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Growing pains for others: Using holidays to identify the pollution spillover between China and South Korea

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ABSTRACT

Transboundary pollution spillovers have emerged as an important global issue in designing optimal regional economic policies. In particular, China and South Korea have been at odds over which country is the "source of evil" and responsible for their air pollution. This study investigates this issue and identifies the burden of the environmental externalities of pollution between China and South Korea. There are two novelties of this study: first, we employ a unique daily pollution indicator, that is, air visibility, to address data limitations. Second, we propose a novel identification strategy to examine the pollution spillovers of economic activities by exploiting the different holiday arrangements between China and South Korea. Evidence indicates significant bilateral environmental externalities between China and South Korea. Therefore, China and South Korea should make joint efforts to deal with their environmental challenges.

1. Introduction

Air pollution is not a local issue; rather, it is a regional and international issue. Studies have shown the significance of transboundary pollution spillovers[1] for optimizing emission tax rates, trade policies, and reducing free-rider issues (Chen et al., 2020; Conconi, 2003; Copeland & Taylor, 1995; Markusen, 1975; Missfeldt, 1999; Sigman, 2005). In the real world, one country often shoulders the blame for polluting the environment of its closest neighbors. For example, Singapore frequently puts the blame on Indonesia for worsening the air quality in the region due to its forest fires (Lin, Wijedasa, & Chisholm, 2017). Transboundary pollution spillovers are also found along the U.S.-Mexico and U.S.-Canada borders.

This study investigates the transboundary pollution between China and South Korea. The two countries have been at odds over which country is the "source of evil" and responsible for their air pollution. In 2017, South Korea made public accusations against the economic activity in China as the source of domestic pollution in Korea. China refuted the accusations by pointing to the lack of

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[1] Pollution spillover is closely related to environmental externalities. Environmental externalities are defined as the environmental impact that seemingly unrelated activities in one place can have on the environment of other places. For example, the acrid smell of smoke from the fireplace of one house can greatly affect the neighbors.

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scientific evidence in support of their claim. In January 2019, the origins of air pollution in the region once again stirred controversy between China and South Korea. Therefore, research work on this bilateral pollution problem is timely, with important implications for a future solution.

Our paper addresses the knowledge gap and examines air pollution spillovers due to economic activities by exploiting different holiday arrangements. Manufacturing operations in the source country are suspended during public holidays, which in turn, greatly reduces the emission of air pollutants. If externalities exist, the air quality could be improved in the receiving country during the suspension period. In other words, public holidays could improve the air quality of both the sending and receiving countries. Using air visibility data from 100 weather stations located in 9 administrative divisions in China and 120 weather stations in South Korea, we find significant bilateral externalities of air pollution between China and South Korea. Specifically, the results show that the air quality in South Korea is improved by 5.5% during holidays in China. Meanwhile, the air quality in China is improved by 1.6% during holidays in South Korea.

In addition, this paper contributes to the literature with a novel empirical strategy to shed light on this bilateral environmental externality. First, bilateral spillover of air pollution could be addressed by using the differences in public holiday arrangements. This complements the literature that only examines one direction[2] by examining the possible impacts of air pollution spillover from China to South Korea and vice versa. Second, air visibility[3] data used in this paper has seldom been exploited in the literature as a proxy for air quality. Jia and Ku (2019) use Asian dust as the identification instrument to analyze the pollution spillover effects of China on the mortality rate in South Korea. However, dust storms usually blow in one direction which does not result in bilateral spillover. Jia and Ku (2019) acknowledge that there are no dust storms in most of the countries worldwide. In comparison, air visibility has been commonly monitored and reported daily across the world for several decades whereas the records of air quality indicators are much harder to obtain. Our strategy is relatively easy to implement whenever there are holiday differences between any two countries. Therefore, this method can be used to broadly examine pollution spillover issues.

2. Data and empirical model

2.1. Data

The air visibility data are obtained from the United States National Climatic Data Center (NCDC). The air visibility is based on the daily measured levels of pollution at the stations. Fig. 1 shows the longitudinal and latitudinal locations of the stations. Our dataset covers 100 weather stations located in 9 administrative divisions[4] in China and 120 weather stations in South Korea.

There are two reasons why we only selected these regions to represent China. First, these areas represent >41.1% of the entire Chinese gross domestic product (GDP) and contain the two major Chinese heavy industry regions, which are Hebei[5] and the northeast region. The heavy industries use coal and emit large amounts of dust and sulphates into the air. Besides, the emission of air pollutants greatly depends on the type of industry (Fujii, Managi, & Kaneko, 2013; Lu & Streets, 2011). The northeast region is the heavy industrial centre in China which manufactures steel, iron, petrochemicals, and heavy machinery. Shanghai and Jiangsu, which are part of the Yangtze-River Delta region, have textile, automobile, and electronic industries. Second, these areas are geographically close to South Korea. Since China is geographically large, the spillover effect might be dominated by other factors. In terms of station selection in South Korea, we include all of them because South Korea is smaller in size in comparison to China.

The literature has adopted various indicators to measure air quality. Typical indicators include sulfur dioxide (SO_2), particulate matters (PM 10 and PM 2.5), and carbon oxide (CO) among others. This paper uses air visibility. Compared to the typical indicators, air visibility has the following advantages. First, air visibility data are more reliable. Ghanem and Zhang (2014) argue that air visibility is less politically sensitive. Since the environmental issues may affect the promotion of local officials in China (Zheng, Kahn, Sun, & Luo, 2014), traditional pollution air quality data, which are usually managed by the government, may fail to accurately represent the true air quality in China. Second, the lack of cost-effective measurement devices can cause omission problems in a dataset of typical air pollutants. PM 2.5 (fine particulate matter) data are lacking in most regions of China prior to 2014. In this study, the sample period spans from 2000 to 2016. Therefore, the PM 2.5 data is not the optimal indicator in this study. In contrast, air visibility has been systematically recorded globally since the 1930s. Moreover, air visibility might represent more comprehensively ambient particulate matter. Tsai (2005) shows that the correlation coefficient between PM 10 and air visibility is −0.95. Besides, Sloane, Watson, Chow, Pritchett, and Willard Richards (1991) show that PM 2.5 is the primary cause of the degradation of visibility. The U.S. Environmental Protection Agency shows that particulate matter, as one of the anthropogenic emission sources, is of some significance to visibility impairment. Air visibility has also been used as a proxy of air quality in the economics literature (Li, Xu, & Yuan, 2015; Li, Yuan, Song, & Wei, 2014; Rosenfeld et al., 2007).

Table 1 provides the data source and the summary statistics. The holiday arrangements are obtained from the State Council of

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[2] Studies (Han et al., 2011; Kim et al., 2017) utilize the atmospheric model and indicate that China is the possible source for the high fine particulate matter (PM 2.5) concentration in rural South Korea. Zhang et al. (2017) use several global models and find that PM 2.5 produced in China is associated with premature deaths in Western Europe and the U.S.

[3] According to Malm (1983), the definition of air visibility is “the greatest distance at which an observer can just see a black object viewed against the horizon sky.”

[4] These 9 administrative divisions are: Beijing, Tianjin, Shanghai, Heilongjiang, Jilin, Jiangsu, Liaoning, Hebei, and Shandong.

[5] Hebei Province is one of the most air-polluted provinces. In 2016, 6 of the 10 most polluted cities in China were located in Hebei Province.

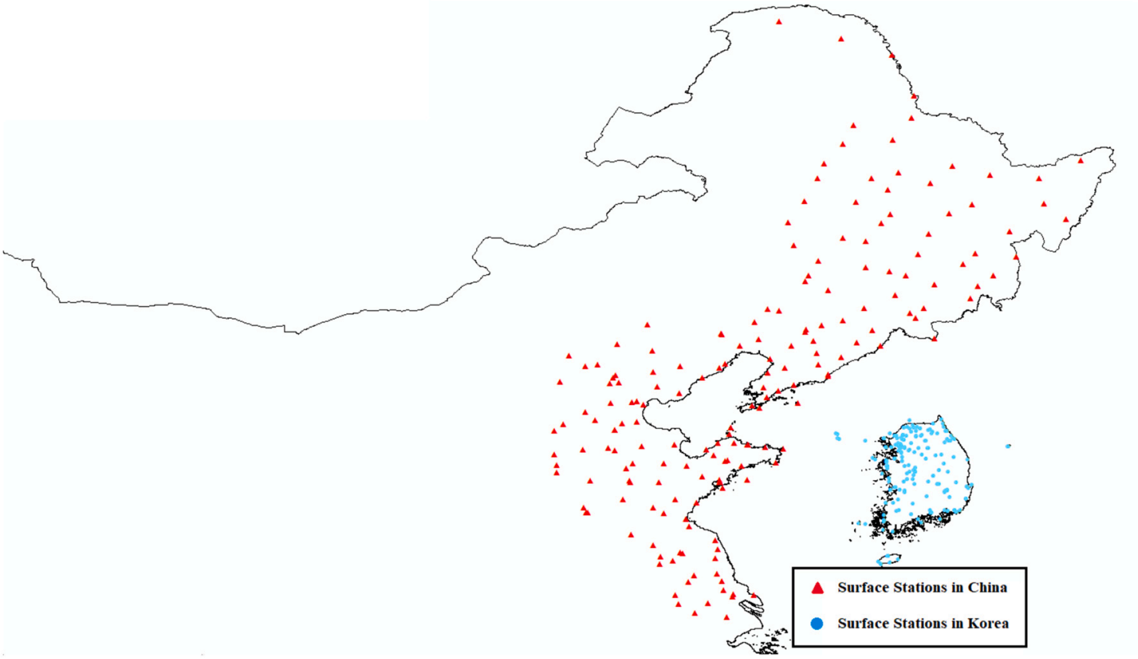

Fig. 1. The location of the stations based on their longitudes and latitudes is plotted on this map. We only show the weather station used in the baseline regression for conciseness. The red triangles and blue points represent weather stations in China and South Korea, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

China and the Korea Tourism Organization, respectively. All of the public holidays are listed in Table 2. Besides, we obtain the annual GDP per capita from the World Development Indicators.[6] To ensure a clean identification, identifying the holiday is critical. If a holiday in the polluting country happens to be on a Sunday, then the polluting and neighboring countries will cease the majority of their economic production activities on that weekend. The spillover effects will not be completely captured by the holiday if we still consider this day to be like a "normal" holiday. Thus, we eliminate the effect of the weekend in setting the holiday dummy variable. The Chinese central government provides a list of the exact dates of the public holidays each year, and clearly shows the actual holidays and makeup workdays.[7] We have already considered this circumstance in the regression. Both China and South Korea have some holidays arranged on a fixed date of the lunar year. Hence, China and South Korea have many similar holiday arrangements. To ensure a clean identification, we also exclude the same holiday arrangements.

2.2. Empirical model

Holiday arrangements change economic activities in a way that usually results in reduced productivity. According to the Labor Law of China, Article 44 requires that the employer pays "no less than 300 percent of the normal wages if the extended hours are arranged on statutory holidays". In South Korea, the employer is required to pay an extra 50% of the wages to employees on holidays. Therefore, higher human capital costs on holidays will result in fewer production activities. As a result, the pollution from production activities is halted for a short period of time. Air visibility will increase under this circumstance. Therefore, we first test for the impact of public holidays on local air visibility. Specifically, we consider the following model:

$$LnVis_{i,s,t} = \alpha_{i,s,t} + \beta Holiday_{i,t} + \gamma X_{i,t} + \theta_s + \tau_t + \varepsilon_{i,s,t}, \tag{1}$$

where $LnVis_{i,\ s,\ t}$ is the logarithm value of air visibility measured at a weather station s in country i on day t. $Holiday_{i,\ t}$ a dummy variable and set to one when the day, t, is a public holiday in country i. β measures the holiday effects. If holiday effects are present, we expect that β is significant with a positive sign. The equation also includes a control variable (X_{it}), GDP per capita, to reflect the economic development in country i at time t. Furthermore, the station fixed effects, θ_s, control for all unobserved idiosyncrasies across the stations. The year fixed effects, τ_t, are adjusted for the air visibility patterns. Standard errors are clustered at the station level.

The exogenous shock due to social events may not only affect the pollution source, but also the neighboring region. The environmental improvement in one country will also benefit its neighboring regions in the same way as environmental deterioration.

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[6] The World Development Indicators can be retrieved at: https://data.worldbank.org/.

[7] To the best of our knowledge, South Korea does not have makeup workdays, which are working weekends to compensate for holidays. In this situation, we set the holidays exactly according to Korean official arrangements.

Table 1
Data source and summary statistics.

Panel A. Data source

Data	Description	Unit	Data Source
Visibility	Mean air visibility for a day	0.1 miles	NCDC
GDP per Capita	GDP per capita	US dollars	World Bank

Panel B. Summary statistics of key variables

Variable	Country	Obs	Mean	Std. Dev	Min	Max
Visibility	China	526,893	9.44	4.37	0.10	22.30
Visibility	South Korea	369,009	7.79	3.36	0.10	31.10
GDP per capita	China	526,893	3993.20	1644.19	1771.74	6894.46
GDP per capita	South Korea	369,009	20,613.36	5325.14	11,254.30	27,804.50

Table 2
Public holiday arrangements.

Panel A. Chinese public holidays

No.	Holiday	Date
1	New Year's Day	Jan 1
2	Spring Festival	1st day of the lunar year
3	Qingming Festival	April 4 or April 5
4	Labor Day	May 1
5	Dragon Boat Festival	5th day of the 5th lunar month
6	Mid-Autumn Festival	15th day of the 8th lunar month
7	National Day	Oct 1

Panel B. South Korean public holidays

No.	Holiday	Date
1	New Year's Day	Jan 1
2	Seollal	1st day of the lunar year
3	Independence Movement Day	Mar 1
4	Arbor Day	March 2
5	Buddha's Birthday	8th day of 4th lunar month
6	Children's Day	May 5
7	Memorial Day	June 6
8	Constitution Day	July 17
9	Liberation Day	Aug 15
10	National Foundation Day	October 3
11	Chuseok	15th day of 8th lunar month
12	Mid-Autumn Festival	15th day of 8th lunar month
13	Hangeul Day	October 9
14	Christmas Day	Dec 25

Notes
1. Qingming, Dragon Boat, and Mid-Autumn Festivals were not considered as official Chinese public holidays until 2008.
2. Since 2008, Constitution Day in South Korea is no longer a public holiday with time off.
3. Since 2005, Arbor Day in South Korea is no longer a public holiday.

Hence, we test for the impact of the exogenous shock in one country on its neighboring regions and use the impact to represent the environmental spillover effects. Specifically, we aim to identify the pollution spillover between China and South Korea from a positive perspective. We adopt the equation below:

$$LnVis_{i,s,t} = \alpha_{i,s,t} + \beta Holiday_{j,t} + \gamma X_{i,t} + \theta_s + \tau_t + \varepsilon_{i,s,t} \tag{2}$$

where $Holiday_{j,\ t}$is a dummy variable and set to one when the day in the neighboring country j is a public holiday. β measures the spillover effects.

In contrast to the local pollution issue, transboundary pollution spillover may need some time to transmit from a country to its neighbors. The estimation also tests more than one-day lag of the holiday dummy.[8] The approach is similar to the event approach in the atmospheric science literature, in which significant natural events, such as dust storms, are used to estimate their effect on other regions. The difference in our approach is that we use human events (holidays) rather than natural events.

3. Results

3.1. Impact of holidays on local air quality

We first examine whether public holidays have a significant effect on local air visibility by using Eq. (1). Table 3 presents the result of the holiday effects on air visibility. We are primarily interested in the coefficient of the holiday dummy. Columns (1) to (3) show the impact of Chinese holidays on the air visibility of China. The results for South Korea are presented in Columns (4) to (6). The holiday time lag is different for each column on both sides of the table. *L.Holiday* is the one day lag of the holiday dummy defined above. *L2. Holiday* is the two days lag of the holiday dummy. All of the estimations include year and station fixed effects. In Column (1), the coefficient on *Holiday* is 0.025 with a t-value of 7.114. This suggests that the air visibility in China is increased by 2.5% during its public holidays. The estimates in Column (2), which use a one-day lag of the holiday dummy, report that Chinese air quality is improved on the day after the holiday. The regression results are still robust when we adopt more than one-time lag of the holiday dummy. For South Korea, the results are in line with the results of China. Column (4) shows the result of holiday effects on air visibility. In Column (4), The coefficient on Holiday is 0.055 with a t-value of 13.531. Compared to China, the air visibility in South Korea is improved by 5.5% during the Korean public holidays.

In terms of the control variable, the coefficients of GDP per capita for China and South Korea are contradicting. This phenomenon could be attributed to the Environmental Kuznets Curve (EKC)[9] stage of development of the country. A large volume of empirical evidence suggests that the relationships between economic growth and the environment follow an inverse U-shaped pattern.[10] According to Panel B of Table 1, the GDP per capita for China and South Korea is US$ 3993.20 and US$ 20,613.36, respectively. Using cross-country data, Grossman and Krueger (1995) estimate that the turning point of the EKC occurs before a country reaches a per capita income of US$ 8000. Per capita income is only a portion of GDP per capita, which means that the GDP per capita in China is less than US$ 8000. This suggests that the level of air pollutant in China has yet to reach the peak of its EKC and will likely continue to increase before declining as the GDP per capita continues to grow. Thus, the coefficient of GDP per capita should be negative. In contrast, the GDP per capita in South Korea in our study period is higher than US$ 8000, which surpassed the peak of its EKC. Thus, the sign of GDP per capita for South Korea is positive, which suggests that a higher GDP per capita leads to greater air visibility. Both signs of GDP per capita support the findings in Grossman and Krueger (1995).

In sum, the results above show that public holidays have significant effects on local air visibility and support our hypothesis that the suspension of manufacturing activities reduces the emission of air pollutants. We further discuss the burden of the environmental externalities of pollution between China and South Korea.

3.2. Spillover effects of holidays

We apply Eq. (2) to estimate the environmental externalities. Table 4 presents the results of the spillover effects. Columns (1) to (3) present the impact of Chinese holidays on air visibility in Korea. In Column (1), our main interest is *Holiday*. The coefficient on *Holiday* is 0.055 with a t-value of 13.656. This result suggests that the air visibility of South Korea will be increased around 5.5% during Chinese holidays. To explore the impact of distance on the externality, Columns (2)–(3) show the results for different time lags of *Holiday*. All of the coefficients on *Holiday* are positive and statistically significant, which means that the air quality in South Korea will improve during a Chinese holiday. In other words, there is “clean air” moving from China to South Korea. Rather than negative impacts, we identify a positive externality,[11] which means that a “shock” that happens in China will benefit the air environment of South Korea. In terms of the environmental externality, our finding is consistent with those in the atmospheric literature (Han, Kim, & Jung, 2011; Kim et al., 2017).

The impact of Korean holidays on air visibility in China is presented in Columns (4) to (6). Column (4) presents the impact of Korean holidays on air visibility in China. The coefficient on *Holiday* is 0.016 and statistically significant. It can be observed that air visibility in China will increase by 1.6% during Korean public holidays. Columns (5) and (6) report a similar estimation with different time lags.

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[8] Our dataset is based on daily frequency. We use lags up to two days after the current time in the estimation. The dummies are one-day lag (*L. Holiday*) and two-day lag (*L2.Holiday*).

[9] An inverse U-shape is found when the pollutant level increases with the GDP per capita at first but decreases once the GDP per capita reaches a certain turning point. This relationship is also called Environmental Kuznets Curve because the pattern is similar to the time-series pattern of income inequality proposed by Kuznets (1955).

[10] In the last few decades, there have been a growing number of studies on the relationship between economic growth and the environment (Dinda, 2004; Grossman & Krueger, 1995; Li et al., 2015; Selden & Song, 1994).

[11] A positive externality is a benefit that is enjoyed by a third-party as a result of an economic activity. For example, planting roses and lilies in one's front garden benefits others who walk by.

Table 3
Impact of public holidays on local air quality.

	Holiday in China			Holiday in Korea		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.025***			0.055***		
	(−7.114)			(−13.531)		
L.Holiday		0.017***			0.025***	
		(−4.938)			(−6.296)	
L2.Holiday			0.016***			0.011***
			(−3.953)			(−3.586)
Ln(GDPperCapita)	−0.117***	−0.117***	−0.116***	0.065**	0.061**	0.061**
	(−3.716)	(−3.709)	(−3.700)	(−2.162)	(−2.106)	(−2.11)
Constant	1.886***	1.888***	1.885***	1.727***	1.765***	1.768***
	(−7.575)	(−7.576)	(−7.568)	(−5.912)	(−6.253)	(−6.306)
Observations	526,893	525,647	525,450	369,009	364,647	363,067
R-squared	0.399	0.399	0.399	0.262	0.261	0.261
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Standard errors are clustered at the station level. This table presents the result of the holiday effects on air visibility. The coefficients of *Holiday*, *L.Holiday,* and *L2.Holiday* are positively and statistically significant, which show that air visibility increases during public holidays.

Table 4
Baseline results: The spillover effects.

	China to Korea			Korea to China		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.055***			0.016***		
	(−13.656)			(−2.630)		
L.Holiday		0.059***			0.017***	
		(−15.051)			(−4.500)	
L2.Holiday			0.050***			0.028***
			(−13.176)			(−6.989)
Ln(GDPperCapita)	0.063**	0.059**	0.059**	−0.116***	−0.116***	−0.116***
	(−2.103)	(−2.046)	(−2.064)	(−3.693)	(−3.692)	(−3.680)
Constant	1.744***	1.781***	1.780***	1.881***	1.883***	1.880***
	(−5.97)	(−6.303)	(−6.349)	(−7.553)	(−7.562)	(−7.548)
Observations	369,009	364,647	363,067	526,893	525,647	525,450
R-squared	0.262	0.261	0.261	0.399	0.399	0.399
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Standard errors are clustered at the station level. This table presents the result of the spillover effects on air visibility. Our main interest lies in the coefficients of *Holiday*, *L.Holiday,* and *L2.Holiday*. The estimated spillover effects on China and South Korea are significant. There are bilateral pollution spillover effects between the two countries.

These results suggest that Chinese air quality will improve during Korean public holidays and provides evidence of the environmental externality on China.

In sum, the estimated spillover effects on China and South Korea are significant. There is a bilateral pollution spillover effect between the two countries.

4. Further checks and discussions

4.1. Robustness checks

This section elaborates on six robustness checks that are done to ensure the pollution spillover effects.

4.1.1. Entire region of China

Due to the geographical vastness of China, we only include 9 administrative divisions in the baseline results. As this non-random selection might generate sample selection bias, we enlarge the sample and re-examine the impact of Korean holidays on the entire

Table 5
Robustness check: all regions of China.

	Station Level			City Level		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.017***			0.017***		
	(8.104)			(−6.148)		
L.Holiday		0.015***			0.018***	
		(7.292)			(−7.420)	
L2.Holiday			0.024***			0.030***
			(11.335)			(−11.979)
Ln(GDPperCapita)	−0.143***	−0.143***	−0.144***	−0.152***	−0.152***	−0.153***
	(−12.407)	(−12.438)	(−12.456)	(−10.307)	(−10.336)	(−10.363)
Constant	2.857***	2.856***	2.857***	3.390***	3.393***	3.396***
	(33.100)	(33.110)	(33.131)	(−29.353)	(−29.415)	(−29.454)
Observations	2,409,050	2,404,393	2,403,570	1,528,364	1,526,086	1,525,640
R-squared	0.545	0.545	0.545	0.481	0.481	0.481
Station FE	YES	YES	YES	NO	NO	NO
City FE	NO	NO	NO	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. In Columns (1)–(3), the standard errors are clustered at the station level. In Columns (4)–(6), the standard errors are clustered at the city level. Due to the geographical vastness of China, we only include nine administrative divisions in the baseline results. As this non-random selection might generate sample selection bias, we enlarge the sample and re-examine the impact of Korean holidays on the entire region of China by using 482 stations across 34 administrative divisions. The results are consistent with the baseline results and address the concern of sample selection bias.

Table 6
Robustness check: PM 2.5.

	China to Korea			Korea to China		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (PM 2.5)			Dependent variable: Ln (PM 2.5)		
Holiday	−0.024***			−0.065***		
	(−6.176)			(−25.566)		
L.Holiday		−0.106***			−0.060***	
		(−21.630)			(−13.171)	
L2.Holiday			−0.147***			−0.038***
			(−28.772)			(−7.806)
Ln(GDPperCapita)	−0.031	−0.061	−0.079	0.070**	0.077**	0.075**
	(−0.162)	(−0.318)	(−0.414)	(2.300)	(2.525)	(2.434)
Constant	3.232*	3.530*	3.709*	3.214***	3.145***	3.169***
	(1.699)	(1.868)	(1.970)	(10.767)	(10.497)	(10.530)
Observations	128,216	127,776	127,486	542,623	539,686	537,728
R-squared	0.053	0.055	0.056	0.225	0.224	0.224
Province FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors are clustered at the city level. The coefficients of *Holiday*, *L.Holiday*, and *L2.Holiday* are negative and statistically significant, which indicates the level of PM 2.5 decreasing during holidays. The results support our baseline findings.

region of China by using 482 stations across 34 administrative divisions. The result is presented in Table 5. Apart from the data obtained at the stations, we also present an additional check by using city-level data. On the left side, we present the spillover effects by using station-level data. The coefficients of *Holiday* are positively and statistically significant. As shown, this robustness check addresses the concern of sample selection bias and indicates that the baseline estimation is robust.

4.1.2. PM 2.5 as an alternative air quality indicator

For robustness concerns, we use PM 2.5 as the air quality measurement and apply Eq. (3) to recheck the bilateral pollution spillover effect. The PM 2.5 for China and South Korea was obtained from Berkeley Earth,[12] which provides city-level PM 2.5 data. The sample

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[12] The data can be retrieved at: http://berkeleyearth.org/

Table 7
Robustness check: wind direction.

	China to Korea			Korea to China		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.062*** (−10.717)			0.020** (−2.341)		
L.Holiday		0.074*** (−12.839)			0.016* (−1.949)	
L2.Holiday			0.056*** (−9.576)			0.021** (−2.429)
Ln(GDPperCapita)	0.079*** (−10.459)	0.078*** (−10.229)	0.078*** (−10.23)	−0.146*** (−28.791)	−0.146*** (−28.742)	−0.145*** (−28.545)
Constant	8.885*** (−118.724)	8.899*** (−118.38)	8.896*** (−117.841)	9.420*** (−216.906)	9.421*** (−216.562)	9.414*** (−216.361)
Observations	187,884	186,374	185,480	171,430	171,209	171,151
R-squared	0.281	0.281	0.28	0.361	0.36	0.361
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Wind Direction	Westerly	Westerly	Westerly	Easterly	Easterly	Easterly
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Standard errors are clustered at the station level. We use the daily average wind direction to address the impact of the wind. Based on the relative location of China and South Korea, we investigate the impact of Chinese public holidays on air visibility in Korea with the westerly winds that blow from China to South Korea. The coefficients of *Holiday*, *L.Holiday,* and *L2.Holiday* are positively and statistically significant, which show that the spillover effects still exist after we control for the wind direction.

Table 8
Robustness check: meteorological conditions.

	China to Korea			Korea to China		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.020*** (6.434)			0.014*** (3.027)		
L.Holiday		0.024*** (7.851)			0.018*** (5.775)	
L2.Holiday			0.033*** (10.435)			0.020*** (5.864)
Ln(GDPperCapita)	0.052* (1.769)	0.050* (1.743)	0.049* (1.748)	−0.120*** (−3.865)	−0.119*** (−3.850)	−0.119*** (−3.844)
Constant	1.648*** (5.770)	1.669*** (5.999)	1.672*** (6.104)	1.673*** (6.868)	1.670*** (6.856)	1.668*** (6.849)
Observations	368,845	364,497	362,917	526,823	525,592	525,396
R-squared	0.493	0.493	0.493	0.570	0.569	0.569
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Meteorological Factors	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors are clustered at the station level. The coefficients on the *Holiday*, *L. Holiday*, and *L2.Holiday* are positive and statistically significant, which indicates the spillover effects still exist after we include the dew point, temperature, and meteorological conditions in the regression.

period of PM 2.5 spans from 2014 to 2016. Specifically, we consider the following model:

$$LnPM\ 2.5_{i,c,t} = \alpha_{i,c,t} + \beta Holiday_{j,t} + \gamma X_{i,t} + \theta_c + \tau_t + \varepsilon_{i,c,t} \tag{3}$$

where $LnPM\ 2.5_{i,\ c,\ t}$ is the logarithm value of PM 2.5 measured at a city c in country i on day t. $Holiday_{j,\ t}$ a dummy variable and set to one when the day, t, is a public holiday in the neighboring country j. β measures the spillover effects. If spillover effects are present, we expect that the estimated β is significant with a negative sign.

We report the related results in Table 6. Columns (1) to (3) present the impact of Chinese holidays on PM 2.5 in Korea. In Column (1), our main interest is *Holiday*. The coefficient on *Holiday* is −0.024 with a t-value of 6.176. This result suggests that the level of PM 2.5 in South Korea will be decreased by 2.4% during Chinese holidays. Columns (2)–(3) report a similar estimation with different time lags. Columns (4) to (6) present the impact of Korean holidays on PM 2.5 in China. The coefficients suggest that China's air quality will improve during South Korean public holidays. The results in Table 6 indicate a bilateral pollution spillover effect between the two

Table 9
Robustness check: trade, FDI, and technological advancement.

	China to Korea			Korea to China		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.055***			0.016***		
	−13.278			−3.394		
L.Holiday		0.059***			0.017***	
		−14.29			−3.464	
L2.Holiday			0.050***			0.028***
			−12.058			−5.823
Constant	0.855	132.304***	0.603	4.056	35.743	−0.257
	0	−15.87	0	−0.001	−0.011	(−0.000)
Observations	369,009	364,647	363,067	526,893	525,647	525,450
R-squared	0.262	0.261	0.261	0.399	0.399	0.399
Controls	YES	YES	YES	YES	YES	YES
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and* $p < 0.1$. Standard errors are clustered at the station level. Air quality can be also affected by international trade, foreign direct investment, and technological advancement. In this robustness check, we incorporate these factors and re-estimate the spillover effects. The controls are GDP per capita, trade openness, FDI, R&D, and the number of patents. To provide a concise table, we only show the coefficients of our main interest-*Holiday*.The coefficients of *Holiday*, *L.Holiday,* and *L2.Holiday* are positively and statistically significant, which show that spillover effects still exist after we include additional controls in the estimation.

countries. Note that, due to the limitation of time span and coverage, the PM 2.5 data is not the optimal air quality indicator in the baseline results.

4.1.3. *Wind direction*

Wind direction has a considerable impact on regional climate differences and pollutant movement. Both China and South Korea are affected by the East Asian monsoon which is driven by the temperature differences between the Pacific Ocean and East Asia. To determine the influence of this monsoon, we control the daily average wind direction and re-estimate the baseline regression. Based on the relative location, we study the impact of Chinese holidays on air visibility in Korea with the westerly winds that blow from China to Korea. Similarly, we study the impact of Korean holidays on the air visibility in China with the easterly winds that blow from South Korea to China. We report the results in Table 7 which show that the results are still robust after we control for the wind direction.

4.1.4. *Meteorological conditions*

Air visibility is also associated with dew point, temperature, and meteorological conditions. To address this concern, we propose a robustness test. Specifically, we include the dew point, temperature, and meteorological conditions in the estimation. The meteorological conditions contain fog, rain, snow, hail, thunder, and tornado. We use dummy variables to present these meteoritical conditions. For instance, Rain is a dummy variable that is 1 for a given day if that day rains, 0 otherwise. The corresponding results are reported in Table 8. For concision reasons, we only report coefficients of key variables in the manuscript. The coefficients on the *Holiday*, *L.Holiday*, and *L2.Holiday* are positive and statistically significant, which indicates the spillover effects still exist after we include the dew point, temperature, and meteorological conditions in the regression.

4.1.5. *Trade, foreign direct investment, and technological advancement*

Air quality can also be also affected by international trade (Le, Chang, & Park, 2016; Lin et al., 2014), foreign direct investment (FDI) (Huynh & Hoang, 2019; Zheng, Kahn, & Liu, 2010), and technological advancement (Ben Youssef, 2009). We use trade openness[13] to proxy international trade. Technological advancement is captured by research and development (R&D) input and the number of patents. These controls are also obtained from the World Development Indicators. The FDI and R&D are scaled by the GDP of the country. Using these variables as the controls, we re-estimate the spillover effects and report the corresponding results in Table 9.[14] The coefficients of *Holiday*, *L.Holiday*, and *L2.Holiday* are positive and statistically significant, which shows that spillover effects still exist after we include additional controls in the estimation.

4.1.6. *Short time window*

The climate and wind direction vary even in the same season. Thus, we use a short time window to reduce the changes in the wind

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[13] Trade openness is the sum of imports and exports normalized by the GDP.

[14] The controls (GDP per capita, trade openness, FDI, R&D, and the number of patents) are highly correlated and a multicollinearity problem exists, which leads to sensitive sign and significance. To address the multicollinearity issue, we incorporate only one control variable at a time and the main results hold. All corresponding results are available upon request.

Table 10
Robustness check: short time windows.

China to Korea						
	Time Window:7 Days			Time Window:10 Days		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.009**			0.021***		
	(−2.280)			(7.006)		
L.Holiday		0.016***			0.023***	
		(−4.062)			(6.672)	
L2.Holiday			0.009**			0.013***
			(−2.169)			(3.355)
Ln(GDPperCapita)	0.042***	0.040***	0.037***	−0.011	−0.009	−0.003
	(−3.922)	(−3.532)	(−3.147)	(−0.354)	(−0.302)	(−0.101)
Constant	1.972***	1.997***	2.019***	2.490***	2.478***	2.420***
	(−18.332)	(−17.688)	(−17.102)	(8.070)	(8.326)	(8.253)
Observations	102,657	96,027	90,315	134,393	127,441	121,873
R-squared	0.31	0.306	0.305	0.300	0.300	0.301
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Standard errors are clustered at the station level. The climate and wind direction vary even in the same season. Thus, we adopt an additional check - a short time window to reduce the change in the wind direction caused by meteorological fluctuations. The climate and wind characteristics during a short period of time have less variation than those during an entire season. This table estimates the impact of Chinese holidays on air visibility in Korea. These results provide strong support for the baseline results.

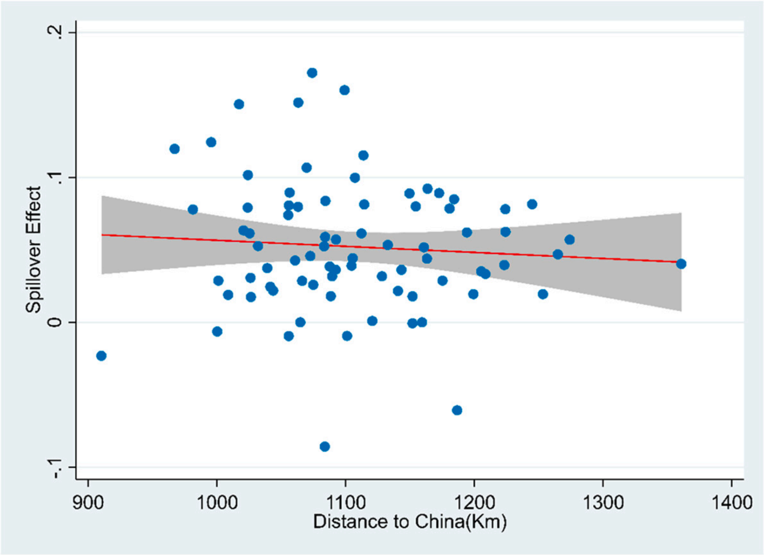
Table 11
Robustness check: short time windows.

Korea to China						
	Time Window:7 Days			Time Window:10 Days		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLE	Dependent variable: Ln (Visibility)			Dependent variable: Ln (Visibility)		
Holiday	0.015***			0.013***		
	(7.019)			(6.104)		
L.Holiday		0.013***			0.011***	
		(6.098)			(5.318)	
L2.Holiday			0.022***			0.021***
			(10.109)			(9.659)
Ln(GDPperCapita)	−0.144***	−0.143***	−0.142***	−0.150***	−0.149***	−0.149***
	(−12.318)	(−12.312)	(−12.266)	(−12.839)	(−12.797)	(−12.764)
Constant	2.919***	2.914***	2.909***	2.923***	2.917***	2.914***
	(33.413)	(33.460)	(33.492)	(33.380)	(33.390)	(33.378)
Observations	952,701	898,491	846,318	1,255,307	1,206,984	1,161,558
R-squared	0.548	0.547	0.548	0.550	0.549	0.550
Station FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Lag	0	1	2	0	1	2

T-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Standard errors are clustered at the station level. The climate and wind direction vary even in the same season. Thus, we adopt an additional check - a short time window to reduce the change in the wind direction caused by meteorological fluctuations. The climate and wind characteristics during a short period of time have less variation than those during an entire season. This table estimates the impact of Korean holidays on air visibility in China. These results provide strong support for the baseline results.

direction caused by meteorological fluctuations. The meteorological characteristics during a short period of time have less variation than those during an entire season. The time span of the window is critical for eliminating the "noise" caused by climate changes. If the time window is too short, the spillover effect is limited due to the lack of observation. By contrast, the "noise" cannot be eliminated if we set the time window for an overly long period. Specifically, we apply the week before and after a holiday as the time span used in this robustness test. In addition, we also extend the time span from a week to 10 days in order to provide an additional check for this test. The spillover effects of China and South Korea are shown in Tables 10 and 11, respectively. Columns (1) to (3) and Columns (4) to (6) report the short time window for 7 days and 10 days, respectively. All the coefficients of *Holiday*, *L1. Holiday* and *L2.Holiday* are positive and significant, which indicate significant bilateral environmental externalities between China and South Korea.

A: From China to South Korea



B: From South Korea to China

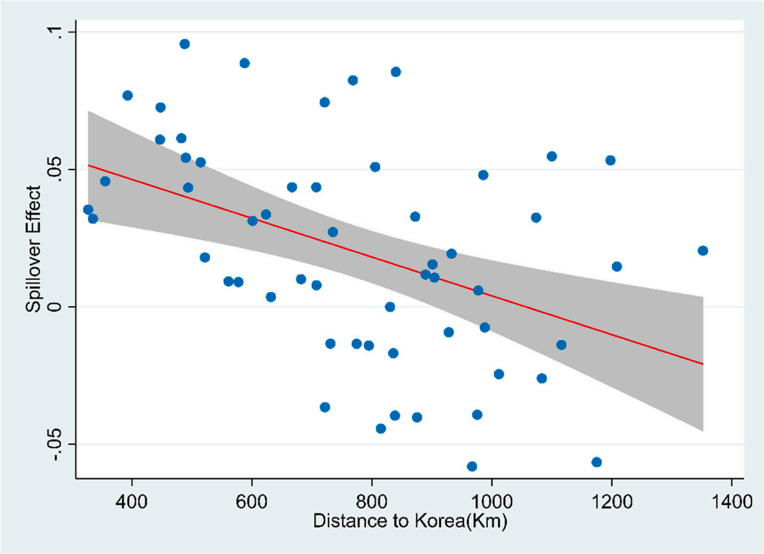


Fig. 2. Distance effect. Panel A shows the impact of distance on the spillover effect during Chinese holidays. Panel B shows the impact of distance on the spillover effect during South Korean holidays. The paler shading is the 95% confidence interval. The downside trend indicates that the spillover effects are diminishing with increasing distance from the pollutant source.

4.2. Impact of distance on spillover effect

The distance to the source of pollution has a critical role in identifying environmental externalities. The air visibility of a city is supposed to be less affected by the pollution source if it is located farther away from the pollution source. Using a geographic information system, we calculate the distance from the receiving station to the capital of the source country. We re-estimate the spillover effects for each station and maintain the coefficients of each station. Then, we plot the distance between each weather station and the capital of the source country against the obtained coefficient and yield a downside trend in both cases shown in Fig. 2. The figure suggests that the spillover effects are reduced with increasing distance from the pollutant source.

5. Conclusions

China and South Korea have been intensely debating over who should accept responsibility for their environmental issues. Several meetings between their environmental ministers have failed to cease their angst. In response, we propose a strategy to identify and examine pollution spillover from economic activities by exploiting the different holiday arrangements between China and South Korea. Specifically, this study identifies the environmental externality from a positive perspective, which means that a "shock" that happens in one country will benefit the environment of the other country.

By applying econometric methods, we provide evidence that pollution spreads bilaterally between China and South Korea. We further find evidence that distance plays a key role in identifying the magnitude of the environmental externality. Our quantitative evidence provides a basis to suggest that, in the face of severe environmental challenges, China and Korea should make joint efforts to address and manage air pollution issues. Indeed, we are delighted to witness some joint action in progress in recent years. For instance, China, Japan, and South Korea launched Tripartite Joint Action Plan on Environmental Cooperation (2021–2025) in 2021. This plan could enhance air pollution control, dust and sandstorm control, environmental education, chemical management, and a transition to a green economy. We like to see more environmental cooperation between China and South Korea over air quality and common waters, which could benefit both countries to have environment-friendly development.

Data availability

Data will be made available on request.

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