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SPECIAL ISSUE PAPER

# Air pollution, economic spillovers, and urban growth in China

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**Abstract** This paper empirically tests the interactive effects of air pollution and economic spillovers in Chinese cities from 2003 to 2010. The results show that Chinese cities benefit from the economic spillovers from surrounding cities, but bear the costs of negative air pollution externalities created by neighboring cities. We use wind direction and the administrative boundaries of provinces to disentangle possible multicollinearity between air pollution emissions and economic spillovers across cities. However, the results could not reject the growth-restricting effects of air pollution from neighboring cities. The results imply that the development of a city surrounded by polluters is likely to be constrained.

**JEL Classification** R1 · Q5

## 1 Introduction

Air pollution is transboundary by nature; pollution transmissions are neither confined to nor enclosed by geographical boundaries. Air quality in a city is affected by its own pollutant emissions, as well as emissions from neighboring cities. Likewise, a city's economic growth is also closely intertwined with the economic activities of

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neighboring cities and susceptible to risk spillovers from neighboring cities. Air pollution externalities and economic spillovers coexist simultaneously, and both cannot be neglected in an urban system. This study empirically tests the interactive effects of air pollution and economic growth using city-level data from Chinese cities for the year 2003–2010. We empirically test the net effects caused by (negative) pollution externalities and (positive) economic spillover in cities and disentangle the effects to identify the respective constituents that coexist in an integrated urban system.

Air pollution increases marginal social costs in the urban growth process (e.g., see Glaeser 1998; Kahn 2006). As pollution externalities have no jurisdictional boundaries, a city bears the costs of pollution emitted by neighboring cities. Pollution externalities can create serious environmental problems (e.g., see Markusen 1975; Dockner and Van Long 1993; Eyckmans 1997). They adversely affect housing prices in both developed (Kenneth and Greenstone 2005; Harrison Jr and Rubinfeld 1978) and developing countries (Zheng et al. 2014). Kahn (2009) shows that households avoid living in neighborhoods with heavy pollution emissions. While the existing empirical literature focuses mainly on transboundary pollutions across different jurisdictions (e.g., see Gray and Shadbegian 2004; Sigman 2002, 2005), few studies have found direct empirical evidence on interactive effects of economic outputs and pollution externalities.

Like the pollution externalities, economic activities, in the Marshallian sense, could also spillover from one city to its neighboring cities. Economic spillovers are interactive forces in an urban system that drive economic agglomeration and city formation (Glaeser 1998). A big economic center increases capital or knowledge transfers from its market to the neighbors (Glaeser and Kahn 2003; Hanson 2005; Rosenthal and Strange 2001). The new economic geography (NEG) theory argues that agglomeration strengthens competitiveness in the product and labor markets of a city center (Krugman 1991, 1993). Economic growth and pollution emissions simultaneously influence the development of neighboring areas. However, the simultaneity effects, if ignored, could lead to underestimation of emission externalities on the one hand and overestimation of externalities of economic activities on the other hand.[1]

The rapid economic growth, industrialization, and urbanization of recent decades have raised serious pollution concerns in China. Today, China is the largest emitter of sulfur dioxide ($SO_2$) in the world. The World Bank estimates that the total health costs associated with air pollution in China amounted to 3.8 % of GDP. The World Bank also reports that crop losses due to $SO_2$ emissions and acid rains accounted for approximately RMB 30 billion in 2003. Approximately 80 % of economic losses were due to lower vegetable yields, and nearly half of the total costs were incurred in the three provinces Hebei, Hunan, and Shandong (World Bank 2007). Rapid urbanization and pollution emissions in Chinese cities continue to draw the attention of researchers (see Zheng and Kahn 2013).

We use air pollutant emissions from neighboring Chinese cities as a proxy for pollution externalities and regress them on city growths controlling for economic spillovers

[1] As air pollution is usually a byproduct of economic growth, we expect air pollution in a city to be highly correlated with its economic activities. The estimation of economic spillovers (air pollution) effects on its neighbors without controlling air pollution (economic spillovers) effects is biased.

from surrounding cities. Recognizing the multicollinearity between air pollution and economic activities from neighboring cities, we use two exogenous variables (1) wind directions for pollution emissions from neighboring cities and (2) political boundaries for economic spillovers, to explicitly deal with possible multicollinearity in the models. Our empirical results show significant simultaneity effects between negative air pollution externality and positive economic spillovers in Chinese cities.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the data used in the analysis. Section 4 tests the impact of pollution emissions and economic activities on urban growth. Section 5 discusses possible mechanisms generating pollution emission externalities. Section 6 concludes the paper.

## 2 Literature review: urban growth and neighboring cities

"Why are some cities more successful than others?" Glaeser et al. (1995) show that growth of US cities between 1960 and 1990 is dependent on various urban characteristics in 1960. City growth is positively correlated with initial schooling, but negatively correlated with unemployment rate and initial share of manufacturing employment. Au and Henderson (2006) examine the net urban agglomeration economies in Chinese cities and find a hump-shaped relationship of net outputs or value-added per worker with city size.

Beeson et al. (2001) examine the long-run growth of the US cities and the effects of transportation networks using the US county-level census data between 1840 and 1990. They show that the access to transportation networks, either natural (oceans) or produced (railroads), was an important factor driving city growth over the sample period. Other studies in the USA (Rosenthal and Strange 2001) and Brazilian (da Mata et al. 2007) cities find positive evidence of agglomeration effects on production outputs.

Krugman (1991) proposes the new "core -periphery" model that focuses on interactions among cities and considers location factors such as industry competitiveness, returns to scale, and transportation cost. The model consists of two sectors. One sector employs unskilled workers to produce a homogeneous good that is perfectly competitive and freely traded. The second sector employs skilled workers to produce a differentiated good that is monopolistically competitive and costly traded (see, e.g., Fujita and Thisse 1996; Ottaviano and Thisse 2002). The city size is finally determined by the equilibrium for both the product and the labor markets.

Pollution is closely associated with economic activities, particularly in developing countries. After the seminal work by Grossman and Krueger (1995), numerous papers find hump-shaped relationships between various measures of environmental quality and different time periods and across different countries. However, a discussion on economic linkages among cities would be incomplete without considering the impact of pollution across boundaries.

Because pollution is a type of negative externality that spills across boundaries, the freeriding effects among regions have been examined in many empirical studies. For example, using the Hebei province in China in their study, Duvivier and Xiong

(2013) find that "dirty" firms are more likely to set up in the border counties than in the interior area. Cai et al. (2013) show that water-polluting production activities are approximately 30 % larger in a downstream county of a Chinese province.

Few studies have examined the simultaneous impact of economic spillover and pollution emissions among cities. The international trade literature shows that pollution is imported into developing countries via foreign investments. Using a pollution heaven story, Copeland et al. (1994, 1995) show that an open economy with relatively weak environmental policy (typically associated with low income) attracts greater production from dirty industries. Using provincial-level data from China, He (2009) finds that $SO_2$ emissions increase by 0.098 % with a 1 % increase in foreign direct investments. In our paper, however, pollution externalities are not caused strictly by physical investment, but could be generated by free-riding polluters.

## 3 Data

China is organized into 34 provincial-level administrative regions, which include 23 provinces primarily populated by Han Chinese, 5 autonomous regions populated by minority races, 4 municipality cities, and 2 special administrative regions (SARs) that are Hong Kong and Macau. The 2 SARs with different political institutions are excluded from our sample. The 2 provinces in Hainan and Taiwan, which are islands located outside the mainland and the 2 autonomous regions that are Xinjiang and Tibet with low population density in western China are also excluded from our research.

Prefecture cities are administrative regions in every province that consist of several urban districts and rural counties.[2] We use prefecture cities as the administrative units to define cities in our statistical results. Our sample includes 278 prefecture cities from the 24 provinces, the 3 autonomous regions, and 4 municipality cities, which have similar administrative structure as prefecture cities,[3] and a dummy is used to differentiate the two types of cities in regressions. Our final sample covers 282 cities in China from 2003 to 2010. Figure 1 shows the map of the sample Chinese cities, and the circle size reflects the GDP scale in each city for 2010. The figure shows that agglomeration economies among Chinese cities producing large economic outputs are concentrated mainly on the east coast of China.

We use city-level GDP to measure the total output and strength of economic activities in a city. The cross-sectional and temporal variations in Chinese cities by size and economic growth reflect differences in the scale of city productivity. Population size is also used in the literature as an alternative measure for the scale of productivity of a city (da Mata et al. 2007; Glaeser and Gyourko 2005; Henderson 2003). However, the registration of "Hukou" policy that restricts free migration across Chinese cities raises some concerns when using the population statistics in China. The official statistics fail to report the number of people, who may work in a city, but without registering

[2] Besides the prefecture cities, the two other prefectural-level administrative regions are organized by rural counties and autonomous prefectures with mainly population from minor races.

[3] Municipality cities are the provincial-level cities made up of several urban districts and rural counties, and their administration areas are larger than prefecture cities.

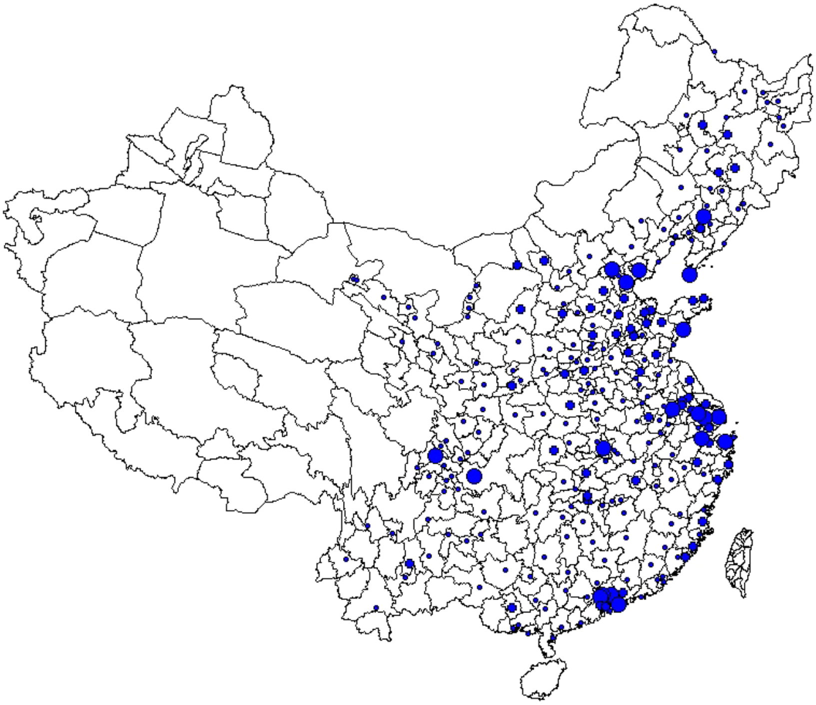

**Fig. 1** Cities in the sample by GDP in 2010. *Notes* cities in our sample are shown in this map. The *size of circle* represents the scale of GDP in 2010 of each city

their "Hukou."[4] As a large number of migrant workers without local "Hukou" are excluded from official population statistics, the size of the large cities in China is often underestimated. We use the GDP measure to minimize possible measurement errors.

We measure economic spillover to surrounding areas based on the total output of economic activities in neighboring cities. Additionally, total labor income and investment represent the consumption and production activities in the cities. Table 1 shows the summary statistics of these variables; the data are obtained from the *China City Statistical Yearbooks*. We observe significant variations in economic development among the Chinese cities. GDP for the top quartile cities is approximately four times that of the bottom quartile cities. Despite the strong growth in all the cities from 2003 to 2010, the GDP gap remains unchanged. The total investment in Chinese cities is much larger than the total income for these cities, which implies that China's economic growth is largely investment-driven (Krugman 1994; Yu 1998).

Economic activities that generate a large amount of pollutants impose negative externalities on neighbors. China has the highest ambient concentration of total

[4] In analyzing the China 1990 census data, Chan et al. (1999) find that approximately half of the migrants do not have "Hukou" in their new locations. Migrants without "Hukou" are more likely to move to economically developed coastal provinces.

**Table 1** Summary statistics

| Variables | Obs. | Mean | SD | 25th | Median | 75th |
|---|---|---|---|---|---|---|
| A: Full sample | | | | | | |
| GDP/10,000 RMB | 2252 | 8981,784 | 13,100,000 | 2,712,915 | 5,000,100 | 9,408,795 |
| Income/10,000 RMB | 2242 | 868,345 | 1,873,519 | 258,357 | 431,572 | 791,311 |
| Investment/10,000 RMB | 2253 | 4,578,107 | 6,254,297 | 1,166,098 | 2,447,835 | 5,252,170 |
| Dust emissions/T | 2237 | 25,273 | 25,031 | 8,804 | 18,234 | 33,090 |
| $SO_2$ emissions/T | 2236 | 63,479 | 63,409 | 22,731 | 50,748 | 83,858 |
| B: Year = 2003 | | | | | | |
| GDP/10,000 RMB | 280 | 4,823,151 | 6,403,514 | 1,622,603 | 2,706,332 | 5,029,186 |
| Income/10,000 RMB | 280 | 483,800 | 933,409 | 170,877 | 263,063 | 426,072 |
| Investment/10,000 RMB | 280 | 1,885,535 | 2,813,294 | 550,959 | 966,216 | 2,059,134 |
| Dust emissions/T | 279 | 27,401 | 30,301 | 9,431 | 18,705 | 35,966 |
| $SO_2$ emissions/T | 279 | 54,590 | 60,891 | 16,664 | 37,467 | 68,666 |
| C: Year = 2010 | | | | | | |
| GDP/10,000 RMB | 282 | 12,700,000 | 17,100,000 | 4,455,816 | 7,014,945 | 13,400,000 |
| Income/10,000 RMB | 276 | 1,228,953 | 2,578,235 | 405,223 | 668,835 | 1,021,775 |
| Investment/10,000 RMB | 282 | 7,585,256 | 8,365,884 | 2,894,336 | 4,920,462 | 8,348,102 |
| Dust emissions/T | 275 | 19,611 | 17,025 | 7,641 | 15,123 | 27,288 |
| $SO_2$ emissions/T | 275 | 60,267 | 55,726 | 23,537 | 51,879 | 82,960 |

Summary statistics of GDP, total labor income, total investment, industrial dust emissions, and $SO_2$ emissions our sample. Panel A is the statistics from 2003 to 2010; panel B is based on the data in 2003; panel C is the statistics of 2010

suspended particulates (TSP) and $SO_2$ among world cities (World Bank 2007). Particulates and $SO_2$ are mainly generated from industrial dust emissions, and coal burning has been the primary source of pollutant emissions. We use industrial dust and $SO_2$ emissions as proxies for pollutant emissions in each city. Our sample study period is 2003–2010. Table 1 reports the summary statistics on air quality data, ambient concentration of particulate matters smaller than 10 $\mu$m (PM10), and $SO_2$. The data are obtained from the *China City Statistical Yearbooks* and the *China Environmental Statistical Yearbooks*. The yearly statistics include a total of 28 provincial capital cities.

We identify city geographical coordinates using the map and calculate the straight-line distance between two cities. The geographical distance measure is used to define the weighting factor $[e^{-d}]$, where $d$ is the distance. It assumes that air pollution and economic spillover decrease exponentially. The distance weight is dropped for cities that are located more than 300 km apart. In the robustness test, wind direction is also used to more accurately measure the spillover effects of pollutants from neighbors. Based on the *China Meteorological Database,* the data on dominant wind directions are obtained for each year. The wind direction in each city is identified from the statistics reported by the closest monitoring stations.

We use several controls for instrumental variables in the models, which include the city size measured by the total administration area and the annual average temperature computed from the *China Meteorological Database* including approximately 300 observation stations. The average annual temperature for each city is computed for the 1990s using the statistics reported by the closest meteorological station to the city. The distance to one of the 14 closest coastal cities identified as open ports by Chinese government at the beginning of 1980s is used to represent international trade activities in the Chinese cities.[5]

## 4 Empirical evidence

Our study empirically tests the interactive effects of economic spillovers and air pollution on urban growth. We identify the neighboring cities for each city and then measure the economic activities and pollution emissions from them. We examine the interactive effects using different estimation methods.

### 4.1 Empirical strategy

For each referenced city, we draw a circle with a radius of 300 km on the map around the city center. Other cities located within the circle are defined as neighboring cities to the referenced city. The aggregate impact of economic spillover and pollution emissions from the neighboring cities weighted by the distance is calculated.[6] We perform regressions using the city-level data to explain the economic and pollution impacts of neighboring cities on the output growth of the referenced city:

$$\ln Y_{i,t} = \lambda \ln \sum_{j \in N_i} \mathrm{e}^{-d_{i,j}} X_{j,t}^{\text{emission}} + \phi \ln \sum_{j \in N_i} \mathrm{e}^{-d_{i,j}} X_{j,t}^{\text{economy}} + \beta X_{i,t} + \delta_{i,t}$$

where $Y_{i,t}$ measures the economic and development activities in a referenced city $i$ in year $t$; $X_{j,t}^{\text{emission}}$ is the pollutant emissions from city $j$ in year $t$; $X_{j,t}^{\text{economy}}$ is the strength of economic activities in city $j$ in year $t$; $d_{i,j}$ is the distance between city $i$ and city $j$ where $i \neq j$; $N_i$ is the number of neighboring cities surrounding the referenced city $i$; $X_{i,t}$ is a vector of control variables for city $i$ and time dummies, and $\delta_{i,t}$ is the residual of the regression. $\sum_{j \in N_i} e^{-d_{i,j}} X_{j,t}^{\text{emission}}$ measures the aggregate effects of air pollution from neighboring cities on the referenced city $i$ in year $t$, and $\sum_{j \in N_i} e^{-d_{i,j}} X_{j,t}^{\text{economy}}$ measures the aggregate impact of economic spillover from neighboring cities on the referenced city $i$ in year $t$.

Different types of pollutants, which include industrial dust and $SO_2$ emissions, are considered separately in the regressions. We measure economic activities using

[5] They include important ports on the east coast of China such as Tianjin, Shanghai, Dalian, Qinhuangdao, Yantai, Qingdao, Lianyungang, Nantong, Ningbo, Wenzhou, Fuzhou, Guangzhou, Zhanjiang, and Beihai.

[6] Recent studies have found significant impact of transboundary air pollutions on environmental quality, for example the interstate transport of NOx emissions in the USA (Tong and Mauzerall 2008), the impact of aerosol emissions in East Asia (Saikawa et al. 2009), and intercity pollution in China (Zheng et al. 2014).

three variables that include total output (GDP), consumption, and investment spillover effects. Total output (GDP) measures the total economic activities of neighboring cities. The consumption effects are correlated with the total labor income of neighboring cities. Total investment represents spillover effects in the production sector.

In the regressions, we control for geographical region effects[7] using different spatial dummies that identify municipality cities and capital cities in each province. The distance to the closest port (in logarithm terms) is a proxy for international trade activities. We use the distance to Hong Kong in our regressions to control for possible effects associated with the economic reform process, which started in the southern China region close to Hong Kong. Total area is used to control for the size effect of production activities in a city. Year dummies are added to control for time effects.

The multicollinearity in air pollution emissions and economic activities between neighboring cities, if not explicitly controlled, could lead to biased regression results. We use two exogenous instruments to address the multicollinearity problems in our regression. First, because air pollution is carried through wind, neighboring cities located in the wind direction are more likely to carry pollutants to a referenced city compared to other cities located against the wind direction. For example, a reference city is negatively affected to a greater extent by pollutants from northern cities than southern cities with the north-blowing wind. However, wind direction is exogenous to economic activities and economic spillover from neighboring cities. Our data show that the correlation coefficients between pollutant emissions from cities located in a dominant wind direction and economic spillover from these cities are less than 25 % regardless of the variables used for pollutant emissions and economic activities. Therefore, the use of wind direction as an instrument in our regressions could disentangle the effects of pollutant externalities from economic spillover from other neighboring cities.[8]

Second, we use two spatial measures as instrument variables for the economic spillover effects from neighboring cities to the referenced city: (i) the linear distance of neighboring cities must fall within 300 km from a referenced city and (ii) the neighboring cities must be in the same province as the referenced city. Cities within the same province are governed by the same provincial committee and are typically led by a secretary appointed by the communist party. Cities in the same province share the same resource pool and are economically more connected than other cities outside the province. The provincial borders are defined geographically purely for administrative purposes; they cannot, however, stop transboundary air pollution from crossing the borders.

[7] China is geographically divided into eastern, central, and western regions based on different geographical, cultural, and economic attributes. The eastern region includes provinces such as Hebei, Heilongjiang, Jilin, Liaoning, Shandong, Jiangsu, Zhejiang, Anhui, Fujian, Guangdong, Hainan, Beijing, Tianjin, and Shanghai; the center region includes provinces such as Shanxi, Hubei, Hunan, Henan, Jiangxi, and Inner Mongolia; and the remaining provinces are grouped into the western region.

[8] Zheng et al. (2014) show that a 10 % reduction in imported pollution from neighboring cities via wind increases Beijing's house prices by 0.76 %. In their research, they also construct a similar variable with consideration of wind direction to measure how city is affected by dust and smoke emissions from nearby cities' manufacturing firms.

In addition, economic growth in a referenced city is also likely to be correlated with economic spillover from neighboring cities. The spillover effect is twofold. The reference city enjoys the spillover from its neighboring cities while that city's economic activities also greatly affect its neighbors. The lagged proxy of economic spillover is used as the instrumental variable in our regressions to mitigate potential endogeneity. Additionally, we use region dummies, a municipality dummy, a province capital dummy, year dummies, log of distance to the closest port, log of city areas, log of distance to Hong Kong, and temperature to allow for other exogenous variations in the models. The time-invariant geographical variables could further reinforce the identification of geographical-based distributions of economic spillover. These exogenous variables pass the specification test and are significant in the first-stage regression results.

### 4.2 Empirical results

Tables 2, 3, and 4 show the results of the regressions with economic output, log(GDP), as the dependent variable. Table 2 shows the baseline models with two pollutant emission measures. Table 3 considers wind direction to measure emissions from neighbors. Table 4 uses the 2SLS estimation methodology using a set of instrument variables in the first-stage regression. The predicted economic spillover variable is then included in the second-stage regression to predict the economic output.

Table 2 considers pollution emissions and economic spillover from all neighboring cities, and the results are estimated by the OLS estimator. Columns (1) to (3) show the industrial dust emissions, and Columns (4) to (6) include the $SO_2$ emissions. Economic spillover from the neighboring cities is measured by the respective total output, labor income, and investment. The results report significant evidence affirming negative externalities of air pollution and positive spillover effects. The magnitude of air pollution-induced externalities ranges from −0.06 to −0.15, and the effect of economic spillover is estimated at 0.40. The results imply that every 1 % increase in air pollutant emissions from neighboring cities will cause an approximate 0.1 % decline in economic growth in the referenced city, and every 1 % increase in the economic growth of neighboring cities leads to a 0.4 % spillover effect on the economic growth of the referenced city.

The results show that the municipality cities and the provincial capitals have experienced relatively stronger economic growth than other cities, and significant heterogeneity is found in economic development across different cities by region. Cities in the eastern region grow relatively faster than cities in other regions. Cities located closer to the ports and Hong Kong experience relatively faster economic growth than other cities with weaker international trade links. Cities with a greater administrative area enjoy some scale economies and greater development capacity to achieve faster economic growth. These results are consistent with China's current economic growth patterns.

Table 3 considers the pollutant emissions from cities located in the dominant wind direction. The results show a lower correlation of economic spillover with the referenced city. Columns (1) to (3) show significant and also relatively stronger negative effects of the dust emissions from cities located in the dominant wind direction regions

**Table 2** OLS regression of urban growth on neighbors' emissions and economic spillovers

| Dependent variable | ln(GDP) | | | | | |
|---|---|---|---|---|---|---|
| | Dust emissions | | | $SO_2$ emissions | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Emissions from neighbors | −0.123*** | −0.059** | −0.061** | −0.183*** | −0.070* | −0.153*** |
| | (0.028) | (0.028) | (0.027) | (0.037) | (0.036) | (0.039) |
| Output spillovers | 0.459*** | | | 0.529*** | | |
| | (0.029) | | | (0.039) | | |
| Consumption spillovers | | 0.387*** | | | 0.404*** | |
| | | (0.029) | | | (0.038) | |
| Investment spillovers | | | 0.354*** | | | 0.441*** |
| | | | (0.025) | | | (0.037) |
| *Control variables* | | | | | | |
| Province capital | 1.334*** | 1.334*** | 1.320*** | 1.339*** | 1.334*** | 1.330*** |
| | (0.043) | (0.044) | (0.043) | (0.043) | (0.044) | (0.043) |
| Municipality dummy | 1.907*** | 1.877*** | 1.909*** | 1.908*** | 1.875*** | 1.912*** |
| | (0.105) | (0.106) | (0.106) | (0.105) | (0.106) | (0.106) |
| East region dummy | 0.145*** | 0.167*** | 0.223*** | 0.125*** | 0.167*** | 0.188*** |
| | (0.038) | (0.039) | (0.037) | (0.039) | (0.040) | (0.038) |
| West region dummy | −0.403*** | −0.446*** | −0.428*** | −0.331*** | −0.417*** | −0.389*** |
| | (0.038) | (0.039) | (0.038) | (0.037) | (0.036) | (0.036) |
| ln(distance to port) | −0.138*** | −0.154*** | −0.149*** | −0.143*** | −0.157*** | −0.151*** |
| | (0.010) | (0.010) | (0.010) | (0.010) | (0.010) | (0.010) |
| ln(area) | 0.216*** | 0.201*** | 0.211*** | 0.214*** | 0.199*** | 0.213*** |
| | (0.017) | (0.017) | (0.017) | (0.017) | (0.017) | (0.017) |
| ln(distance to Hong Kong) | 0.039* | 0.003 | −0.048** | 0.035 | −0.002 | −0.054*** |
| | (0.023) | (0.023) | (0.021) | (0.022) | (0.022) | (0.021) |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2244 | 2244 | 2244 | 2244 | 2244 | 2244 |
| $R^2$ | 0.668 | 0.659 | 0.661 | 0.669 | 0.659 | 0.663 |

This table is estimated by OLS. The dependent variable is the log GDP in the center city, and the main explanatory variables are the neighbors' emissions and economic spillovers. The control variables included province capital dummy, municipality dummy, regional dummies, log of distance to closest port, log of area, log of distance to Hong Kong, and year dummies. Columns (1) to (3) consider the dust emissions, and Columns (4) to (6) consider the $SO_2$ emissions. Standard errors are in parentheses
***, ** and * denote significance level at 1, 5 10 %, respectively

on the urban growth of referenced cities. Columns (4) to (6) show that $SO_2$ emissions from neighboring cities located in the dominant wind direction regions have significant and negative impact on the urban growth of the referenced cities.

In Table 3, we include both variables on economic spillover and interact the economic spillover term with the neighboring city dummy. The results show that the economic spillover effects have significant positive effects on urban growth. The coefficients on the interactive terms are also significant and positive, which implies that

**Table 3** OLS regression of urban growth on emissions from dominant wind direction

| Dependent variable | ln(GDP) | | | | | |
|---|---|---|---|---|---|---|
| | Dust emissions | | | $SO_2$ emissions | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Emissions from dominant wind direction | −0.025*** | −0.021** | −0.023** | −0.017** | −0.013 | −0.017* |
| | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) |
| Output spillovers | 0.353*** | | | 0.346*** | | |
| | (0.020) | | | (0.021) | | |
| Consumption spillovers | | 0.334*** | | | 0.326*** | |
| | | (0.021) | | | (0.022) | |
| Investment spillovers | | | 0.300*** | | | 0.297*** |
| | | | (0.019) | | | (0.019) |
| Output spillovers within province | 0.038*** | | | 0.037*** | | |
| | (0.008) | | | (0.008) | | |
| Consumption spillovers within province | | 0.039*** | | | 0.037*** | |
| | | (0.009) | | | (0.009) | |
| Investment spillovers within province | | | 0.040*** | | | 0.039*** |
| | | | (0.008) | | | (0.008) |
| *Control variables* | | | | | | |
| Province capital | 1.346*** | 1.353*** | 1.342*** | 1.340*** | 1.346*** | 1.338*** |
| | (0.043) | (0.044) | (0.044) | (0.043) | (0.044) | (0.044) |
| Municipality dummy | 2.568*** | 2.458*** | 2.563*** | 2.530*** | 2.418*** | 2.536*** |
| | (0.166) | (0.167) | (0.167) | (0.166) | (0.166) | (0.167) |

**Table 3** continued

| Dependent variable | ln(GDP) | | | | | |
|---|---|---|---|---|---|---|
| | Dust emissions | | | $SO_2$ emissions | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| East region dummy | 0.175*** | 0.161*** | 0.213*** | 0.183*** | 0.170*** | 0.218*** |
| | (0.034) | (0.035) | (0.034) | (0.034) | (0.035) | (0.034) |
| West region dummy | −0.380*** | −0.443*** | −0.422*** | −0.372*** | −0.436*** | −0.414*** |
| | (0.037) | (0.037) | (0.036) | (0.037) | (0.037) | (0.037) |
| ln(distance to ports) | −0.142*** | −0.154*** | −0.149*** | −0.146*** | −0.157*** | −0.152*** |
| | (0.010) | (0.010) | (0.010) | (0.010) | (0.010) | (0.010) |
| ln(area) | 0.218*** | 0.207*** | 0.218*** | 0.219*** | 0.207*** | 0.217*** |
| | (0.017) | (0.018) | (0.018) | (0.017) | (0.018) | (0.018) |
| ln(distance to Hong Kong) | 0.022 | 0.006 | −0.044** | 0.019 | 0.003 | −0.045** |
| | (0.021) | (0.022) | (0.021) | (0.021) | (0.022) | (0.021) |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2244 | 2244 | 2244 | 2244 | 2244 | 2244 |
| $R^2$ | 0.670 | 0.662 | 0.664 | 0.669 | 0.661 | 0.664 |

This table is estimated by OLS. The dependent variable is the log GDP in the center city, and the main explanatory variables are the emissions from the cities located in dominant wind direction of center city, economic spillovers, and economic spillovers from the neighbor city located in the same province. The control variables include province capital dummy, municipality dummy, regional dummies, log of distance to closest port, log of area, log of distance to Hong Kong, and year dummies. Columns (1) to (3) consider the dust emissions, and Columns (4) to (6) consider the $SO_2$ emissions. Standard errors are in parentheses

***, ** and * denote significance level at 1, 5, 10 %, respectively other neighboring cities within the province contribute to economic growth in the referenced cities.

The results are consistent with the strand of literature that attributes China's economic growth to competition among local government officials (Zhou 2009; Xu 2011). From this perspective, local political leaders may choose to contain economic growth in their own provinces and limit spillover to benefit economic growth in their neighboring cities. Employing a spatial econometric model, Yu et al. (2013) find strong spatial effects in city-level total investments that drive short-run economic growth in cities. The spatial effects are found only in cities within the same province but not in neighboring cities from different provinces.

Table 4 shows the results from the two-stage least squares (2SLS) regressions. In the first stage, we use log city area, log distance to Hong Kong, log distance to the closest port, temperature, region dummies, municipality dummy, provincial capital dummy, year dummies, and lagged economic spillover as instrumental variables and regress them on the economic spillover variable. The estimated economic spillover variable is then used in the second-stage regressions together with the pollutant emissions variable from cities located in the wind direction.

The results in Columns (1) to (3) significantly reaffirm the negative effects of industrial dust emissions from neighboring cities and the positive effects of economic spillover on the referenced cities. A 1 % increase in industrial dust emissions from neighboring cities reduces urban growth by approximately 0.013–0.016 % in the referenced cities. However, a 1 % increase in economic activities from neighboring cities generates spillover effects of approximately 0.35 % in our model. Columns (4) to (6) use $SO_2$ emissions as proxies for air pollution. The coefficients on $SO_2$ emissions are negative but not significant. However, the effects of economic spillover remain significantly positive.

Our results are robust.[9] The estimates for the control variables in Tables 3 and 4 are consistent with the results in Table 2. The above empirical results support the hypothesis that economic development in a city is not independent of the economic activities in the city's surrounding areas. A city benefits from the economic activities of its neighbors, but also suffers from their pollution emissions. Our model predicts that a city generates positive externality for its neighbors only when its economy grows faster than its pollution emissions. The externality on the economic growth of a city is the trade-off between economic spillover and pollutant emissions from neighboring cities.

## 5 Air quality and pollution transmission mechanisms

In this section, we examine potential mechanisms that produce negative externalities from pollution emissions. We first test the relationship between air quality and pollution emissions from neighboring cities. For pollution emissions to have a negative externality effects on neighboring cities, we must establish that air quality in one city

[9] We have computed Conley's (1999, 2008) standard errors and used simultaneous equation regressions to model the endogenous effects of pollution on economic growth. The results are robust, but are not reported in this paper.

**Table 4** 2SLS regression of urban growth on neighbors' emissions and economic spillovers

| Dependent variable | ln(GDP) | | | | | |
|---|---|---|---|---|---|---|
| | Dust emissions | | | $SO_2$ emissions | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Emissions from dominant wind direction | −0.016** | −0.013* | −0.013** | −0.009 | −0.005 | −0.008 |
| | (0.006) | (0.007) | (0.007) | (0.006) | (0.006) | (0.006) |
| Output spillovers | 0.377*** | | | 0.368*** | | |
| | (0.021) | | | (0.021) | | |
| Consumption spillovers | | 0.355*** | | | 0.345*** | |
| | | (0.022) | | | (0.022) | |
| Investment spillovers | | | 0.328*** | | | 0.323*** |
| | | | (0.018) | | | (0.018) |
| *Control variables* | | | | | | |
| Province capital | 1.327*** | 1.333*** | 1.320*** | 1.322*** | 1.328*** | 1.317*** |
| | (0.037) | (0.039) | (0.038) | (0.037) | (0.039) | (0.038) |
| Municipality dummy | 1.923*** | 1.898*** | 1.932*** | 1.915*** | 1.891*** | 1.926*** |
| | (0.106) | (0.119) | (0.106) | (0.107) | (0.119) | (0.106) |
| East region dummy | 0.202*** | 0.186*** | 0.245*** | 0.208*** | 0.193*** | 0.249*** |
| | (0.035) | (0.036) | (0.035) | (0.035) | (0.036) | (0.035) |

**Table 4** continued

| Dependent variable | ln(GDP) | | | | | |
|---|---|---|---|---|---|---|
| | Dust emissions | | | $SO_2$ emissions | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| West region dummy | −0.374*** | −0.429*** | −0.406*** | −0.370*** | −0.424*** | −0.402*** |
| | (0.036) | (0.037) | (0.036) | (0.037) | (0.037) | (0.036) |
| ln(distance to ports) | −0.143*** | −0.153*** | −0.149*** | −0.146*** | −0.155*** | −0.151*** |
| | (0.013) | (0.013) | (0.013) | (0.013) | (0.013) | (0.012) |
| ln(area) | 0.205*** | 0.194*** | 0.205*** | 0.206*** | 0.195*** | 0.205*** |
| | (0.018) | (0.019) | (0.018) | (0.019) | (0.019) | (0.018) |
| ln(distance to Hong Kong) | 0.023 | −0.004 | −0.053* | 0.018 | −0.008 | −0.055* |
| | (0.034) | (0.033) | (0.032) | (0.034) | (0.033) | (0.032) |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1965 | 1965 | 1965 | 1965 | 1965 | 1965 |
| $R^2$ | 0.653 | 0.646 | 0.648 | 0.653 | 0.645 | 0.648 |

This table is estimated by 2SLS. The dependent variable is the log GDP in the center city, and the main explanatory variables are the emissions from the cities located in dominant wind direction of center city and economic spillovers. The control variables include province capital dummy, municipality dummy, regional dummies, log of distance to closest ports, log of area, log of distance to Hong Kong, and year dummies. The log of area of cities, log of distance to Hong Kong, log of distance to closest port, temperature, region dummies, municipality dummy, province capital dummy, year dummies, and lagged economic spillovers are used as instrumental variables. Columns (1) to (3) consider the dust emissions, and Columns (4) to (6) consider the $SO_2$ emissions. Standard errors are in parentheses

***, ** and * denote significance level at 1, 5, 10 %, respectively

**Table 5** Determinants of air quality in cities

| Dependent variable | ln(PM10) | | $\ln(SO_2)$ | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Dust from neighbors | 0.167*** | | | |
| | (0.031) | | | |
| Dust emission | | 0.069*** | | |
| | | (0.025) | | |
| $SO_2$ from neighbors | | | 0.401*** | |
| | | | (0.044) | |
| $SO_2$ emission | | | | 0.256*** |
| | | | | (0.041) |
| Temperature | −0.002*** | −0.002*** | −0.002*** | −0.001** |
| | (0.000) | (0.000) | (0.001) | (0.000) |
| ln(area) | −0.020 | −0.076** | 0.208*** | −0.018 |
| | (0.029) | (0.032) | (0.044) | (0.045) |
| East region dummy | 0.025 | −0.037 | −0.315*** | −0.425*** |
| | (0.046) | (0.032) | (0.062) | (0.066) |
| West region dummy | 0.099* | −0.003 | 0.003 | −0.120* |
| | (0.053) | (0.051) | (0.067) | (0.071) |
| Municipality dummy | 0.082* | 0.083 | 0.140* | 0.048 |
| | (0.050) | (0.053) | (0.072) | (0.087) |
| Year effects | Yes | Yes | Yes | Yes |
| Observations | 224 | 223 | 224 | 223 |
| $R^2$ | 0.293 | 0.215 | 0.455 | 0.362 |

The dependent variables are the ambient concentrations of particulate matter $< 10\,\mu m$ (PM10) and sulfur dioxide ($SO_2$). The main explanatory variables are the industrial dust and $SO_2$ emission from the city itself and neighbor. Standard errors are in parentheses. ***, ** and * denote significance level at 1, 5, 10 %, respectively

is affected by its neighboring cities' pollutant emissions. This is the channel through which a city's neighbors' pollutant emissions influence its urban economic growth. We regress air quality of the referenced cities against the neighbors' pollutant emissions in a linear model. Because of data limitations, we are limited to the air quality data for 28 provincial capital cities in the sample. The ambient concentration of particulate matters that are smaller than $10\,\mu m$ (PM10) and the $SO_2$ are used as proxies for air quality in referenced cities.

Table 5 shows the regressions of the air quality variables on the neighboring cities' pollutant emissions. Columns (1) and (2) use the ambient PM10 concentration, and Columns (3) and (4) use $SO_2$ as the dependent variables. Columns (1) and (3) include emissions from neighboring cities as explanatory variables, whereas Columns (2) and (4) include emissions from the referenced cities themselves as explanatory variables. Other control variables in the regressions include temperature, city size, regional dummies, and year dummies.

**Table 6** 2SLS regression of urban growth on air quality

| Dependent variable | ln(GDP) | | | | | |
|---|---|---|---|---|---|---|
| | PM10 | | | $SO_2$ | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Air quality | −0.672** | −1.535*** | −1.059** | −0.690*** | −0.750*** | −0.663*** |
| | (0.330) | (0.432) | (0.428) | (0.209) | (0.257) | (0.227) |
| Output spillovers | 0.600*** | | | 0.775*** | | |
| | (0.072) | | | (0.108) | | |
| Consumption spillovers | | 0.573*** | | | 0.642*** | |
| | | (0.087) | | | (0.119) | |
| Investment spillovers | | | 0.545*** | | | 0.689*** |
| | | | (0.075) | | | (0.112) |
| *Control variables* | | | | | | |
| Municipality dummy | 0.883*** | 1.190*** | 1.004*** | 0.844*** | 0.952*** | 0.808*** |
| | (0.130) | (0.156) | (0.156) | (0.131) | (0.149) | (0.134) |
| East region dummy | 0.270** | 0.468*** | 0.332** | −0.101 | −0.056 | −0.096 |
| | (0.119) | (0.158) | (0.141) | (0.192) | (0.204) | (0.197) |
| West region dummy | −0.144 | −0.236* | −0.270** | −0.139 | −0.222** | −0.229** |
| | (0.096) | (0.130) | (0.113) | (0.096) | (0.107) | (0.102) |
| ln(distance to ports) | 0.019 | 0.119** | 0.042 | −0.011 | 0.000 | −0.039 |
| | (0.041) | (0.052) | (0.050) | (0.035) | (0.040) | (0.037) |
| ln(area) | 0.358*** | 0.258*** | 0.360*** | 0.471*** | 0.479*** | 0.526*** |
| | (0.061) | (0.080) | (0.071) | (0.072) | (0.084) | (0.079) |
| ln(distance to Hong Kong) | −0.066 | −0.223** | −0.187** | 0.014 | −0.205* | −0.100 |
| | (0.091) | (0.102) | (0.092) | (0.130) | (0.120) | (0.122) |
| Year dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 224 | 224 | 224 | 224 | 224 | 224 |
| $R^2$ | 0.773 | 0.623 | 0.702 | 0.722 | 0.655 | 0.700 |

This table is estimated by 2SLS. The dependent variable is the log GDP in the center city, and the main explanatory variables are air quality and economic spillovers. The control variables include municipality dummy, regional dummies, log of distance to closest port, log of area, log of distance to Hong Kong, and year dummies. The log of area of cities, temperature, region dummies, municipality dummy, year dummies, and emissions from neighbors are used as instrumental variables. Columns (1) to (3) consider the ambient concentrations of particulate matter $<10\,\mu$m (PM10) and Columns (4) to (6) consider the ambient concentrations of sulfur dioxide ($SO_2$). Standard errors are in parentheses

***, ** and * denote significance level at 1, 5, 10 %, respectively

All the regressions show that self-emissions of pollutants from the referenced cities and pollution emissions from the neighboring cities significantly impact the air quality in the referenced cities. The coefficients on the pollution emissions from neighboring cities are larger than the coefficients on the self-emissions from the referenced cities. More importantly, the adjusted $R$-square of the models with emissions from the neighboring cities is higher than that of the models with self-emissions from the referenced cities themselves. The results imply that neighboring cities' pollutant emissions have significant and positive effects and cannot be neglected when modeling the referenced cities' air quality.[10]

Next, we examine the impact of air quality on urban growth. In our baseline model, we use air quality in the referenced cities instead of pollution emissions from neighboring cities to model air pollution externalities controlling for the economic spillover effects. The air quality of a city is highly correlated with its economic development. We overcome the endogeneity issues by instrumenting the pollution emissions from neighboring cities from the regressions in Table 5.

Table 6 shows the results of the 2SLS regressions estimated from the sample of 28 provincial capital cities. The air quality is measured by ambient particulate matter concentration (PM10) and $SO_2$, which are instrumented by the industry dust and $SO_2$ emissions, respectively, from the neighboring cities in the first-stage regressions. The coefficients on the air quality variable are significantly negative, which implies that poor air quality has a negative impact on the economic development of a city. Table 6 also finds significant positive economic spillover after controlling for air quality.

From the consumption perspective, households prefer a better living environment and value clean air in their utility function (Gabriel and Rosenthal 2004; Zheng et al. 2014). Poor air quality affects both quality of life and labor productivity in a city. Our results support the emerging literature that shows the negative effects of air pollution on productivity and the labor supply. Graff Zivin and Neidell (2012) show that air pollution reduces labor productivity. Hanna and Oliva (2015) show that improvements in air quality increase work hours in Mexico City.

## 6 Conclusion

Pollutant emissions are highly correlated with economic activities in cities. Negative externalities created by air pollution cannot be neglected when measuring the spillover of economic activities from neighboring cities. Our empirical results show that positive economic spillovers could be substantially discounted if air pollution externalities are simultaneously created. Chinese cities benefit from economic spillovers from the surrounding cities but, at the same time, they suffer and bear substantial social costs from air pollution emitted by their neighboring cities.

China faces a series of challenging environmental problems. Our results show that a large number of Chinese cities have faced negative consequences of the economic development of their larger and more prosperous neighboring cities, which have generated air pollutants and transmitted them to these cities. Policy makers should, therefore, establish urban plans and strategies that promote the development of cleaner and denser regional centers, which produce positive economic spillover without generating excessive air pollution in neighboring cities.

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[10] The result implies that pollution emissions from neighboring cities are a possible instrumental variable for air quality, which has been used by Zheng et al. (2014).

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## References

Au C, Henderson JV (2006) Are Chinese cities too small? Rev Econ Stud 73:549–576
Beeson P, DeJong D, Troesken W (2001) Population growth in U.S. counties, 1840–1990. Reg Sci Urban Econ 31:669–699
Cai H, Chen Y, Qing G (2013) Polluting thy neighbor: the case of river pollution in China (unpublished)
Chan KW, Liu T, Yang Y (1999) Hukou and non-hukou migrations in China: comparisons and contrasts. Int J Popul Geogr 5:425–448
Copeland B, Taylor MS, Scott M (1994) North-south trade and the environment. Q J Econ 109:755–787
Copeland B, Taylor MS, Scott M (1995) Trade and transboundary pollution. Am Econ Rev 85:716–737
Conley TG (1999) GMM estimation with cross sectional dependence. J Econom 92(1):1–45
Conley TG (2008) Spatial econometrics. In: Durlauf SN, Blume LE (eds) The new Palgrave dictionary of economics. Palgrave Macmillan, Basingstoke
da Mata D, Deichmann U, Henderson JV, Lall SV, Wang HG (2007) Determinants of city growth in Brazil. J Urban Econ 62:252–272
Dockner EJ, Van Long N (1993) International pollution control: cooperative versus noncooperative strategies. J Environ Econ Manag 25:13–29
Duvivier C, Xiong H (2013) Transboundary pollution in China: a study of polluting firms' location choices in Hebei province. Environ Dev Econ 18(4):459–483
Eyckmans J (1997) Nash implementation of a proportional solution to international pollution control problem. J Environ Econ Manag 33:314–330
Fujita M, Thisse J-F (1996) Economics of agglomeration. J Jpn Int Econ 10:339–378
Gabriel SA, Rosenthal SS (2004) Quality of the business environment versus quality of life: do firms and households like the same cities? Rev Econ Stat 86:438–444
Glaeser EL (1998) Are cities dying? J Econ Perspect 12:139–160
Glaeser E, Scheinkman J, Shleifer A (1995) Economic growth in a cross-section of cities. J Monet Econ 36:117–143
Glaeser EL, Gyourko J (2005) Urban decline and durable housing. J Polit Econ 113:345–375
Glaeser EL, Kahn ME (2003) Sprawl and urban growth. National Bureau of Economic Research working paper series no. 9733
Gray WB, Shadbegian RJ (2004) "Optimal" pollution abatement—whose benefits matter, and how much? J Environ Econ Manag 47:510–534
Graff JZ, Neidell M (2012) The impact of pollution on worker productivity. Am Econ Rev 102(7):3652–3673
Grossman GM, Krueger AB (1995) Economic growth and the environment. Q J Econ 110:353–377
Hanna R, Oliva P (2015) The effect of pollution on labor supply: evidence from a natural experiment in Mexico City. J Public Econ 122:68–79
Hanson HG (2005) Market potential, increasing returns and geographic concentration. J Int Econ 67:1–24
Harrison D Jr, Rubinfeld DL (1978) Hedonic housing prices and the demand for clean air. J Environ Econ Manag 5:81–102
He J (2009) China's industrial $SO_2$ emissions and its economic determinants: EKC's reduced vs. structural model and the role of international trade. Environ Dev Econ 14:227–262
Henderson JV (2003) The urbanization process and economic growth: the so-what question. J Econ Growth 8:47–71
Kahn ME (2006) Green cities: urban growth and the environment. Brookings Institution Press, Washington
Kahn ME (2009) Regional growth and exposure to nearby coal fired power plant emissions. Reg Sci Urban Econ 39:15–22
Kenneth YC, Greenstone M (2005) Does air quality matter? Evidence from the housing market. J Polit Econ 113:376–424
Krugman P (1991) Increasing returns and economic geography. J Polit Econ 99:483–499
Krugman P (1993) First nature, second nature, and metropolitan mocation. J Reg Sci 33:129–144
Krugman P (1994) The myth of Asia's miracle. Foreign Aff 73:62–78
Markusen JR (1975) Cooperative control of international pollution and common property resources. Q J Econ 89:618–632

Ottaviano GIP, Thisse J-F (2002) Integration, agglomeration and the political economics of factor mobility. J Public Econ 83:429–456
Rosenthal SS, Strange WC (2001) The determinants of agglomeration. J Urban Econ 50:191–229
Saikawa E, Naik V, Horowitz LW, Liu J, Mauzerall DL (2009) Present and potential future contributions of sulfate, black and organic carbon aerosols from China to global air quality, premature mortality and radiative forcing. Atmos Environ 43(17):2814–2822
Sigman H (2002) International spillovers and water quality in rivers: do countries free ride? Am Econ Rev 92:1152–1159
Sigman H (2005) Transboundary spillovers and decentralization of environmental policies. J Environ Econ Manag 50:82–101
Tong D, Mauzerall D (2008) Summertime state-level source-receptor relationships between nitrogen oxide emissions and downwind surface ozone concentrations over the continental United States. Environ Sci Technol 42(21):7976–7984
World Bank (2007) Cost of Pollution pollution in China: economic estimates of physical damageseconomic estimates of physical damages. http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf
Xu C (2011) The fundamental institutions of China's reforms and development. J Econ Lit 49:1076–1151
Yu Q (1998) Capital investment, international trade and economic growth in China: evidence in the 1980–1990s. China Econ Rev 9:73–84
Yu L, Zhou LA, Zhu G (2013) Strategic interaction in political competition: evidence from the spatial effects across Chinese cities. Peking University working paper
Zheng S, Cao J, Kahn ME, Sun C (2014) Real estate valuation and cross-boundary air pollution externalities: evidence from Chinese cities. J Real Estate Finance Econ 48:398–414
Zheng S, Kahn ME (2013) Understanding China's urban pollution dynamics. J Econ Lit 51:731–772
Zhou LA (2009) Incentives and governance: China's local governments. CENGAGE Learning, Boston