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The pollution haven strikes back?–Evidence from air quality daily variation in the Jing-Jin-Ji region of China☆

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ABSTRACT

Pollution havens create environmental inequality issues. China's recent policy of directing high-pollution firms to migrate out of its capital, Beijing, offers a case of a pollution haven that was mandated, rather than resulting from firms' responses to environmental regulation. More importantly, it leads to a question that has been less discussed in previous literature: does a pollution haven strike back? After the highly polluting enterprises moved out of Beijing to neighboring Hebei province, Hebei has been blamed for the continuing poor air quality in Beijing, based on a perception that the pollutants emitted in Hebei are being blown back to Beijing. This paper investigates the existence of a pollution haven in Hebei and quantifies the contribution of Hebei's emissions to Beijing's air quality. We find that the proportion of output values and the relative concentration of high-pollution industries in Hebei increased when the large-scale out-migration began, while the indicators in Beijing decreased. We also find higher emissions of enterprises in Hebei than their counterparts in Beijing. Together, these findings indicate the existence of a "manmade" pollution haven. Further, based on high-frequency spatial data, we combine an Autoregressive Distributed Lag model and a Spatial Autoregressive Model and decompose the factors that affect Beijing's air quality into local and regional transport of air-borne pollutants. We find a significant effect of the neighboring cities' air pollution on Beijing's air quality. This indicates that the pollution haven indeed struck back. These findings imply the importance of regional policies to control air pollution.

1. Introduction

Environmental inequality can come from many sources, such as differences in environmental endowments, economic structure, regulatory stringency, and resources for abating environmental pollution. Pollution havens[1] due to spatial differences in regulatory stringency have been well studied as one type of environmental inequality.[2] However, pollution havens mandated by administrative decisions other than environmental regulation have been paid little attention so far. An example of a "manmade" pollution haven that is worsening environmental inequality is the government-ordered migration of high-pollution enterprises from Beijing (the "Jing" of the Jing-Jin-Ji region) to its geographic and economic neighbors in the same region, which are cities in Hebei province (the "Ji" in the Region).[3] After the out-migration of the high-pollution enterprises, however, air quality in Beijing seems not to have improved. The enterprises in Hebei are now blamed for

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[1] In the pollution haven hypothesis, pollution havens refer to countries or regions where highly polluting firms prefer to locate. As will be discussed later, there are various reason for becoming a pollution haven, such as low environmental regulatory stringency.

[2] An incomplete list of the literature includes McConnell and Schwab (1990); Copeland and Taylor (1994); Jaffe et al. (1995); Markusen et al. (1995); Levinson (1996); Becker and Henderson (2000); Antweiler et al. (2001); List et al. (2003); Levinson and Taylor (2008); Morgan and Condliffe (2009); and Zeng and Zhao (2009).

[3] Beijing ("Jing"), Tianjin ("Jin"), and Hebei ("Ji") constitute the "Jing-Jin-Ji" Region and are geographically and economically connected. In this paper, we focus on Beijing and Hebei, because Tianjin was not the main destination of the out-migrated high-pollution enterprises. Besides, Tianjin is not generally being blamed for offsetting Beijing's efforts on emission control, because Tianjin is geographically small compared to Hebei and its air quality level is similar to that of Beijing.

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emissions that diffuse or are blown back to Beijing. Is this blame reasonable? How can we solve this type of environmental inequality? To answer these questions, this paper investigates the manmade pollution haven in Hebei and its "striking back" by contributing to Beijing's air pollution, and draws policy implications based on the findings.

As the capital city of China, Beijing has unique political significance. It also has grown very quickly in the past four decades to become the center of economic activities in northern China. Along with its rapid economic growth and geographic expansion, environmental quality has deteriorated greatly. Since the early 2000 s, triggered by the need to meet the air quality requirements of the 2008 Olympic Games, many measures have been taken to reduce pollution in Beijing.[4] One important measure has been shutting down polluting manufacturing facilities located in Beijing. With demand for manufactured goods continuing to rise due to economic growth in Beijing, many of the suppliers were required to move to adjacent areas such as Hebei. However, the environmental regulations are much less stringent in Hebei. Consequently, emissions from these areas have increased. However, this was not a classic case of firms freely choosing to move to a location with less stringent regulation. The policy of suppressing polluting industries in Beijing has created a pollution haven surrounding Beijing by administrative force.

Air quality improvement under this measure has been dubious to say the least. Due to its unique geographical setting, Beijing is part of an air-shed formed of cities a few hundred kilometers to its south and west. Wind can bring air pollutants generated from the upstream cities downstream to Beijing in a few hours. With lower standards of environmental regulation, manufacturing facilities newly moved to the upstream cities are probably emitting more, making total emissions greater in the whole air-shed. It is hard to believe that Beijing's air quality would actually improve by simply relocating the polluters in the same air-shed. Beijing's environmental authority has been attributing severe air pollution in Beijing largely to regional pollutant transfers.[5] During the 2008 Olympic Games and during many recent periods of severe pollution alerts, the government has had to order full stoppage of production activities in the neighboring provinces in order to ensure air quality to meet the required standard. This is additional evidence of regional linkages in air quality dynamics.

This implies that a rather powerful policy intervention to improve air quality in China's capital city has created two interlinked issues: a pollution haven surrounding Beijing and its unintended negative impacts on Beijing's air quality. The former issue has certainly shifted the environmental burden to neighboring areas and has increased political risk to local governments as well. The latter could greatly compromise the efforts put into environmental protection in Beijing. Whether the effort is completely offset depends on the amount of the increased emissions in the pollution haven as well as to what extent the pollution haven strikes back. This leaves an open question for empirical study.

The pollution haven hypothesis suggests that environmental policies affect the location of polluting industries, in the case of free trade, because these industries tend to move to countries or regions with looser environmental regulations, turning these areas into a pollution haven. The theoretical studies of the pollution haven hypothesis have been derived primarily from the Heckscher-Ohlin model. Copeland and Taylor (1994) developed a North-South general equilibrium model and showed that, in the case of free trade, polluting industries will locate in the global South, where pollution taxes are relatively low. Copeland and Taylor's model has been further extended, and more theoretical support for the pollution haven hypothesis has been provided (e.g., Markusen et al., 1995; Antweiler et al., 2001; Levinson and Taylor, 2008; Zeng and Zhao, 2009). As for empirical studies on pollution havens, early empirical studies found weak or even no evidence for the existence of pollution havens (e.g., Tobey, 1990). Most of these studies used cross-sectional data (e.g., Levinson, 1996; McConnell and Schwab, 1990; Jaffe et al., 1995), which may lead to mis-estimations caused by unobserved heterogeneity and endogeneity (Levinson and Taylor, 2008). More recent studies using panel data and better-developed estimation techniques have found more supporting evidence for the pollution haven hypothesis. Research shows that air quality regulations have an impact on plant location or plant birth (e.g., Becker and Henderson, 2000; List et al., 2003; Morgan and Condliffe, 2009). Heterogeneous effects also have been studied. Zheng and Shi (2017) showed that the implementation of a pollution discharge fee encourages industrial relocation, while air pollution-intensive industries dominated by state-owned capital are insensitive to legal policy instruments. Hutchinson and Kennedy (2008) found that states have an incentive to enforce standards less stringently on firms located close to downwind borders, and this leads to excessive interstate pollution, while Konisky et al.'s study (Konisky and Woods, 2010) showed that this kind of free riding is only significant when counties are bordering another country, rather than other states of the US. Recent pollution haven papers also consider carbon emissions as a global emission. They generally find that GDP, Foreign Direct Investment (FDI), and trade openness increase carbon emissions (e.g., Ahmad et al., 2019, Li et al., 2021, Liu et al., 2021).

Some pollution outsourcing studies also discuss the relationship between pollution relocation and environmental regulation although they do not explicitly raise the concept of pollution havens. For example,) Antonietti et al. (2017) find that a stricter environmental regulation is related to a higher probability of production being outsourced to foreign suppliers. Cole et al. (2014) develop a theoretical model of international environmental outsourcing and empirically test their prediction. Their results show that pollution-intensive firms facing high regulatory costs are more likely to outsource. Utilizing a unique dataset of approximately 4000 Japanese firms for the period 2009–2013, Cole et al. (2021) find that outsourcing does appear to reduce the emissions intensity for all firms in the year of outsourcing and the following years.

Contradictory to the pollution haven hypothesis, the pollution halo hypothesis proposes that FDI tends to choose countries or regions with higher standards of environmental regulation, and that FDI can bring new technologies that improve the environment of the host countries or regions (e.g., Birdsall and Wheller, 1993; Antweiler et al., 2001; Fisher and Jefferson, 2004; Huang et al., 2017). Comparing these contrasting hypotheses, Ahmad et al. (2021) estimated the heterogeneous influence of FDI inflows and income on CO_2 emissions across the Chinese provinces at different development levels. They found that different provinces experienced either a pollution haven or a pollution halo response to FDI.

The other strand of related literature is regional transport of airborne pollutants. Scientific studies focusing on particulate matter (e.g., Yang et al., 2013; Z. Wang et al., 2014; L. T. Wang et al., 2014; Y. Wang et al., 2014) provide evidence that regional transport can be a key contributor to local air pollutant concentrations (Zheng et al., 2015). Economic studies have been interested in spillover effects. For example, Maddison (2006) found that per capita emissions of SO_2 and NOx were heavily influenced by the emissions per capita of neighboring countries; Ma et al. (2016) found that adjacent areas receive spillovers of smog or haze; Cheng et al. (2017) developed a dynamic spatial panel model and found positive $PM_{2.5}$ concentration spatial lag coefficients, indicating that urban $PM_{2.5}$ has a significant spatial spillover effect; Wang et al. (2017) quantified the spatial spillover effects of industrial water and air pollutant emissions at enterprise level and found that the spatial

[4] The government issued a number of policy documents, including *The Beijing Olympic action plan, the Measures for the Treatment of Air Pollution, the Clean Air Act, and the Implementation Plan for Relocating Industrial Enterprises within the Third and Fourth Ring Road of Beijing,* etc.

[5] Based on media releases from the Beijing Environmental Protection Bureau in 2014 and 2018, around 30 % of fine particulates were from sources outside Beijing. On severe pollution days, this share could surpass 50 %. (http://www.gov.cn/xinwen/2014–04/16/content_2660927.htm; http://www.ce.cn/xwzx/gnsz/gdxw/201807/02/t20180702_29587171.shtml)

spillover effects were significant in almost all the industrial sectors; and Wu et al. (2017) showed that a 1 % increase in the $PM_{2.5}$ values of neighboring provinces led to a 0.78 % increase in $PM_{2.5}$ of one province. All this research used econometric models incorporating a spatial weight matrix, but they seldom modeled wind direction in detail.

In this paper, we provide insights into how both meteorological factors and neighboring industrial activity contribute to the local pollution concentration. By modeling wind direction in detail, we examine the air pollution spillover effects in one specific direction: how Beijing's air quality is affected by neighboring cities' air pollution. The other contribution of this paper is that we establish linkages between the pollution haven effect and the air pollution spillover effect to answer the puzzle of why Beijing's air quality hasn't improved after high-polluting enterprises were moved out. Our analysis takes the following steps: (1) investigating the migration of high-polluting enterprises from Beijing to Hebei; (2) measuring the emission differences between enterprises in Beijing and their counterparts in Hebei; and (3) estimating the contribution of Hebei's air-borne pollutants to Beijing's air quality. The first two steps aim to find out whether the government created a pollution haven. The last step is to answer to what extent the pollution haven strikes back to affect air quality in Beijing.

By comparing the trends of industry composition in Beijing and Hebei between 2003 and 2013, the intensive period of out-migration of Beijing's high-pollution enterprises, we find that the proportion of high-pollution industry output values in Hebei increased by 0.45 % each year on average, while the proportion in Beijing decreased by 0.97 %. By exploiting a high-frequency emission dataset, we find higher emissions by enterprises in Hebei than by their counterparts in Beijing. This indicates the existence of a pollution haven. This finding is supported by related literature. For example, Luo et al. (2021) characterized the spatial and temporal characteristics of pollution-intensive industries in the Jing-Jin-Ji region, and found that Hebei has become the site of incoming pollution-intensive industries that have relocated from Beijing. Using a discrete choice model and the Monte Carlo method, Li et al. (2019) simulated the relocation process of Beijing's manufacturing industry. Their results showed that Beijing's industrial emissions will decrease by 6.7–36 %, while environmental pressures may intensify in neighboring cities in Hebei, such as Langfang and Shijiazhuang, which are designated to host 65 % of all relocated industries.

By exploiting the daily variation in $PM_{2.5}$ concentrations in Beijing and cities in Hebei, we distinguish the effects of local and neighboring factors on Beijing's air quality and find a significant effect of Hebei's air pollution. Based on a back-of envelop calculation, we find that thirteen to forty eight percent of Beijing's effort could be offset by the striking back of the manmade pollution haven, depending on the distribution of the related enterprises.

Our study calls for rethinking environmental economic policy and theory. In pollution control and climate action, we are often content to use a piecemeal approach and lead by example. However, with such strong regional patterns of pollution interaction, one model city leading an environmental campaign may change its environmental quality for worse. Identifying a proper regional scope to simultaneously act on pollution is the only way to achieve pollution reduction goals. This means that policy must provide incentives to regional joint actions. These have been largely lacking in policy making in China.

The remainder of this paper proceeds as follows. Section 2 introduces the methodologies and data. Section 3 presents the empirical results as well as a discussion. Section 5 concludes with further policy implications.

2. Materials and methods

2.1. High-pollution enterprises' migration from Beijing to Hebei

To alleviate its air pollution problem, Beijing started to restrict the production of high-pollution industries and related high-pollution enterprises in the early 2000 s. The main policies include the "*Measures for the Treatment of Air Pollution*", the "*Clean Air Act*", and the "*Implementation plan for relocating industrial enterprises within the third and fourth ring road of Beijing*", with the goal of reducing the proportion of industrial land to 7% or less of the planned downtown area in five years (2000 through 2005). After successfully competing to host the 2008 Olympic Games, Beijing heightened the campaign of air quality improvement. *The Beijing Olympic action plan*, formulated in March 2002, tightened the pollution control of metallurgical, chemical, electric, and cement industries. The government put forward the goal of completing the relocation of 200 high-polluting enterprises in the southeast chemical industry area and those in the areas within the fourth ring road (the more central area). The Capital Steel Company, which had been in Beijing, was ordered to complete a structural adjustment and reduce production by 2 million tons of steel by 2008.[6] The "*Development Policy for the Iron and Steel Industry*", promulgated in 2005, made it clear that the Capital Steel Company should be relocated and reorganized with the iron and steel industry in Hebei. Since then, many high-pollution enterprises followed suit and migrated to Hebei.

The government continued to carry out policies to alleviate air pollution after the 2008 Olympic Games. In 2013, the General Office of the People's Government of Beijing Municipality issued the *Decomposition of Key Tasks of the Beijing Clean Air Action Plan for 2013–2017*, entailing the closure of 1200 polluting enterprises in Beijing.[7] According to the Beijing Municipal Commission of Development and Reform,[8] more than 80 industrial projects were relocated from Beijing to Hebei by July 2015. The gross investment involved is more than 120 billion yuan (about 18 billion US dollars). The most massive relocations include the fourth plant of the Beijing-Hyundai Auto Enterprise to Cangzhou City, the Capital Steel Jing-Tang second phase to Tangshan city, and Lingyun Construction Material and Chemical Company to Hadan city.

Since the full list of the migrating enterprises is not publicly available, we look for suggestive evidence of migration by analyzing the trajectories of production values and location quotients[9] of the high-pollution enterprises in Beijing and Hebei. We also investigate the spatial pattern of the migration, to obtain evidence about the regional transport of air-borne pollutants.

Table 1
Annual change of output value proportions of the high-pollution industries in the Jing-Jin-Ji Region.

	(1) Beijing	(2) Tianjin	(3) Hebei
year	-0.97%***	0.52%***	0.45%***
	(0.00)	(0.00)	(0.00)
constant	19.69***	-10.26***	-8.43**
	(2.73)	(2.85)	(2.74)
observations	11	11	11
R-squared	0.85	0.60	0.55

Notes: OLS estimators. The dependent variable is the output value proportion of the high-pollution industries in the Jing-Jin-Ji Region. Standard errors are in parentheses. ***, **, and * indicate significance at the 1 %, 5 %, and 10 % significance level, respectively.
Source: Data are from the Chinese industrial enterprises database.

[6] http://www.china.com.cn/chinese/PI-c/124760.htm
[7] http://www.beijing.gov.cn/zfxxgk/110001/szfbgtwj/2013–08/24/content_86ab088e43a1458387c9343e556ca4b7.shtml
[8] http://news.xinhuanet.com/fortune/2015–07/16/c_128027393.htm
[9] LQ was originally introduced by Florence (1939) and has been widely used by researchers in economic geography and regional economics since the 1940 s to measure spatial concentration (Miller et al., 1991). Industry LQ is stated as a ratio of ratios, quantifying the relative concentration level of an industry in an area (e.g., a city or province), compared to the concentration of the industry in a larger geographic area (e.g., a region or country).

Table 2
Difference in the regulations between Beijing and Hebei.

	Beijing	Hebei
Atmospheric control targets and standards	formulate air pollution control measures that are stricter than the national regulations	meet the specified atmospheric environmental quality standards
Industrial pollution prevention	prohibit the construction and expansion of high-pollution industrial projects	require strict control of the construction, reconstruction and expansion of high-pollution industrial projects
Dust pollution prevention	require strict control of dust pollution at construction sites and bare ground with more detailed regulations	require control of dust pollution at construction sites and encourage the control of bare ground

Notes: These are the key points summarized from *Air Pollution Prevention and Control Ordinance* of Beijing and Hebei. A more detailed comparison is presented in Table A1 in the Appendix.

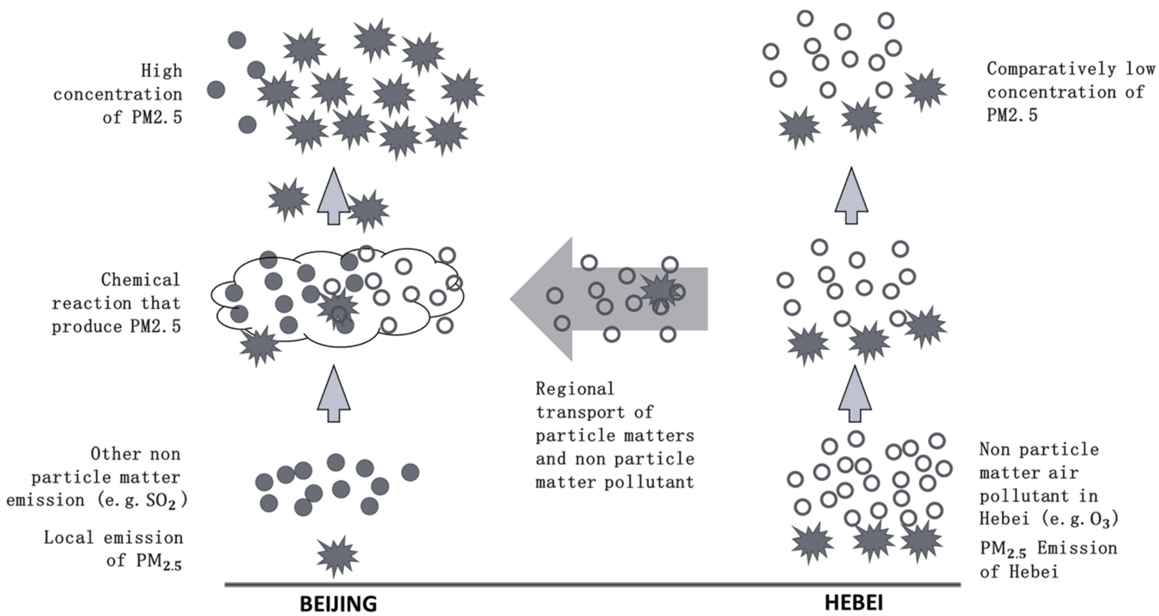

Fig. 1. Regional Transport of Particulate Matter.

2.1.1. Value trajectory of high-pollution industries

Using the enterprise-level panel data from the Chinese industrial enterprises database,[10] we calculate the total output values of high-pollution industries[11] and their proportions in the "Jing-Jin-Ji" Region. We use output value to be the proxy of production capacity, because we do not have data on production capacity, which would be the ideal variable to show the migration of enterprises. The advantage of using output value is that it is highly correlated with production capacity and the information is well-documented in the dataset. The disadvantage of using output value to proxy production capacity is that output value is affected by markets; it could change when the price changes or the utilization of production capacity changes, even if production capacity remain the same. To alleviate this concern, we compare the annual output changes in Beijing and Hebei, as in Eq. (1) below, because this comparison can difference out the effect of common shocks. In Eq. (1), we investigate the magnitude and the significance of the changes, through the regression of output value proportion on years.

$$Output\ value\ proportion_t = \beta_0 + \beta_1 * year_t + \varepsilon_t \tag{1}$$

2.1.2. Location quotient trajectories of high-pollution Industries

We further look at the location quotient (LQ) of the high-pollution industries. We focus on the 14 high-pollution industries (denoted as *j*) in Beijing, Tianjin, and Hebei (denoted as *k*). The larger geographic area is the Jing-Jin-Ji Region (denoted as *region*). We calculate industry *j*'s LQ in area *k* as follows:

$$LQ_k^j = \left(\frac{output_k^j}{output_k^{total}}\right) \Big/ \left(\frac{output_{region}^j}{output_{region}^{total}}\right) \tag{2}$$

where LQ_k^j is the LQ of industry *j* in area *k*, the numerator $\frac{output_k^j}{output_k^{total}}$ is the share of output value of industry *j* in area *k*, and the denominator $\frac{output_{region}^j}{output_{region}^{total}}$ is the share of output value of industry *j* in the Jing-Jin-Ji region.

If $LQ_k^j = 1$, industry *j* in area *k* is at the same concentration level as that in the Jing-Jin-Ji region. If $LQ_k^j > 1$, industry *j* in area *k* is more concentrated than the average concentration level of that industry in the Jing-Jin-Ji region. The larger LQ_k^j is, the more concentrated industry *j* is

[10] The Chinese industrial enterprises database covers the industrial enterprises in mainland China above a designated size, including state-owned enterprises, collective enterprises, joint stock cooperative enterprises, private enterprises, enterprises invested by Hong Kong, Macao and Taiwan, foreign invested enterprises, etc. The database covers thorough production and management information of these enterprises, with a detailed classification catalog and high accuracy requirements. The statistical data are submitted to the National Bureau of Statistics by the statistics departments of the provincial government every year. So, it forms an enterprise level panel.

[11] High-pollution industries, in this paper, are defined as those whose annual industrial exhaust gas emissions exceed 100 billion cubic meters. The 14 high-pollution industries in China include coal mining, food processing, food production, textile, paper and paper products, petroleum processing and coking, chemical raw materials and products manufacturing, pharmaceutical manufacturing, chemical fiber manufacturing, nonmetallic mineral products, ferrous metal smelting and calendaring, nonferrous metal smelting and calendaring processing, transportation equipment manufacturing, and electricity, steam and hot water production and supply.

Fig. 2. Spatial distribution of air quality monitors and meteorological stations. *Source:* Data are from the Chinese Ministry of Environmental Protection and China Meteorological Administration.

Table 3
Summary statistics of the emission data.

	Industry	Pollutant	Mean	Std. Dev.	Max	Min	Obs
Beijing	Petroleum processing and coking	SO_2	2.05	1.66	33.28	0.00	15,186
		NO_x	28.06	8.78	74.95	0.02	17,017
		Smoke	1.28	0.92	3.90	0.00	5586
	Nonmetallic mineral products	SO_2	3.33	1.71	16.08	0.05	3011
		NO_x	85.12	22.07	173.55	0.65	3018
		Smoke	5.35	0.89	10.31	0.07	3127
	Electricity, steam and hot water production and supply	SO_2	6.17	6.27	78.14	0.05	6100
		NO_x	23.92	37.16	225.13	0.00	39,364
		Smoke	2.69	1.88	18.80	0.01	5052
Hebei	Petroleum processing and coking	SO_2	28.06	9.27	50.27	0.01	1327
		NO_x	334.84	76.05	475.58	0.17	1320
		Smoke	9.63	3.46	21.43	1.63	1315
	Nonmetallic mineral products	SO_2	2.37	6.78	196.66	0.01	2233
		NO_x	162.27	70.90	1218.58	0.02	2226
		Smoke	7.19	10.28	264.95	0.01	2246
	Electricity, steam and hot water production and supply	SO_2	8.39	4.88	28.23	0.03	1979
		NO_x	32.56	15.88	91.07	0.01	1898
		Smoke	3.23	2.21	9.13	0.18	1801

Notes: The data are from the Chinese Ministry of Environmental Protection. The emission concentration data are the hourly snapshot records from the monitoring devices installed by the MEP, from May of 2017 to May of 2018. The measurement units for SO_2, NO_x and smoke are mg/m^3.

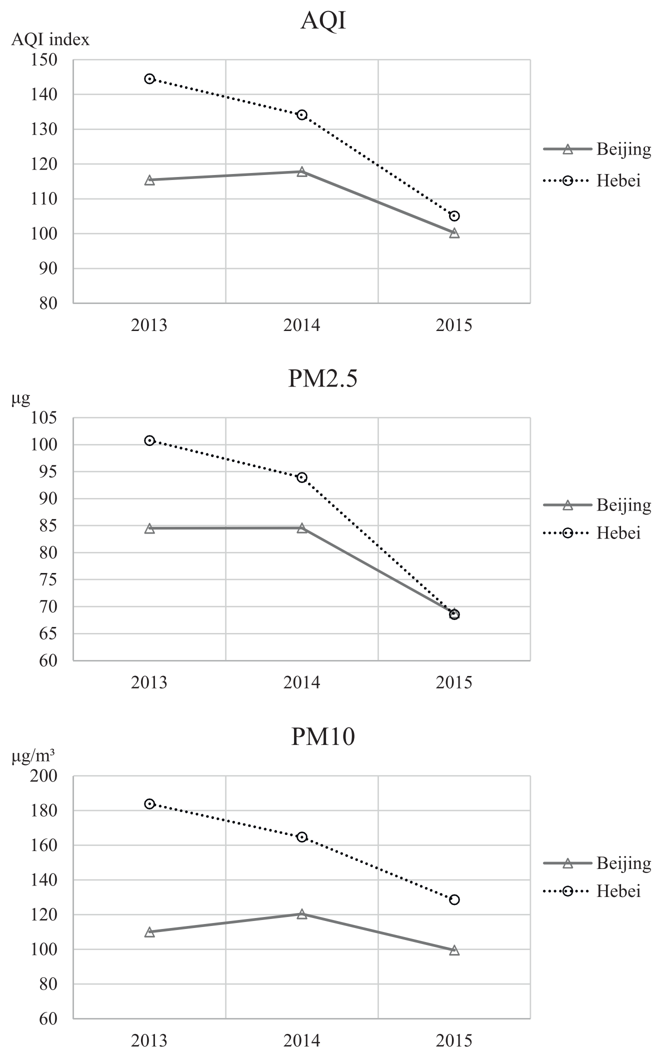

Fig. 3. The trend of air quality in Beijing and Hebei. *Source:* Data are from the Chinese Ministry of Environmental Protection.

in area k. The migration is expected to result in an increase in the LQs of high-pollution industries in Hebei, and a decrease in Beijing.

2.1.3. Spatial pattern of the migration

In this subsection, we study the spatial pattern of the migration. We expect different pollution spillover effects across cities, since some of the 11 cities in Hebei are adjacent to Beijing, while others are relatively far away from Beijing.

Following the idea of location quotient, we first define a ratio r as below:

$$r_{i,t}^{j} = \left| \frac{\Delta output_{i,t}^{j}}{\Delta output_{region,t}^{j}} \right| \tag{3}$$

where $\Delta output_{i,t}^{j}$ is the change of output value of industry j in district i of Beijing or Tianjin, or city i of Hebei at year t. $\Delta output_{region,t}^{j}$ is the change of output value of industry j in the Jing-Jin-Ji region at year t. $\Delta output_{i,t}^{j}$ is expected to be positive if industry j migrates into district or city i, and negative if industry j migrates out of district or city i. Since $\Delta output_{region,t}^{j}$ is the trend of industry j in the Jing-Jin-Ji region, a ratio larger than 1 with positive $\Delta output_{i,t}^{j}$ indicates that industry j migrates into district or city i during period t, and a ratio larger than 1 with negative $\Delta output_{i,t}^{j}$ indicates that industry j migrates out of district or city i. By comparing $r_{i,t}^{j}$ and $r_{k,t}^{j}$ for different districts or city i and k, we can see which city is more intensive in industry migration.

To get a more visualized figure of the spatial pattern, we give each district or city a "score" to characterize the overall migration of high-pollution industries by defining a count variable f_i as follows:

$$\begin{aligned} f_i &= frequency(out)_i = \sum_j frequency(out)_i^j - \sum_j frequency(in)_i^j \\ &= \textstyle\sum_j \sum_t \mathbf{1}(r_{i,t}^{j} > r_{c,t}^{j} \text{ for any district or city } c \text{ in the region } \& \Delta output_{i,t}^{j} < 0) \\ &\quad - \sum_j \sum_t \mathbf{1}\left(r_{i,t}^{j} > r_{c,t}^{j} \text{ for any district or city } c \text{ in the region} \& \Delta output_{i,t}^{j} > 0\right) \end{aligned} \tag{4}$$

Table 4
Differences in polluting emissions between Beijing and Hebei.

	(1) Three industries	(2) Petroleum processing and coking	(3) Nonmetallic mineral products	(4) Electricity, steam and hot water production and supply
Panel 1: SO_2 Emission				
BJ dummy	-6.71	-25.66***	1.61***	-3.54
	(5.99)	(0.34)	(0.01)	(3.47)
Weekend dummy	YES	YES	YES	YES
Holiday dummy	YES	YES	YES	YES
Year and month dummies	YES	YES	YES	YES
Observations	29,836	16,513	5244	8079
R-squared	0.20	0.85	0.06	0.08
Panel 2: NO_x Emission				
BJ dummy	-136.69**	-300.59***	-79.65***	-11.11
	(48.02)	(4.94)	(0.18)	(11.15)
Weekend dummy	YES	YES	YES	YES
Holiday dummy	YES	YES	YES	YES
Year and month dummies	YES	YES	YES	YES
Observations	64,843	18,337	5244	41,262
R-squared	0.37	0.93	0.41	0.01
Panel 3: Smoke Emission				
BJ dummy	-3.96**	-8.49**	-1.92**	-1.45
	(1.42)	(0.47)	(0.04)	(1.65)
Weekend dummy	YES	YES	YES	YES
Holiday dummy	YES	YES	YES	YES
Year and month dummies	YES	YES	YES	YES
Observations	19,128	6902	5373	6853
R-squared	0.00	0.00	0.06	0.28

Notes: The data are from the Chinese Ministry of Environmental Protection. Standard errors are clustered at enterprise level. ***, **, and * indicate significance at the 1 %, 5 %, and 10 % significance level, respectively.

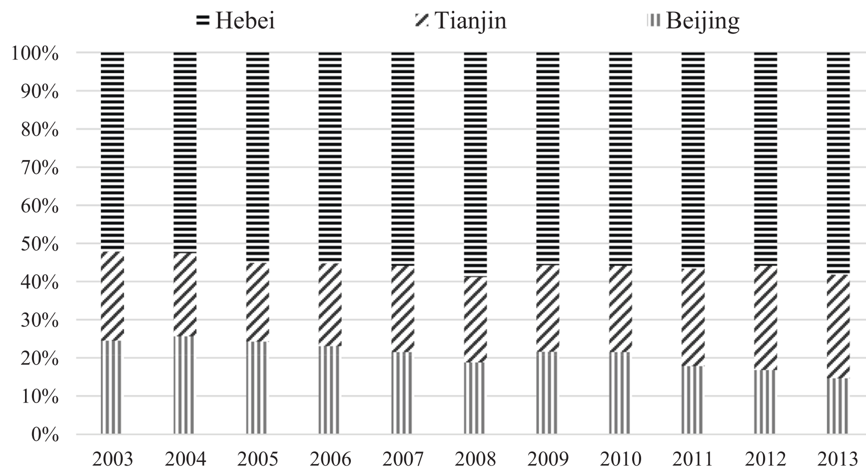

Fig. 4. Output Value Proportions of High-pollution Industries in the Jing-Jin-Ji Region. *Source:* Data are from the Chinese industrial enterprises database.

The count variable f_i can be positive or negative. A positive f_i indicates that the high-pollution enterprises migrate out from area *i* more frequently, while a negative f_i indicates that the high-pollution enterprises migrate into area *i* more frequently. The larger the absolute value of f_i is, the higher the frequency is.

2.2. Emissions difference between Beijing and Hebei

The enterprises, after migration, may emit a larger amount of pollutants in Hebei, compared to the emissions when they were in Beijing, because of the less stringent environmental regulation in Hebei. Table 1 presents the comparison of the air pollution prevention and control regulations in Beijing and Hebei. The regulations in the two areas are similar in content, but different in the extent of strictness. For example, new and expanded high-pollution industrial projects are officially forbidden in Beijing, while they are allowed in Hebei under strict controls. In general, the provisions made by the Beijing government are stricter than those in Hebei. The reason is that the Beijing government is required to formulate measures for air pollution control that are stricter than the national regulations, while local governments in Hebei are required to reach the standard of the national regulations. We also use observed industrial emissions to verify the difference between Beijing and Hebei.

2.2.1. Empirical analysis of emissions differences

We adopt formal econometric methods to identify the magnitude and the significance of the emissions difference between Beijing and Hebei. The regression is specified as follows:

$$Emission_{i,t} = \beta_0 + \beta_1 * BJ_i + \beta_2 * weekend_t + \beta_3 * holiday_t + \delta_t + \varepsilon_{it} \quad (5)$$

where $Emission_{it}$ is the emission concentration of SO_2, NO_x or smoke, recorded in enterprise *i* at time *t*; BJ_i is a dummy variable which equals one if enterprise *i* is in Beijing, zero otherwise; $weekend_t$ and $holiday_t$ are dummy variables which equal one if the observation is on a weekend or during a holiday, respectively; δ_t is a vector of dummies, including year and month dummies; and ε_{it} is the error term.

We control for the date characteristics, because the production activities could be different on weekends or holidays, and therefore the concentration of emissions could be different. We control for year and month, because production activities could have serial patterns. Considering that the characteristics of enterprises could affect emissions, we also intend to control for the characteristics of enterprises. One of the important characteristics is which industry the enterprise belongs to. Therefore, we also run the regression for each industry separately, in order to allow for the effects of other control variables to vary across industry.

2.2.2. Pollution emissions data

The data we use for the empirical analysis of emissions differences between Beijing and Hebei are from the Chinese Ministry of Environmental Protection (MEP). Since 2010, the MEP of China started to publicly identify major air, water, and soil pollution sources all over the country (MEP, 2009). Once identified, these sources are installed with monitoring devices. Hourly snapshot records of the emissions concentration of major pollutants are taken and uploaded to the server of the MEP. The main air pollutants recorded in both Beijing and Hebei are SO_2, NO_x and smoke. The pollution dataset spans May of 2017 to May of 2018. From the list of pollution sources in Beijing and Hebei, there are 86 enterprises monitored in Beijing and 87 enterprises in Hebei, including four industries: (1) petroleum processing and coking, (2) nonmetallic mineral products, (3) electricity, steam and hot water production and supply, and (4) environmental management industry. The first three industries belong to high-pollution industries as defined in this paper. Table 2 provides summary statistics of the emissions data in each industry in Beijing and Hebei.

2.3. The effects of the pollution haven on Beijing's air quality

After analyzing the existence of the government-created pollution haven in Hebei, we investigate whether the pollution haven has affected Beijing's air quality. We focus on particulate matter, which is one of the most important air-borne pollutants in the Jing-Jin-Ji region. We first explore the mechanism of the regional transport of particulate matter from Hebei to Beijing and then employ econometric methods to empirically identify the effect of Hebei's air quality on Beijing's air quality.

2.3.1. Mechanism : Regional transport of particulate matter

Beijing and Hebei are connected by two air pathways. Beijing is half surrounded by Yan Mountain and Taihang Mountain. The two mountains form two air pathways through Beijing (Ren et al., 2004). One pathway connects Beijing and Tangshan, an industrial city in Hebei. The other connects Beijing and Baoding, Shijiazhuang, Xingtai, and Handan, which are all highly polluted cities in Hebei, to the south of Beijing.

Table 5
Summary of air quality data.

City	Province	AQI	$PM_{2.5}$	PM_{10}	Distance to Beijing
Beijing	Beijing	117.15	84.07	117.22	0.00
Langfang	Hebei	137.91	99.12	163.69	66.44
Tianjin	Tianjin	124.18	87.93	142.93	120.60
Chengde	Hebei	86.09	50.61	104.70	132.37
Zhangjiakou	Hebei	72.46	37.19	86.19	163.67
Tangshan	Hebei	143.32	104.44	172.05	166.31
Baoding	Hebei	171.71	124.89	216.63	177.04
Cangzhou	Hebei	123.85	87.10	139.73	192.29
Qinhuangdao	Hebei	99.99	62.46	124.18	263.84
Datong	Shanxi	82.06	45.29	100.43	267.40
Shijiazhuang	Hebei	177.36	125.36	235.15	271.41
Hengshui	Hebei	155.08	107.30	199.32	284.14
Dezhou	Shandong	145.77	109.60	162.75	293.91
Chifeng	Inner Mongolia	84.74	46.49	108.11	316.80
Binzhou	Shandong	122.26	89.66	139.92	333.56
Dongying	Shandong	118.88	80.51	150.36	340.35
Xingtai	Hebei	180.54	129.55	239.73	362.71
Huludao	Liaoning	92.06	58.52	111.22	363.01
Yangquan	Shanxi	110.49	66.62	143.90	369.72
Jinan	Shandong	126.47	88.39	161.02	394.15
Zibo	Shandong	138.60	98.51	172.80	409.41
Liaocheng	Shandong	147.22	108.19	184.60	409.95
Hohhot	Inner Mongolia	93.90	48.43	126.42	420.49
Jinzhou	Liaoning	95.15	62.90	103.00	425.61
Tai'an	Shandong	118.22	82.48	142.79	427.13
Laiwu	Shandong	133.33	97.42	148.10	431.42
Handan	Hebei	158.26	115.96	202.62	431.63
Taiyuan	Shanxi	106.66	70.02	132.94	433.13
Weifang	Shandong	122.43	85.16	152.83	455.24
Dalian	Liaoning	81.69	54.04	86.83	461.13
Anyang	Henan	133.45	95.93	152.52	464.80
Yingkou	Liaoning	70.86	44.33	76.53	498.67
Panjin	Liaoning	86.83	58.32	92.30	501.89
Changzhi	Shanxi	100.96	67.87	118.86	508.27
Yantai	Shandong	83.85	55.28	93.80	509.42
Jining	Shandong	133.63	96.40	164.63	519.53
Heze	Shandong	147.28	109.59	175.72	537.42
Qingdao	Shandong	89.78	58.14	110.74	548.65
Linyi	Shandong	140.17	98.78	181.08	567.12
Ordos	Inner Mongolia	62.63	27.69	74.28	576.18
Weihai	Shandong	71.25	45.14	74.11	578.30
Anshan	Liaoning	100.67	70.22	121.09	581.49
Baotou	Inner Mongolia	105.38	57.60	144.52	581.53
Rizhao	Shandong	96.80	65.10	115.93	583.71
Jiaozuo	Henan	123.49	87.74	146.70	599.17
Zaozhuang	Shandong	140.47	99.18	181.12	605.42
Shenyang	Liaoning	106.44	72.57	121.75	611.83
Linfen	Shanxi	91.88	63.23	97.81	612.11
Benxi	Liaoning	86.31	56.72	98.22	621.65
Kaifeng	Henan	118.36	82.31	132.98	631.78
Fushun	Liaoning	90.84	57.77	106.76	636.08
Zhengzhou	Henan	137.07	97.99	163.14	657.41
Dandong	Liaoning	76.24	50.84	87.85	675.12
Luoyang	Henan	111.71	76.77	131.08	707.40
Sanmenxia	Henan	114.10	76.89	132.90	758.42
Pingdingshan	Henan	127.04	91.45	149.06	770.88

Notes: The data are from the Chinese Ministry of Environmental Protection. The average level of AQI, $PM_{2.5}$ and PM_{10} are provided above. The measurement unit for $PM_{2.5}$ and PM_{10} is μg/m^3, and the measurement unit for distance is km.

Those cities' air pollutants can easily travel to Beijing by these air pathways. As shown in Cheng et al. (2016), during two typical pollution periods in Beijing, the pollution level increased gradually from south to north at the beginning of the period, and the pollution level decreased gradually from north to south at the end of the period. This indicates the pollutants' transport pattern in this region.

The regional transport of particulate matter affects the recipient city's air quality both directly and indirectly. Fig. 1 illustrates the two ways that regional transport of pollutants affects Beijing's air quality. While Beijing and Hebei have their own local emissions, including both particulate matter and non-particulate emissions, such as SO_2 and O_3, Hebei's particulate matter can drift or be blown to Beijing. This is the direct way that Hebei's emissions affect Beijing's air quality.

The indirect way is that non-particulate pollutants emitted by Hebei also drift or are blown to Beijing. They meet other non-particulate pollutants on the way to Beijing or in Beijing, and generate secondary particles through physical and chemical reactions. When these kinds of reactions occur intensively in Beijing, it is possible that the concentration of $PM_{2.5}$ in Beijing is higher than in its neighborhood. In these two ways, regional transport of pollutants can make Beijing's air quality worse, no matter whether the air quality in the areas around Beijing is worse or better than Beijing.

2.3.2. *Empirical strategy for regional air-borne transport*

To empirically identify the transport of particulate matter from Hebei to Beijing, we first summarize the factors that affect a recipient city's particulate matter concentration. A city's particulate matter concentration is affected by both local and neighboring factors. Local factors include local emissions and local weather conditions, and neighboring factors include particulate matter that travels from neighboring areas to Beijing.

The transfer of particulate matter and non-particulate matter from neighboring areas depends on wind speed and direction, and on the concentration levels in the upwind places. Therefore, in the regression models, we take into account both wind speed and direction in the upwind and tailwind parts of Beijing. We expect a positive sign on the pollution concentration of Beijing's neighboring cities – given the same wind, a larger pollution concentration would result in a larger effect. We also expect a positive sign on the interaction term of wind speed and concentration – given the same concentration, a stronger wind would bring in more pollutants if the upwind area has a larger concentration.

Besides wind speed, local weather conditions include precipitation and temperature. We expect negative signs on precipitation, because precipitation washes away air-borne pollutants (Hu et al., 2006). We expect positive signs on temperature, because high temperature and strong sunshine help the formation of particulate matter (Song et al., 2002). To address the daily variation in local emissions, we include in the models the following dummy variables: (1) Heating season dummy: In the period studied in this paper, heating in Beijing was provided mainly from gas combustion in urban areas and coal combustion in rural areas. Burning coal emits particulate matter directly. Burning gas does not emit particulate matter directly, but it emits nitrogen oxide, which helps the formation of $PM_{2.5}$ (Jiang et al., 2014). Therefore, we expect the sign of the heating season dummy to be positive. (2) Weekend and holiday dummies: Cars emit particulate matter and other pollutants which help the formation of $PM_{2.5}$. Driving patterns differ on weekends and holidays. On one side, the number of commuters is smaller on weekends and therefore commuting driving is less. On the other side, the amount of discretionary driving, such as driving to parks, shopping malls, or rural areas for leisure, is larger. The industrial activities also differ on weekends and holidays. Therefore, the sign of the weekend or holiday dummy is ambiguous, depending on which effect dominates. (3) Driving restriction dummy: During the period of this study (2013–2015), Beijing implemented driving restrictions, based on the last digits on the license plate. About 20% of the vehicles are restricted each week day, while there is no restriction on weekends. In a few extreme cases, all even/odd numbers are restricted on a week day. We expect negative signs on the driving restriction dummy.

To identify the effect of Hebei's air quality on Beijing's air quality, we combine an Autoregressive Distributed Lag model and a Spatial Autorgressive Model and decompose the factors that affect Beijing's air quality into local and regional transport factors. The regression equaiton is as follows:

$$AQI_{Bt} = \beta_0 + \beta_1 * AQI_{Bt-1} + \beta_2\left(\sum_{j=1}^{J}\frac{AQI_{jt}}{distance_j}\right) + \beta_3\left(\sum_{j=1}^{J}\frac{AQI_{jt} * wind_{jt} * WDtoBJ_{jt} * BJWDfrom_{jt}}{distance_j}\right) + \boldsymbol{\beta_4} \bullet \boldsymbol{Weather_{Bt}} + \boldsymbol{\beta_5} \bullet \boldsymbol{Datechara_t} + \varepsilon_t \quad (6)$$

where AQI_{Bt} is the air quality index of Beijing on day t, AQI_{jt} is the air quality index of city j on day t, $distance_j$ is the distance of city j to Beijing, $wind_{jt}$ is wind speed in city j on day t, and $WDtoBJ_{jt}$ is a dummy variable, which equals one if city j has wind blowing in the direction of Beijing on day t. $BJWDfrom_{jt}$ is also a dummy variable, which equals one if Beijing has wind blowing from the direction of city j on day t. $wind_{Bt}$ is wind speed in Beijing on day t. $\boldsymbol{Weather_{Bt}}$ is the control variable of the local weather conditions in Beijing, including wind speed, precipitation and temperature. $\boldsymbol{Datechara_t}$ is a control variable addressing the daily variation in local emissions, including heating season dummy, weekend and holiday dummies and driving restriction dummy.

When there is no wind, Beijing's air quality on day t (AQI_{Bt}) is affected by: (1) Beijing's air quality one day before, AQI_{Bt-1}; (2) the diffusion of neighboring cities' air-borne pollutants, $\left(\sum_{j=1}^{J}\frac{AQI_{jt}}{distance_j}\right)$, where we aggregate neighboring cities' air quality using the weight of the inverse of distance to Beijing. and (3) the local emissions, $\boldsymbol{Datechara_t}$.

When there is wind, it plays an important role in Beijing's air quality. On one hand, wind helps dissipate air-borne pollutants. We use $wind_B$ to capture this effect. We expect the coefficient of $wind_B$ to be negative, because more wind accelerates the dissipation of pollutants. On the other hand, wind brings air-borne pollutants if the wind comes from a neighbor with air-borne pollutants. We use variable $\left(\sum_{j=1}^{J}\frac{AQI_{jt}*wind_{jt}*WDtoBJ_{jt}*BJWDfrom_{jt}}{distance_j}\right)$ to capture these effects. By $\left(\sum_{j=1}^{J}\frac{AQI_{jt}*wind_{jt}*WDtoBJ_{jt}*BJWDfrom_{jt}}{distance_j}\right)$, we again aggregate neighboring cities into one variable. The effect of wind that brings in neighbors' pollutants depends on the neighbors' air quality and the wind speed, as well as wind direction. We use $WDtoBJ_{jt}$ and $BJWDfrom_{jt}$ to depict wind direction. We expect the coefficient of $\left(\sum_{j=1}^{J}\frac{AQI_{jt}*wind_{jt}*WDtoBJ_{jt}*BJWDfrom_{jt}}{distance_j}\right)$ to be positive.

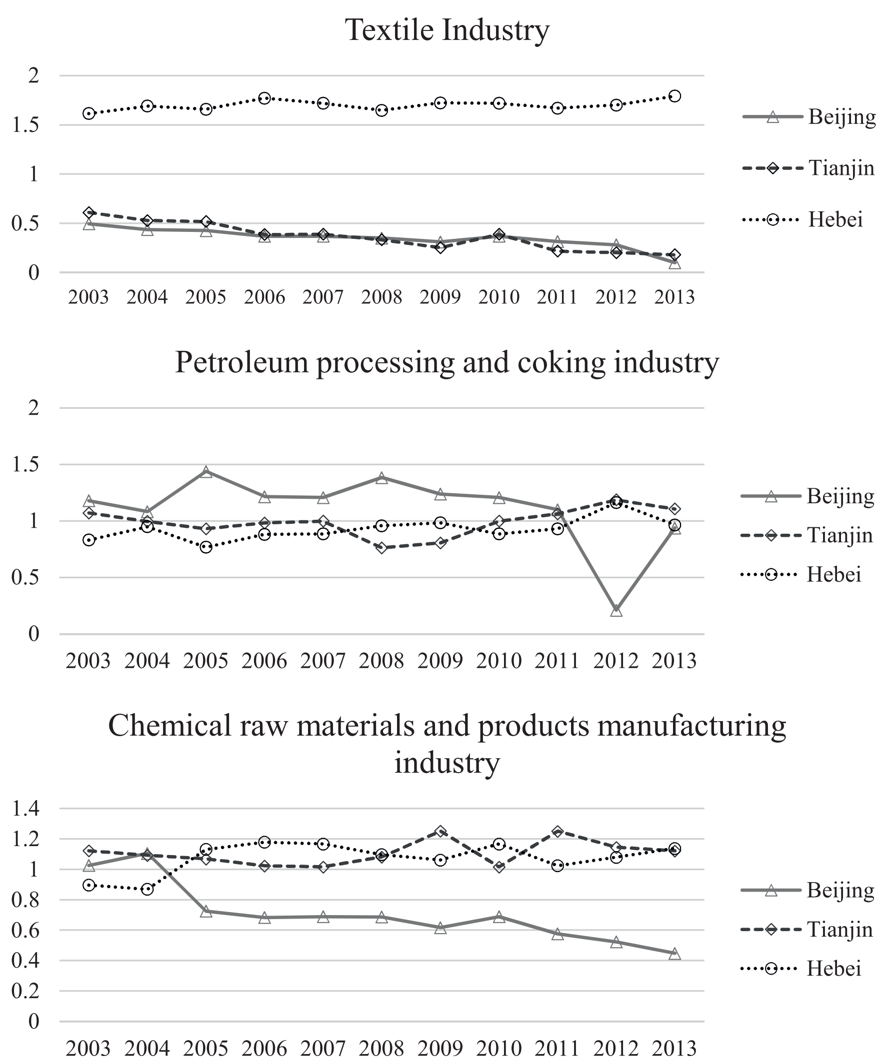

Fig. 5. Location quotient trajectories of high-pollution industries in the Jing-Jin-Ji Region. *Source:* Data are from the Chinese industrial enterprises database.

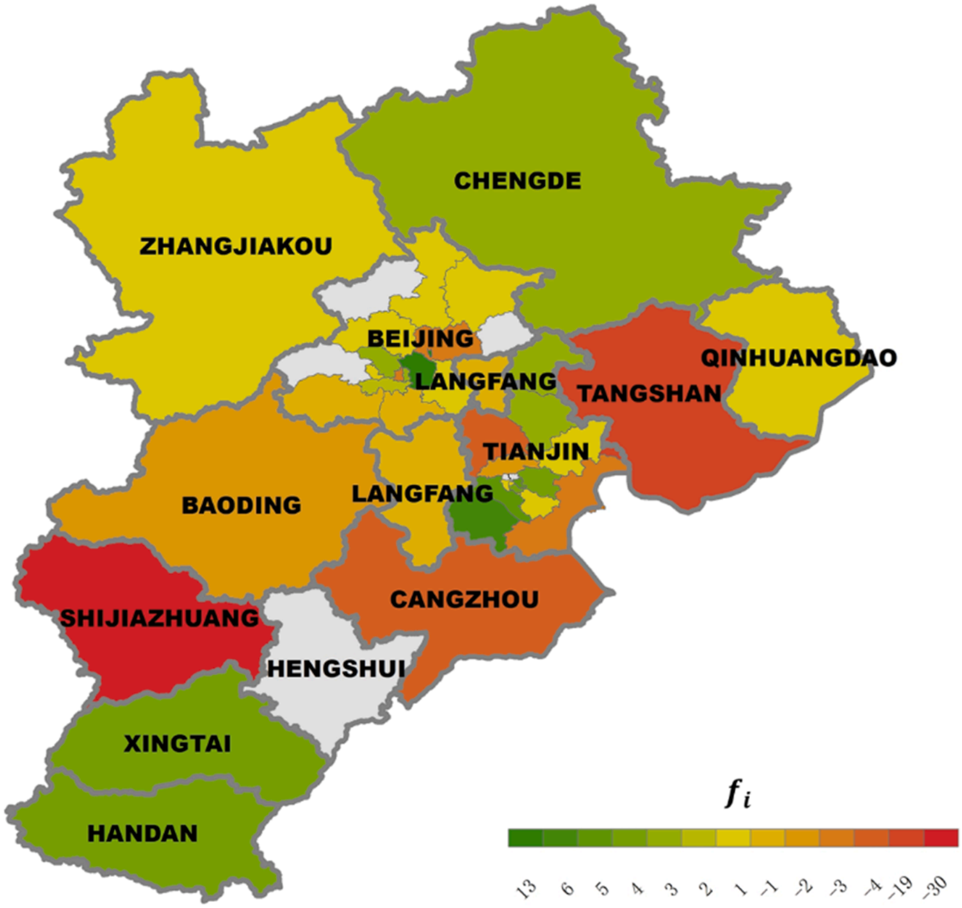

Fig. 6. The spatial pattern of high-pollution industry transfer in the Jing-Jin-Ji region.

Two key points in constructing Eq.5 are: (1) $\sum_{j=1}^{J}\frac{AQI_{jt}}{distance_j}$ is the spelled out form of a spatial model, where $\frac{1}{distance_j}$ is the elements in the spatial weighting matrix. (2) we put $wind_{jt} * WDtoBJ_{jt} * BJWDfrom_{jt}$ together, rather than interacting each of them with AQI, because, when any of the three variables equals zero, neighboring cities affect Beijing only through diffusion of pollutants (β2 captures this effect), not by wind.

According to Stock and Watson (2010), the assumptions for a Distributed Lag model to identify a causal effect include: 1. $E(ut|Xt,Xt\text{–}1,Xt\text{–}2,\ldots) = 0$ (X is exogenous); 2. (a) Y and X have stationary distributions; (b) (Yt,Xt) and $(Yt\text{–}j,Xt\text{–}j)$ become independent as j gets large; 3. Y and X have eight nonzero finite moments; and 4. There is no perfect multicollinearity. When the four assumptions are satisfied, OLS yields consistent estimators. We are aware that including lagged dependent variables (AQI_{Bt}) leads to a violation of the strict exogeneity assumption and thus may lead to biased estimates of the coefficient, while excluding the lagged dependent variable may lead to omitted variable bias. Therefore, we run a regression as follows to test whether the estimation results are sensitive to the exclusion of the lagged dependent variable.

$$AQI_{Bt} = \gamma_1 + \gamma_2\left(\sum_{j=1}^{J}\frac{AQI_{jt}}{distance_j}\right) + \gamma_3\left(\sum_{j=1}^{J}\frac{AQI_{jt} * wind_{jt} * WDtoBJ_{jt} * BJWDfrom_{jt}}{distance_j}\right) + \gamma_4 \bullet \boldsymbol{Weather}_{Bt} + \gamma_5 \bullet \boldsymbol{Datechara}_t + \varepsilon_t \quad (7)$$

Table 6
Summary of meteorological data of Beijing.

Variables	Obs	Mean	Std. Dev.	Min	Max
Wind speed (0.1 m/s)	864	20.218	8.253	7.250	58.500
Wind direction	864	9.013	2.555	2.500	15.750
Temperature (0.1 °C)	864	110.501	108.962	-111.500	297.500
Precipitation (0.1 mm)	863	12.748	47.009	0.000	648.000

Notes: The data are from China Meteorological Administration. Wind speed, temperature and precipitation are daily average, while wind direction is the direction of the highest wind speed for each day.

2.3.3. *Air quality and meteorology data*

The data use for the empirical analysis for *regional air-borne transport are* hourly air quality collected from the website of the MEP of China. The concentrations of $PM_{2.5}$ (fine particulates), PM10 (larger particulates), nitrogen oxides, carbon monoxide, sulfur dioxide, and ozone are recorded by the monitors and reported by a real-time reporting system. Greenstone et al. (2022) shows that the quality of air pollution data has improved significantly since the real-time reporting system of MEP was adopted.

The data we use in this paper are from January 2013 to October 2015 and cover all of the hundreds of air quality monitors in 56 large cities in

Table 7
The effects of neighboring cities' air quality on Beijing's air quality.

	Including cities in and around the Jing-Jin-Ji Region			Only cities in the Jing-Jin-Ji Region		
Variables	(1) AQI	(2) $PM_{2.5}$	(3) PM_{10}	(4) AQI	(5) $PM_{2.5}$	(6) PM_{10}
Lagged dependent variable	0.35***	0.33***	0.26***	0.19***	0.19***	0.18***
	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)
Weighted air quality of neighbors	4.03***	4.21***	3.89***	11.85***	10.97***	8.92***
	(0.50)	(0.59)	(0.45)	(0.81)	(1.04)	(0.71)
Weighted air quality of neighbors when wind is blowing toward Beijing	0.16***	0.19***	0.14***	0.17***	0.21***	0.17***
	(0.04)	(0.05)	(0.03)	(0.04)	(0.07)	(0.04)
Wind speed	-2.01***	-2.05***	-1.87***	-1.33***	-1.40***	-1.39***
	(0.26)	(0.26)	(0.29)	(0.19)	(0.20)	(0.23)
Temperature	0.01	-0.01	0.04	0.04*	0.02	0.07***
	(0.04)	(0.03)	(0.04)	(0.02)	(0.02)	(0.03)
Precipitation	-0.07***	-0.06***	-0.08***	-0.06***	-0.06***	-0.08***
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Weekend	-11.69	-13.69**	-6.63	-5.29	-8.52	2.89
	(7.75)	(6.14)	(8.14)	(6.92)	(6.11)	(7.72)
Holiday	-4.83	-7.75	-2.89	5.03	0.43	9.37
	(7.54)	(5.58)	(8.97)	(6.28)	(4.84)	(8.83)
Driving Restricted	-8.38	-11.60*	-6.36	-0.63	-4.98	4.92
	(7.73)	(6.15)	(7.77)	(6.92)	(6.25)	(7.34)
Heating	-9.37	-10.68	-6.70	-7.20	-10.13*	-1.11
	(9.21)	(6.94)	(8.50)	(7.20)	(5.82)	(7.59)
Constant	51.25***	58.69***	39.50**	6.07	27.55***	5.52
	(13.54)	(12.10)	(16.13)	(10.48)	(10.27)	(13.19)
Observations	862	862	862	862	862	862

Notes: Data are from the Chinese Ministry of Environmental Protection and China Meteorological Administration. Newey-West standard errors are in parentheses with the maximum lag order of autocorrelation at 7. ***, **, and * indicate significance at the 1 %, 5 %, and 10 % significance level, respectively.

and around the Jing-Jin-Ji Region. Besides Beijing, Tianjin, and all 11 cities in Hebei province, the 56 sample cities include 43 large cities from the five bordering provinces of the Jing-Jin-Ji Region, namely Shanxi, Inner Mongolia, Liaoning, Shandong, and Henan. The spatial distribution of the monitors is depicted in Fig. 2. Hourly concentrations of $PM_{2.5}$, O_3, PM_{10}, SO_2, NO_2, and CO are recorded by the monitors and the Air Quality Index (AQI) is calculated based on the concentration of the pollutants. In this paper, we focus on $PM_{2.5,}$ $PM_{10,}$ and AQI, because the most important pollutant in Beijing is particulate matter.

Table 3 provides the average level of air quality of the 56 cities in our sample period. For a city that has several monitors, we take the average over the monitors and use the average as the pollution level for that city.

Fig. 3 shows the trend of air quality in Beijing and Hebei from 2013 to 2015. We can see that, on average, the air quality of Hebei is worse than Beijing, but the air quality shows a trend of improvement in both Beijing and Hebei.

The data on weather conditions, including wind, precipitation, temperature, and pressure data, are collected from the China Meteorological Administration. Weather stations for recording the data are distributed more evenly than air quality monitoring stations, as shown in Fig. 2. We merge the two datasets at city level. We assign values to the variables $WDtoBJ_{jt}$ and $BJWDfrom_{jt}$ based on wind direction and the relative location of Beijing and city j. Table 4 shows the summary statistics of the meteorological data for Beijing.

3. Results and discussion

3.1. High-pollution enterprises' migration from Beijing to Hebei

We first look at the output value of the high-pollution industries. Fig. 4 depicts the output value portions of the three areas in the region from 2003 to 2013. It shows that high-pollution industries in Hebei account for over half of the total output value in the Jing-Jin-Ji region during all these years, and the proportion increased steadily. Meanwhile, the output value proportion of Beijing decreased gradually from 25 % in 2003 to 15 % in 2013. Table 5 presents the regression results of Eq. (1). On average, the output value proportion of Beijing decreased by 0.97 % points each year, while the proportions of Tianjin and Hebei increased by 0.52 % and 0.45 % points, respectively. The changes are all statistically significant at the 1 % significance level. This is consistent with the migration of high-pollution industries from Beijing to it neighboring areas.

The output value trajectories we explore in this paper cover only the period after the migration due to data availability. For this reason, one could raise the issue that there already was a downward trend in the proportion of the output value in Beijing prior to the policy. However, due to the relocation policy and the well-reported massive migration from Beijing to Hebei after the policy (Fig. A1 in the Appendix), we can at least say that part of the downward trend is due to the migration policy. Although a pre-existing trend would bias the estimation of the effect of the policy on industry structure, we do not quantify such an effect in this paper. By looking into the output value trend of high-pollution enterprises, we aim for qualitative evidence of the manmade pollution haven. One reassuring finding is that the output value proportion for the low-pollution industries in Beijing does not show a downward trend as obvious as that of the high-pollution industries, as shown by Fig. A2 in the Appendix.

Another concern in interpreting the output value trend is that this finding is also consistent with industries moving from Beijing to outside of the Jing-Jin-Ji region and industries outside of the Jing-Jin-Ji region moving to Hebei and Tianjin. However, according to the policy documents, Hebei was the major destination of the high-pollution enterprises. Research also shows that Hebei has been the main destination of the enterprises migrating out of Beijing. For example, Luo et al. (2021) characterized the spatial and temporal characteristics of pollution-intensive industries in the Jing-Jin-Ji region, and found that

Hebei has become the recipient of pollution-intensive industries that have relocated from Beijing. Because Hebei is geographically and economically connected to Beijing, the relocation cost could be relatively low, and these enterprises could remain in the Jing-Jin-Ji regional market. Combining the policy documents and the findings on output value changes, we can arguably rule out the case of industries moving from Beijing to outside of the Jing-Jin-Ji region. Regarding the possibility of industries outside of the Jing-Jin-Ji region moving to Hebei and Tianjin, although we have no data to rule this out, there were no dramatic changes in relocation rules or regional markets during our study period, except the migration policy we discuss in this paper.

For the LQ analysis, Fig. 5 depicts the trajectories of three typical high-pollution industries (textile, petroleum processing and coking, and chemical raw materials and products manufacturing) in the Jing-Jin-Ji region. It shows that the LQs of these industries in Beijing are much smaller than those in Hebei. The trajectories are decreasing in Beijing, while they are fluctuating upward in Hebei. We do not find similar trends in other high-pollution industries in this region. This suggests that the migration of production was more intensive in these three industries. To conclude, the findings in this section provide evidence for our first hypothesis: with the migration policy, high-pollution firms moved from Beijing to Hebei.

For the spatial pattern of migration, Fig. 6 depicts the indicator f_i from Eq. (4) on the region map.[12] Districts or cities with positive f_i are in colors ranging from green to yellow, while those with negative f_i are in colors ranging from orange to red. Places in gray are those cities or districts with no enterprise migration, i.e., their $frequency(in)$ and $frequency(out)$ equal 0. In Fig. 6, the central area of Beijing is dark green to green, while cities to the south and the east form an orange and red semi-ring around Beijing. The finding is consistent with the action plans and the massive relocations mentioned above. It indicates that high-pollution industries have mainly migrated from urban Beijing to the surrounding areas, especially to the south and the southeast areas.

3.2. Emissions difference between Beijing and Hebei

Based on the emission data, we run the regression of Eq. (5) and summarize the results in Table 6. Column 1 of each panel shows the difference in the concentration of emissions between Beijing and Hebei in the three high-pollution industries which have emissions records, while columns 2–4 display regression results by each of the three high-pollution industries.

The coefficients of variable *BJ* in column 1 are all negative, indicating that, on the whole, the emissions of high-pollution industries are lower in Beijing than Hebei. On average, the concentration of SO_2 in Beijing is 6.71 mg/m^3 lower than Hebei, NO_x is 136.69 mg/m^3 lower, and smoke is 3.96 mg/m^3 lower. The coefficients of NO_x and smoke emission are significant, while the coefficient of SO_2 is not significant. If we look at different industries in columns 2–4, the coefficients of the three pollutants are all significantly negative in the petroleum processing and coking industry and the nonmetallic mineral products industry, except for the SO_2 emission of the latter. The reason is that the emissions data for this industry are collected from only one enterprise in Beijing and another in Hebei, and the distributions of emissions of the two enterprises are quite different, with a median of 0.99 mg/m^3 and maximum of 196.66 mg/m^3 for the Hebei enterprise and a median of 3.62 mg/m^3 and maximum of 16.08 mg/m^3 for the Beijing enterprise.

To conclude, the findings in this section are consistent with our second hypothesis: Hebei has lower standards and higher pollution compared to Beijing. Together with the first hypothesis, we can reasonably infer that, after migration, the high-pollution enterprises emit a larger amount of pollutants in Hebei, compared to the emissions when they were in Beijing.[13] That is, the government unintendedly created a pollution haven in Hebei by mandating the migration of high-pollution enterprises from Beijing to Hebei.[14]

3.3. The effects of the pollution haven on Beijing's air quality

Based on the air quality and meteorology data, we run regressions of both Eqs. (6) and (7). As the two equations yield similar results, we report one in the main text and the other in the Appendix for a robustness check. We present the results of Eq. (6) in the first three columns of Table 7 and that of Eq. (7) in Table A3 in the Appendix. Column 1 of Table 7 shows the estimated coefficients using AQI as the dependent variable, while columns 2 and 3 show the regression results for $PM_{2.5}$ and PM_{10} respectively. Because Hebei was the main destination of the enterprises that migrated out of Beijing, we restrict the sample to the Jing-Jin-Ji region, rerun the regression for Eq. (6), and present the estimation results in the last three columns of Table 7. Compared to the results on the full sample, the results remain qualitatively stable and the quantitative differences are reasonable. In the new results, the coefficients of the lagged dependent variables get smaller and the weighted air quality of neighbors gets larger, compared to the old results. This change is as expected, because cities within the Jing-Jin-Ji region are expected to have a larger effect on Beijing's air quality, because they are closer to Beijing compared to the cities outside the region. Because we focus on the effect of Hebei's emissions on Beijing's air quality, we take the results with the sample of the cities in the region as the main results.

Table 7 shows that the coefficients of the lagged dependent variable (β_1) are positive. This indicates that a higher concentration of air pollutants in the previous period leads to a higher concentration of air pollutants in the present period. Due to the natural dissipation of air pollutants, the concentration of pollutants will decrease in the absence of external effects. Therefore, the coefficient is smaller than 1.

The coefficients of the weighted sums of pollution concentrations in nearby cities (β_2) are positive, indicating that the concentration levels of pollutants in neighboring cities are positively correlated when there is no wind. Since we use the reciprocal of distance as the weight, this result also shows that the positive correlation decreases as the distance increases. Taking $PM_{2.5}$ as the example, the magnitude of 10.97 indicates that, when the concentration of $PM_{2.5}$ increases by 100 μg/m^3 in an area 100 kilometers away from Beijing, the concentration level of $PM_{2.5}$ in Beijing will increase by 10.97 μg/m^3. The interpretation is similar for AQI and PM_{10}. This effect is impressive, considering that there are 11 cities in Hebei province and more cities around the Jing-Jin-Ji region.

The coefficients of the weighted values of nearby cities when there is wind blowing to Beijing (β_3) are also positive. The magnitude of 0.17 means that, when the concentration of $PM_{2.5}$ increases by 100 μg/m^3 in an area 100 kilometers away from Beijing, the concentration level of $PM_{2.5}$ will increase by 3.4 μg/m^3, if the wind speed is 20 km/h, the

[12] The values of f_i for all the cities/districts are provide in Table A2 in the Appendix.

[13] We indeed see that, after the migration started in 2000, the air quality in Hebei became worse relative to Beijing, as shown by Fig. A3 in the Appendix.

[14] The pollution halo phenomenon could also exist in our case if some enterprises' migration brought more advanced technologies from Beijing to Hebei and thereby reduced the emissions of other enterprises in Hebei. With our data limitations, we could not investigate whether the migration led to a pollution halo phenomenon, because we could observe city-level air quality only since 2003, which is after the mandatory migration. However, unlike the case in which FDI might bring greener technology, enterprises moving from one nearby province to another are not likely to have very different technologies. In fact, when they were ordered to move to a region with lower environmental standards, they probably had little reason to upgrade their pollution control technologies. So, the pollution halo phenomenon is not likely to happen in our case. In addition, we observe that, on average, enterprises in Hebei (including those located in Hebei before the relocation policy and those that moved from Beijing) have worse emissions compared to their counterparts in Beijing (Table 4).

speed of a gentle or moderate breeze.

We take Langfang, a Hebei city 66 km away from Beijing, as an example and compare our estimation results to other atmospheric studies regarding the pollution transport among Jing-Jin-Ji regions. Based on our estimation results, a back-of-the-envelope calculation show that, when the wind speed is 20 km/h, Langfang, with its average $PM_{2.5}$ concentration at 99 μg/m3, contributes to Beijing's $PM_{2.5}$ concentration by 21.56 μg/m3, (10.97 *99/66 +0.17 *99/66 *20 = 21.56), which is a 25.64 % increase. Chang et al. (2018) estimated that the $PM_{2.5}$ inflow from Zhangjiakou and Baoding constitute 57% of the $PM_{2.5}$ concentration in Beijing in winter and that from Langfang and Baoding constitute 73 % in summer. Chang et al. (2019) estimate that the local contributions in Beijing accounted for only 33 % and 38 % in July and October (62 % and 69 % in January and March), and that nearby cities in Hebei, as well as in a large range of regions in the south, contribute substantially through regional transport. Zhang et al. (2019) estimated that 62.89 % of the surface PM2.5 in Beijing came from local emissions, with the remaining 23.69% and 13.42%, on average, originating from short- and long-range transport. Therefore, we can see that our finding is consistent with the findings in the previous literature.

4. Conclusions

This paper looks into the Chinese government's creation of a pollution haven through moving highly pollution enterprises from Beijing to Hebei province, and investigates whether the pollution haven struck back through the diffusion of air-borne pollutants. We find that the proportion of high-pollution industry output values in Hebei increased by 0.45% each year from 2003 to 2013 on average, while the proportion in Beijing decreased by 0.97 % each year. We also find higher emissions by enterprises in Hebei than their counterparts in Beijing, which is evidence of the existence of a pollution haven.

Furthermore, we exploit the daily variation in Beijing's $PM_{2.5}$ concentrations, and distinguish the effects of local and neighboring factors on Beijing's air quality. We find that, when the concentration of $PM_{2.5}$ increases by 100 $\mu g/m^3$ in an area 100 kilometers away from Beijing, the concentration level of $PM_{2.5}$ in Beijing will increase by 10.97 $\mu g/m^3$. This number will increase by 3.4 $\mu g/m^3$ when there is a gentle or moderate breeze blowing from this area to Beijing. These results show that the pollution haven struck back.

Based on these results, we quantify to what extent the increase of pollution in Hebei can offset the regulatory efforts in Beijing. We start by assuming that the relocation of the high-pollution enterprises caused Beijing's $PM_{2.5}$ concentration from local emissions to decrease from 200 to 40 $\mu g/m^3$, and that these enterprises which contributes to the 160 $\mu g/m^3$ $PM_{2.5}$ concentration all go to Langfang in Hebei, which is one destination city for polluting industries.[15] Second, based on the results shown in Tables 3 and 4, we estimate that the emissions would be more than double if these enterprises migrated to Hebei due to the less strict environment regulation in Hebei.[16] That is, after relocation, this 160 $\mu g/m^3$ pollution goes to Hebei, and doubles to become 320 $\mu g/m^3$.[17] Next, we calculate how much of this doubled pollution will go back to Beijing. According to Table 7, the coefficient of the weighted sum of pollution concentration in nearby cities (β_2) indicates that, when the concentration of $PM_{2.5}$ increases by 320 $\mu g/m^3$ in an area 66 kilometers away from Beijing (that is, the distance from Langfang to Beijing), the concentration level of $PM_{2.5}$ in Beijing will increase by $10.97 \times 320/66 = 53.19$ $\mu g/m^3$ when there is no wind. When there is a moderate breeze (e.g., wind speed = 25 km/h), the concentration level of $PM_{2.5}$ will further increase by $0.17 \times 25 \times 320/66 = 20.61$ $\mu g/m^3$. That is, when there is moderate wind, about (53.19 + 20.61)/160 = 46 % of Beijing's effort to decrease air pollution by relocating high-pollution enterprises will be offset by the increase of Hebei's air pollution, i.e., by the creation of a pollution haven in Hebei. From the calculation, we can see that, when the distance is farther away, the pollution haven strike-back effect will be smaller. If the relocation is uniformly distributed in the cities in Hebei, we can calculate that 13% of Beijing's effort would be offset by the increase in Hebei's air pollution.

The findings of this study have important policy implications. Measures to solve environmental problems should be formulated and implemented in a broader region. It is important to form an economic policy system targeting regional joint control of pollution. This system may be achieved by a uniform environmental tax within the same region. In addition, stricter environmental regulations should be accompanied by measures that help enterprises abate pollution at a lower cost, to avoid the problem of creating a pollution haven.

Because we do not have a list by name of enterprises that migrated from Beijing, we cannot identify whether the technology of these firms was upgraded after the migration, and therefore we cannot fully exclude the possibility of a pollution halo. In addition, due to the lack of emission data and air quality data before the migration, we mainly consider differences in the strictness of regulations and the monitored emission data after the migration. These comparisons are consistent with our hypothesis of a "manmade" pollution haven, but are not enough to be direct proof of the existence of the pollution haven. Further researchers may further look at this question and directly estimate the pollution haven effect when the data are available.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

See Appendix Fig.s A1 and A2 and Tables A1–A3 here.

[15] We have to make this assumption for the calculation because, due to data limitations, we do not have a list by name of the enterprises that migrated from Beijing, nor do we have the destination of their migration. Later we also make the assumption that these enterprises are uniformly distributed in Hebei's city. The results with the two different assumptions provide us a rough range of the impact of the migration. We make the assumption of the local emissions decrease based on the fact that Beijing's annual average concentration of $PM_{2.5}$ was around 80 μg/m3 after the period of relocation. The literature shows that half could be contributed by regional transfer (Chang et al., 2018, 2019; Zhang et al., 2019). Therefore, we assume that Beijing's $PM_{2.5}$ concentration from local emissions after migration is 40 μg/m3. Before the relocation, 80% of local emissions were from these high-pollution enterprises (estimated from total coal consumption and that consumed by industry. https://wenku.baidu.com/view/aed71cfc941ea76e58fa0437.html). Based on these facts, we calculate the $PM_{2.5}$ concentration from local emissions before the migration to be 200 μg/m3.

[16] Take smoke as an example, Table 3 shows that the average emission concentration of smoke in Beijing is around 6.5 units. Table 4 shows that the smoke emission concentration will be 3.96 units lower, which is 60% lower in Beijing, if all other factors are the same.

[17] We are fully aware that doubling emissions does not necessarily mean doubling ambient pollutant concentration, which is affected by many factors such as weather. We make this assumption only for the convenience of calculation.

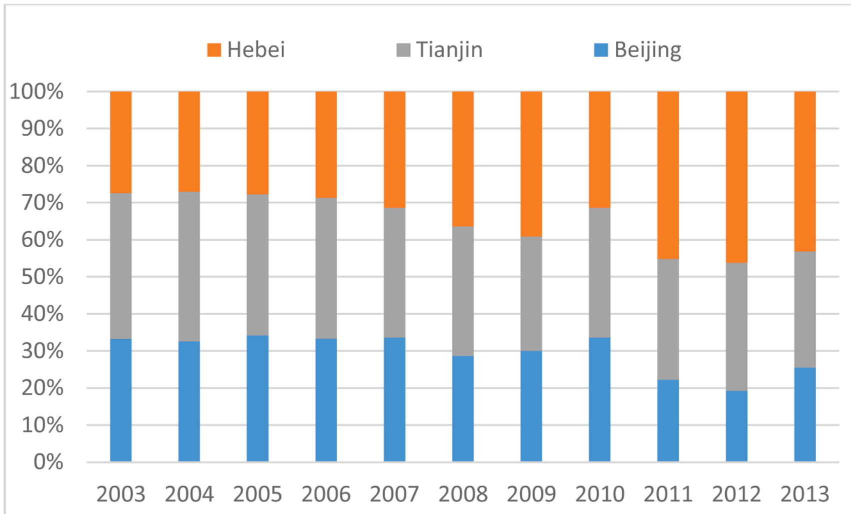

Fig. A1. Output value proportions of low-pollution Industries in the Jing-Jin-Ji Region. *Notes: The* data are from the Chinese industrial enterprises database.

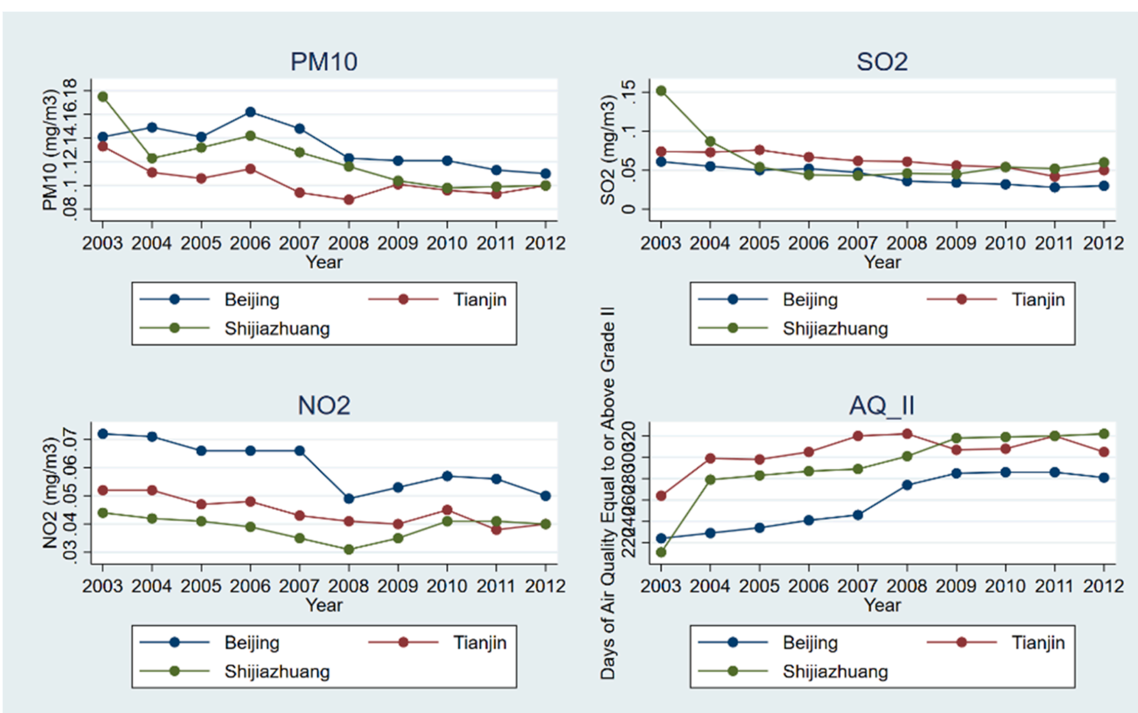

Fig. A2. Air Quality Trends in Beijing, Tianjin, and Hebei. *Notes:* Shijiazhuang is the capital of Hebei. The data are from the MEP of China, and are organized by the Chinese Research Data Services Platform (CNRDS). Year 2003 is when the available data starts. The data are only for the province capital cities. They include four air quality indicators: SO2, NO2, PM10, and the number of days on which air quality is "Good" and above. As shown by the graph below, the air quality in Hebei's capital indeed become worse relative to Beijing. This finding provides one more piece of supportive material of the "manmade" pollution haven.

Table A1
Comparison of the regulations between Beijing and Hebei.

	Beijing	Hebei
Atmospheric control targets and standards	**Article 13** The Municipal People's Government shall, in accordance with the work objectives of meeting the deadlines, formulate atmospheric gas environmental quality compliance planning and air pollution control phase measures that are stricter than the state regulations, and may formulate municipal air pollutant emission and control standards that are stricter than national standards, and organize implementation.	**Article 11** The municipal people's government that does not meet the national atmospheric environmental quality standards shall, in accordance with the national and provincial air pollution control target requirements and regional atmospheric environmental quality conditions, formulate an annual implementation plan for atmospheric environmental quality deadlines and air pollution prevention and control, and adopt strict air pollution control measures to meet the specified atmospheric environmental quality standards on schedule.
Industrial pollution prevention	**Article 14** This Municipality prohibits the construction and expansion of high-pollution industrial projects. The Municipal People's Government shall regularly formulate or revise the list of newly-constructed and expanded high-pollution industrial projects, the list of highly polluting industrial industries, and the list of high-pollution process equipment, and publish them to the public.**Article 53** This Municipality prohibits the construction and expansion of new and expanded refineries, cement, coking, steel, non-ferrous metal smelting, casting, flat glass, ceramics, asphalt waterproofing membranes, wood-based panels, clay bricks, etc. and other mineral resources development projects.	**Article 28** The Ministry of Industry and Information Technology of the Provincial People's Government, in conjunction with the provincial development and reform, environmental protection, quality supervision and other departments, proposes the elimination of backward production processes, equipment and product catalogs in accordance with the national guidelines for the elimination of backward production process equipment and products. This was implemented after being approved by the provincial people's government.**Article 29** According to the national industrial policy, the construction, reconstruction and expansion of steel, cement, flat glass, chemical synthetic pharmaceutical, non-ferrous metal smelting, chemical and other industrial projects shall be strictly controlled.
Dust pollution prevention	**Article 82** The construction site of a construction project shall take the following measures in accordance with the relevant provisions of the city's green construction:(1) Before the construction project starts, the construction unit shall set up an enclosure around the construction site in accordance with the standard, and the construction unit shall maintain the enclosure;(2) The construction unit shall publicize the person in charge of the construction site, the environmental supervision supervisor, the dust pollution control measures, and the reporting telephone at the entrance and exit of the construction site;(3) The construction unit shall harden the main roads and material storage sites in the construction site, cover or temporarily green other sites, and concentrate the earthwork on the earthwork and adopt coverage or solidification measures;(4) When the wind speed of the meteorological forecast reaches level four or more, the construction unit shall stop earthwork operations, demolition operations and other construction operations that may cause dust pollution;(5) The construction site shall be provided with flushing vehicle facilities at the exit of the construction site, and a video surveillance system shall be installed in accordance with the provisions of this Municipality; the construction vehicle shall be driven out of the construction site after mud removal and flushing, and shall not be driven on the road; the vehicle cleaning station shall be equipped with drainage. Mud sedimentation facility;(6) Construction roads and roads within 100 m of the construction site shall be free of dirt and construction waste;(7) During the construction process of road excavation, the construction unit shall timely cover the damaged pavement and take measures such as watering to prevent dust pollution; the road surface shall be repaired in time after completion of road excavation;(8) Other provisions of the State and this Municipality concerning construction site management:This Municipality will incorporate the dust-breaking behavior of the construction site of the construction unit into the credit evaluation system for the market behavior of construction enterprises in this city.**Article 87** The bare ground shall be greened or paved in accordance with the following provisions:(1) The construction land to be developed shall be covered by the construction unit for covering the exposed ground; for more than three months, temporary greening	**Article 38** The construction unit shall incorporate the construction dust pollution prevention and control costs into the project budget, and clarify the construction unit's responsibility for dust pollution prevention and control in the construction contract. The construction unit shall formulate specific construction dust pollution prevention and control plans and be responsible for implementation.The construction unit and construction unit shall abide by the following provisions: (1) Before starting construction, install enclosures around the construction site and carry out maintenance; the construction land that has not been started yet shall cover the exposed ground; if it has not started for more than three months, dust prevention measures such as temporary greening shall be adopted;(2) publicizing the construction site in charge, environmental supervision supervisor, dust pollution control measures, reporting telephones, etc. at the construction site entrance and exit;(3) Providing vehicle washing facilities at the exit of the construction site and supporting drainage and mud sedimentation facilities. The construction vehicles shall not drive on the road, and construction roads and roads around the exit shall not retain construction waste and soil;(4) Hardening treatment measures at the entrance and exit of the construction site, main roads, processing areas, etc.;(5) Stacking materials such as cement, lime soil, sand and gravel, etc., which are prone to dust pollution in the construction site, and construction waste, construction dregs, and construction earthwork stored on the site shall be covered, sealed or other dust suppression measures undertaken;(6) Fully closed measures shall be taken for loading, unloading and transporting muck, sand, construction waste and other materials that are prone to dust pollution;(7) When heavy weather conditions occur, the construction unit shall stop the earthwork operations, demolition work and other construction activities that may cause dust pollution.**Article 42** The people's governments at all levels shall actively promote the control of bare farmland and rural wasteland, and prevent and control dust pollution.The housing and urban and rural construction, urban management, water conservancy and other departments of the people's government at or above the county level shall, according to their duties, carry out greening or permeable pavement on the municipal rivers and along the rivers, exposed grounds of public land and exposed areas of

(continued on next page)

Table A1 (*continued*)

	Beijing	Hebei
	or paving shall be carried out;(2) The exposed roads along the municipal roads and rivers and public green spaces shall be organized by the traffic, water, and landscaping administrative departments to carry out greening or paving according to the plan;(3) Other exposed grounds shall be responsible for greening or paving by the user or management unit, and shall take dust-proof measures. The competent agricultural administrative department shall encourage measures such as biological coverage, stubble and no-tillage on exposed farmland to prevent and control dust pollution. **Article 89** The construction site of this city is prohibited from mixing concrete on site. On-site mixing of mortar is prohibited by construction projects invested by the government and construction projects within the designated areas of this Municipality. For other construction projects where a mortar mixer is installed at the construction site, dust and dust prevention devices shall be provided.The city is forbidden to build or expand concrete mixing stations; completed enterprises that do not meet the environmental management plan shall be closed within the time limit prescribed by the Municipal People's Government.	other towns to reduce dust pollution.

Notes: Articles are from *Air Pollution Prevention and Control Ordinance* of Beijing and Hebei respectively.

Table A2
The value of f_i for the Jing-Jin-Ji region.

City/District	Freq.	City/District	Freq.
Shijiazhuang	-30	Dagang District, Tianjin	1
Tangshan	-19	Heping District, Tianjin	1
Cangzhou	-4	Jinnan District, Tianjin	1
Tanggu District, Tianjin	-4	Nankai District, Tianjin	1
Wuqing District, Tianjin	-4	Ninghe County, Tianjin	1
Shunyi District, Beijing	-3	Zhangjiakou	1
Xicheng District, Beijing	-3	Fengtai district, Beijing	2
Binhai New Area,Tianjin	-3	Hangu District, Tianjin	2
Baoding	-2	Dongcheng District, Beijing	3
Beichen District, Tianjin	-2	Haiding district, Beijing	3
Daxing District, Beijing	-1	Chengde	3
Fangshan District, Beijing	-1	Baodi District, Tianjin	3
Langfang	-1	Ji County, Tianjin	3
Xuanwu District, Beijing	0	Handan	4
Changping district, Beijing	1	Dongli District, Tianjin	4
Huairou District, Beijing	1	Hexi District, Tianjin	4
Miyun County, Beijing	1	Xingtai	4
Shijingshan District, Beijing	1	Hedong District, Tianjin	5
Tongzhou District, Beijing	1	Xiqing District, Tianjin	5
Qinhuangdao	1	Jinghai County, Tianjin	6

Table A3
The Effects of neighboring cities' air quality on Beijing's air quality.

Variables	(1) AQI	(2) $PM_{2.5}$	(3) PM_{10}
Weighted air quality of neighbors	5.82***	6.20***	5.02***
	(0.54)	(0.64)	(0.45)
Weighted air quality of neighbors when wind is blowing toward Beijing	0.17***	0.20***	0.15***
	(0.04)	(0.06)	(0.04)
Wind speed	-1.48***	-1.47***	-1.42***
	(0.27)	(0.25)	(0.29)
Temperature	0.06	0.04	0.09**
	(0.04)	(0.03)	(0.04)
Precipitation	-0.00	-0.00	-0.04
	(0.03)	(0.02)	(0.02)
Weekend	-15.79*	-16.44**	-8.39
	(9.31)	(7.54)	(9.04)
Holiday	-8.45	-10.22	-4.41
	(9.45)	(7.16)	(10.15)
Driving Restricted	-14.05	-15.44**	-8.91
	(9.29)	(7.53)	(8.70)
Heating	-5.07	-7.91	-1.50
	(12.56)	(9.77)	(11.21)
Constant	49.49***	48.52***	33.79**
	(15.88)	(13.71)	(17.21)
Observations	863	863	863

Notes: The data are from the Chinese Ministry of Environmental Protection and China Meteorological Administration. Newey-West standard errors are in parentheses with the maximum lag order of autocorrelation at 7. ***, **, and * indicate significance at the 1 %, 5 %, and 10 % significance level, respectively.

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