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The Spatial Correlation between Foreign Direct Investment and Air Quality in China and the Potential Channel

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Abstract: Due to the attention given to air pollution, the impact of foreign direct investment (FDI) on air quality has led to many discussions on this topic; however, there is a lack of literature discussing the correlation between FDI and air quality from a spatial perspective. In China, the discontinuity of ground monitoring data further limits research in this area. Using a new air pollution dataset, this paper constructs a dynamic panel of 259 prefecture-level Chinese cities over the period 2013–2018 and reveals that FDI on average induces the pollution halo effect in host cities but shows direct correlation with air pollution in the outer conurbation areas. Further examination supports the main findings by showing that FDI presents the same correlation with coal consumption and thermal power generation of the local and the outer conurbation areas. The heterogeneity analysis finds that the industrialization stage, ecological construction, and technology development are important moderators for FDI's pollution effect. The findings of this paper generate potential policy implications for regional green development regarding FDI.

Keywords: foreign direct investment; pollution halo effect; spatial Durbin model; regional corporation; green development

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1. Introduction

While foreign direct investment (FDI) plays a key role in the economic development of host countries [1], host countries with relatively weak environmental institutions may attract FDI to pollution-intensive sectors, which leads to environmental deterioration [2]. For this topic, the largest developing country, China, is of great study value. China, ranking as the largest FDI recipient among developing countries, has experienced both rapid economic development and observable environmental decay since establishing its world trade system. Comparing 2018 with 2011, when China first joined the World Trade Organization, annual FDI increased from 4688 million dollars to 121,257 million dollars, an annual average growth rate of 21.09% (data cited from China National Bureau of Statistics, website: http://www.stats.gov.cn/, 1 December 2020). Meanwhile, China has been experiencing environmental decay, and its air quality deterioration has caused global concern [3]. Although atmospheric protection has reached unprecedented levels, according to the 2018 China Environmental Status Bulletin, 217 cities, or 64.2% of the 338 cities in China, still exceeded the ambient air quality standard. While FDI promotes economic development, the role of FDI in changes in the air quality of host countries has become an important topic of discussion in the environmental and economic fields.

The existing literature generally supports two opposite hypotheses regarding the correlation between FDI and environmental indicators. One of these hypotheses, the pollution haven hypothesis (PHH), argues that FDI has a negative impact on the environment in host countries because FDI transfers pollution-intensive industries to countries with relatively weak environmental institutions and leads to environmental decay in these countries [4,5]. Another hypothesis, the so-called pollution halo hypothesis, suggests that FDI shows a positive effect on the environment in the host countries because FDI promotes

cleaner production technology and advanced environmental management systems and then improves the environmental performance in host countries [6–8].

Multiple studies have explored FDI's pollution effects and support one of the above hypotheses with empirical evidence. To provide a brief overview of the existing literature, Appendix A Table A1 lists 25 empirical studies released between 2010 and 2021 that discuss the PHH; this table lists the sample composition, types of pollutants under study, the methods, heterogeneity considerations, and the main conclusions.

Studies employ various environmental quality or pollution variables, as different pollutants illustrate FDI's pollution effect in different fields; studies may also involve different environmental indexes to provide robustness checks involving the PHH or the reverse. Due to data limitations, current studies mainly focus on carbon-related emissions, industrial SO_2 emissions, satellite sensed $PM_{2.5}$, wastewater, industrial soot, dust, or employ composite indices [3,9–12]. Some papers find FDI's pollution effect has significant heterogeneity across types of pollution; however, such papers usually compare pollutants that cannot be used to measure the same environmental medium, for example, wastewater and industrial soot [13]. The reform of the air quality index system in 2013 has caused studies that often have long-term observations to seldom consider ground monitored air pollutant concentrations. The Chinese air quality index system before 2013 employed API which represented the highest pollution level among monitored pollutants that include SO_2, PM_{10}, NO_2, and O_3. Since 2013, API has become AQI and added $PM_{2.5}$ and CO into the pollutant monitoring list. Moreover, ground-based monitoring data can lead to endogeneity in most studies since the location choice is not random and the distribution of locations is not fixed across cities [14]. This endogeneity problem can be solved by using an evenly distributed reanalysis dataset. This paper considers six routinely monitored air pollutants (SO_2, NO_2, O_3, $PM_{2.5}$, PM_{10}, and CO) included in the recently released CN reanalysis [15,16] dataset for 2013–2018 to examine whether FDI has a robust impact on air quality. This study complements current studies on PHH.

In terms of sample composition and econometric methods, studies often employ an autoregressive distributed lag (ARDL) to analyze time series [17,18] and ordinary least squares (OLS), generalized least squares (GLS), two-stage least squares (2SLS), generalized two-stage least squares (G2SLS), fixed effects, or random effects to study static panel data [1,10,11,19]. Due to the development of spatial econometrics, the spatial spillover effect of FDI has been taken into consideration. Compared with omitted variables, ignoration of the spatial dependence of dependent variables and independent variables can create more bias [20]. FDI and pollutants have been proven, in several papers, to have significant spatial autocorrelations [3,9,13,21]. The consideration of spatial spillover effects not only addresses estimation bias [22] but also shows the effect of FDI on neighborhood areas, providing information for interregional cooperation supporting green development. However, the existing literature is very inadequate in terms of considering the spatial spillover effect. This inadequacy is reflected in the small number of articles considering the spatial spillover effect and in the numerous defects that appear in studies when they use a spatial econometric model. The first problem arises when the spatial correlation of explanatory variables is ignored. Ignoring the spatial autocorrelation of the explanatory variables will produce estimation bias. The second problem is that articles seldom consider the dynamics of factors, that is, the time lag effect of the explained variable, which can also produce estimation bias. The third problem is that even when studies employ a dynamic spatial econometric model, they fail to distinguish between the long-term and short-term direct and indirect effects of FDI when reporting the estimation results, which reduces the meaning of the results of dynamic panel regression models. Following existing literature [3,9], this paper employs the dynamic spatial Durbin model and decomposes FDI's pollution effect into direct, indirect, and total effects, both in the short term and long term.

Existing papers generally agree that FDI shows heterogeneous pollution effects when multiple factors are considered. Several studies divide the whole sample of China into eastern, western, and central regions and find that the results for the full sample are

consistent with the situation of the eastern region but not always reflective of the situation of the western or the central regions because cities that accept FDI are mostly located in the eastern area. [10,11,23]. In addition, due to the availability of data on FDI origins, several studies distinguish FDI as ethnically linked FDI (FDI from Hong Kong, Taiwan, and Macau) and non-ethnically linked FDI (FDI from other countries) and find that ethnically linked FDI often appears to have pollution halo effects, while nonethnic FDI tends to have opposite effects or insignificant effects [1,24]. Some articles distinguish FDI's effects based on the socio-economic characteristics of the host regions, such as the industrialization stage (IS), institutional development, and human capital [1,9,25]. These factors are often found to reduce FDI's pollution haven effect. The existing literature argues that FDI simultaneously affects the environment through scale effects, technique effects, and composition effects [26]. Empirical papers that follow this argument employ simultaneous equations to estimate FDI's effects and find that FDI often shows negative environmental externalities through scale effects and composition effects, while its positive environmental externalities are often achieved through technique effects [12,27–29]. In this way, the overall effect of FDI that most researchers prefer to present depicts only the dominant effect. Further mechanism studies are seldom carried out based on a heterogeneity analysis and thus this issue needs to be further explored.

Here, a panel of 259 Chinese prefecture-level cities from 2013 to 2018 and the dynamic spatial Durbin model (SDM) are used to conduct a spatial analysis between FDI and air quality, and to examine the existence of PHH in China in the last few years. This paper is different from the existing literature and makes contributions in the following ways: (1) this paper considers FDI's pollution effect and decomposes the effect into long-term/short-term effects and direct/indirect effects to compare the dynamic and spatial differences; (2) it updates the observation period to 2018 and compares the effects of FDI on six pollutants to provide robust conclusions; and (3) this paper further examines the spatial correlation by employing energy variables and traffic variables (the potential channel) and exploring the potential moderating effect of city-specific variables.

2. Materials and Methods

2.1. Spatial Autocorrelation

Before the econometric model is developed, this paper employs global Moran's I (GMI) to examine the spatial autocorrelation of six measures of air pollution and the key explanatory variable, FDI. *GMI* is calculated with STATA 16, based on the following formula [9,13]:

$$GMI = \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(y_i - \overline{y})(y_j - \overline{y}) / Var(y) \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij} \quad (1)$$

where y stands for the examined variable, and $\overline{y}$ and $Var(y)$ are its mean and variance, respectively. w_{ij} is the spatial weight between city i and city j. N is the total number of cities.

Z score is employed to identify the significance of *GMI* and is calculated as follows:

$$Z = (1 - E(I)) / \sqrt{Var(I)} z = (1 - E(I)) / \sqrt{Var(I)} \quad (2)$$

Moran's I is a standardized index with a range of [–1,1]. A negative value indicates a negative spatial correlation, a positive value indicates a positive spatial autocorrelation, and the values of zero indicate there is no spatial autocorrelation [13,27].

In addition to global Moran's I, a local index of spatial agglomeration (LISA) map is employed to present the regional spatial autocorrelation of the examined variable. The *LISA* map is drawn with ArcMap 10.7, based on local Moran's I (LMI). The formulas to calculate *LMI* are as follows:

$$LMI_i = Z_i \sum_{j=1}^{n} w_{ij} Z_j \quad (3)$$

where w_{ij} is the same as in Formula (1), and $Zi(j)$ is the standardized observed value of city $i(j)$, calculated as follows:

$$Z_{i(j)} = \left(y_{i(j)} - \overline{y}\right) / Var(y) \quad (4)$$

when *LMI* is significantly positive, there is either an H-H cluster if high value is surrounded by similarly high values or an L-L cluster if low value is surrounded by similarly low values. When *LMI* is significantly negative, there is either an H-L outlier if the high value is surrounded by dissimilarly low values or an L-H outlier if the low value is surrounded by dissimilarly high values [13]. The LISA map, with color, shows H-H and L-L clusters, H-L and L-H outliers, and areas with insignificant LMI.

2.2. Model Specifications

To deal with the spatial autocorrelation of variables, the spatial lag model (SLM), spatial error model, and spatial Durbin model (SDM) are often used. Compared with ordinary econometric models, the SLM considers the spatial autocorrelation of the explained variables. The SEM considers the spatial autocorrelation of missing variables, that is, the spatial autocorrelation of the error term. The SDM considers not only the spatial autocorrelation of the explained variable but also that of the explanatory variables. The specifications are as follows, respectively:

$$\text{SEM}: \ lny_{i,t} = \rho w_{ij} lny_{j,t} + \beta_1 lnx_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$\text{SEM}: \ lny_{i,t} = \beta_1 lnx_{i,t} + \varepsilon_{i,t}, \text{ and } \varepsilon_{i,t} = \lambda \sum w_{ij} \varepsilon_{j,t} + \mu_{i,t} \quad (6)$$

$$\text{SDM}: \ lny_{i,t} = \rho w_{ij} lny_{j,t} + \beta_1 lnx_{i,t} + \beta_2 w_{ij} lnx_{j,t} + \varepsilon_{i,t} \quad (7)$$

In the SDM, the causal effect of the explanatory variables on the explained variable is decomposed into direct effects (the local causal effect) and indirect effects (the spatial spillover effect). When there is no significant spatial autocorrelation of the explanatory variables, the SDM degenerates into the SLM, and the direct effect reported by the SDM equals the total effect reported by the SLM [20]. The SDM does not consider the spatial correlation of the error term [13]. Lesage and Pace (2009) proposed that the cost of ignoring the spatial autocorrelation of the explanatory variables is higher than that of ignoring omitted variables. Ignoring the spatial autocorrelation of the error term reduces only the efficiency of the model; however, a maximum likelihood estimation (MLE) can compensate for the lack of efficiency of OLS.

Many studies ignore the time lag effect of pollution, although the pollution in an earlier period is proven to have a significant impact on the current period [9]. This article takes the time lag effect of the explained variable into consideration, that is, a dynamic panel is constructed to avoid potential estimation bias. A dynamic specification is available only for the SDM and SLM; therefore, this paper employs the following dynamic SDM:

$$\begin{aligned} lnAP_{i,t} = \tau lnAP_{i,t-1} + \rho \sum w_{ij} lnAP_{j,t} + \beta_1 lnFDI_{i,t} + \beta_2 \sum w_{ij} lnFDI_{j,t} + \gamma_1 lnControl_{i,t} \\ + \gamma_2 \sum w_{ij} lnControl_{j,t} + \gamma_i + \eta_t + \varepsilon_{i,t} \end{aligned} \quad (8)$$

where *AP* stands for air pollution and *Control* includes a series of control variables that are both correlated with *AP* and *FDI*. The spatial weight matrix w_{ij} is a geographical inverse distance matrix calculated with the coordinates of city centers that come with *CN-reanalysis* observations through the econometric software STATA 16.0. γ_i controls the city fixed effect and η_t controls the year fixed effects.

To further validate the main regression and explore the moderating effect of city-specific variables, this paper carries out a heterogeneity analysis by employing the interaction terms of FDI with the interested urban variables and the spatial factors of these terms. The model is specified as follows:

$$lnAP_{i,t} = \tau lnAP_{i,t-1} + \rho \sum w_{ij} lnAP_{j,t} + \beta_1 lnFDI_{i,t} + \beta_2 \sum w_{ij} lnFDI_{j,t} + \theta_1 lnFDI_{i,t} lnFactor_{i,t} + \theta_2 \sum w_{ij} lnFDI_{j,t} lnFactor_{j,t} + \gamma_1 lnControl_{i,t} + \gamma_2 \sum w_{ij} lnControl_{j,t} + \gamma_i + \eta_t + \varepsilon_{i,t} \quad (9)$$

where AP represents $PM_{2.5}$, PM_{10}, SO_2, O_3, and CO, sequentially (the regression of NO_2 is not presented because its dynamic term is omitted). FDI's direct pollution effect (the effect of $FDI_{i,t}$ on $AP_{i,t}$) is expressed by $\beta_1 + \theta_1 Factor_{i,t}$, and the spatial spillover effect of FDI (the effect of $FDI_{i,t}$ on $AP_{j,t}$) is expressed by $\beta_2 w_{ij} + \theta_2 w_{ij} Factor_{i,t}$.

This paper further explores the potential channels through which FDI may affect air quality. The model specification is as follows:

$$lnFactor_{i,t} = \tau lnFactor_{i,t-1} + \rho \sum W_{ij} lnFactor_{j,t} + \beta_1 lnFDI_{i,t} + \beta_2 \sum W_{ij} lnFDI_{j,t} + \gamma_1 lnControl_{i,t} + \gamma_2 \sum W_{ij} lnControl_{j,t} + \gamma_i + \eta_t + \varepsilon_{i,t} \quad (10)$$

where *Factor* represents *IS*, *Tech/Pop*, *Coal/Pop*, *Gasoline/Pop*, *Thermal/Pop*, *Tra1/Pop*, and *Tra2/Pop* sequentially. The subscripts and other variables are the same as those in Model (8).

2.3. Variable Descriptions

2.3.1. Explained Variable: Air Pollution (*AP*)

Six pollutants, SO_2, NO_2, O_3, $PM_{2.5}$, PM_{10}, and CO, are sequentially used as proxies of air pollution. This paper exploits the CN-reanalysis dataset to eliminate the endogeneity of the locations of ground monitoring stations. This dataset not only includes these six main pollutant concentrations but also resamples the observations into grids of $0.25^\circ \times 0.25^\circ$ through atmospheric transportation models. This paper first extracts observations of each city and then averages these values to obtain the daily average of pollutant concentration of the city. Finally, the daily values of the city average are again averaged into annual values. Averaging over space and long periods is efficient for eliminating data uncertainty.

2.3.2. Key Explanatory Variable: *FDI/GDP*

The actual use of foreign capital derived from the 2014–2019 China City Statistical Yearbook is used as a proxy for FDI. The original unit is US dollars. This paper first converts the values to RMB using the annual average exchange rate and then converts them to a comparable amount based on 2013 values with GDP deflators. Following Cheng et al. (2020) and Huang et al. (2018), the key explanatory variable is then constructed based on the proportion of FDI in the GDP.

2.3.3. Other Variables

Following the existing literature, this study selects the population, economic development, average wage, IS, ecological construction, and technology level as control variables [3,9,30,31].

1. Population: Since the annual average population better represents the number of actual residents than the household population, the population is measured as the annual average population (*Pop*) provided in the China City Statistical Yearbook.
2. Economic Development: The GDP is a commonly used indicator that characterizes the total economic output of a region, and thus here is used as the variable for the economic development of each city. The GDP deflator is employed to convert all data into a comparable amount based on 2013 values. GDP per capita (*GDP/Pop*) is employed here. To address the potential nonlinear effects of economic development on air pollution, the quadratic term of GDP per capita is also controlled for in the regressions [13].
3. Attraction to Talent: The average wage of laborers (*AW*) is used to measure the level to which a city attracts talent since a higher wage can attract more advanced laborers. Additionally, in contrast to the average years of education, the wage level directly represents the quality of human resources.
4. Ecological Construction: Green areas are used as proxies for the ecological construction level of a city. The green areas per capita (*EC/Pop*) are employed in the model.

5. Industrialization Stage: The industrialization stage is an important mediator of FDI's pollution effect and is generally discussed in studies herein [9]. The industrialization stage is measured as the proportion of tertiary industry to secondary industry (*IS*).
6. Technology: Expenditures on science and technology per capita (*Tech/pop*) are used as proxies for the technology level of a city.
7. Energy Production: Emissions from coal-based electricity generation are important sources of local air pollution. Out of environmental consideration, thermal power generation per capita (*Thermal/Pop*) is employed.
8. Energy Consumption: Emissions from energy consumption are the main sources of air pollution among which coal consumption is mainly from the industrial sector and gasoline consumption is an ideal agent of emissions from the transportation sector. Therefore, this paper employs total energy consumption per capita (*Total Energy/Pop*) to control emissions from energy consumption. In addition, coal consumption per capita (*Coal/Pop*) and gasoline consumption per capita (*Gasoline/Pop*) are employed to study the potential channel through which FDI affects the air quality.
9. Traffic: Highway passenger volume over population (*Tra1/Pop*) and highway freight volume over population (*Tra2/Pop*) are employed to control the traffic structure.

Data on the control variables were obtained from the 2014–2019 China City Statistical Yearbook and China Energy Statistical Yearbook (the 2014–2019 yearbooks report the data of 2013–2018). The natural logarithms of all variables except *IS* are employed in the regressions to explore the relative rate of change between variables and solve the autocorrelation of time series. This paper supplements missing values through interpolation methods and constructs a strongly balanced panel of 259 municipal cities. The descriptive statistics of the variables of the balanced panel are given in Table 1.

Table 1. Summary statistics of the variables.

Variable	Explanation	Unit	N	Mean	Std. Dev.	Min	Max
SO_2	Air pollutant concentration	$\mu g/m^3$	1548	17.57	10.79	2.97	74.73
NO_2		$\mu g/m^3$	1548	22.50	10.52	2.07	52.95
$PM_{2.5}$		$\mu g/m^3$	1548	46.00	18.53	9.73	122.18
PM_{10}		$\mu g/m^3$	1548	70.18	29.98	11.16	226.98
O_3		$\mu g/m^3$	1548	60.64	7.65	40.13	84.98
CO		mg/m^3	1548	0.83	0.33	0.19	2.80
Pop	Annual average population	10^6 capita	1548	4.57	3.23	0.31	33.97
GDP		Billion yuan	1548	261.97	346.38	21.00	2936
FDI	Foreign direct investment	Billion yuan	1548	6.38	14.82	0	199.09
Tech	Expenditure on science and technology	Billion yuan	1548	1.15	3.60	0	49.87
IS	Industrialization stage	1	1548	1.03	2.11	0.21	81.72
AW	Average wage	10^4 yuan	1548	5.70	1.48	2.48	14.98
EC	Green areas	10^6 hectares	1548	8.37	16.57	0.15	147.05
Trans1	Highway passenger volume	10^4 capita	1548	7271.242	13,260.73	56	195,597
Trans2	Highway freight volume	10^4 tons	1548	12,548.46	16,760.29	558	292,426
Total Energy	Total energy consumption	10^4 tce	1548	18,740.44	8872.27	1720	40,581
Coal	Coal consumption	10^4 tons	1548	17,643.3	10,872.11	276.19	48,940.14
Gasoline	Gasoline consumption	10^4 tons	1548	994.618	2557.308	18.77	21,362
Thermal	Thermal power generation	10^8 kWh	1548	1888.887	1305.44	122	5546.69

Note: in this table, GDP, FDI, and Tech have been converted to comparable amounts based on 2013 values. Furthermore, 0 indicates that at a minimum, the first two decimal places of the figure are zero.

3. Results and Discussion

3.1. Spatial Autocorrelation Tests

Cross-sectional data on the six pollutants and FDI from 2013 to 2018 were used to calculate the GMI, and the results are shown in Table 2. These seven variables all have significant positive GMI, which means that high-high clusters and low-low clusters exist. PM_{10} has the strongest spatial autocorrelation, while FDI ranks the lowest. For the air pollutants, the value of GMI is close to that reported in Huang et al. (2017) (0.119 and 0.246) but much smaller than that reported in Cheng et al. (2020) (between 0.7 and 0.8).

Table 2. Moran's I and significance level of the six air pollutants and FDI from 2013 to 2018.

Moran's I	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	0.215 ***	0.203 ***	0.226 ***	0.234 ***	0.228 ***	0.241 ***
PM_{10}	0.222 ***	0.224 ***	0.242 ***	0.252 ***	0.250 ***	0.262 ***
SO_2	0.226 ***	0.225 ***	0.232 ***	0.221 ***	0.189 ***	0.172 ***
NO_2	0.170 ***	0.163 ***	0.179 ***	0.191 ***	0.185 ***	0.181 ***
O_3	0.129 ***	0.082 ***	0.076 ***	0.107 ***	0.167 ***	0.166 ***
CO	0.204 ***	0.150 ***	0.185 ***	0.191 ***	0.179 ***	0.152 ***
FDI	0.022 ***	0.020 ***	0.018 ***	0.017 ***	0.016 ***	0.016 ***

*** $p < 0.01$.

The LISA map of the six pollutants and FDI was then calculated and displayed on maps with ArcGIS. From 2013–2018, the spatial agglomeration did not change much, except for O_3 (the change is presented in Appendix B Figure A1). Due to space considerations, Figure 1 displays only the LISA map for 2018 as an example to show the spatial distribution of air pollution and FDI. For air pollution, high-high clusters are mainly concentrated in the middle and lower reaches of the Yellow River and the Yangtze River, which indicates that these areas have high pollution levels and high spatial correlation values for air pollution. Low-low clusters are mainly concentrated in the southeast and the northeast, which indicates a low pollution level and weak spatial correlations. The FDI shows a much weaker spatial correlation than air pollution, and its low-low clusters are mainly concentrated in the southwest and the northeast, while the high-high clusters are mainly concentrated in the Yangtze Delta. The LISA map again illustrates the need to incorporate the spatial lag term of both the explained variable and explanatory variables into the spatial econometric model.

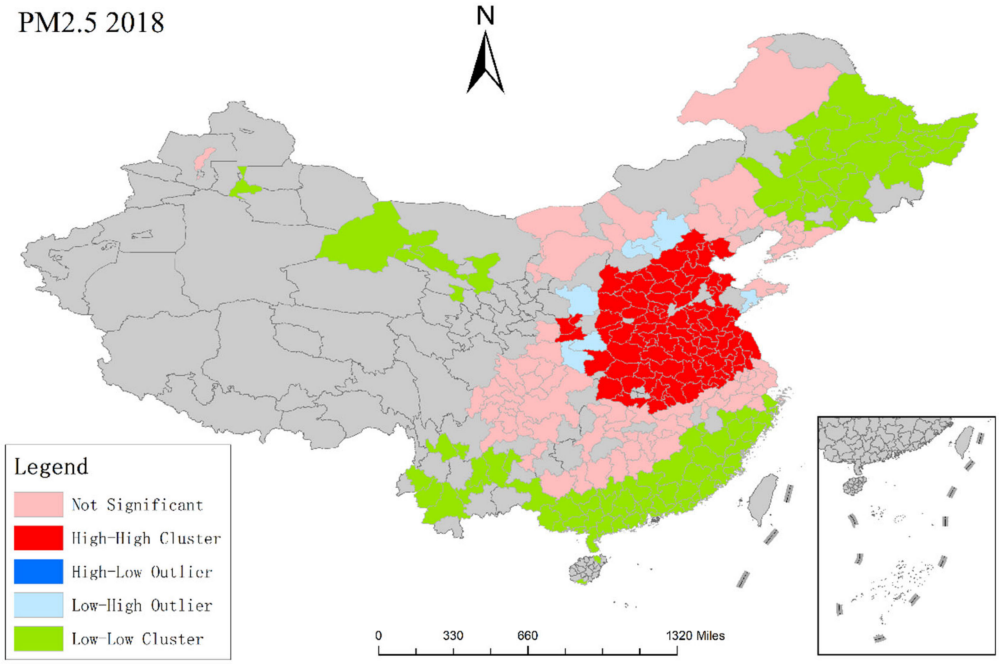
3.2. Results of the Main Regression

This section shows the estimation results of Model (8). Based on the results of the Hausman tests, the following regressions were conducted with fixed effects. Supplementary Appendix C Table A2 shows the dynamic term (namely, τ in Model (8)) and other information regarding the regressions, which validates the inclusion of the dynamic factor and the spatial factor of the explained variables.

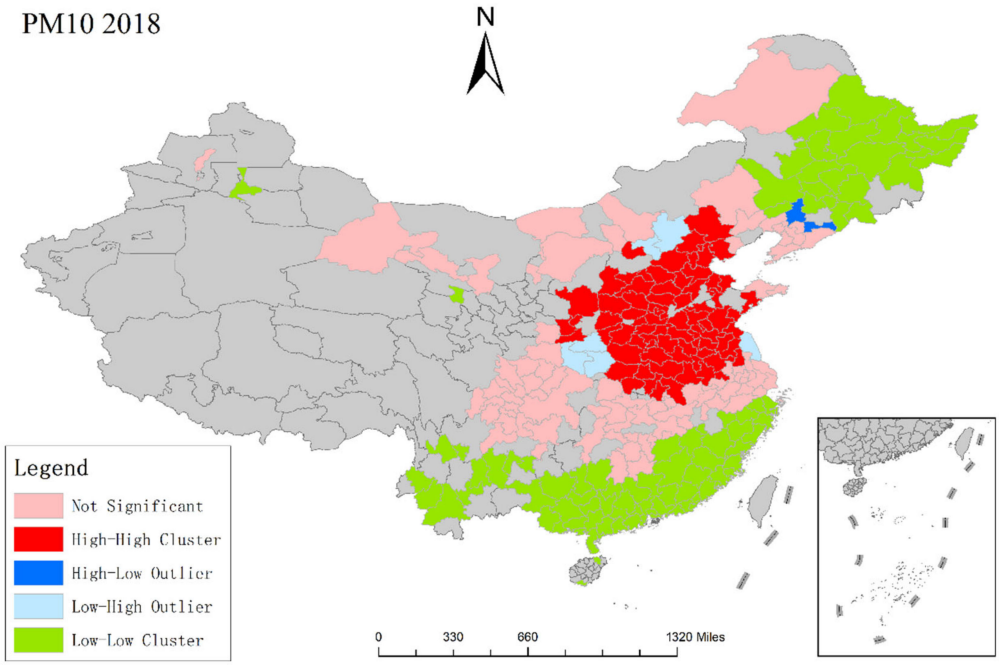
In contrast to the existing literature that controls for the spillover effect to eliminate estimation bias, this article addresses the spatial spillover effect of FDI and the local impact of FDI. Empirical studies relying on simple spatial estimators may lead to biased conclusions [3]. To identify the impacts arising from different sources, Lesage and Pace (2009) suggest reporting the summary indicators of the direct, indirect, and total effects. The calculation methods and significance of these three estimators are detailed in multiple studies [32–34].

3.2.1. Short-Term Effects

Employing a dynamic panel enables us to distinguish the impact of the explanatory variables on the explained variables in the long term and short term. Table 3 reports the short-term direct, indirect, and total effects of the explanatory variables on air pollutants.

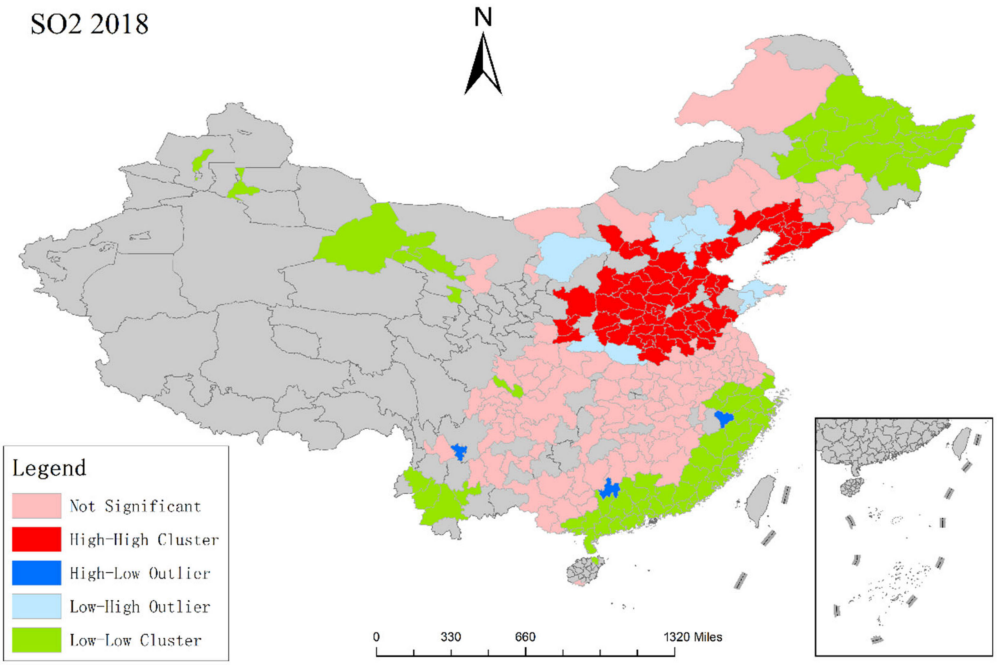


(**a**)

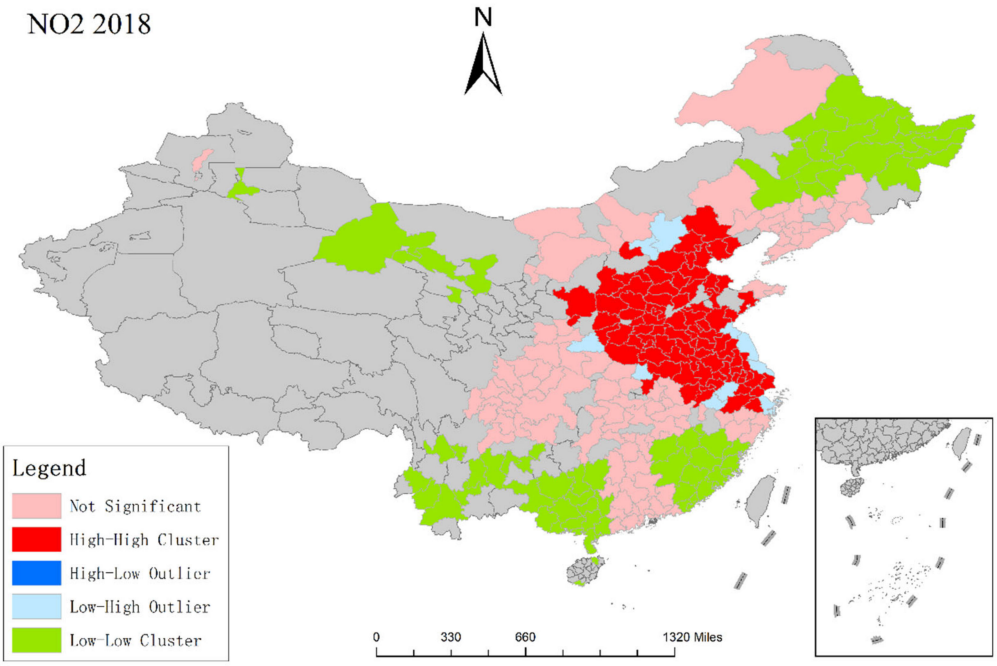


(**b**)

Figure 1. *Cont*.

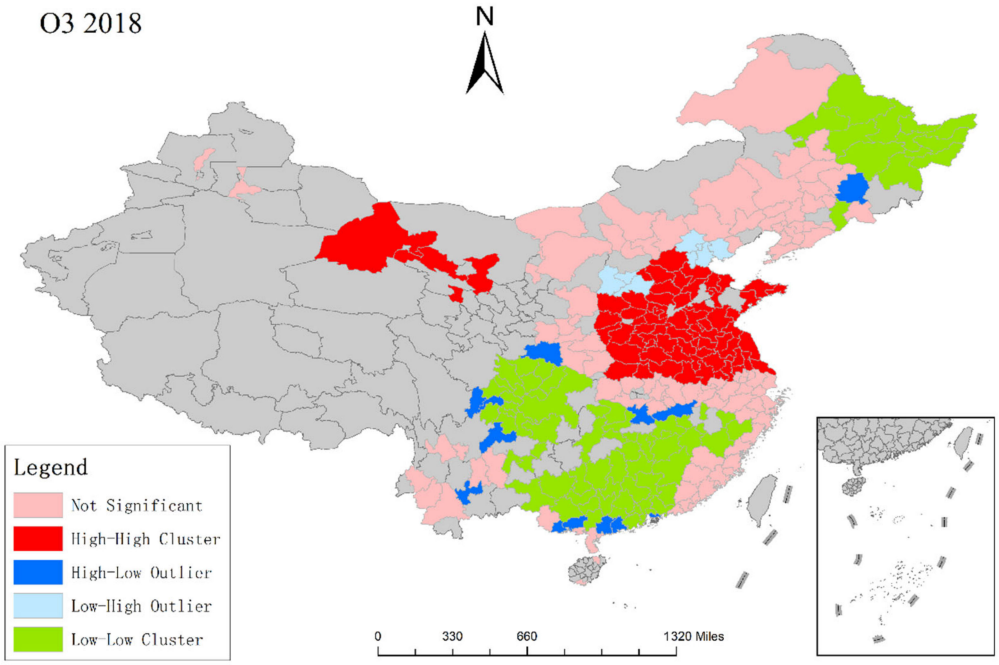


(**c**)

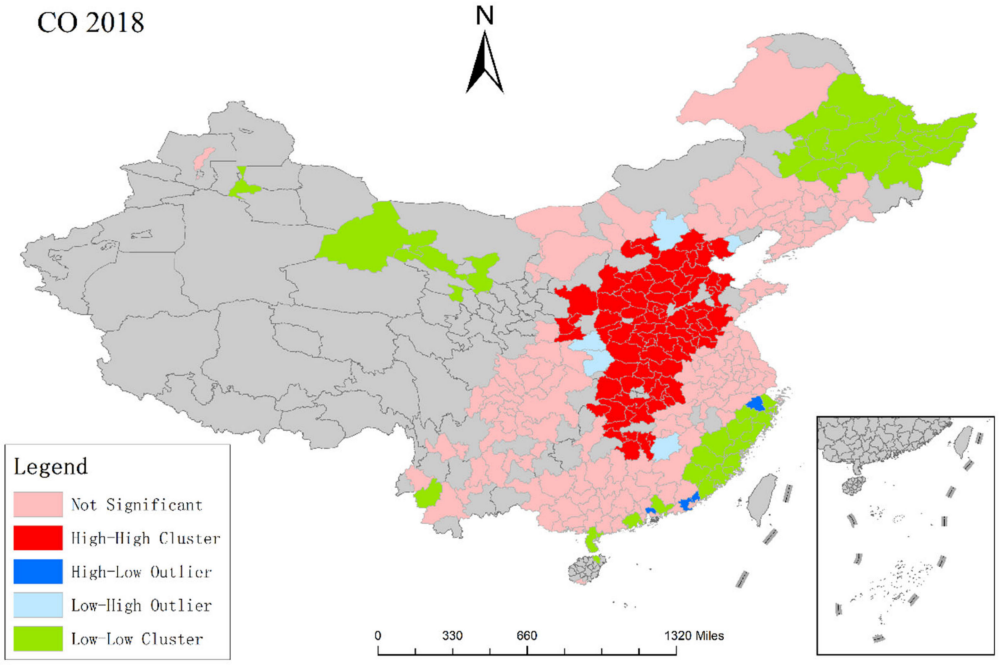


(**d**)

Figure 1. *Cont.*

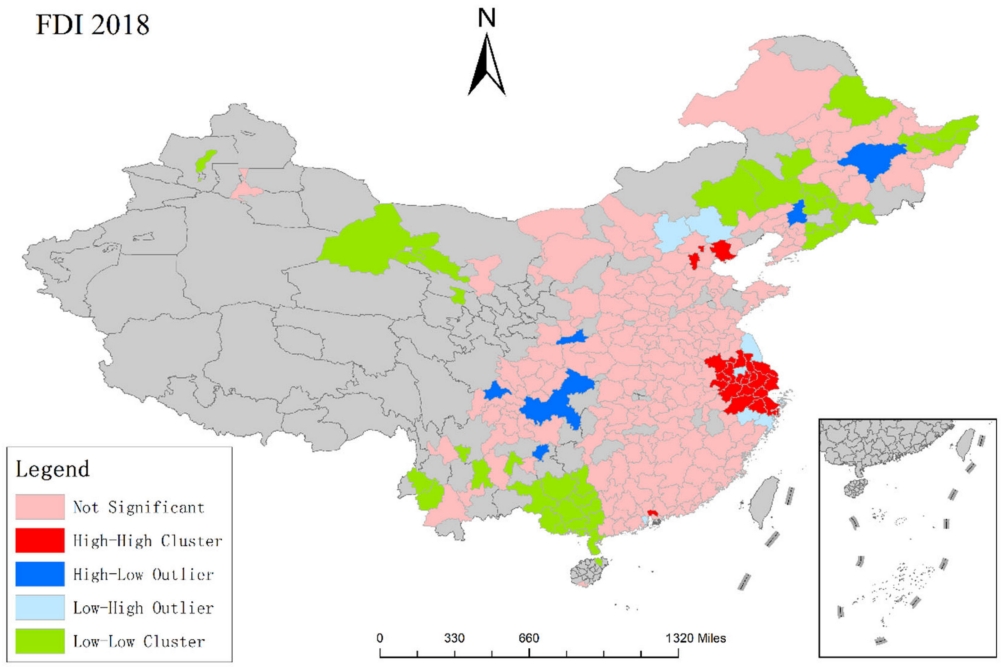


(**e**)



(**f**)

Figure 1. *Cont*.



(**g**)

Figure 1. The LISA maps of the six air pollutants and FDI of 2018: (**a**–**g**) denote the LISA maps of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, CO, and FDI in 2018, respectively. Note: this map is based on the balanced panel data of 259 cities; however, the cities for which data are missing are also listed here, colored in gray. The map was created by using the cluster-outlier analysis function of software ArcMap 10.7.

Table 3. Statistical results indicating FDI's short-term pollution effects based on the dynamic SDM.

Explanatory Variables	Explained Variables				
	Ln(PM_{10})	**Ln($PM_{2.5}$)**	**Ln(SO_2)**	**Ln(O_3)**	**Ln(CO)**
	Panel A: Statistical results indicating direct effects				
Ln(FDI/GDP)	−0.0154 ***	−0.0374 ***	−0.00905 **	−0.00381	−0.00139
	(0.00330)	(0.00304)	(0.00395)	(0.00263)	(0.00818)
Ln(GDP/Pop)	−21.48 ***	1.267 *	−42.27 ***	−10.26 ***	−0.154
	(0.961)	(0.727)	(0.802)	(0.466)	(0.484)
$Ln(GDP/Pop)^2$	1.008 ***	−0.0661 *	1.970 ***	0.481 ***	0.0152
	(0.0457)	(0.0345)	(0.0367)	(0.0215)	(0.0248)
Ln(Tech/Pop)	−0.0464 ***	−0.0579 ***	−0.0866 ***	−0.0269 ***	−0.0722 **
	(0.00613)	(0.00584)	(0.00937)	(0.00512)	(0.0326)
Ln(Pop)	1.065 ***	2.486 ***	0.859 ***	0.139	0.810
	(0.140)	(0.112)	(0.174)	(0.0903)	(1.038)
Ln(AW)	−0.471 ***	−0.513 ***	−0.695 ***	−0.132 ***	−0.447 ***
	(0.0451)	(0.0417)	(0.0662)	(0.0344)	(0.0893)
SI	0.00575 ***	0.0143 ***	0.00401 ***	−0.000515 ***	−0.0164
	(0.000523)	(0.000346)	(0.000360)	(0.000144)	(0.0106)
ln(FC/Pop)	−0.0711 ***	−0.305 ***	−0.00411	0.00234	0.0638 ***
	(0.0116)	(0.00890)	(0.0133)	(0.00757)	(0.0169)
Ln(Total Energy/Pop)	0.905 ***	0.955 ***	1.595 ***	0.270 ***	−0.614 ***
	(0.116)	(0.0960)	(0.168)	(0.0838)	(0.147)
Ln(Thermal/Pop)	0.0812 *	0.212 ***	0.00595	−0.00555	−0.443 *
	(0.0460)	(0.0416)	(0.0611)	(0.0381)	(0.246)
Ln(Tra1/Pop)	−0.0677 ***	−0.127 ***	−0.0383 **	−0.0292 ***	0.0809 ***
	(0.0121)	(0.0112)	(0.0192)	(0.0110)	(0.0108)
Ln(Tra2/Pop)	0.0798 ***	0.0645 ***	0.109 ***	0.0528 ***	−0.0343 **
	(0.00903)	(0.00925)	(0.0101)	(0.00897)	(0.0161)

Table 3. *Cont.*

Explanatory Variables	Explained Variables				
	Ln(PM_{10})	**Ln($PM_{2.5}$)**	**Ln(SO_2)**	**Ln(O_3)**	**Ln(CO)**
	Panel B: Statistical results indicating indirect effects				
Ln(FDI/GDP)	0.207 ***	0.723 ***	5.649 ***	0.210 ***	−0.00367
	(0.00744)	(0.0293)	(0.232)	(0.00674)	(0.00755)
Ln(GDP/Pop)	−161.8 ***	−744.5 ***	−5651 ***	−125.4 ***	−0.193
	(0.989)	(4.359)	(134.4)	(1.383)	(0.442)
$Ln(GDP/Pop)^2$	7.612 ***	34.93 ***	265.1 ***	5.880 ***	0.0102
	(0.0464)	(0.203)	(6.311)	(0.0647)	(0.0231)
Ln(Tech/Pop)	−0.0757 ***	0.116 *	−0.0275	−0.0209	−0.0172
	(0.0158)	(0.0701)	(0.464)	(0.0284)	(0.0324)
Ln(Pop)	−13.37 ***	−54.74 ***	−393.3 ***	−9.899 ***	0.531
	(0.170)	(0.588)	(10.53)	(0.264)	(1.030)
Ln(AW)	0.452 ***	2.157 ***	19.02 ***	0.377 ***	−0.0630
	(0.0521)	(0.134)	(1.036)	(0.0623)	(0.0898)
SI	−0.105 ***	−0.329 ***	−2.239 ***	−0.0454 ***	−0.00543
	(0.00170)	(0.00849)	(0.0791)	(0.00262)	(0.0105)
ln(FC/Pop)	2.149 ***	7.991 ***	56.81 ***	1.435 ***	0.00971
	(0.0244)	(0.110)	(1.438)	(0.0561)	(0.0169)
Ln(Total Energy/Pop)	−2.316 ***	−5.753 ***	−28.30 ***	−1.307 ***	−0.0584
	(0.137)	(0.523)	(3.332)	(0.153)	(0.132)
Ln(Thermal/Pop)	−0.288 ***	−1.596 ***	−16.87 ***	−0.0240	0.151
	(0.0436)	(0.138)	(0.911)	(0.0436)	(0.245)
Ln(Tra1/Pop)	0.582 ***	2.075 ***	13.50 ***	−0.243 ***	−0.00393
	(0.0234)	(0.0839)	(0.616)	(0.0359)	(0.00825)
Ln(Tra2/Pop)	0.125 ***	−0.108	−3.177 ***	0.532 ***	−0.00515
	(0.0230)	(0.0933)	(0.592)	(0.0348)	(0.0138)
	Panel C: Statistical results indicating total effects				
Ln(FDI/GDP)	0.191 ***	0.685 ***	5.640 ***	0.206 ***	−0.00505 **
	(0.00747)	(0.0290)	(0.232)	(0.00753)	(0.00214)
Ln(GDP/Pop)	−183.3 ***	−743.3 ***	−5693 ***	−135.7 ***	−0.347
	(0.881)	(4.623)	(134.9)	(1.557)	(0.289)
$Ln(GDP/Pop)^2$	8.620 ***	34.87 ***	267.1 ***	6.361 ***	0.0254 *
	(0.0414)	(0.215)	(6.337)	(0.0729)	(0.0138)
Ln(Tech/Pop)	−0.122 ***	0.0579	−0.114	−0.0478	−0.0894 ***
	(0.0171)	(0.0698)	(0.468)	(0.0296)	(0.00616)
Ln(Pop)	−12.30 ***	−52.26 ***	−392.4 ***	−9.760 ***	1.341 ***
	(0.152)	(0.600)	(10.56)	(0.273)	(0.0624)
Ln(AW)	−0.0193	1.644 ***	18.32 ***	0.245 ***	−0.510 ***
	(0.0292)	(0.122)	(1.034)	(0.0494)	(0.0113)
SI	−0.0990 ***	−0.315 ***	−2.235 ***	−0.0459 ***	−0.0219 ***
	(0.00163)	(0.00824)	(0.0792)	(0.00262)	(0.000544)
ln(FC/Pop)	2.078 ***	7.686 ***	56.81 ***	1.437 ***	0.0735 ***
	(0.0226)	(0.108)	(1.444)	(0.0570)	(0.00943)
Ln(Total Energy/Pop)	−1.411 ***	−4.798 ***	−26.71 ***	−1.037 ***	−0.673 ***
	(0.169)	(0.568)	(3.420)	(0.183)	(0.0437)
Ln(Thermal/Pop)	−0.207 ***	−1.383 ***	−16.87 ***	−0.0296	−0.292 ***
	(0.0424)	(0.154)	(0.945)	(0.0411)	(0.0107)
Ln(Tra1/Pop)	0.515 ***	1.948 ***	13.47 ***	−0.272 ***	0.0769 ***
	(0.0185)	(0.0807)	(0.618)	(0.0341)	(0.00617)
Ln(Tra2/Pop)	0.205 ***	−0.0438	−3.068 ***	0.585 ***	−0.0394 ***
	(0.0197)	(0.0893)	(0.591)	(0.0345)	(0.0114)

Robust standard errors are in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The dynamic term of NO_2 is omitted due to collinearity; therefore, results regarding the short-term effect of NO_2 are not available. In Table 3, Panel A, the coefficients of FDI/GDP on PM_{10}, $PM_{2.5}$, and SO_2 are significant and negative and those on O_3 and CO are negative but insignificant. The coefficients in Panel A indicate the local-to-local effect of FDI on air pollution. Therefore, the statistical results support a reverse correlation between FDI inflow and local air pollution, which supports the pollution halo hypothesis from the local-to-local perspective. The results are robust across pollutant types.

Panel B presents the coefficients indicating indirect effects (namely the local-to-surroundings effect). The coefficients of FDI/GDP on PM_{10}, $PM_{2.5}$, SO_2, and O_3 are significantly positive and those on CO are insignificant. The results indicate FDI inflow shows direct correlation with air pollution in the surrounding areas. While Panel A indicates FDI shows the pollution halo effect from the local-to-local perspective, the results in Panel B may reveal a more complex channel of FDI inflow to air quality of the surrounding areas. Panel C shows the effects from a total perspective. The results are highly consistent with indirect effects because the magnitudes of the coefficients in Panel B overwhelm those in Panel A, which generates the main findings that during 2013–2018 the pollution halo effect generally existed while FDI may have threatened air quality in the surrounding areas to a greater extent.

The direction of the direct effects (Panel A) of most variables (*Tech/Pop*, *AW*, *FC/Pop*, *Total Energy/Pop*, *Thermal/Pop*, *Tra2/Pop*) on air pollution is consistent with general un-

derstandings. For example, the negative coefficients of *Tech/Pop*, *AW*, and *FC/Pop* can be explained by the fact that the technology development, human resource quality, and ecological construction level benefits the air quality. The positive coefficients of variables indicating energy generation, consumption, and transportation volume can be explained by the fact that more emissions are positively correlated to the air pollution level.

3.2.2. Long-Term Effects

The coefficients of the direct and indirect effects of FDI and other variables on air pollution are consistent with the short-term case, among which the short-term and long-term effects of FDI/GDP on PM_{10} and SO_2 are robust while the long-term effects on $PM_{2.5}$ (Table 4 Panel A and B) are insignificant. Furthermore, the effects of FDI on O_3 and CO are not robust/significant, which indicate the correlations between FDI and these pollutant types are weak. Since the temporal lag terms in the regression of NO_2 are omitted, the insignificant coefficients may result from the setting of the models instead of a weak correlation between FDI and NO_2.

Table 4. Statistical results indicating FDI's long-term pollution effects based on dynamic SDM.

Explanatory Variables	Explained Variables					
	Ln(PM_{10})	**Ln($PM_{2.5}$)**	**Ln(SO_2)**	**Ln(NO_2)**	**Ln(O_3)**	**Ln(CO)**
Panel A: Statistical results indicating direct effects						
Ln(FDI/GDP)	−0.0478 ***	−5.484	−0.214 ***	−0.00195	0.00637	0.0104 **
	(0.0113)	(86.28)	(0.0361)	(0.00542)	(0.0575)	(0.00436)
Ln(GDP/Pop)	−78.90 ***	3815	−72.67 ***	3.341 ***	−43.11 *	0.428
	(2.550)	(62,208)	(22.80)	(0.871)	(22.37)	(0.476)
$Ln(GDP/Pop)^2$	3.703 ***	−179.4	3.338 ***	−0.156 ***	2.020 *	−0.0170
	(0.121)	(2924)	(1.072)	(0.0402)	(1.050)	(0.0229)
Ln(Tech/Pop)	−0.163 ***	−4.008	−0.482 ***	−0.0145	−0.0862 ***	−0.0128 *
	(0.0217)	(59.84)	(0.0492)	(0.0102)	(0.0215)	(0.00756)
Ln(Pop)	3.340 ***	399.9	16.15 ***	−0.264	−0.422	−0.912 ***
	(0.457)	(6300)	(2.027)	(0.230)	(2.546)	(0.155)
Ln(AW)	−1.623 ***	−36.89	−4.430 ***	0.208 **	−0.383 *	−0.250 ***
	(0.154)	(560.6)	(0.415)	(0.104)	(0.225)	(0.0840)
SI	0.0172 ***	2.354	0.0870 ***	−0.00240 **	−0.00567	0.00203 ***
	(0.00126)	(36.95)	(0.0113)	(0.00119)	(0.0114)	(0.000290)
ln(FC/Pop)	−0.189 ***	−55.13	−1.664 ***	−0.0255	0.133	0.0317 ***
	(0.0301)	(869.8)	(0.285)	(0.0201)	(0.371)	(0.00937)
Ln(Total Energy/Pop)	3.082 ***	80.60	9.716 ***	0.0113	0.733	−0.388 **
	(0.402)	(1228)	(0.906)	(0.219)	(0.558)	(0.169)
Ln(Thermal/Pop)	0.274 *	18.69	0.520	−0.207 *	−0.0189	−0.816 ***
	(0.159)	(274.6)	(0.333)	(0.121)	(0.122)	(0.0985)
Ln(Tra1/Pop)	−0.219 ***	−17.07	−0.604 ***	0.0142	−0.113 **	0.0823 ***
	(0.0408)	(260.3)	(0.132)	(0.0124)	(0.0445)	(0.0137)
Ln(Tra2/Pop)	0.280 ***	4.277	0.699 ***	−0.0451 ***	0.213 **	−0.0145 *
	(0.0311)	(56.40)	(0.0646)	(0.0168)	(0.0895)	(0.00857)
Panel B: Statistical results indicating indirect effects						
Ln(FDI/GDP)	0.212 ***	5.879	1.470 ***	−0.718	0.151 ***	−0.0155 ***
	(0.0114)	(86.28)	(0.0638)	(0.709)	(0.0573)	(0.00409)
Ln(GDP/Pop)	−78.69 ***	−4244	−1195 ***	241.6 **	−60.12 ***	−0.778 *
	(2.330)	(62,208)	(17.99)	(96.26)	(22.22)	(0.413)
$Ln(GDP/Pop)^2$	3.707 ***	199.5	56.15 ***	−10.81 **	2.819 ***	0.0426 **
	(0.110)	(2924)	(0.845)	(4.473)	(1.043)	(0.0191)
Ln(Tech/Pop)	0.0582 ***	4.042	0.457 ***	−2.345	0.0499 *	−0.0772 ***
	(0.0206)	(59.85)	(0.109)	(1.686)	(0.0268)	(0.00739)
Ln(Pop)	−13.92 ***	−430.1	−103.6 ***	1.959	−7.003 ***	2.262 ***
	(0.436)	(6300)	(1.705)	(15.90)	(2.537)	(0.138)
Ln(AW)	1.606 ***	37.84	8.511 ***	−0.299	0.570 **	−0.263 ***
	(0.154)	(560.6)	(0.474)	(2.707)	(0.231)	(0.0890)
SI	−0.102 ***	−2.536	−0.585 ***	−0.462 **	−0.0292 ***	−0.0240 ***
	(0.00193)	(36.95)	(0.0140)	(0.212)	(0.0112)	(0.000646)
ln(FC/Pop)	1.976 ***	59.57	14.32 ***	−2.975	0.961 ***	0.0423 ***
	(0.0339)	(869.8)	(0.286)	(3.039)	(0.367)	(0.0120)
Ln(Total Energy/Pop)	−4.294 ***	−83.37	−15.66 ***	−4.910	−1.522 ***	−0.288 *
	(0.336)	(1228)	(0.822)	(11.34)	(0.541)	(0.155)
Ln(Thermal/Pop)	−0.452 ***	−19.49	−4.278 ***	3.586	−0.00363	0.522 ***
	(0.144)	(274.6)	(0.270)	(2.705)	(0.112)	(0.0953)
Ln(Tra1/Pop)	0.662 ***	18.20	3.604 ***	0.512	−0.0939*	−0.00483
	(0.0455)	(260.3)	(0.180)	(0.691)	(0.0495)	(0.0127)
Ln(Tra2/Pop)	−0.104 ***	−4.302	−1.382 ***	−1.373	0.231 ***	−0.0252 *
	(0.0374)	(56.41)	(0.165)	(1.912)	(0.0890)	(0.0147)

Table 4. *Cont.*

Explanatory Variables	Explained Variables					
	Ln(PM_{10})	**Ln($PM_{2.5}$)**	**Ln(SO_2)**	**Ln(NO_2)**	**Ln(O_3)**	**Ln(CO)**
	Panel C: Statistical results indicating total effects					
Ln(FDI/GDP)	0.164 ***	0.396 ***	1.256 ***	−0.720	0.157 ***	−0.00509 **
	(0.00643)	(0.0166)	(0.0475)	(0.710)	(0.00572)	(0.00216)
Ln(GDP/Pop)	−157.6 ***	−429.4 ***	−1268 ***	245.0 **	−103.2 ***	−0.350
	(0.752)	(2.307)	(7.900)	(96.31)	(1.146)	(0.291)
$Ln(GDP/Pop)^2$	7.410 ***	20.14 ***	59.49 ***	−10.97 **	4.839 ***	0.0256 *
	(0.0353)	(0.108)	(0.372)	(4.476)	(0.0536)	(0.0139)
Ln(Tech/Pop)	−0.105 ***	0.0334	−0.0255	−2.360	−0.0363	−0.0900 ***
	(0.0147)	(0.0403)	(0.104)	(1.691)	(0.0225)	(0.00620)
Ln(Pop)	−10.58 ***	−30.19 ***	−87.41 ***	1.694	−7.425 ***	1.349 ***
	(0.130)	(0.329)	(1.017)	(15.90)	(0.207)	(0.0628)
Ln(AW)	−0.0166	0.950 ***	4.081 ***	−0.0913	0.187 ***	−0.513 ***
	(0.0251)	(0.0700)	(0.209)	(2.736)	(0.0376)	(0.0114)
SI	−0.0851 ***	−0.182 ***	−0.498 ***	−0.464 **	−0.0349 ***	−0.0220 ***
	(0.00140)	(0.00467)	(0.0116)	(0.213)	(0.00198)	(0.000547)
ln(FC/Pop)	1.786 ***	4.440 ***	12.65 ***	−3.000	1.093 ***	0.0740 ***
	(0.0194)	(0.0618)	(0.157)	(3.052)	(0.0429)	(0.00949)
Ln(Total Energy/Pop)	−1.213 ***	−2.772 ***	−5.948 ***	−4.899	−0.789 ***	−0.677 ***
	(0.145)	(0.328)	(0.743)	(11.24)	(0.139)	(0.0440)
Ln(Thermal/Pop)	−0.178 ***	−0.799 ***	−3.757 ***	3.378	−0.0225	−0.294 ***
	(0.0365)	(0.0886)	(0.197)	(2.687)	(0.0312)	(0.0108)
Ln(Tra1/Pop)	0.442 ***	1.125 ***	2.999 ***	0.526	−0.207 ***	0.0774 ***
	(0.0159)	(0.0465)	(0.120)	(0.692)	(0.0259)	(0.00621)
Ln(Tra2/Pop)	0.176 ***	−0.0253	−0.683 ***	−1.418	0.445 ***	−0.0397 ***
	(0.0170)	(0.0516)	(0.130)	(1.919)	(0.0261)	(0.0115)

Robust standard errors are in parentheses, and *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In brief, although FDI, to some extent, shows heterogeneous effects across the pollutants, it generally shows reverse correlation with the air pollution of host cities but direct correlation with air pollution in the outer conurbation areas.

3.3. Heterogeneity of FDI's Pollution Effect

The existing literature generally recognizes the heterogeneity of FDI's pollution effect; however, there is a lack of comprehensive heterogeneity analyses on urban variables under the spatial view which can provide valuable information for interregional cooperation in green development regarding FDI.

The results of these regressions are shown in Table 5 panels A–C. The *Main* coefficient indicates the moderating function of the studied variables on FDI's local-to-local effect. For example, if the main coefficient is significantly positive, the higher the value of the variable of the host city, and the FDI inflow is correlated with higher air pollution of the host city. The *Wx* coefficient indicates the moderating function of the studied variables on FDI's local-to-surroundings (or surroundings-to-local) effect. Specifically, if this coefficient is significantly positive: the larger the variable of the host city, the more FDI is correlated with air pollution in the outer conurbation areas.

Table 5. Heterogeneity of FDI's effect across key urban characteristics.

Variables	$Ln(PM_{10})$		$Ln(PM_{2.5})$		$Ln(SO_2)$		$Ln(O_3)$		Ln(CO)	
	Main	**Wx**	**Main**	**Wx**	**Main**	**Wx**	**Main**	**Wx**	**Main**	**Wx**
Panel A: Heterogeneity on Industrialization Stage (*IS*)										
Ln(FDI/GDP)	−0.0277 ***	−7.566 ***	−0.0291 ***	−7.213 ***	−0.0292 ***	−10.39 ***	−0.00857 *	−3.189 ***	0.0427 ***	−2.706 ***
	(0.00517)	(0.0799)	(0.00546)	(0.0722)	(0.0103)	(0.105)	(0.00458)	(0.0506)	(0.0156)	(0.201)
Interaction term	0.0158 ***	5.665 ***	0.0181 ***	5.468 ***	0.0206 **	7.724 ***	−0.00516	1.335 ***	0.00144	2.516 ***
	(0.00389)	(0.0704)	(0.00509)	(0.0610)	(0.00841)	(0.0891)	(0.00325)	(0.0352)	(0.0116)	(0.152)
R^2	0.009	0.009	0.442	0.442	0.323	0.323	0.003	0.003	0.012	0.012
Panel B: Heterogeneity on Ecological Construction (*EC/Pop*)										
Ln(FDI/GDP)	0.0696 ***	1.725 ***	0.0650 ***	1.595 ***	0.110 ***	2.106 ***	−0.0203 ***	−2.383 ***	0.000513	0.820 **
	(0.00646)	(0.107)	(0.00624)	(0.112)	(0.0101)	(0.195)	(0.00692)	(0.0765)	(0.0214)	(0.350)
Interaction term	−0.0344 ***	−1.031 ***	−0.0321 ***	−0.919 ***	−0.0524 ***	−1.426 ***	0.00121	0.546 ***	0.00535	−0.328 **
	(0.00201)	(0.0413)	(0.00219)	(0.0427)	(0.00379)	(0.0765)	(0.00209)	(0.0310)	(0.00837)	(0.136)
R^2	0.601	0.601	0.525	0.525	0.359	0.359	0.001	0.001	0.018	0.018
Panel C: Heterogeneity on Technology Development (*Tech/Pop*)										
Ln(FDI/GDP)	0.184 ***	5.353 ***	0.169 ***	4.996 ***	0.297 ***	8.028 ***	0.0608 ***	0.398 ***	−0.0347	0.291
	(0.00981)	(0.124)	(0.0104)	(0.122)	(0.0133)	(0.205)	(0.00739)	(0.0819)	(0.0288)	(0.268)
Interaction term	−0.0490 ***	−1.683 ***	−0.0449 ***	−1.542 ***	−0.0769 ***	−2.556 ***	−0.0178 ***	−0.278 ***	0.0119 *	−0.0626
	(0.00239)	(0.0304)	(0.00255)	(0.0311)	(0.00334)	(0.0500)	(0.00166)	(0.0230)	(0.00722)	(0.0692)
R^2	0.583	0.583	0.501	0.501	0.362	0.362	0.006	0.006	0.011	0.011
Control variables	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dynamic factor: τ	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Spatial factor: ρ	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290
City ID	258	258	258	258	258	258	258	258	258	258

Robust standard errors are in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The *Main* coefficient of the interaction term of FDI and IS (Table 5 Panel A) is significantly positive for PM_{10} ($p < 0.01$), PM25 ($p < 0.01$), and SO_2 ($p < 0.05$), and insignificant for O_3 and CO. The spatially weighted coefficient of the interaction term, *Wx*, is significantly positive at the 1% level and larger in magnitude for all pollutants. This result implies that the IS (ratio of tertiary to secondary industry) can intensify FDI's pollution effect. In other words, FDI inflows to cities with higher tertiary industry ratios have a larger air pollution effect on the host city and even larger spillovers to neighboring cities. Areas with a higher IS are special economic zones: Beijing, Shanghai, Shenzhen, and tourist cities, and tourist cities account for the majority. These cities are characterized by low background concentrations of pollutants and underdeveloped industries (heavy industries in special economic zones are being reallocated to the outer conurbation areas). The relationship between pollution emissions and air quality usually has a marginal diminishing relationship. Therefore, the inflow of unit FDI into areas with better air quality has a greater marginal effect on pollution. Since the industrial sector is still an important flow of FDI, this suggests that special economic zones dominated by financial and service industries and tourist destination cities with better ecological conditions should pay more attention to introducing clean FDI from the service industry.

The *Main* coefficient and *Wx* coefficient of the interaction terms in Panel C and Panel D (*FDI* × *EC* and *FDI* × *Tech*) are all significantly negative at the 1% level for most of the pollutants (PM_{10}, $PM_{2.5}$, and SO_2), which indicate that the ecological construction level and technological development play a significant role in helping FDI achieve the pollution halo effect, to both the local and outer conurbation areas. The findings regarding FDI heterogeneity across ecological construction and technological development are consistent with expectations and findings in the existing literature [12].

3.4. Potential Channels

Section 3.3 explores the moderating effect of four urban variables which are not necessary to correlate with FDI inflows. However, FDI can affect air quality through several channels which can be explored by analyzing the potential mediators. Different from the moderating effect, the potential mediators must have a significant correlation with FDI. Therefore, this section studies the potential channels of FDI's pollution effects via Model (10). The control variables are the same as Table 3 unless extra clarification is required. Table 6 reports the results.

This section first examines FDI's contribution to the technology development of a city. As shown in Table 6, the coefficient indicating the direct effect of FDI on technology development is significantly positive ($p < 0.05$) while the coefficient indicating indirect effect is insignificant. The results support that one potential channel through which FDI benefits local air quality is by promoting local technology development.

The effect of FDI on IS is examined, but the coefficients indicating direct and indirect effects are insignificant. The results illustrate that although FDI does not have a significant effect on the ratio of tertiary-to-secondary industry, there is an overall tendency that FDI flows more into the secondary industry since the coefficients are negative. Therefore, IS acts as a moderator of FDI's pollution effect.

Table 6. Potential channels through which FDI can affect air quality.

	Ln(Tech/Pop)	IS	Ln(Coal/Pop)	Ln(Gasoline/Pop)	Ln(Thermal/Pop)	Ln(Tra1/Pop)	Ln(Tra2/Pop)	Ln(AW)	Ln(EC/Pop)
Coefficients indicating the direct effect									
Ln(FDI/GDP)	0.0342 **	−0.0199	−0.0677 ***	−0.0254 *	−0.0231 ***	−0.00360	−0.0127 *	0.000720	−0.0364 *
	(0.0153)	(0.153)	(0.0151)	(0.0150)	(0.00277)	(0.00851)	(0.00720)	(0.00209)	(0.0196)
Coefficients indicating the indirect effect									
Ln(FDI/GDP)	0.0853	−0.409	0.358 ***	−2.520	1.783 ***	−0.582	0.179	0.0969	−0.0305
	(0.306)	(0.270)	(0.0120)	(3.206)	(0.0455)	(0.801)	(0.142)	(0.128)	(0.0576)
Coefficients indicating the total effect									
Ln(FDI/GDP)	0.120	−0.428 ***	0.291 ***	−2.545	1.760 ***	−0.586	0.166	0.0976	−0.0668
	(0.304)	(0.127)	−0.00806	(3.215)	(0.0464)	(0.803)	(0.145)	(0.128)	(0.0590)
Control variables	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1290	1290	1290	1290	1290	1290	1290	1290	1290
R^2	0.673	0.023	0.021	0.144	0.007	0.128	0.187	0.653	0.671
City ID	258	258	258	258	258	258	258	258	258

Robust standard errors are in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The effects of FDI on coal consumption are examined. The control variables eliminate total energy consumption and thermal power generation to avoid collinearity. The results show a significant ($p < 0.01$) negative relationship between FDI and local coal consumption but a positive relationship between FDI and coal consumption in the outer conurbation areas. The results support the main regression results and reveal one potential channel through which FDI's pollution effect is correlated with coal consumption. Coal is mainly consumed in the secondary industry and thermal power generation consumes the biggest amount of coal. Therefore, this article further examines the correlation between FDI and the thermal power generation amount. The direction and significance level of the coefficients are the same as those for coal consumption. The results are consistent with those on coal consumption and air quality, which suggest FDI's air pollution effect is significantly correlated with coal consumption and thermal power generation. Based on the fact that most big cities in China do not have thermal plants and buy electricity from the outer conurbation areas (because for environmental purposes, big cities that have higher economic development level and bigger attraction to FDI tend to reallocate the energy-intensive industry to the outer conurbation areas which seek industrial development), the empirical results warn of the potential enhancing effect of FDI on the spatial energy–supply structure, which is cause for further concern by the city managers.

The effects of FDI on the transportation sector are examined. First, this paper estimates FDI's contribution to gasoline consumption. *Tra1/Pop* and *Tra2/Pop* are eliminated from control variables to avoid collinearity. The coefficient indicating direct effect is negative but at a lower significance level ($p < 0.1$). The coefficient indicating indirect effect is insignificant. Since gasoline is the main fuel of vehicles and most of the gasoline is consumed in the transportation sector, the results indicate that FDI's effect in the transportation sector is not as big or significant as that in the industrial sector. This article further estimates FDI's effect on highway passenger volume and highway freight volume, and the results support the statement.

This article further examines the correlation between FDI and average wage, and between FDI and ecological construction. The coefficients are insignificant, or significant at a low level ($0.05 < p < 0.1$). Therefore, EC acts more like a moderator instead of a channel variable.

4. Conclusions and Policy Implications

Between 2013 and 2018, FDI showed a reverse correlation with local air pollution, which supports the existence of the pollution halo hypothesis. This finding is consistent with multiple articles that study the existence of PHH in China and other countries [11,12]. However, there is a direct correlation between FDI and air pollution in the outer conurbation areas. Some literature does report the spatial pollution spillover of FDI while reporting the pollution haven effect of FDI [9]. However, the existing literature has not reported the finding, by these authors, that FDI shows direct correlation with air pollution in the outer conurbation areas while it has a positive effect on local air quality. Therefore, this finding has become the main interest of this article.

In the heterogeneity analysis, this article finds that the industrialization stage, ecological construction level, and technology development level have a significant moderating effect on FDI's pollution effect. FDI tends to show a higher marginal effect on air pollution in cities with a higher tertiary-to-secondary industry ratio. According to the statistical data, cities with higher IS are mostly tourist destination cities. The common characteristic of these cities is that the background air pollution concentration is small. Therefore, the moderating effect of IS is consistent with the marginal diminishing relationship between emissions and air pollution. In addition, this article finds that FDI tends to show a lower marginal effect on air pollution in cities with higher technology development levels and ecological construction levels.

In the analysis of potential channels through which FDI affects air quality, the coefficients of FDI on coal consumption and the thermal power generation amount are consistent with the main findings; meanwhile, the coefficients of FDI on variables from

transportation sectors and urban-specific characteristics are insignificant or significant at a low level ($0.05 < p<0.01$). These results further validate the main findings by providing a potential channel where FDI shows direct correlation with coal consumption and the thermal generation amount of the outer conurbation areas. One explanation is that FDI increases the electricity consumption of host cities, which are usually big cities that buy electricity from the nearby cities. In addition, the direct correlation between FDI and local technological development supports that FDI may improve the air quality by bringing advanced technology, which is the main mechanism of the pollution halo hypothesis stated in the existing literature.

The findings generally support the existence of the pollution halo effect of FDI in China in the past few years and provide primary evidence of FDI's direct correlation with air pollution concentration of the outer conurbation areas. The policy implications are mainly on the aspect of regional cooperation in green development regarding FDI. While FDI brings advanced technology into host cities, the urban and environmental managers should pay attention to the direct correlation between FDI and air pollution of the outer conurbation areas, especially in the aspect of the spatial pattern of the power supply.

Author Contributions: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Resources, Writing—Original Draft, and Visualization: X.X.; Validation, Data Curation, Writing—Review & Editing, Supervision, Project Administration, and Funding Acquisition: X.W. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found here doi:10.11922/sciencedb.00053 (9 November 2020), and http://www.stats.gov.cn/ (accessed on 1 December 2020).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

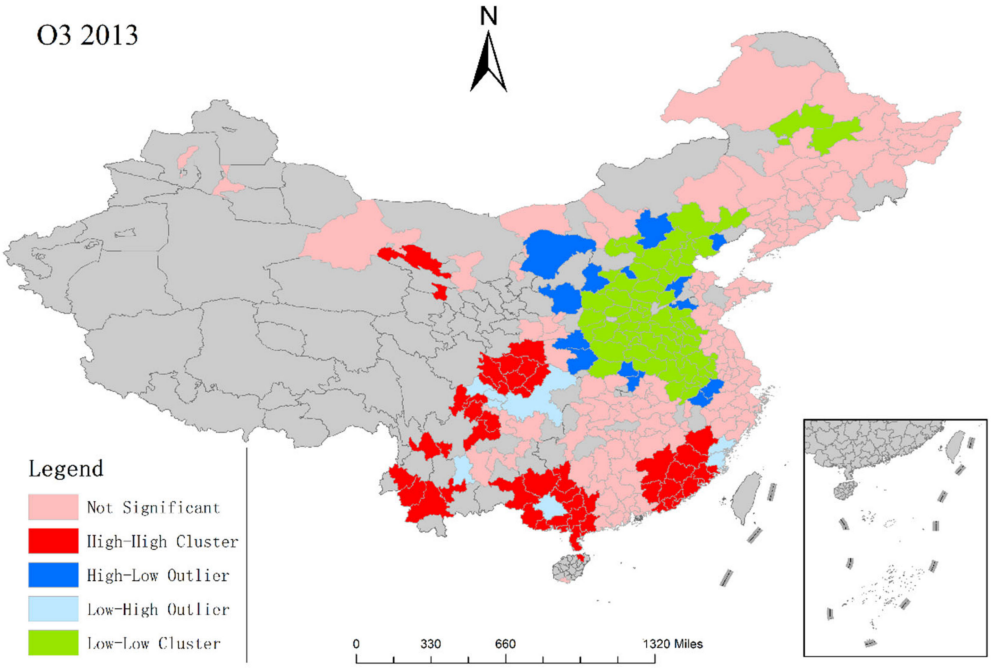
Table A1. A summary of studies that study the existence of PHH.

Authors	Period	Sample Composition	Environmental Measurements	Methodology	PHH	Heterogeneity Analysis
Panel A: PHH literature that focuses on China						
Sun, Zhang and Xu [18]	1980–2012	Time-series	CO_2 emission	ARDL	Yes.	-
Jalil and Feridun [17]	1978–2006	Time-series	CO_2 emission	ARDL	No.	-
Cheng, Li and Liu [9]	2003–2016	panel of 285 cities	$PM_{2.5}$	Dynamic SDM	Yes.	PHH tends to exist in initial industrialization stage.
Lin [35]	2004–2011	panel of 312 cities	SO_2, NO_2, aerosol	OLS	Yes.	-
Jiang [19]	1997–2012	panel of 28 provinces	SO_2 emission	FE, FD, RE, OLS, SAR	Yes. The effect is realized through the former's impacts on the input of natural resources or the industry mix.	-
Wang and Chen [1]	2002–2009	panel of 287 cities	industrial SO_2 emission	FE	Yes.	Institutional development; FDI origins: Investments from OECD countries increase sulfur dioxide emissions, whereas FDI from Hong Kong, Macau, and Taiwan show no significant effect. Institutional development reduces the impacts of FDI across the board.
Wang, Gu, Tse and Yim [24]	1999–2005	panel of 287 cities	SO_2 emissions	FE, GLS	Yes.	Institutional development; FDI origins: The host city's institutional development is found to enhance the positive impacts of FDI and reduce its negative ones and the moderating effect is smaller for ethnically linked FDI than for non-ethnically linked FDI.
Cole, Elliott and Zhang [2]	2001–2004	panel of 112 major cities	Two water pollution indicators: wastewater, petroleum-like matter; four air pollution indicators: waste gas, SO_2, dust, soot	FE, RE, GLS, G2SLS	Yes.	Origin: The share of output of domestic and foreign-owned firms increases several pollutants in a statistically significant manner while output of firms from Hong Kong, Macao, and Taiwan either reduces pollution or is statistically insignificant.
Huang, Chen, Huang and Yang [3]	2001–2012	panel of 30 provinces	Composite pollution index covering seven pollutants: industrial wastewater, COD, NO_X, industrial gas, industrial SO_2, industrial soot and dust, industrial solid waste, and a greenhouse gas	SDM	No.	Origin: FDI from Hong Kong, Macau, and Taiwan (HMT) significantly improves the host region's environmental outcome; FDI from other origins has no measurable impacts on the environmental outcome.
Zhang and Zhou [11]	1995–2010	panel of 29 provinces	CO_2 emission	FE	No. Foreign firms can export greener technologies from developed to developing countries and conduct business in an environmentally friendly manner.	Regional heterogeneity: FDI's impact on CO_2 emissions decreases from the western region to the eastern and central regions.
Hao and Liu [23]	1995–2011	panel of 29 provinces	CO_2 emission	Two-equation model; FE; GMM, SYS-GMM	No. The negative direct effect of FDI on carbon emissions dominates the positive indirect effect through FDI's influence on per capita GDP.	-
Kirkulak, Bin and Wei [10]	2001–2007	panel of 286 cities	Industrial SO_2 emission	FE; RE; GLS	No. FDIs are perceived as main sources of advanced technology in China.	Regional heterogeneity: One of the striking findings of the paper shows that FDI has no significant impact on air quality in the central and western cities. The reason is that low level of FDI inflows to cities located in the center and west.

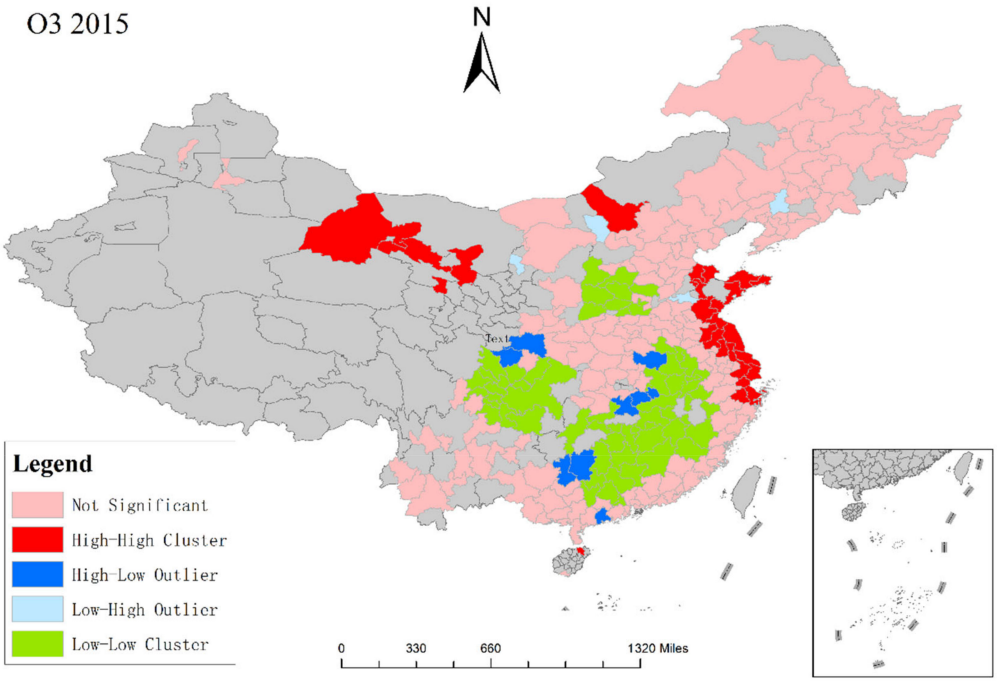
Table A1. *Cont.*

Authors	Period	Sample Composition	Environmental Measurements	Methodology	PHH	Heterogeneity Analysis
Bao, Chen and Song [12]	1992–2004	panel of 29 provinces	Industrial SO_2, industrial dust, industrial polluted water, industrial solid wastes and chemical oxygen demand in industrial water pollution	Simultaneous equations estimation; 3SLS	No. The role of FDI in pollution reduction can be mainly attributed to its technique effect.	The environmental impacts of FDI vary significantly among different regions and for different pollutants in China.
Li et al. [21]	2000–2017	panel of 30 provinces	Haze pollution	Spatial Durbin model	No. When FDI increases by 1%, haze pollution in local and neighboring areas will be reduced by 0.066% and 0.3538%, respectively.	The impact of FDI on haze pollution is heterogeneous in different stages of economic development.
Zheng et al. [36]	1997–2006	panel of 35 major cities	SO_2, PM_{10}	OLS, IV	No.	-
Cheng et al. [37]	1997–2014	panel of 30 provinces	CO_2 emission	Dynamic spatial panel models	Insignificant	-
Liu, Wang, Zhang, Zhan and Li [13]	2003–2014	panel of 285 cities	Waste soot and dust, sulfur dioxide, and wastewater	SEM; SLM	Dependent on pollutant types.	Pollutant type: the inflow of FDI was found to have reduced waste soot and dust pollution to a certain extent, while it increased the degree of wastewater and sulfur dioxide pollution.
Lan, Kakinaka and Huang [25]	1996–2006	panel of 30 provinces	Water, soot, SO_2	FE, RE	Dependent on human capital level.	FDI shows a direct correlation with pollution emissions in provinces with the higher levels of human capital; whereas, FDI is positively related to pollution emissions in provinces with the lower levels of human capital. The sign of FDI's effect on each pollutant's emission requires the different threshold level of human capital.
Panel B: PHH literature that focuses on other countries.						
Singhania and Saini [38]	1990–2016	21 developed and developing countries	CO_2 emission	GMM	Yes	FDI were detected to have significant influence on energy use in the GCC.
Shahbaz et al. [39]	1990–2015,	Middle East and North African (MENA) region	CO_2 emission	GMM	N-shaped association between FDI and CO_2 emission	
Solarin et al. [40]	1980–2012	Ghana	CO_2 emission	ARDL	Yes	
Seker et al. [41]	1974–2010	Turkey	CO_2 emission	ARDL	Yes	
Rafindadi et al. [42]	1990–2014	GCC	CO_2 emission	Pooled Mean Group	No	
Abbas et al. [43]	2001–2018	27 Asian Economies	GHGs emission	GMM	No	
Kim [44]	1981–2014	Korea	GHGs emission	ARDL	Yes. The inflow of FDI has led to the increase of greenhouse gases, but the coefficients are negligible.	

Appendix B

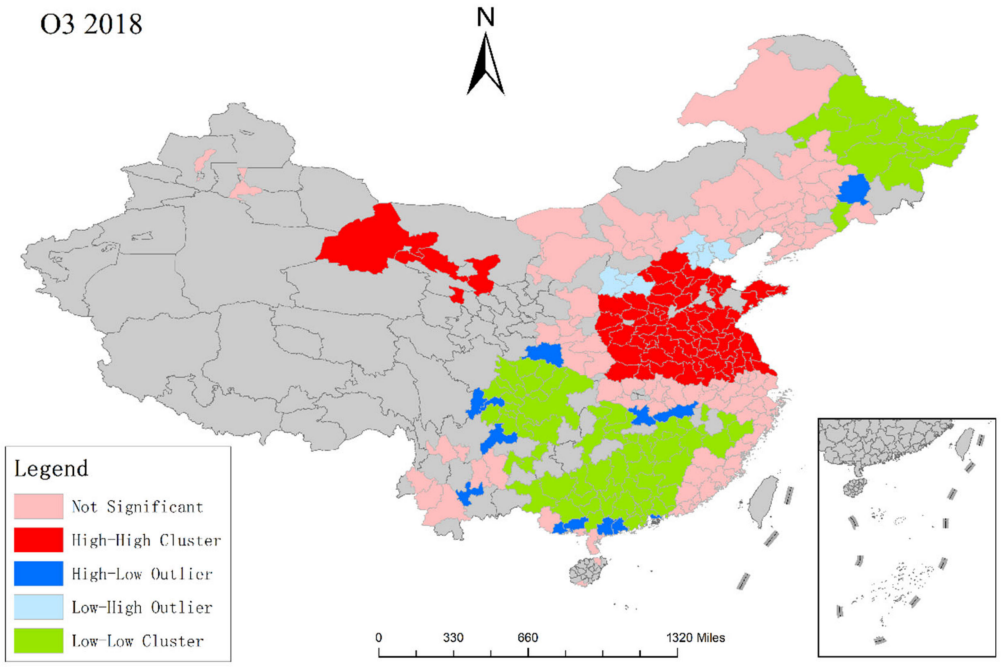


(**a**)



(**b**)

Figure A1. *Cont*.



(**c**)

Figure A1. The change of LISA of O_3, 2013–2018. (**a**–**c**) Denote LISA of O_3 in 2013, 2015, and 2018, respectively. These maps indicate O_3 has a positive spatial autocorrelation. Low-low clusters of O_3 tend to move southward, and high-high clusters tend to concentrate in the North Plain.

Appendix C

Table A2. Statistical results of the main regressions conducted with Model (8).

Explanatory Variables	Explained Variable					
	Ln($PM_{2.5}$)	**Ln(PM_{10})**	**Ln(SO_2)**	**Ln(NO_2)**	**Ln(O_3)**	**Ln(CO)**
Dynamic factor: τ	0.787 ***	0.748 ***	0.812 ***	-	0.749 ***	−0.139 **
	(0.0245)	(0.0274)	(0.0283)		(0.0270)	(0.0709)
Spatial factor: ρ	2.076 ***	5.579 ***	1.233 ***	0.931 ***	3.384 ***	22.94 ***
	(0.00417)	(0.00632)	(0.00535)	(0.00672)	(0.0110)	(0.0376)
Observations	1290	1290	1290	1548	1290	1290
R^2	0.395	0.001	0.365	0.100	0.001	0.003
City ID	258	258	258	258	258	258

Note: both the dynamic factor and spatial factor are significant at the 1% level, which supports the inclusion of the spatial and dynamic terms. However, the dynamic term is automatically omitted by STATA in the regression of $\ln NO_2$ due to collinearity. The larger values of R^2 of regressions regarding $\ln PM_{2.5}$ and $\ln SO_2$ indicate the dynamic SDM has a better explanation on these two pollutants. Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$.

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