deaths (Mean 10.69)						
CN Pollution*#Dust	0.073***	0.035***	0.069***	0.068***	0.080***	0.033*	0.084*
	(0.018)	(0.012)	(0.017)	(0.017)	(0.018)	(0.017)	(0.048)
CN Pollution	-0.023	0.054	-0.049	-0.019	0.052	0.046	0.085***
	(0.070)	(0.072)	(0.076)	(0.065)	(0.066)	(0.049)	(0.017)
#Dust	-0.017	-0.003	-0.011	-0.020	-0.023	0.035	-0.031
	(0.024)	(0.025)	(0.024)	(0.025)	(0.024)	(0.022)	(0.024)
Dist. FE*Year FE	Y	Y	Y	Y	Y	Y	Y
Ring FE*Mon. FE	Y	Y	Y	Y	Y	Y	Y
KR Energy	Y	Y	Y	Y	Y	Y	Y
KR Energy*Dust	Y	Y	Y	Y	Y	Y	Y
Weather	Y	Y	Y	Y	Y	Y	Y
Observations	31,570	31,570	31,570	31,570	31,570	31,570	31,570

Notes: This table shows that the baseline pattern holds using different measure of Chinaâs pollution. Each measure of Chinaâs pollution is standardized to have a mean zero with a standard deviation of unity. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.6: Alternative Measures of China's Influence
Using Year-on-Year Growth of Industrial Value-added

D.V. (Year-on-year growth)	(1) Respir.(g)	(2) Respir.(g)	(3) Cardio.(g)	(4) Cardio.(g)
CN Industrial Value-added Growth * # Dust Growth	1.514**	1.437**	0.614	0.663
	(0.706)	(0.710)	(0.436)	(0.442)
CN Industrial Value-added Growth	1.535*	1.469*	0.306	0.301
	(0.809)	(0.816)	(0.432)	(0.437)
#Dust Growth	-0.286**	-0.273**	-0.119*	-0.127*
	(0.117)	(0.118)	(0.070)	(0.071)
Dist. FE*Year FE	Y	Y	Y	Y
Ring FE* Month FE	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y
Weather Conditions		Y		Y
Observations	7,235	7,132	7,412	7,304
R-squared	0.334	0.334	0.323	0.325

Notes: This table shows that the baseline pattern holds when using industrial valued-added information in China (available between 2000-2006). However, this information is only available in the form of year-on-year growth, so all the variables are measured as year-on-year growth. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.7: Distance to Dust Stations

	(1)	(2)	(3)	(4)	(5)	(6)
	#Respiratory Deaths			#Cardiovascular Deaths		
Distance to dust stations	10KM	30KM	50KM	10KM	30KM	50KM
CN Pollution*#Dust	0.851***	0.504***	0.530***	0.693**	0.674***	0.632***
	(0.230)	(0.131)	(0.108)	(0.314)	(0.165)	(0.136)
CN Pollution	1.126	-1.060	-1.624	-4.161	-4.983***	-4.734***
	(2.222)	(1.235)	(1.027)	(3.263)	(1.683)	(1.416)
#Dust	0.026	-0.015	-0.024	0.026	0.004	-0.025
	(0.040)	(0.024)	(0.020)	(0.055)	(0.031)	(0.025)
Dist. FE*Year FE	Y	Y	Y	Y	Y	Y
Ring FE* Month FE	Y	Y	Y	Y	Y	Y
KR Energy, KR Energy*#Dust	Y	Y	Y	Y	Y	Y
Weather Conditions	Y	Y	Y	Y	Y	Y
CN Pollution*Weather	Y	Y	Y	Y	Y	Y
Observations	8,785	21,985	30,041	8,785	21,985	30,041
R-squared	0.649	0.675	0.668	0.757	0.810	0.816

Notes: This table indicates that the main results are robust to the method of matching with dust stations. Columns (1) and (4) include districts with a monitoring station within 10 KM; columns (2) and (5), within 30 KM; and columns (3) and (6), within 50 KM, respectively. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.8: Moving-Average Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	#Respiratory Deaths					#Cardiovascular Deaths				
	5-day	15-day	30-day	45-day	60-day	5-day	15-day	30-day	45-day	60-day
CN Pollution*#Dust	0.107***	0.219***	0.446***	0.489***	0.517***	0.027	0.217***	0.421***	0.460***	0.503***
	(0.034)	(0.069)	(0.086)	(0.093)	(0.103)	(0.040)	(0.080)	(0.099)	(0.116)	(0.130)
China Pollution	0.014***	0.012**	0.011	0.008	0.004	0.028***	0.026***	0.014	0.015	0.009
	(0.004)	(0.005)	(0.007)	(0.008)	(0.009)	(0.006)	(0.008)	(0.010)	(0.012)	(0.013)
#Dust	-0.010	-0.013	-0.030**	-0.016	-0.006	0.005	-0.004	-0.013	-0.003	0.005
	(0.007)	(0.011)	(0.013)	(0.015)	(0.018)	(0.009)	(0.013)	(0.016)	(0.020)	(0.023)
District FE * Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Day FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	980,664	980,664	980,664	980,664	980,664	980,664	980,664	980,664	980,664	980,664
R-squared	0.253	0.499	0.663	0.746	0.797	0.417	0.682	0.812	0.868	0.899

Notes: This table reports moving-analysis results based on daily information. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.

Table A.9: Impacts on Different Pollutants (Mean and Max Concentration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	PM10		SO2		NO2		Ozone		CO	
	avg	max	avg	max	avg	max	avg	max	avg	max
Mean of D.V.	56	260	0.006	0.027	0.022	0.066	0.023	0.072	0.622	1.911
CN Pollution*#Dust			0.004**	0.085***	0.035***	0.199***	0.009**	0.044***	-0.360	5.229***
			(0.002)	(0.017)	(0.005)	(0.075)	(0.005)	(0.015)	(0.233)	(0.926)
CN Pollution			0.006***	0.020***	0.010***	0.030***	0.005*	0.029*	0.386***	1.119***
			(0.000)	(0.002)	(0.001)	(0.004)	(0.003)	(0.015)	(0.031)	(0.107)
#Dust	110.00***	2,197.31***	-0.001**	-0.012***	-0.010***	-0.071***	-0.015***	-0.064**	-0.063**	-0.051
	(2.220)	(51.713)	(0.000)	(0.003)	(0.001)	(0.026)	(0.005)	(0.027)	(0.030)	(0.137)
District FE*Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ring FE*Month FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
KR Energy, Energy*#Dust	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Weather Condition	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	28,250	28,250	28,501	28,501	28,512	28,512	28,515	28,515	28,476	28,476
R-squared	0.72	0.49	0.651	0.633	0.773	0.247	0.312	0.188	0.690	0.585

Notes: Columns (1) and (2) show that Dust is strongly positively correlated with PM10 (one of the criteria of defining the incidence of dust). Columns 3 through 10 report the impact of Chinaâs pollution and Asian Dust on different pollutants. The pollutants in odd (even) numbered columns are the monthly mean (maximum) of the hourly concentration. #Dust and CN Pollution are the monthly mean of the daily data. Standard errors are clustered at the district level. Significance levels: *** 1%, ** 5%, **** 10%.