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The Impact of Heterogeneous Environmental Regulations on Location Choices of Pollution-Intensive Firms in China

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The spatial transfer pattern and dynamic mechanisms of pollution-intensive industries are key issues for national and regional sustainable development. Although previous studies have emphasized the impact of environmental regulations on the transfer of pollution industries, there is a lack of firm-level analysis of the combined effects of different types of environmental regulations and other factors on them, which has led to the pollution haven hypothesis remaining contested. In order to provide micro evidence to test the pollution haven hypothesis, this paper reveals the temporal and spatial evolution of pollution-intensive foreign firms' distribution in China, and explores the impact of heterogeneous environmental regulations on the location choices by using spatial analysis and zero-inflated negative binomial regression. The empirical results were as follows: Firstly, pollution-intensive foreign firms were highly concentrated in the eastern developed region and have a strong path dependency in China. Secondly, environmental regulations, especially the market-based environmental regulation, had a significant negative impact on the location choices of pollution-intensive foreign firms. Thirdly, the spatial distribution of pollution-intensive foreign firms was strongly influenced by new economic and geographic factors. Fourthly, pollution-intensive foreign firms have a significant pollution border effects in developed regions but not in economically less-developed regions due to transportation costs. The governments are expected to adopt heterogeneous environmental regulations based on the level of regional economic development to avoid the pollution haven phenomenon, thus achieving a sustainable development.

Keywords: pollution-intensive firms, pollution haven hypothesis, location choice, zero-inflated negative binomial regression, border effect

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1 INTRODUCTION

Since the 1990s, the international division of labor has been continuously refined, and a new wave of global industrial restructuring has been formed (Luo et al., 2021). In the process, polluting industries have been transferred from developed countries to developing countries with lenient environmental regulations (Ghosh and Wang, 1993). However, environmental pollution and ecological damage are worsening in many countries (Bashir et al., 2021; Zhou et al., 2021), hindering the global sustainable development. Therefore, environmental regulations are implemented by many developed countries and emerging economies government to reduce the excessive concentration of pollution-intensive firms and emissions of pollution. Such as Germany, France and Italy, which have adopted environmental taxes as the environmental regulation (Sharma et al., 2021), and Singapore, Korea, Thailand and Malaysia, which have adopted command-and-control and market-based environmental regulations to avoid their negative effects (Shahzad et al., 2021; Waris et al., 2021; Paramati et al., 2022). In this background, the influencing factors and economic effects of polluting industries have become the focus of multi-disciplinary study (Tole and Koop, 2011; Ramanathan et al., 2016; Liu 2019). Since joining the WTO, China has also become an important destination for international industrial transfer (Celik and Orbay, 2011). As the largest developing country, China has become the world's manufacturing factory and reshaped the global economic geography (Xu and Li, 2021). In many emerging economies, foreign firms advance economic development, technological progress, and export expansion (Sajid and Sizhong, 2014). However, they have also caused a series of pollution (Ayamba et al., 2019), widening the development gap between countries (Wu et al., 2019). This is typical and representative for verifying whether the pollution haven hypothesis (PHH) applies to the transfer of pollution industries in emerging economies (Shen et al., 2019; Pan et al., 2021). Therefore, studies are required to analyze the combined effects of different types of environmental regulations and other factors on the location choices of pollution-intensive firms, thus providing the micro evidence to test the pollution haven hypothesis. Furthermore, this study would not only contribute to alleviating the excessive concentration of polluting enterprises so as to reduce pollution emissions (SDG-7: Affordable and clean energy; SDG-13: Climate Action) (Ishikawa and Okubo, 2017; Shahzad, 2020), but also help to promote the sustainable growth of urban economy and environment and reduce environmental inequalities between countries (SDG-10: Reduce inequality within and among countries; SDG-11: Sustainable Cities and Communities) (Laplue, 2019). It is this way that dedicates to the achievement of global sustainable development goals.

Previous studies mainly focused on the transnational transfer and economic performance of polluting industries in developed countries and developing countries (Zeng and Zhao, 2009; Cole et al., 2010; Peng et al., 2021). Some cross-sectional studies focused on agrochemical-based pollution emissions in emerging economies (Forslid et al., 2018; Elahi et al., 2019; Shahzad, 2020), but less attention has been paid to the regional spatial pattern of pollution-intensive firms (Ghazouani et al., 2021). Therefore, this paper put emphasis on tackling the following questions: 1) From the perspective of evolution, what are the characteristics of pollution-intensive foreign firms' spatial distribution, and whether there is a PHH in China? 2) Given regional and industry heterogeneity, do heterogeneous environmental regulations have a differential impact on the location choices of pollution-intensive firms? 3) Is there a border effect on the location choices of pollution-intensive firms under the influence of agglomeration economy and environmental regulations? To solve these problems, micro data of industrial firms from 1998 to 2014 was used as the basis to analyze the spatial pattern of pollution-intensive foreign firms. In addition, the differential impact of command-and-control and market-based environmental regulations on the location choices of pollution-intensive foreign firms was analyzed by using zero-inflated negative binomial regression (ZINB). This study had the following contributions: 1) Based on the new economic geography theory, the influence of factor endowment, agglomeration economy and environmental regulations on pollution-intensive firms' location choices was analyzed theoretically. 2) In previous studies, the environmental regulation was too single, failing to comprehensively reflect its heterogeneity. In this paper, environmental regulations were divided into the command-and-control and market-based types, and the heterogeneous impact of them on the location choices of pollution-intensive firms was explored with stronger policy relevance, which provided microscopic evidence to prove the pollution haven hypothesis in the emerging economies. 3) This study explored the border effect of location choices of pollution-intensive firms, revealing that the pollution border effect existed in the economically developed regions but was not significant in the economically less-developed regions.

2 REVIEW OF LITERATURE AND CONSTRUCTION OF RESEARCH HYPOTHESIS

2.1 Factor Endowments and Location Choices of Pollution-Intensive Foreign Firms

In the competitive market, the Factor Endowment Hypothesis (FEH) suggests that differences in factor endowments determine the comparative advantage of products and firms. Firms with strong demand for production factors of diverse types tend to locate in regions with abundant endowment factors. The pollution-intensive foreign firms are located in material production areas to take advantage of natural factor endowments (Levinson and Taylor, 2008). For example, Sukkoo (1995) found that natural factor endowments had a significant impact on the placement of pollution-intensive industries in the United States. The comparative advantage of pollution-intensive products is also derived from relative factor endowment differences and influences the location choices of pollution-intensive firms. For example, Tobey (1990) used 11-item factor endowment variables such as capital, labor, technology and land to analyze these factor's impact on the location choices of pollution-intensive firms. In addition, based on the Heckscher-Ohlin-Vanek (HOV) model, Lu (2009) also found that human capital and raw material endowments had comparative advantages for pollution-intensive firms. Based on the above analysis, hypothesis one is proposed: The location choice of pollution-intensive foreign firms is positively influenced by the factor endowments effect.

2.2 Economic Agglomeration and the Location Choices of Pollution-Intensive Foreign Firms

The location choices of pollution-intensive firms are influenced by transportation costs. For example, Holl (2004) found that foreign firms prefer to locate areas with better transportation accessibility. The tax rate also affects the location choices of foreign firms. In addition, foreign firms have an “outsider disadvantage” in purchasing raw materials and discovering markets (He, 2003). Therefore, factors such as transportation, tax and information costs influence the location choices of pollution-intensive firms through the production cost effect (Zhao and Zhao, 2014). Krugman (1991) has found that under the impact of increasing transportation costs, location choices of firms are mainly concentrated in areas with higher market demand. Based on the core-periphery model, Quaas and Lange (2004) introduced environmental externalities into the equation, arguing that most pollution-intensive firms are clustered in one area and a small number in another. In terms of measures, scholars have drawn on indicators such as location economy and urbanization economy to reflect industrial agglomeration (Sun et al., 2012; Xie and Li, 2021). Besides, scholars have also directly identified the degree of industrial agglomeration through the number of firms (Alañón-Pardo and Arauzo-Carod, 2013). Based on the above analysis, hypothesis two is proposed: The location choice of pollution-intensive foreign firms is negatively influenced by the production cost effect but positively influenced by the agglomeration economic effect.

2.3 Environmental Regulation and Location Choices of Pollution-Intensive Foreign Firms

Environmental regulations has become an important policy tool for developed countries and regions to cope with the transfer of polluting industries (Shao et al., 2021). Walter and Ugelow (1979) proposed PHH by examining the transfer of polluting industries in developed countries. It is argued that pollution-intensive firms tend to move to regions with looser environmental regulations than previous ones (Chung, 2014). This theory has been explored in terms of international trade (Copeland and Scott, 1994), foreign direct investment (FDI) (Xi et al., 2016) and firm placement (Zhu et al., 2014). Some scholars argue that environmental regulations significantly inhibit the location choices of pollution-intensive foreign firms (Wu et al., 2019), while others believe no significant impact is exerted by environmental regulations. For example, Porter and Linde (1995) argue that appropriate environmental regulations promote technological innovation and productivity, thus generating the induced innovation to offset the increase in governance costs brought by environmental regulations. In addition, the government has an incentive to relax the enforcement of environmental regulations in border areas, thus leading to the pollution border effect (Sun, 2021). Based on the above analysis, hypothesis three is proposed: The location choice of pollution-intensive foreign firms is negatively influenced by environmental regulations with a pollution border effect.

In summary, the location choices of pollution-intensive firms and its influencing factors have been explored by establishing multiple models, but there are still some problems. Firstly, in terms of research scales, previous studies mainly focused on the cross-country transfer of pollution-intensive firms. Secondly, in terms of research objects, the overall layout of pollution-intensive industries was mainly analyzed from an industry perspective but less from the firm-level perspective. Thirdly, in terms of influencing factors, scholars have explored environmental regulation on the location choices of pollution-intensive firms while lack consideration for the combined impact of factors. Therefore, in this paper, the combined impact of environmental regulations, agglomeration economy, and factor endowments on the location choices of pollution-intensive firms were identified (see **Figure 1**).

3 RESEARCH DATA AND METHODS

3.1 Data Sources

3.1.1 Pollution-Intensive Industries

Since firms directly or indirectly cause varying degrees of pollution, this paper refers to pollution-intensive industries that produce large amounts of pollutants in their production. Scholars define pollution-intensive industries mainly through the cost of environmental management, the intensity of pollutant emissions, and official documents (Cui and Zhao, 2015). Therefore, the pollution emission intensity index for each industry was calculated based on the classification method proposed by Becker and Henderson (2000). Also, the 27 industrial sub-sectors were classified into heavy and light pollution industries. On this basis, 13 heavily polluting industries were selected as pollution-intensive industries[1].

3.1.2 Data Sources

Since the database of Chinese industrial enterprises is updated to 2014, this paper obtained the data of Chinese firms in pollution-intensive industries by industry codes from 1998 to 2014. Since the *National Economic Classification of Industries* was revised in 2002 and 2011, this paper used the industry standard of 2002 for classification and adjusted the industrial classification and administrative divisions of 1998 and 2011 to ensure the uniformity of data (Yu and Sun, 2011). On this basis, the pollution-intensive foreign firms were screened out based on the controlling shareholders of pollution-intensive firms. Meanwhile, the longitude and latitude coordinates of the firm

[1]13 heavily polluting industries: non-ferrous metal mining and selection, non-metallic mining and selection, the agro-food processing industry, food manufacturing, beverage manufacturing, the textile industry, the paper and paper products industry, the petroleum processing/coking and nuclear fuel processing industry, chemical raw materials and chemical products manufacturing, chemical fiber manufacturing, the non-metallic mineral products industry, the ferrous metal smelting and rolling processing industry, and the electricity/heat production and supply industry.

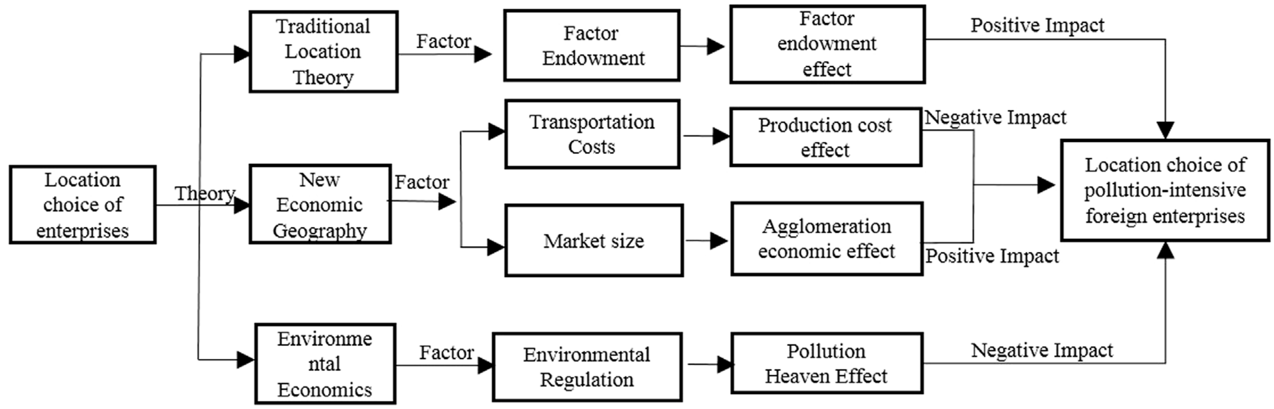

FIGURE 1 | Influencing factors in the location choices of pollution-intensive firms.

data were obtained using Python software, and GIS software was used to spatial them. Data for other variables were obtained by consulting the *China City Statistical Yearbook* and the *China Regional Economic Statistical Yearbook*.

3.2 Research Methods

3.2.1 Kernel Density Estimation

Kernel density estimation (KDE) allows discrete points smoothing and calculation of the density of their distribution in the surrounding, widely used to analyze the spatial distribution and clustering characteristics of elements (Smętkowski et al., 2021). Based on the KED by using GIS software, pollution-intensive foreign firms were taken as "points." Five time points were selected to analyze the spatial evolution characteristics of pollution-intensive foreign firms (Zhan et al., 2020). Assuming that the density at the point p to be estimated is $\lambda_h p$, then the functional form of its estimate $\lambda_h p$ is as follows:

$$\lambda_h(p) = \sum_{i=1}^{n} \frac{3}{\pi h^4}\left\{1 - \frac{(p-p_i)^2}{h^2}\right\}^2 \quad (1)$$

In **Eq. 1**, p_i is the location of the pollution-intensive foreign firm i, falling within a circle with point p as the center and h as the radius; h denotes the step length, the broadband of the surface extended in space with p as the source point.

3.2.2 Standard Deviation Ellipse Analysis

Using the standard deviational ellipse (SDE), a spatial distribution ellipse was drawn with the center, long axis, short axis, and azimuth as the basic parameters. These characterize the middle, direction, and spatial pattern of the spatial distribution of geographical factors from the global and spatial perspectives to reveal the spatial pattern of economic factors.

$$SDE_x = \sqrt{\sum_{i=1}^{n} (x_i - X)^2 / n}, \quad (2)$$

$$SDE_y = \sqrt{\sum_{i=1}^{n} (y_i - Y)^2 / n} \quad (3)$$

In **Eq. 2** and **Eq. 3**, x_i *and* y_i denote the geographical coordinates of the element point i, X and Y denote the mean centers of elements, and n denotes the overall number of elements.

3.2.3 Zero-Inflated Negative Binomial Regression

Drawing on Condliffe and Morgan (2009), variables were incorporated into a partial equilibrium model. The number of regional pollution-intensive foreign firms is assumed to be Y_{it} ($\prod(X_{it}, e_{it})$) in a particular year t. X_{it} is a factor of city i affecting the profit function $\prod$, e_{ijt} is a random error term, and the number of firms in the city is proportional to firm profits.

$$Y_{ijt} = f(X_{ijt}) + e_{ijt} \quad (4)$$

In **Eq. 4**, Y_{ijt} is the number of firms in city i at time t, X_{ijt} represents the factors affecting the firm location choices, e_{ijt} is a random error term with independent distribution, and Y_{ijt} obeys the Poisson distribution.

$$prob(Y_{ijt}) = \lambda_{ijt}^{Y_{ijt}} e^{-\lambda_{ijt}} / Y_{ijt}!, \lambda_{ijt} > 0, Y_{ijt} = 0, 1, 2, 3 \ldots n \quad (5)$$

In **Eq. 5**, λ_{ijt} is a parameter of the Poisson distribution, indicating the expected value of the number of firms Y_{ijt} in industry j in city i at time t, which can be expressed in the following form:

$$\lambda_{ijt} = e^{X_{ijt}\beta + \alpha_{ij}} \quad (6)$$

The logarithm of both sides is obtained:

$$ln\,\lambda_{ijt} = X_{ijt}\beta + \alpha_{ij} \quad (7)$$

In **Eqs 6, 7**, β is the parameter to be estimated and α_{ijt} represents the unobserved city-level factors influencing the location choice of pollution-intensive foreign firms.

In the studies of firm location choice and foreign investment strategies, scholars use econometric models such as Logit, Poisson, and negative binomial (NB) for analysis (Yu and Sun, 2011; Duvivier and Xiong, 2013). However, Poisson models need to satisfy the assumption that the variance of independent variables is equal to the mean, which is not required for the NB regression. In addition, if there are more zero outcome in the

TABLE 1 | The descriptive statistics analysis of variables.

Variable	Variable name	Measurement method	Obs	Mean	Std. Dev	Min	Max
Firms	Number of Firms	Number of pollution-intensive foreign firms	2,319	36.57	98.243	0	1,359
Environmental Regulations (ER)	Environmental Regulations	Removal rate of three waste pollutants	2,319	13.54	15.162	0.002	90.826
		City sewage rate	2,319	5.324	0.856	3.04	7.947
New Economic Geography (ED)	Transportation Costs	Road network density of per capita	2,319	9.745	6.696	0.02	85.2
	Information Costs	Number of internet broadband access users	2,319	1.130	0.571	−1.626	3.714
	Tax cost	Proportion of income tax to output value	2,319	2.033	11.864	−0.098	74.630
	Market Potential	estimated by the Harris (1954) formula	2,319	4.607	0.522	3.272	6.307
	Industry Cluster	Number of industrial firms	2,319	108.7	346.324	0.301	4,773
		Number of foreign firms	2,319	2.713	0.533	0	4.274
Resource Endowment (EF)	Natural Resource Endowment	Proportion of people employed in the extractive industry to the local workforce	2,319	3.613	0.839	1.176	5.221
	Technology Endowment	Percentage of R&D expenditure to GDP.	2,319	0.069	0.079	0.01	0.974
	Capital Endowment	The balance of loans from financial institutions	2,319	6.595	0.533	5.449	8.793
	Labor Endowment	Average wage level of employees	2,319	4.349	0.292	3.294	5.774
	Land Endowment	Total area of urban built-up area	2,319	99.61	182.148	0	2,429
Controlled variables (Z)	Industrial structure	Proportion of secondary and tertiary industries	2,319	81.99	15.848	4.094	99.930
	Degree of openness to the outside	Proportion of foreign capital utilized to the regional GDP.	2,319	0.004	0.010	0.01	0.275
	Administrative Level	Dummy variable	2,319	0.107	0.309	0	1
	Location conditions	Dummy variable	2,319	0.305	0.677	0	1
	Border Rate	Proportion of the number of border counties	2,319	0.422	0.304	0	1

data, the zero-inflated Poisson (ZIP) model and zero-inflated negative binomial regression (ZINB) regression model could be considered. Based on the descriptive statistical information of the variables, the standard deviation of the explained variables was found to be 2.68, failing to meet the conditions for the Poisson model. In addition, a large number of zero outcome in the data makes it difficult to satisfy the pre-condition for the use of spatial models (variables obeying an asymptotic normal distribution). Therefore, the ZINB model was used in this paper to validate and further select the applicable model. This econometric method is commonly used for count data that obey the Poisson distribution and is applied in regression models with a large number of zero outcome. Compared with the Logit and Poisson models, the variance of the independent variables is larger than mean in the ZINB, which solves the problem of fewer alternative spatial scales and "over-dispersion" of the data. This ZINB model could be widely used in studies related to firm location choice and foreign direct investment, which improves the adaptability of the counting model and the accurate results.

$$Firm_i = \beta_0 + \beta_1 EF_i + \beta_2 ED_i + \beta_3 ER_i + \beta_4 Z_i + \varepsilon \tag{8}$$

In **Eq. 8**, $Firm_i$ denotes the number of pollution-intensive foreign firms in city *i*, EF_i denotes the factor endowment of city *i*, ED_i denotes the degree of economic agglomeration in city *i*, ER_i denotes the intensity of environmental regulation in city *i*, Z_i denotes other control variables, and ε is a random error term. In addition, the specific names and measures of the variables are shown in **Table 1**(see **Table 1**).

Although environmental regulations represent diverse forms, scholars classify them as command-and-control, market-based and informal types (Peng and Li, 2016). Command-and-control environmental regulation refers to that government departments use administrative tools to compel firms to take responsibility for pollution control (Luo et al., 2021; Peng et al., 2021). Market-based environmental regulation means that market mechanisms are established to control pollution emissions using economic tools (Ren et al., 2019). Informal environmental regulation means that the public voluntarily reports and monitors polluting firms (Ren et al., 2016). Given the availability and representativeness of data, this paper measured the intensity of environmental regulation by constructing two indicators: removal rate of three waste pollutants (industrial wastewater, SO_2, and dust) and sewage charge rate. The removal rate of industrial wastewater refers to the rate of firms specialized in the treatment of industrial wastewater due to government request, which is an important cost of pollution treatment for firms and thus influences the location choice of pollution firms. The removal rate of three waste pollutants is involved in the command-and-control environmental regulation. The city sewage rate is involved in the market-based environmental regulation for government departments to charge firms for their emissions.

$$P_{tj} = \left(WP_{ij} + AP_{ij} + DP_{ij}\right)/3 \tag{9}$$

In **Eq. 9**, P_{jt} denotes the removal rate of three waste pollutants of city *i* in a year *t* WP_{ij}, AP_{ij} and DP_{ij} denote the removal rates of industrial wastewater, SO_2, and dust.

However, sewage charges are only counted at the provincial scale, while city-scale indicators are lacking in China. The level of environmental regulation is highly correlated with the regional gross industrial output value. For this reason, drawing on the approach of Zhang et al. (2018), this paper used the product of the share of urban gross industrial output value in the gross provincial industrial output value and the provincial, regional

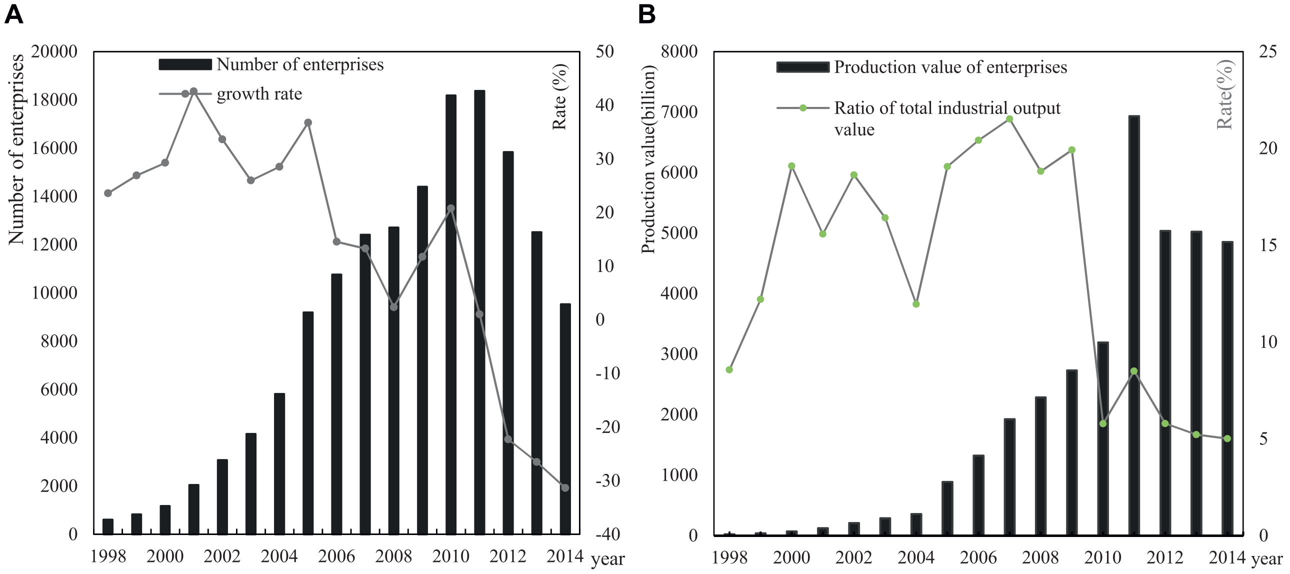

FIGURE 2 | Trends of the development of pollution-intensive foreign firms in China.

sewage costs to estimate city sewage costs. Meanwhile, drawing on the approach of Yang et al. (2015), the environmental regulation indicators were constructed, considering the pollution emission intensity, from the perspective of environmental treatment inputs and outputs. These indicators were used as an environmental regulation indicator represented by the city sewage charges rate. This indicator not only depends on the intensity of government pollution emission charges but also takes into account the reduction of pollution emission. It better reflects the impact of market-based environmental regulation measures on the pollution emissions of firms.

Firstly, the calculation of city sewage charges is based on the proportion of the total industrial output value of the city to the total provincial industrial output value.

$$fe_{ii} = FE_{qj} \cdot \left(ue_{ij}/UE_{qj}\right) \tag{10}$$

In **Eq. 10**, fe_{ij} denotes the emission cost of city i, FE_{qj} denotes the emission cost of province q where city i locate, ue_{ij} denotes the total industrial output value of city i, and UE_{qj} denotes the total industrial output value of province q where city i locate.

Secondly, the emission intensity (em_{ij}) of the city i is calculated based on the city's "three waste" emissions.

$$em_{ij} = \left(en_{ij} + mn_{ij} + sn_{ij}\right)/dv_{ij} \tag{11}$$

In **Eq. 11**, en_{ij}、mn_{ij}、sn_{ij} denote the "three waste" emissions of city i, and dv_{ij} denote the industrial added value of city i.

Thirdly, the environmental regulation intensity index of cities er_{ij} (city sewage rate) is calculated under pollution emission intensity em_{ij}.

$$er_{ij} = fe_{ij}/em_{ij} \tag{12}$$

The market potential indicator is mainly calculated by drawing on Harris's (1954) measure.

$$MP = GDPi/di + \sum j \neq iGDPj/dij \tag{13}$$

In **Eq. 13**, the intra-city distance di = (2/3) $\sqrt{Si/\pi}$, Si is the area of the city, dij is the distance between the centers of two cities, and GDP is the gross regional product of each city.

4 TEMPORAL AND SPATIAL OF POLLUTION-INTENSIVE FOREIGN FIRMS

4.1 Temporal Evolution of Pollution-Intensive Foreign Firms

Based on the trend in the number and output value of firms, the pollution-intensive foreign firms have three stages of development, reflecting the pollution haven effect (see **Figure 2**). Specifically, 1) 1998–2004 represented a slow development in which the number and output value of pollution-intensive foreign firms grew, but the scale of the industry was limited, less than 20% of the total industrial output value. At the early stage of reform and opening-up, the development of pollution-intensive foreign firms was slump due to the imperfect market economy environment. 2) 2005–2011 saw rapid growth in which the number of pollution-intensive foreign firms and their output value were both higher, accounting for more than 20% of the total. With the continuous progress of reform and opening-up, China attracted a large number of pollution-intensive foreign firms with its cheap labor and lenient environmental regulations, reflecting the transnational transfer of pollution-intensive industries consistent with the PHH (Jensen, C., 2021). 3) Structural transformation appeared from 2012 to 2014, and the number of pollution-intensive foreign firms and their output value showed a decreasing trend. Starting in 2010, China abolished some tax incentives for foreign firms. At the same time, city and region development had become more

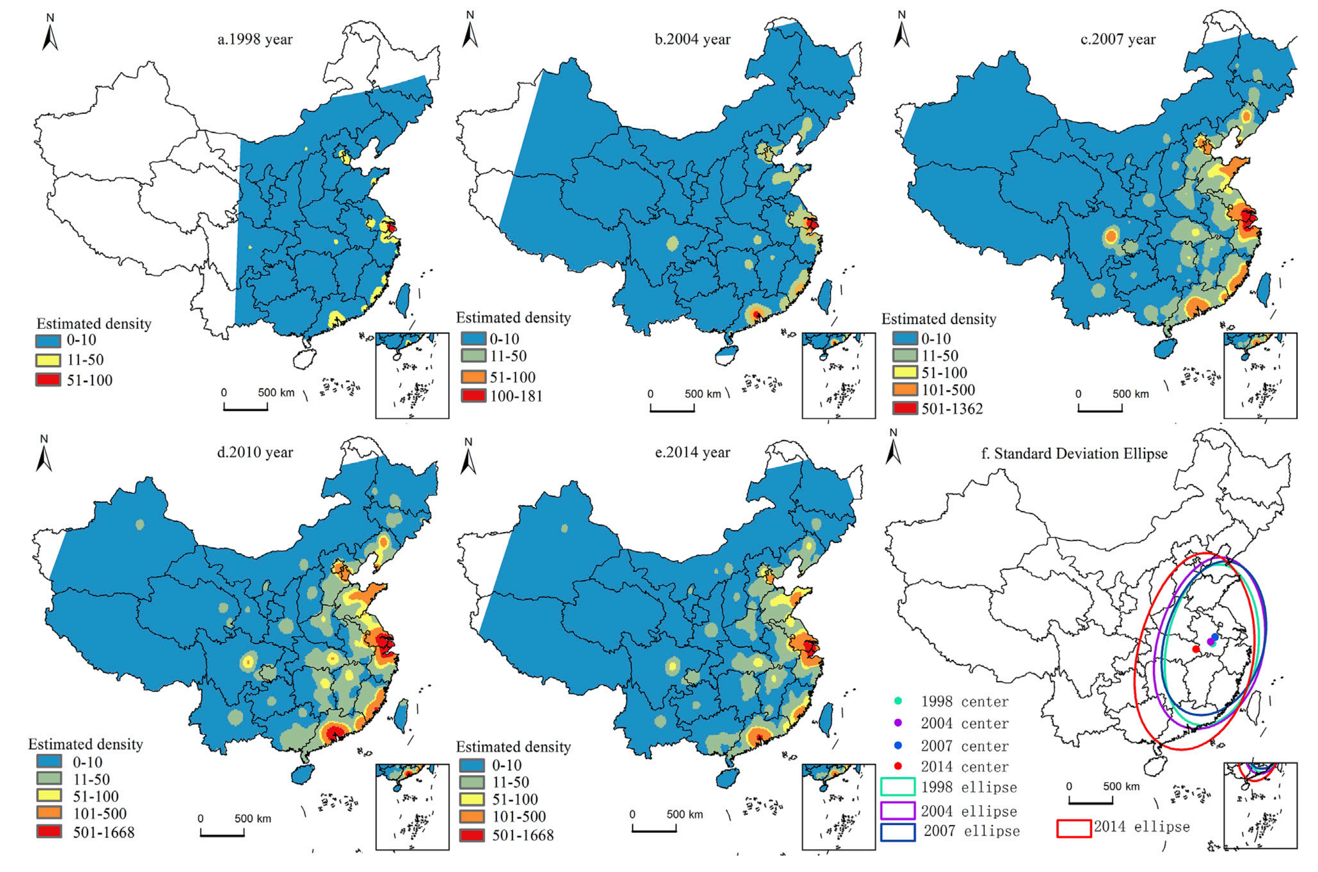

FIGURE 3 | Spatial evolution of pollution-intensive foreign firms in China.

focused on environmental protection by taking measures such as increasing sewage charges (Liu, 2019).

4.2 Spatial Evolution of Pollution-Intensive Foreign Firms

Pollution-intensive foreign firms are concentrated in the eastern developed regions and have path dependence in China. In 1998, most of them were concentrated in Guangdong, Shanghai, and other eastern developed regions, while few were scattered in the middle and western regions of China. In 2004, the number of pollution-intensive foreign firms in the Pearl River Delta, the Yangtze River Delta, and other developed regions along the eastern coast increased and expanded to Henan, Hubei, and Sichuan. In 2010, the number of pollution-intensive foreign firms clustered in the Bohai Rim, the Yangtze River Delta and the Pearl River Delta increased sharply, forming a wide range of contiguous clusters. In 2014, the eastern developed regions such as the Yangtze River Delta, Shandong Peninsula and the Pearl River Delta still attracted a high concentration of pollution-intensive foreign firms by virtue of their developed market economy and perfect infrastructure, showing strong path-dependent characteristics (Wang et al., 2019). However, with the intensification of environmental pollution problems in these developed areas, the number of pollution-intensive foreign firms has decreased in the Pearl River Delta, the Yangtze River Delta, and other eastern coastal regions due to increased environmental awareness (see **Figure 3**).

Through standard deviational ellipse analysis, the direction and path of cross-regional transfer of pollution industries could be visualized, thus providing empirical evidence for understanding the location choices of pollution firms. From 1998 to 2014, the spatial scope of pollution-intensive foreign firms expanded, showing the characteristics of transferring from the eastern developed regions to the middle and western less developed regions. The area of the standard deviation ellipse expanded from 1998 to 2014, reflecting the trends of diffusion of pollution-intensive foreign firms and expanding geographical coverage. The long and short axes of the standard deviation ellipse of pollution-intensive foreign firms became longer from 1998 to 2014. However, the long sleeve changed even more, further verifying the characteristics of the shift of pollution-intensive foreign firms mainly from the eastern coastal region to the middle and western region. This is primarily attributed to the increased level of economic development in coastal region, which has led to higher demands for environmental quality and stronger intensity of environmental regulations. Therefore, the production costs of pollution firms is increased, by this way, force

TABLE 2 | Regression results of pollution-intensive foreign firms by different models.

Variables	ZIP		NB		ZINB	
Number of firms	(1)	(2)	(3)	(4)	(5)	(6)
Removal rate of three waste pollutants	0.004 (0.03)		−0.002*** (−6.70)		−0.054*** (-19.2)	
City sewage rate		7.692*** (3.80)		0.264*** (22.84)		−0.163*** (−3.72)
Transportation Cost	0.311 (0.81)	0.209 (0.56)	0.002*** (4.83)	0.01 (−0.15)	0.028*** (3.69)	0.015*** (4.00)
Information cost	−4.279 (−1.07)	−4.585 (−1.14)	−0.067*** (−4.60)	−0.066*** (−4.48)	0.27*** (2.62)	0.173*** (3.08)
Tax cost	−0.14 (−0.52)	−0.126 (−0.48)	−0.001 (−0.49)	−0.001 (−0.42)	−0.05*** (−5.43)	−0.018*** (−3.76)
Market potential	20.372*** (2.82)	15.739** (2.22)	1.152*** (59.83)	0.919*** (42.08)	0.918*** (5.23)	0.772*** (8.15)
Number of industrial firms	21.939*** (3.30)	17.753*** (2.77)	1.628*** (86.50)	1.494*** (76.36)	1.144*** (6.80)	1.378*** (12.60)
Number of foreign firms	0.191*** (6.66)	0.19*** (6.66)	0.01*** (51.09)	0.01*** (47.89)	0.001*** (4.57)	0.001*** (5.61)
Natural Resource endowment	−4.468** (−2.57)	−4.722*** (−2.85)	0.005 (1.19)	−0.019*** (−4.14)	−0.341*** (−7.88)	−0.141*** (−5.82)
Technology endowment	−10.327 (−1.05)	−15.184 (−1.47)	−0.197** (−2.37)	−0.176** (−2.08)	0.88 (1.03)	−0.575 (−2.35)
Capital endowment	4.758 (0.70)	4.652 (0.66)	0.084*** (5.17)	0.041** (2.54)	−0.986*** (−4.73)	−0.233 (−2.91)
Labor endowment	7.055 (0.92)	1.103 (0.15)	−0.054 (−1.56)	−0.187*** (−5.34)	1.221*** (4.22)	0.791*** (5.34)
Land endowment	−0.05 (−1.10)	−0.049 (−1.10)	−0.01*** (−38.3)	−0.001*** (−34.3)	0.01 (−0.22)	0.04 (−1.96)
Industrial structure	0.007 (0.05)	−0.071 (−0.51)	−0.005*** (−6.06)	−0.006*** (−7.46)	−0.02*** (−3.45)	−0.007** (−2.42)
Degree of openness to the outside	45.558* (1.67)	40.17 (1.10)	13.369*** (38.02)	11.685*** (32.19)	14.515 (1.29)	7.305* (1.67)
Administrative level	−3.979 (−0.54)	−3.375 (−0.47)	−0.034** (−2.18)	0.019 (1.22)	0.92*** (4.88)	0.323*** (4.00)
Location conditions	−4.012** (−2.40)	−3.133* (−1.84)	0.081*** (9.03)	0.09*** (10.00)	0.102* (1.81)	0.288*** (8.92)
Border rate	12.405*** (2.91)	11.908*** (2.80)	1.489*** (44.85)	1.444*** (43.64)	1.738*** (5.98)	0.832*** (5.88)
Constant	−173.1*** (−3.88)	−147.1*** (−3.54)	−7.39*** (−57.7)	−6.36*** (−49.8)	−2.981*** (−2.68)	−7.577*** (−13.2)
City/year fixed effect	YES	YES	YES	YES	YES	YES
N	2,319	2,319	2,319	2,319	2,319	2,319
R^2	0.56	0.58	0.46	0.49	0.36	0.62

***p ≤ *0.01,* **p ≤ *0.05, and* *p ≤ *0.10; t-statistics are in parentheses.*

them to move out (De Silva et al., 2021; Wu et al., 2019). However, less developed inland regions still implement looser environmental regulations and introduce a large number of pollution firms in order to achieve rapid economic growth (Pan et al., 2021). From the distribution center, the standard deviation ellipse center of pollution-intensive foreign firms shifted more to the southwest after 2010. With the rapid urbanization in the middle and western regions and the increase in openness to the outside world, western provinces such as Sichuan, Yunnan, and Guangxi of China have also attracted more pollution-intensive foreign firms. However, although these firms contribute to the rapid economic development of these areas, they tend to damage their fragile ecological environment. The negative effects of investment by foreign firms calls for extra attention to avoid inland areas becoming havens in the transfer of pollution-intensive industries.

5. DETERMINANTS OF POLLUTION-INTENSIVE FOREIGN FIRM LOCATION CHOICES

5.1 Basic Regression Result by ZINB Model

In order to improve the accuracy of the estimation results, the baseline regression model was tested for multiple cointegration, serial autocorrelation, and heteroskedasticity. The results show that the model has a mean VIF value of 3.79 and a maximum value of 8.49, and there is no multicollinearity in the model. The *p*-value of the BG test is 0.002, indicating that there is no serial autocorrelation. The models were subjected to ZIP, NB, and ZINB regressions to compare the differences of the different models and their applicability. In different models, the ZINB regression estimated the largest likely function value and the smaller AIC value, reflecting the better fit of the ZINB regression. Therefore, the estimation results are based on the ZINB regression, while the ZIP and NB results are relatively inaccurate and are mainly used to illustrate the importance of the choice of estimation method. The number of pollution-intensive foreign firms will be reduced by about 0.054% for each percentage increase in the removal rate of three waste pollutants, while the number of pollution-intensive foreign firms will be reduced by about 0.163% for each percentage increase in the sewage charge rate. The results show that the pollution haven effect of environmental regulations has a significant negative impact on the location choices of pollution-intensive firms, providing firm-level evidence to prove the pollution haven hypothesis (Shahzad, 2020; Shahzad, et al., 2021). Compared with the command-and-control regulations represented by the removal rate of three waste pollutants, the market-based regulations represented by sewage charge rate has a stronger inhibiting impact on the location choices of pollution-intensive firms (see **Table 2**).

In the new economic geography theory, production cost and economic agglomeration affect the production efficiency of firms. In terms of cost factors, the coefficients of transportation cost and information cost are significantly positive, but information cost has a stronger effect. Since information cost is measured by using the number of internet broadband access users regarded as a

TABLE 3 | Regression results of heterogeneous pollution-intensive foreign firms by ZINB model.

Variables	Water pollution firms (1)		Air pollution firms (2)		East (3)		Middle (4)		West (5)	
Removal rate of three waste pollutants	−0.052*** (−19.4)		−0.058*** (−20.5)		−0.047*** (−15.1)		−0.054*** (−16.72)		−0.076*** (−11.1)	
City sewage rate		−0.125*** (−2.83)		−0.126** (−2.41)		−0.195** (−2.13)		−0.165** (−2.49)		−0.128** (−2.31)
Transportation Cost	0.025*** (3.95)	0.014*** (3.98)	0.028*** (3.90)	0.015*** (4.06)	0.007 (1.13)	0.007 (1.33)	−0.006 (−1.29)	0.006 (1.63)	0.047** (2.49)	0.028*** (3.19)
Information cost	0.279*** (3.02)	0.153*** (2.83)	0.323*** (3.18)	0.301*** (4.64)	0.217 (1.19)	0.196* (1.81)	−0.363 (−2.16)	0.049 (0.39)	0.286 (1.70)	0.089 (1.47)
Tax cost	−0.047*** (−5.32)	−0.016*** (−3.33)	−0.069*** (−7.31)	−0.037*** (−6.76)	−0.16 (−0.79)	−0.155 (−0.86)	−0.026 (−0.84)	−0.014 (−0.56)	−0.148*** (−5.30)	−0.009** (−1.23)
Market potential	0.909*** (5.50)	0.719*** (7.50)	0.723*** (4.56)	0.731*** (7.40)	0.299* (1.45)	0.489*** (3.21)	0.466** (−2.01)	0.151* (0.93)	1.235*** (4.15)	1.049*** (7.88)
Number of industrial firms	1.393*** (9.05)	1.498*** (14.2)	1.14*** (7.07)	1.13*** (10.1)	1.101*** (7.37)	1.421*** (10.1)	2.858*** (11.70)	1.946*** (11.7)	−0.372 (−0.97)	0.175 (1.07)
Number of foreign firms	0.001*** (4.70)	0.001*** (6.04)	0.001*** (4.50)	0.001*** (6.28)	0.001*** (4.20)	0.001*** (5.30)	0.002*** (7.72)	0.001*** (6.38)	−0.018 (−2.68)	0.007 (3.95)
Natural Resource endowment	−0.321*** (−7.96)	−0.128*** (−5.37)	−0.372*** (−7.96)	−0.173*** (−6.58)	−0.289*** (−5.82)	−0.04 (−1.29)	0.226*** (−4.12)	0.171*** (−4.79)	0.014* (0.12)	0.094* (−1.61)
Technology endowment	0.759 (0.97)	−0.511 −2.05)	0.496 (0.84)	−0.255 (−0.84)	−0.953 (−0.83)	−1.232 (−1.56)	0.952* (1.73)	0.352 (0.89)	−3.125*** (−3.12)	−1.175*** (-4.28)
Capital endowment	−0.952*** (−5.12)	−0.212*** (−2.72)	−0.943*** (−5.96)	−0.535*** (−5.72)	−0.484** (−2.26)	−0.107 (−0.80)	−0.25 (−1.11)	−0.277* (−1.95)	−1.374*** (−3.15)	0.037 (0.30)
Labor endowment	1.013*** (3.79)	0.675*** (4.66)	2.005*** (6.88)	1.649*** (9.46)	1.33*** (3.59)	0.98*** (4.16)	0.891** (2.14)	1.031*** (4.23)	3.327*** (4.48)	0.38* (1.67)
Land endowment	0.03 (−0.84)	−0.001 (−2.79)	0.014 (−0.08)	0.003 (−1.36)	−0.02 (0.43)	0.001 (−3.29)	0.002** (3.26)	0.004** (4.54)	0.015*** (3.94)	0.002*** (3.79)
Border rate	1.836*** (6.70)	0.912*** (6.22)	1.499*** (4.93)	0.945*** (5.89)	1.975*** (6.54)	1.226*** (6.64)	−0.44 (−1.39)	−0.302 (−1.56)	−0.806 (−0.75)	−0.941 (−1.85)
Constant	−3.078*** (−2.98)	−7.688*** (−13.6)	−6.207*** (−5.35)	−9.363*** (−14.3)	−3.91** (−2.43)	−7.527*** (−7.95)	−4.023 (−2.72)	−5.941 (−6.10)	−5.028** (−1.96)	−6.288*** (−7.01)
N	2,312	2,312	2,312	2,312	920	920	858	858	541	541
R^2	0.46	0.41	0.416	0.48	0.27	0.19	0.24	0.27	0.17	0.25

****p ≤ 0.01, **p ≤ 0.05, and *p ≤ 0.10; t-statistics are in parentheses. The results of control variables are not reported due to space limitation.*

TABLE 4 | Regression results for new pollution-intensive foreign firms by ZINB model.

Variables	All sample		Water pollution firms		Air pollution firms	
Removal rate of three waste pollutants	−0.057*** (−16.64)		−0.061*** (−18.47)		−0.059*** (−17.16)	
City sewage rate		−0.071*** (−1.15)		−0.123** (−0.39)		−0.205*** (−4.50)
Transportation Cost	0.015** (2.45)	0.008* (1.94)	0.022 (3.42)	0.013 (3.01)	0.01** (0.05)	0.003*** (−0.81)
Information cost	0.322*** (2.64)	0.291*** (3.29)	0.417*** (3.31)	0.397 (4.51)	0.218 (1.96)	0.195 (2.78)
Tax cost	0.007 (0.60)	0.036*** (4.71)	0.007 (0.62)	0.034 (4.37)	−0.015 (−1.58)	0.009 (1.39)
Market potential	0.287* (1.66)	0.31** (2.30)	−0.519*** (−3.15)	0.487 (−3.67)	0.429*** (3.06)	0.192** (1.97)
Number of industrial firms	0.578*** (3.25)	0.529*** (3.96)	0.477*** (2.79)	0.431** (3.25)	0.15* (−1.00)	0.149** (−1.40)
Number of foreign firms	0.001*** (4.05)	0.003*** (3.49)	0.006*** (4.89)	0.012* (3.96)	0.031*** (3.89)	0.021*** (3.52)
Natural Resource endowment	−0.291*** (−5.62)	−0.125*** (−3.31)	−0.279*** (−5.52)	−0.119 (−3.28)	0.204*** (−4.42)	0.006** (−0.19)
Technology endowment	0.978 (1.58)	0.451 (1.12)	1.035* (1.82)	0.471 (1.21)	2.051*** (4.48)	1.437*** (5.63)
Capital endowment	−0.472*** (−2.70)	−0.046 (−0.35)	−0.924*** (−5.31)	−0.498 (−3.92)	−0.638*** (−3.94)	−0.271** (−2.44)
Labor endowment	−0.653 (−1.97)	−1.008 (−4.35)	−0.318 (−0.99)	−0.871 (−3.78)	−0.512** (1.80)	−0.258*** (1.35)
Land endowment	0.14 (0.27)	0.21 (−0.24)	−0.05 (1.18)	0.03 (0.40)	0.001* (1.81)	0.02* (1.29)
Border rate	1.691 (5.19)	1.047*** (4.17)	1.769 (5.59)	1.091 (4.25)	1.111*** (3.92)	0.592*** (2.71)
Constant	5.635*** (4.02)	2.419*** (2.67)	7.843*** (5.80)	5.368 (6.22)	−0.059*** (−17.16)	1.194* (1.67)
N	2,312	2,312	2,312	2,312	2,312	2,312
R^2	0.39	0.44	0.49	0.31	0.38	0.19

***p ≤ *0.01*, **p ≤ *0.05, and* *p ≤ *0.10; t-statistics are in parentheses.*

negative indicator, the result of the indicator is significantly positive, indicating the more number of internet broadband access users in a city means the better network infrastructure, the lower information cost and the more attractive location layout of enterprises. Besides, the coefficient of tax cost is significantly negative, reflecting that local governments have become the main body to promote economic development under decentralization and tax-sharing reform. Regarding market factors, the coefficient of market potential is significantly positive, showing that foreign firms also focus on local market potential and its accessibility, thus achieving economic agglomeration through local market effect. The industrial agglomeration coefficients are significantly positive. When the number of local industrial firms above the scale and the foreign firms increase, a place is more likely to attract the layout of pollution-intensive foreign firms.

Endowment factors also have a differentiated impact on the location choices of pollution-intensive firms. Natural endowments are significantly negative among them, reflecting that traditional natural resources are not highly attractive to foreign firms. Besides, the coefficients of the boundary rate are 1.738 and 0.832 under different environmental regulations and are significant at the 1% level at least. The results indicate that a higher boundary rate of the city will attract more pollution-intensive foreign firms, reflecting the tendency of foreign pollution-intensive firms to move to provincial administrative boundary areas. These increasing environmental regulations verify the pollution border effect.

5.2 Heterogeneity Test by ZINB Model

Due to the differences between water and air polluting firms in industry distribution, product types, and regulations enforcement effects (Xu and Wang, 2020), the samples were divided into water-polluting and air-polluting firms (see **Table 3**). The results showed that environmental regulations also had a significant negative impact on the location choices of pollution-intensive firms, and the impact of the sewage charge rate was greater than that of the removal rate of three waste pollutants. The regression results of factors such as transportation cost and industrial agglomeration were more similar to the baseline regression, further indicating that pollution-intensive foreign firms increased profits and achieved economic agglomeration by reducing production costs and the scale effect of industrial agglomeration.

Regional heterogeneity was further considered due to huge differences in economic development levels between the eastern and western regions. The intensity of environmental regulations had a significant inhibitory impact on different regions. The intensity of the command-based environmental regulations, represented by the removal rate of three waste pollutants, decreased from the west, middle, to east, while the intensity of the market-based environmental regulations represented by the sewage charge rate decreased from the east, middle, to west. The results indicated that the market-based regulations in economically developed regions were more effective on the location choices of pollution-intensive firms, while the command-and-control regulations in economically backward regions were more effective in influencing the location choices of pollution-intensive firms. Besides, the location choices of pollution-intensive firms were promoted in the eastern and middle regions through local market effect and economic agglomeration effect, but not in the western region due to the low level of industrial agglomeration. In terms of factor endowments, natural factor endowments and land endowments have a significant role in promoting pollution-intensive foreign investment firms in middle and western regions, but not in eastern regions. This suggests that traditional factor endowments still have a greater attraction for pollution-intensive foreign firms in economically backward regions, while developed regions mainly attract pollution-intensive foreign firms through new economic factors such as transportation costs and industrial clustering. The boundary rate coefficient was significantly positive in the eastern region but insignificant in the middle and western regions, indicating the good infrastructure and dense industrial distribution in the eastern coastal region. Pollution-intensive foreign firms tended to move to the inter-provincial border areas to reduce the cost of treatment, verifying the pollution border effect. However, in the middle and western regions, the transportation of the provincial border areas was inconvenient with a sparse population.

5.3 Robustness Test by ZINB Model

In order to test the robustness of the previous regression results, the explained variable was replaced with the number of new pollution-intensive foreign firms by ZINB regression (see **Table4**). The results showed that environmental regulations could negatively affect the location choices of pollution-intensive firms, indicating that the previous findings were still robust even with the new pollution-intensive foreign firms. The regression results of market and industrial agglomeration factors were similar to the previous baseline regression results, showing that pollution-intensive foreign firms were prone to form economic agglomeration under market local effect and the economic agglomeration effect. Natural factor endowments mainly have a significant promoting effect on the new air-pollution firms, while labor endowment mainly has a negative inhibiting effect, indicating that heavy industry with air-pollution firms as the main constituent mainly consider natural resource abundance and labor cost in order to reduce production costs. Besides, the border rate mainly contributed significantly to new air pollution-intensive foreign firms, while the impact on new water pollution-intensive firms was not significant. The results showed that the new air pollution-intensive foreign firms had obvious characteristics of shifting to the border area due to their wide pollution scope and treatment difficulty.

6 CONCLUSION AND POLICY RECOMMENDATIONS

6.1 Conclusion

Based on the micro data of industrial firms, this study analyzed the spatial pattern of pollution-intensive foreign firms by spatial analysis. The impact of heterogeneous environmental regulations was explored on the location choices of pollution-intensive firms by ZINB regression. The main conclusion are as follows. Firstly, pollution-intensive foreign firms are highly concentrated in the eastern developed regions with strong path dependence. It is mainly because the eastern economically developed regions were opened to the outside world earlier. The convenient transportation infrastructure, the better marketing environment, attract more pollution-intensive enterprises to aggregate, which expanded the research related to the impact of agglomeration economies on firm distribution in emerging economies (Gokan et al., 2019; Ramachandran et al., 2020). Secondly, environmental regulations negatively affect the location choices of pollution-intensive firms, which provided micro evidence to prove the pollution haven hypothesis (Wang et al., 2019; Shahzad, 2020; Shahzad et al., 2021). In contrast to previous studies that focused on the effects of single type of environmental regulation (Pan et al., 2021; Sharma et al., 2021; Zhou et al., 2021), this study found that the impact of market-based environmental regulations is better than that of command-and-control environmental regulation (Bashir et al., 2021). In addition, the market-based environmental regulations have a stronger impact on economically eastern developed regions, while command-and-control environmental regulations have a stronger impact on the economically backward western regions. Thirdly, in contrast to other scholars' debates on pollution border effect in many developed countries and emerging economies (Kaldellis et al., 2007; Lipscomb and Mobarak, 2017; Coria et al., 2021; Torre et al., 2021), this study found that the pollution border effect exists in the economically eastern developed regions, but not in the economically backward western regions due to inconvenient transportation and sparse population.

6.2 DISCUSSION

This paper analyzes the impact of heterogeneous environmental regulations on the location choices of pollution-intensive firms, which provides micro-empirical evidence for PHH and the useful reference for other countries in the world to scientifically use heterogeneous environmental regulations to effectively reduce excessive concentration of polluting industries and their emissions according to the level of regional economic development (Shahzad, 2020; Bashir et al., 2021; Shahzad et al., 2021). In addition, the ZINB regression model could also be widely used in counting models with over-dispersion problems, making up for the shortcomings of linear regression models. Due to data limitations, two environmental regulations were constructed after trade-offs between geographic levels and industry details. Besides, although long time series data obtained in the study, the latest enterprise data were not available due to the limitation of database update. In future research, on the one hand, the command-and-control, market-based, and informal environmental regulations indicators can be constructed, and the machine learning methods can be adapted to simulate the impact of environmental regulations on the spatial evolution of polluting industries, thus providing sufficient scientific support for the formulation of environmental management policies and construction of the ecological environment. On the other hand, future research can also analyze the impact of heterogeneous environmental regulations on different polluting enterprises, such as state-owned, private, and foreign enterprises, at different stages of their activities to promote sustainable production and sustainable, and inclusive regional economic development.

6.3 Policy Recommendations

In the background of globalization, preventing the transfer of pollution-intensive foreign firms is a real need for governments to achieve inclusive and sustainable economic growth and a key to achieving the world's sustainable development goals. Several policy implications can be drawn as follows. Firstly, when foreign direct investment is introduced, the government in emerging economy countries should set environmental access thresholds and strengthen environmental regulations to restrict the entry of highly polluting foreign firms, thus making pollution-intensive foreign firms develop technological innovations to reduce environmental pollution. Secondly, the government in different countries of the world (both developing and developed countries) should also consider regional heterogeneity and industrial heterogeneity when adopting environmental policies (Shahzad, 2020). The effect of environmental policies is limited because China mainly adopts command-based environmental regulations and does not consider regional heterogeneity in their implementation (Pan et al., 2021; Peng and Zheng, 2021). This study suggests that the market-based environmental regulations are mainly adopted in economically developed regions, while command-based environmental regulations are mainly adopted in less economically developed regions to reduce the excessive concentration of pollution-intensive foreign enterprises and promote inclusive and sustainable economic growth. Finally, local governments in different countries of the world should harmonize environmental regulations standards, take joint environmental management actions, and implement ecological compensation measures to prevent polluting firms from moving to border areas and reduce inter-regional development inequalities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CT: Conceptualization, Methodology, Writing—Original. JD: Methodology, Writing—Reviewing and Editing, Validation, Resources.

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