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EDITED BY
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The University of Haripur, Pakistan
Muhammad Haroon Shah,
Wuxi University, China

*CORRESPONDENCE
Juanfeng Zhang,
✉ juanfengzh@hotmail.com

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Evaluation of the triangle-relationship of industrial pollution, foreign direct investment, and economic growth in China's transformation

Juanfeng Zhang[1]*, Rui Han[2], Zongjun Song[3] and Lihua Zhang[2]

[1]Department of Engineering Management, China Academy of Housing and Real Estate, Zhejiang University of Technology, Hangzhou, China, [2]Department of Engineering Management, Institute of Real Estate Studies, Zhejiang University of Technology, Hangzhou, China, [3]School of Management, Baise University, Baise, China

Unlike previous research on foreign direct investment (FDI), economic growth, and pollution, this study focuses on investigating complex interactions specifically. A dynamic simultaneous equation model is adopted, together with the one-step systematic GMM, drawn upon to empirically analyze 30 Chinese provinces between 2006 and 2017. The results show that FDI does promote economic growth in China which, in turn, positively affects FDI. However, FDI inflow and economic growth both have negative environmental effects. A higher level of environmental pollution corresponds with FDI becoming more attractive. In the case of China, therefore, the pollution-haven hypothesis holds weight. Specifically, industrial environmental pollution is found to positively affect economic growth, indicating this growth to fall on the left side of the environmental Kuznets Curve. Accordingly, therefore, policymakers should look to optimize China's industrial structure, guide the inflow of high-quality FDI, and promote healthy and sustainable development under the country's new development philosophy.

KEYWORDS

triangle-relationship, foreign direct investment, industrial pollution, economic growth, China

1 Introduction

FDI brings funds to a host country and stimulates economic growth *via* foreign-funded enterprises that settle in undeveloped regions. For China's "economic miracle," FDI has played a key role in promoting the country's transformation from a planned to a market-oriented economy. Nevertheless, extensive FDI can trigger numerous problems, such as environmental pollution and resource depletion. The inflow of FDI into developing countries and regions where energy consumption industries are highly concentrated has resulted in environmental degradation (Grimes and Kentor, 2003; Shah et al., 2022). In response, some countries have implemented strict environmental protection policies. For instance, the 2030 Climate and Energy Policy Framework agreement stipulates that, by 2030, the EU plans to reduce its greenhouse gas (GHG) emissions by 40%. The United States has also committed to reducing its GHG emissions by half by 2030, as well as confirming a commitment to zero emissions by 2050. Developing countries with low infrastructure levels, such as Tunisia, Morocco, and Egypt, are more likely to have poor environmental standards. However, despite having environmental protection policies in place, the economic development in China, India, and Vietnam has not seen such policies strictly enforced. These countries mainly receive their FDI from the United States, Japan, and the EU, which can generate a double-edged impact.

Under the impact of a series of major emergencies, such as the complex international situation and the COVID-19 pandemic, global FDI fluctuated sharply. The COVID-19 pandemic has significantly impacted pollution emissions and air quality, ecology, economic development, and FDI (Chossière et al., 2021; Miyazaki et al., 2021; Pei et al., 2021; Su et al., 2021; Syarifuddin and Setiawan, 2022), causing unprecedented economic and social disruption (Azomahou et al., 2021). The impact of the crisis depends mainly on economic conditions and governance before the COVID-19 pandemic (Azomahou et al., 2021). Mukanjari and Sterner (2020) found that establishing formal ESG "climate change policies" does not affect firm performance during the pandemic. Companies with higher carbon intensity were more affected by crisis events. Calls for a green economic recovery have intensified since the COVID-19 pandemic, with events such as the COVID-19 pandemic making it clear that we need to rethink how we live. In response to the impact of significant events such as the COVID-19 crisis, a correct review of the relationship between FDI, economic growth, and industrial pollution will help improve the ability to cope with crises in the social and economic development process and realize the modernization of the country.

From one perspective, scholars confirm a pollution-haven hypothesis (Hoffmann et al., 2005; Acharyya, 2009; Caglar, 2020; Singhania and Saini, 2021). This theory blames FDI for transferring polluting investments to low-income countries in order to reduce production costs. Furthermore, when countries are in the process of expanding their economic scale, they consume more energy and emit more pollutants that gradually damage environmental quality (Sapkota and Bastola, 2017; Shao, 2017). Alternative research, however, finds that FDIs in OECD countries have aggravated CO_2 emissions (Pazienza, 2015), although these factors need to be weighed against the funds, advanced technologies, and knowledge that FDI brings in to drive an economy. Economic growth improves people's living standards, which in turn is conducive to improving environmental quality. All these suppositions lead to the pollution-halo hypothesis (Bergh and Nijkamp, 1994), which theorizes that to abate the negative effects of FDIs some countries have implemented strict environmental regulation policies forcing the use of environmental technologies. The problem with this approach, however, is that the adoption of these technologies only increases FDI costs, thereby generating a crowding-out effect and resulting in economic damages.

In the early 21st century, Asian countries prioritized achieving economic take-off *via* industrialization, rather than addressing environmental problems. Consequently, China's ascendency has shed light on the dynamics at play between FDI, economic growth, and the environment. Given the environmental impact of expanding production scales, economic growth has inevitably led to environmental degradation, with Pakistan being one obvious example of economic development pursued at the expense of its environment (Abbasi and Riaz, 2016; Álvarez-Herránz et al., 2017; Ullah et al., 2022). Other research has explored how the economic growth of 17 countries in the Middle East and North Africa has resulted in a similar negative effect (Abdouli and Hammami, 2017a). China government has begun to shift their focus to improving environmental quality. Such aims, however, may result in conflict with economic development and lead to social issues (Blonigen, 2005; Paul and Singh, 2017).

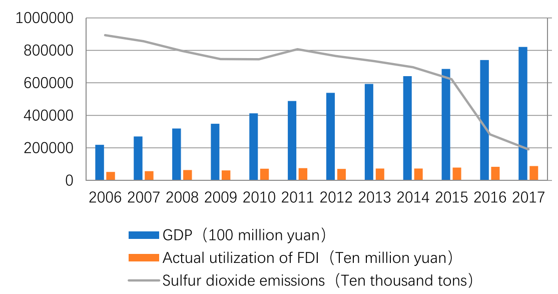

FIGURE 1
China's FDI, industrial pollution, and economic growth.

As a major source of environmental harm, addressing industrial pollution needs prioritizing. The pollutants discharged by industrial enterprises cause serious environmental damage. The 1997 World Bank report China in 2020: Development Challenges in the New Century reveals China to have one of the most serious urban pollution levels in the world, with polluting enterprises and activities estimated to account for 3%–8% of annual GDP. Urbanization inevitably affects environmental quality, with each urbanization stage exerting a different degree of impact.

Figure 1 shows China's economic growth and industrial pollution emissions from 2006 to 2017. To promote green and sustainable development and to comprehensively improve utilization efficiency, China has initiated a green transformation of its economic and social development model. However, the interaction between FDI, economic growth, and industrial pollution is still uncertain. The following questions need to be answered: first, whether China's rapid economic development can be sustained and whether this growth will come at the expense of the environment; Second, whether China's rapid economic development has the potential to attract FDI and whether FDI can become a driving force to promote economic growth; Thirdly, whether FDI inflow improves or worsens China's ecological environment, and whether the more serious environmental pollution is, the more FDI inflow will be attracted. Based on the above considerations, the research objective of this paper is to construct a simultaneous equation model to comprehensively investigate the dynamic evolution characteristics of FDI, industrial pollution, and economic growth in 30 provinces of China during 2006–2017. Furthermore, it explores the interaction effect among the three and provides suggestions on coordinating the relationship between them to achieve green, circular, and sustainable development.

The main contribution of this study to the literature is twofold. Firstly, by combing previous studies on industrial pollution, FDI, and economic growth, the dynamic simultaneous equation model is utilized to evaluate the relationship complexity, including by taking the endogenous problem into consideration. By extending the twoelement analysis framework, a simultaneous equation model is constructed capable of analyzing three elements and evaluating their interactive relationships. Secondly, as previous studies on the relationship between environmental pollution and economic growth mostly conclude that economic growth affects environmental pollution, the GMM method is adopted here to study the bidirectional causality. The results show that FDI does promote economic growth in China which, in turn, positively affects FDI. However, FDI inflow and economic growth both have negative environmental effects. A higher level of environmental pollution corresponds with FDI becoming more attractive. Specifically, industrial environmental pollution is found to positively affect economic growth, indicating this growth to fall on the left side of the environmental Kuznets Curve.

2 Literature review

2.1 Relationship between pollution and FDI

Foreign capital and environmental pollution studies are mainly divided into three streams. The first stream labels FDI’s negative effects as resulting from “Pollution Havens” (Copeland and Scott, 1994; Farooq et al., 2023; Pan H et al., 2023; Shah et al., 2023; Wu and Wang, 2023). Some researchers argue that countries have different policies and environmental standards, with developed countries usually adopting stricter environmental control policies and advanced technologies to reduce environmental pollution (Abdouli and Hammami, 2017b). Other research has confirmed that the challenge of attracting foreign investment and achieving rapid economic development has led to some countries avoiding strict environmental regulations (Shahbaz et al., 2015). Indeed, the strategy of embracing low environmental standards for profit has become increasingly obvious as, to reduce costs, foreign companies place investments in countries with relatively loose environmental regulations. These same investments then contribute to environmental deterioration within the host country, which is transformed into a pollution haven. By using the GMM method to investigate 21 high-polluting developed and developing countries between 1990 and 2016, previous studies have shown how FDI can aggravate environmental pollution, especially in developing countries labeled “pollution havens” (Caglar, 2020; Monica and Neha, 2021). This pollution-haven hypothesis is only valid for low-income countries, however. A positive correlation between pollution emissions and FDI in Latin America, for example, has been identified, calling into question whether low-income countries are capable of improving environmental health by attracting clean and energy-efficient industries through FDI. A study by Hadj and Ghodbane (2021), focusing on the effect of FDI on pollution *via* energy consumption, confirmed close links by using fixed and variable effect models, which validated the pollution-paradise hypothesis.

The second stream focuses on the positive effects of the pollution-halo hypothesis, positing that FDI brings advanced technologies and management experience to less developed regions, improving both resource-use efficiency and environmental quality (Pan X et al., 2023; Teng et al., 2023; Wang et al., 2023; Xie et al., 2023; Yilanci et al., 2023). Examining the location choices of United States Fortune 500 companies from 1972 to 1978 shows a greater interest in benefiting from a high-quality environment than having low-level environmental protection (Bartik, 1988). One research examining five Asian countries between 1981 and 2011 found different factors to have heterogeneous effects on carbon emissions (Zhu et al., 2016). So, although FDI can increase carbon emissions, its effect is not always judged significant. The pollution-paradise hypothesis tends to hold in low-emission countries, but in middle-to-high-emission countries FDI can be conducive to the overall reduction of carbon emissions. Utilizing a dynamic panel data model with generalized moment’s estimation for 54 countries between 1990 and 2011 showed that an increase in carbon dioxide emissions will lead to a decrease in FDI inflows (Omri et al., 2014). Hence, FDI flowing to industrialized economies was beneficial to developing countries and conducive to the improvement of China’s environmental quality (Ashraf et al., 2020). A causal relationship has been found between FDI and PM2.5 pollution in 11 emerging countries and regions, with the overall effect of FDI on PM2.5 negative, thereby supporting the pollution-halo hypothesis (Xie and Sun, 2020).

The third stream argues that FDI has an uncertain environmental impact (Guo et al., 2023). On the one hand, FDI aggravates environmental pollution *via* scale and structural effects. On the other, FDI reduces environmental pollution *via* technological effects, which differ for capital- and labor-intensive industries. One study analyzed China’s FDI and sulfur dioxide emissions, finding these factors to have an inverted U-shaped relationship and that technology adoption increases coal consumption but does not reduce sulfur dioxide emissions. Another study compared 65 countries along “the Belt and Road,” finding FDI to have a pollution-haven effect in low- and middle-income countries and a pollution-halo effect in high-income countries (Muhammad and Long, 2020; Xu et al., 2020). A Turkish study revealed that an FDI decrease leads to a long-term decline in emission growth rate, thereby confirming the asymmetric pollution-halo hypothesis. However, FDI has no effect on environmental pollution in the five BRIC countries: Brazil, Russia, India, China, and South Africa (Shao et al., 2019).

The impact of FDI on environmental pollution in host countries is controversial and can be divided into three categories: first, the pollution-haven hypothesis; The pollution-halo hypothesis; Third, FDI has both positive and negative impacts on the host country’s environment. Such a result is mainly due to scholars’ analysis of the relationship between the two from different perspectives, such as specific industries and specific regions.

Accordingly, hypothesis 1 is proposed: there is a positive (negative) relationship between industrial pollution and FDI inflow, which is consistent with the pollution-haven (halo) hypothesis, and FDI leads to higher emissions in places with weak (strong) environmental regulations.

2.2 Relationship between industrial pollution and economic growth

Previous economic growth and environmental pollution studies have mainly focused on the environmental Kuznets curve (EKC), which assumes an inverted U-curve relationship between economic output and environmental pollution (Omri et al., 2014; Tiba and Omri, 2016; Wu and Wang, 2023). One research avenue argues that environmental pollution increases with economic growth during the early stages of economic development, then decreases with economic growth after the economy reaches a certain level, hence, highlighting the existence of an EKC curve (Isik et al., 2018; Altinoz et al., 2020; Dogru et al., 2020; Alvarado et al., 2021). Some researchers have applied GMM to verify the EKC effect of carbon emissions from 24 emerging economies, finding carbon emissions and economic growth to have an inverted U-shape relationship (Hove and Tursoy, 2019). Other research has used a combined mean group (PMG), panel FMOLS, and panel DOLS to validate the environmental EKC hypothesis for OECD countries. This EKC hypothesis was further validated by the interaction between infrastructure investment in the transportation system and environmental degradation of 21 OECD countries (Erdogan, 2020). Elsewhere, the dynamic link between Pakistan's CO_2 emissions and industrial development was examined for effectiveness, with the variables found to be co-integrated, involving both long- and short-term dynamics that validate the hypothesis (Ali et al., 2021).

An alternative research avenue argues that the EKC curve does not exist (Shah et al., 2023; Farooq et al., 2023). To confirm the hypothesis, therefore, other factors must be considered, such as technological effects, resources, and scale of development. Xie et al. (2023), Khan (2023), and Farooq et al. (2023) found that economic growth has a positive linear relationship with environmental pollution. Within OECD countries, both economic growth and carbon emissions were found to follow a U-shaped relationship (Sohag et al., 2019). Higher levels of economic development, however, contributed to lower levels of pollution emissions, thereby rejecting the EKC hypothesis (Dogan and Inglesi-Lotz, 2020). It was found that CO/CO_2 and NO_2/CO_2 ratios in most developed cities marginally increase along with GDP, but these increase more substantially along with GDP in developing cities, such as Mumbai and Tianjin, whose pollutant emission ratios are very high or even comparable to developed cities (Park et al., 2021). When exploring the effects of economic growth on the use of SO_2, NO_2, and PM2.5 registered air pollutants, researchers found a U- or N-shaped relationship present between GDP *per capita* and air pollutants in eastern, western, and central China. These results suggest that the relationship between air pollutants and economic growth is associated with regional factors and the choice of variables (Xu et al., 2019).

The research on the relationship between economic growth and environmental pollution has not reached a consensus conclusion, mainly including linear and non-linear relationships. Therefore, hypothesis 2 is put forward that there is a positive (negative) relationship between industrial pollution and economic growth, and places with light (severe) pollution will promote (hinder) economic growth.

2.3 Relationship between FDI and economic growth

The relationship between FDI and economic growth has received a great deal of research, one stream of which reveals a positive relationship due to FDI directly promoting economic growth (Romer, 1986; Narteh-Yoe et al., 2022; Asafo-Agyei and Kodongo, 2023; Khan and Imran, 2023). Specifically, FDI inflow increases the host country's capital stock and access to variable funds for financial development, brings in advanced technologies, and promotes economic progression. A higher economic growth sends a positive signal that attracts more FDI (O'Doherty et al., 2003; Jalil and Mahmud, 2009; Saini and Singhania, 2018; Saini and Singhania, 2019).

The Granger causality test has been applied to determine the two-way association between FDI and economic growth within 62 countries between 1975 and 1978, and for 51 countries between 1983 and 1986. The vector error correction model was equipped with an autoregressive distributional lag test to examine the interrelationship among FDI, international trade, and economic growth within 15 selected MENA countries (Kalai and Zghidi, 2019). The results showed the long-standing unidirectional effect of FDI on economic growth. The causal relationship existing among environmental quality, FDI, and economic growth was also analyzed, showing the one-way causal relationship between direct investment stock and economic growth to support the growth hypothesis. In other words, increasing the FDI stock promotes economic growth. By embracing this as a key tool for economic growth, therefore, both developed and developing countries are eager to engage in foreign-to-foreign investment.

Other research finds the relationship between FDI and economic growth to be insignificant or even negative (Pradhan, 2009). As far as its potential (industrial, commercial and financial resources) is concerned, Russia does not attract all the FDI it matches (Fabry and Zeghni, 2002). Economic growth and financial development can develop independently, while FDI cannot affect economic growth by influencing financial development. It has also been argued that FDI can block economic growth by hindering domestic economic development due to lax policies and privatization, with the presence of financial liberalization limiting the role of economic development in attracting FDI inflows (Boyd and Smith, 1992). Furthermore, the OLS method has found no significant short- or long-term relationship between FDI and economic growth in Turkey (Temiz and Gkmen, 2014).

Whether theoretically or empirically, FDI has a positive or negative impact on the host country's economic growth. This impact is related to the host country's development potential. However, the inflow of foreign capital can bring advanced technology and financial support to the host country, which is conducive to economic development. The sustainable economic development of the host country is attractive to the inflow of foreign capital. Therefore, hypothesis 3 is that FDI inflow will promote economic growth, which can attract FDI inflow.

2.4 Relationship between pollution, FDI, and economic growth

FDI accelerates economic development and promotes employment but is also a double-edged sword in that its effects may be negative too, such as with environmental

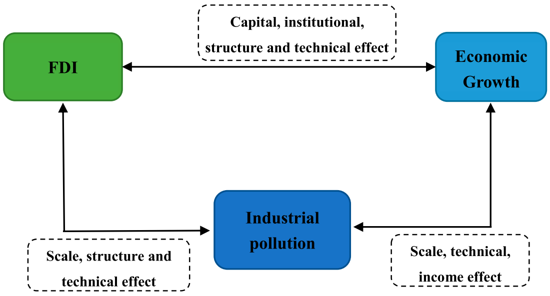

FIGURE 2
The interrelationship of FDI, economic growth, and industrial pollution.

pollution and damage (Bildirici and Çoban Kayıkçı, 2023). An empirical study analyzed the relationship between FDI, economic growth, and pollution for 14 Latin American countries, based on time series data from 1980 to 2010, concluding FDI to be positively associated with environmental pollution, thereby supporting the EKC hypothesis (Sapkota and Bastola, 2017). The researchers added that Latin America should focus on FDI policies that attract clean and energy-efficient industries with the potential to improve environmental health and promote economic growth. This theoretical analysis reveals a complex interrelationship that should be further explored, while the existing problems also need to be addressed to enable further economic development. Accordingly, strategies for managing a healthy relationship between FDI and environmental protection have become a key research problem.

In response, researchers should systematically investigate the influencing mechanisms among the key factors. Specifically, the relationship between FDI and environmental pollution should be further analyzed based on the pollution-haven and pollution-halo hypotheses, which point to the presence of scale, structural, and technology effects as defining (Behera and Dash, 2017; Liu, et al., 2019; Caglar, 2020). The EKC curve model illustrates the interactions between economic growth and pollution *via* the effects of scale, technology, income, and policy (Brock and Taylor, 2005; Lin et al., 2016). Meanwhile, the capital, technology, institutional, and structural effects between FDI and economic growth should be understood based on economic growth theory (Welela, 2018).

In short, many studies have examined the relationship between FDI and environmental pollution, economic growth and FDI, and FDI and economic growth. However, only some studies have analyzed the impact of environmental pollution on economic growth. Moreover, the relationship between the three is complicated (as shown in Figure 2 below), so putting them into the same framework and studying their mutual relationship is necessary. Therefore, this paper constructs a simultaneous equation model and uses the GMM method to evaluate the dynamic evolution characteristics and interaction effects of FDI, economic growth, and industrial pollution in the era of comprehensive green economic and social development transformation.

3 Models and data

3.1 Simultaneous equation models

As shown in previous studies investigating interactions between industrial pollution, FDI, and economic growth, a single regression analysis cannot comprehensively portray the interrelationships. Plus, using the Cobb–Douglas (C–D) production function form to build a simultaneous equation model cannot solve the endogeneity problem caused by two-way causality (Omri et al., 2014; Liu et al., 2018). The basic form of the C–D production function is $Y = AK^{\alpha}L^{\beta}$, which, after introducing environmental pollution and FDI into the economic growth equation, is transformed into the following (Ang, 2008; Anwar and Sun, 2011):

$$Y = AK^{\alpha}P^{\lambda}(FDI)^{\psi}L^{\beta} \tag{1}$$

Where Y denotes economic growth, A denotes total factor productivity, L denotes labor force, K denotes capital stock, and *FDI* denotes the actual amount of *FDI* utilized. At this point, we have $\alpha + \lambda + \psi + \beta = 1$. Following previous literature, total factor productivity (A) is excluded from the model to avoid multicollinearity, and both sides of Eq. 1 are simultaneously divided by labor force (L) and logarithmically processed to obtain the following economic growth equation:

$$\ln\left(\frac{Y}{L}\right)_{it} = \alpha_0 + \alpha_1 \ln\left(\frac{FDI}{L}\right)_{it} + \alpha_2 \ln\left(\frac{P}{L}\right)_{it} + \alpha_3 \ln\left(\frac{K}{L}\right)_{it} + \varepsilon_{it} \tag{2}$$

Where i and t denote the situation of the ith province in year t. By setting output *per capita* $y = \frac{Y}{L}$, capital stock *per capita* $k = \frac{K}{L}$, FDI *per capita* $fdi = \frac{FDI}{L}$, and pollutant emissions *per capita* $p = \frac{P}{L}$, Eq. 2 can be written as Eq. 3:

$$\ln(y)_{it} = \alpha_0 + \alpha_1 \ln(fdi)_{it} + \alpha_2 \ln(p)_{it} + \alpha_3 \ln(k)_{it} + \varepsilon_{it} \tag{3}$$

According to economic growth theory, capital stock (K) is an important factor. Plus, in addition to sulfur dioxide emissions, *FDI*, and GDP *per capita*, economic growth may be affected by population size (*pop*), technology level (*tec*), government intervention (*gov*), and trade openness (*open*). These control variables are added to Eq. 3 as part of the econometric analysis to control for their effects on the dependent variable. Eq. 4 is an economic growth model that describes the effects of industrial pollution (P), *FDI*, and control variables [6, 22, 63]:

$$\begin{aligned}\ln(y)_{it} = {} & \alpha_0 + \alpha_1 \ln(fdi)_{it} + \alpha_2 \ln(p)_{it} + \alpha_3 \ln(k)_{it} + \alpha_4 tec_{it} \\ & + \alpha_5 \ln(pop)_{it} + \alpha_6 gov_{it} + \alpha_7 open_{it} + \varepsilon_{it}\end{aligned} \tag{4}$$

P and Y affect *FDI* at a certain level, and *FDI* considers production costs, such as workers' wages and human capital level (*hum*). According to international trade theory, labor cost is an important measure of a country's comparative advantage, which China has been attracting foreign investment with. However, given that pollution control level (*reg*) and trade openness (*open*) are two other important factors that influence *FDI*, they are used as control variables in the pollution model to obtain the following equation (Wang and Chen, 2014):

$$\begin{aligned}\ln(fdi)_{it} = {} & \beta_0 + \beta_1 \ln(y)_{it} + \beta_2 \ln(p)_{it} + \beta_3 \ln(wage)_{it} + \beta_4 reg_{it} \\ & + \beta_5 open_{it} + \beta_6 \ln(hum)_{it} + \nu_{it}\end{aligned} \tag{5}$$

Another equation is established to describe the effect of *FDI* and economic growth (Y) on industrial pollution (P). Given that the pollution level is also closely related to environmental regulation (*reg*), technology level (*tec*), urbanization level (*urb*), trade openness (*open*), and industrial structure (*str*), all of these variables are added to Eq. 6 as control variables. The following industrial pollution model is then obtained (Dogan and Inglesi-Lotz, 2020; Li et al., 2020):

$$\ln(p)_{it} = \gamma_0 + \gamma_1 \ln(fdi)_{it} + \gamma_2 \ln(y)_{it} + \gamma_3 tec_{it} + \gamma_4 reg_{it} + \gamma_5 urb_{it} + \gamma_6 open_{it} + \gamma_7 str_{it} + \mu_{it} \tag{6}$$

One period of dependent variable lag level (i.e., economic growth, FDI inflow, and industrial pollution) can affect current levels. The lag term of the dependent variables, therefore, is introduced in Eq. 4–6 to construct the following dynamic simultaneous equation models:

$$\begin{cases} \ln(y)_{it} = \alpha_0 + \alpha_1 \ln(y)_{it-1} + \alpha_2 \ln(fdi)_{it} + \alpha_3 \ln(p)_{it} + \alpha_4 \ln(k)_{it} + \alpha_5 tec_{it} \\ \qquad + \alpha_6 \ln(pop)_{it} + \alpha_7 gov_{it} + \alpha_8 open_{it} + \varepsilon_{it} \\ \ln(fdi)_{it} = \beta_0 + \beta_1 \ln(fdi)_{it-1} + \beta_2 \ln(y)_{it} + \beta_3 \ln(p)_{it} + \beta_4 \ln(wage)_{it} + \beta_5 reg_{it} \\ \qquad + \beta_6 open_{it} + \beta_7 \ln(hum)_{it} + \nu_{it} \\ \ln(p)_{it} = \gamma_0 + \gamma_1 \ln(p)_{it-1} + \gamma_2 \ln(fdi)_{it} + \gamma_3 \ln(y)_{it} + \gamma_4 tec_{it} + \gamma_5 reg_{it} + \gamma_6 urb_{it} \\ \qquad + \gamma_7 open_{it} + \gamma_8 str_{it} + \mu_{it} \end{cases} \tag{7}$$

3.2 Variables selection

Economic growth is expressed in terms of GDP and converted to actual values by using CPI, taking 2006 as the base period. Industrial pollution (P) is expressed as industrial sulfur dioxide emissions, while FDI is expressed as the actual amount of FDI utilized by each region, which is initially converted to RMB using the annual average exchange rate of USD to RMB, then converted to actual 2006 values by using CPI.

Among the control variables, capital stock is calculated as follows using the perpetual inventory method: $K_{it} = (1 - \delta_{it})K_{it-1} + I_{it}$, where K_{it} denotes the total fixed asset formation in city i in year t and takes 2006 as the base period, while δ_{it} is the depreciation rate and takes a fixed value of 9.6%. Meanwhile, labor force (L) is expressed as the average number of employees on the job, technology level (*tec*) is expressed as the ratio of national internal expenditure on R&D funds to GDP, population size (*pop*) is expressed as the total population at the end of the year, and government intervention (*gov*) is expressed as the GDP share of government general public budget expenditure.

The level of openness to the outside world (*open*) is expressed as the share of total imports and exports of goods in regional GDP, *wage* is expressed as the average wage, environmental regulation level (*reg*) is expressed as the investment in environmental pollution control as a share of GDP, urbanization level (*urb*) is measured by the share of urban population, human capital level (*hum*) is expressed as the average number of students in higher education per 100,000 population, and industrial structure (*str*) is expressed as secondary industry share (Soytas et al., 2007; Zhu L et al., 2019; Zhu W et al., 2019).

Considering the availability, reliability, and accuracy of the data, this study selected the panel data of 30 provinces and cities in China from 2006 to 2017 for empirical analysis (Tibet was excluded due to missing data) as the observation object, while individual missing data were supplemented according to the mean value method. All data are obtained from the *Wind* database, China Statistical Yearbooks, China Environmental Statistical Yearbooks, China Urban Statistical Yearbooks, China Social Statistical Yearbooks, and the statistical yearbooks of provinces and cities. The symbols, names, and unit attributes of the above statistical variables are specified in Table 1.

3.3 Estimation methods

Given that explanatory variables with one-period lag are included in Eqs 4–6, using the classical OLS approach may lead to biased estimation results. Meanwhile, the generalized method of moments (GMM) can address the endogeneity problem in the models and obtain consistent estimates (Bond, 2002; Hille, 2018; Hashmi and Alam, 2019).

GMM offers two advantages for this study. Firstly, *per capita* pollutant emissions, *per capita* foreign direct inflows, and *per capita* GDP may be determined at the same time. Dynamic panel GMM can effectively control the endogeneity of the explanatory variables by selecting appropriate instrumental variables (Çoban and Topcu, 2013). Secondly, when the unobservable variables are related to explanatory variables or when some influencing factors are omitted, GMM uses differential conversion data to overcome the problem of missing variables. System GMM (SYS-GMM), which includes one- and two-step GMM, is used because the weight matrix of the two-step estimation depends on the estimated parameters and the standard deviation is biased downward, which provides neither significant efficiency improvements nor reliable estimators (Arellano and Bond, 1991; Arellano and Bover, 1995; Monica and Neha, 2021). To test the rationality of the estimation method, the results of one-step difference GMM and one-step SYS-GMM are also presented.

4 Results and discussion

4.1 Panel unit root tests

Given that this article uses large N small T panel data, the HT method is used in the panel unit root test to avoid the regression phenomena in the regression process and to ensure that the results are unbiased and effective. The test results are shown in Table 2.

The three indexes of the original sequence *ln(pop)*, *tec*, and *urb* are non-stationary variables, whereas the other variables are stable. However, after the first-order difference, each variable becomes stable. The next step, therefore, is to test for a long-term co-integration relationship among the variables.

4.2 Panel co-integration tests

Kao test is performed to test the co-integration among economic growth, FDI, and sulfur dioxide emissions for each influence factor. Table 3 reveals the p-values of each equation variable with economic

TABLE 1 Type, definition, and descriptive statistics of variables.

Type	Variable	Units of measurement	Mean	Max	Min	Std. Error
Endogenous variable	*y* (GDP *per capita*)	Chinese Yuan/person	331,533	728,251	3,096	108,731
	p (Industrial sulfur dioxide emissions *per capita*)	Tons/person	0.1940	0.8960	0.0005	0.1830
	fdi (Per capita actually utilized FDI)	Chinese Yuan/person	0.7770	4.1240	0.0065	0.6920
Exogenous variable	*k* (Net value of fixed assets *per capita*)	Chinese Yuan/person	1,294,000	4,069,000	11,241	593,531
	hum (Average number of students in colleges and universities per 100,000 population)	Person	2,404	6,897	903.9000	974.1000
	pop (Total population at the end of the year)	10,000 people	4,467	11,169	548	2,678
	L (Average number of employees)	Person	5,445,000	370,400,000	210,900	19,570,000
	urb (Proportion of urban population)	Percentage	53.4900	89.6000	27.4600	13.7400
	tec (The ratio R&D expenditure to GDP)	Percentage	1.4520	6.0100	0.2000	1.0650
	gov (The government's general public budget expenditure as a proportion of GDP)	Percentage	0.2220	0.6270	0.0837	0.0963
	open (The proportion of total import and export of goods in GDP)	Percentage	0.2960	1.6680	0.0116	0.3360
	reg (Investment in environmental pollution control as a proportion of GDP)	Percentage	1.3720	4.2400	0.3000	0.6880
	wage (Average on-the-job salary)	Chinese Yuan	36,388	103,347	357.5000	14,778
	str (Proportion of secondary industry)	Percentage	46.2700	59.3000	19.0000	8.1070

Note: All data are obtained from the *Wind* database, China Statistical Yearbooks, China Environmental Statistical Yearbooks, China Urban Statistical Yearbooks, and China Social Statistical Yearbooks.

TABLE 2 Results of the HT unit root test of variables.

Variable	Original sequence	First order differential
ln(y)	(0.0000)	(0.0000)
ln(fdi)	(0.0000)	(0.0000)
ln(p)	(0.0000)	(0.0000)
ln(k)	(0.0000)	(0.0000)
ln(L)	(0.0000)	(0.0000)
tec	(0.8618)	(0.0000)
ln(pop)	(0.4258)	(0.0000)
gov	(0.9998)	(0.0007)
(open)	(0.1363)	(0.0049)
ln(wage)	(0.0000)	(0.0000)
reg	(0.0000)	(0.0000)
lnhum	(0.0084)	(0.0000)
urb	(0.4584)	(0.0000)
str	(0.9556)	(0.0000)

Notes: The estimated *p*-values are enclosed in parentheses.

growth, FDI, and SO_2 emissions to be less than 0.1, which passes the significance test and so indicates the presence of a long-term co-integration relationship among economic growth, FDI, and SO_2 emissions.

4.3 Empirical results and analysis

Table 4 presents the estimations obtained using Stata16.0, one-step differential GMM, and one-step system GMM methods, using economic growth, FDI, and industrial pollution and their lagged variable as endogenous variables. For those problems related to order sequence, the regression results of each equation are valid. The Hansen-J value indicates that the selected instrumental variable passes the over-identification test and meets the requirements of correlation and exogeneity. SYS-GMM outperforms differential GMM in terms of the significance of the explanatory variable's coefficient and the Hansen-J value. The SYS-GMM estimation results, therefore, are used for analysis reference.

Model (2) in Table 4 shows that the coefficient of *lnfdi* is 0.149 in the economic growth equation, which is significant at the 1% level. In other words, for every 1 percentage point increase in *FDI per capita*, the regional economy increases by 0.149 percentage points, thereby suggesting that FDI promotes regional economic growth. Meanwhile, the coefficient of *Lnp* is 0.041, which means that, for every 1 percentage point increase in industrial sulfur dioxide emissions *per capita*, the regional economy increases by 0.041 percentage points at the 10% significance level. This positive correlation supports the assumption that China endures environmental damage for the sake of economic growth and confirms the country to be in a stage of rapid industrialization, with high-pollution manufacturing as the supporting industry. Among the control variables, the coefficient of *lnk* is 0.71 and significantly positive, indicating

TABLE 3 Results of the Kao panel co-integration test.

Kao test for Eq. 4	Statistic	*p*-value
Modified Dickey–Fuller t	−1.7544	0.0397
Dickey–Fuller t	−2.7230	0.0032
Augmented Dickey–Fuller t	−3.5927	0.0002
Unadjusted modified Dickey–Fuller t	−1.3797	0.0838
Unadjusted Dickey–Fuller t	−2.5222	0.0058
Kao test for Eq. 5	**Statistic**	***p*-value**
Modified Dickey–Fuller t	−6.0756	0.0000
Dickey–Fuller t	−6.1627	0.0000
Augmented Dickey–Fuller t	−3.6641	0.0001
Unadjusted modified Dickey–Fuller t	−6.2033	0.0000
Unadjusted Dickey–Fuller t	−6.2032	0.0000
Kao test for Eq. 6	**Statistic**	***p*-value**
Modified Dickey–Fuller t	−5.8443	0.0000
Dickey–Fuller t	−6.8921	0.0000
Augmented Dickey–Fuller t	−2.4383	0.0074
Unadjusted modified Dickey–Fuller t	−8.2939	0.0000
Unadjusted Dickey–Fuller t	−7.7031	0.0000

that the stock of fixed capital can positively contribute to the development of China's economy (Hamdi et al., 2014). A comparison of the *lnfdi* and *lnk* coefficients reveals that, during the study period, domestic fixed capital achieves a greater contribution to China's economic development compared with FDI. The coefficient of *lnpop* is 0.137, which is significant at the 1% level, whereas the coefficient of *tec* is 0.055, which is significantly positive at the 10% level. China, therefore, is dominated by labor-intensive industries, featuring a level of technology that, to a certain extent, can also contribute to its economic growth. The coefficient of *gov* is significantly positive at the 1% statistical level, indicating that the Chinese government can reasonably allocate local general budget expenditure costs, allowing them to effectively and reasonably utilize financial resources. The coefficient of *open* is positive yet insignificant, thereby suggesting that foreign opening levels do not have a significant role in promoting economic growth.

In Model (4), the coefficient of *lny* is 0.774 and significant at the 10% level, suggesting that for every 1 percentage point increase in the economy *FDI per capita* increases by 0.774 percentage points. The host country's economic development level is among the key factors that foreign investors consider. A larger scale of economic development indicates a greater market potential and higher potential for attracting foreign investors (Omri and Sassi-Tmar, 2015). The coefficient of *lnp* is 0.141 and significant at the 5% level, suggesting that for every 1 percentage point increase in industrial SO_2 emissions *per capita FDI* increases by 0.141 percentage points. In other words, a greater amount of industrial sulfur dioxide emissions results in more serious environmental pollution. This finding may be ascribed to the fact that, for some industries, higher pollution lowers environmental standards, whereas lower expenditure on environmental protection for foreign investors corresponds to lower costs and greater FDI inflows (Blanco et al., 2013; Bildirici and Çoban Kayıkçı, 2023). Among the control variables, the coefficient of *lnwage* is −0.152 and insignificant, suggesting that even though labor cost can affect FDI entry to some extent, this factor is not of high consideration among foreign investors. The coefficient of *reg* is −0.225 and significant at the 5% level, indicating that environmental regulation has a suppressive effect on FDI inflows. This result validates the pollution-haven hypothesis that a greater degree of pollution can effectively attract more FDI. The coefficient of *lnhum* is significantly positive, indicating that FDI is closely related to local human capital level and that human capital enhances the ability of cities to attract FDI.

In Model (6), the coefficient of *lny* is 0.52 and significant at the 5% significance level, suggesting that for every 1 percentage point increase in economic growth, *per capita* sulfur dioxide emissions increase by 0.52 percentage points. China's economic development stays on the left side of the EKC curve, while the degree of environmental pollution increases with economic growth (Shahbaz et al., 2015; Lau et al., 2014; Bildirici and Çoban Kayıkçı, 2023). The coefficient of *lnfdi* is 0.254 and significant at the 10% significance level, suggesting that for every 1 percentage point increase in *per capita FDI*, *per capita* industrial sulfur dioxide emissions increase by 0.254 percentage points (He, 2006; Acharyya, 2009; Ren et al., 2014; Wu and Wang, 2023). In other words, FDI inflow leads to further environmental degradation, thereby verifying the pollution-haven hypothesis. Among the control variables, the coefficient of *open* is 0.143 and insignificant, thereby indicating that the degree of openness is not the main cause of pollution. Meanwhile, the coefficient of *reg* is 0.161 and significant at the 10% level, indicating that China's environmental regulation is ineffective, that the country may still be in the early stages of implementing environmental protection policies, and that its technical equipment and policy methods are not effective in improving the environment. The coefficient of *urb* is −0.031 and significant at the 1% level, indicating that a higher level of urbanization can reduce industrial pollution for two possible reasons. Firstly, urban areas are not conducive to the establishment of large factories. Secondly, a higher level of development increases people's awareness of the importance of environmental protection and inspires environmental protection initiatives, thereby contributing to pollution reduction. The coefficient of *tec* is 0.065 and insignificant, suggesting that technology level does not have a suppressive effect on SO_2 emissions.

The first-order lagged coefficients of *lny*, *lnfdi*, and *lnp* are all significantly positive. This result also supports the validity of using the dynamic panel model. The coefficient of *L.lnfdi* is 0.446, suggesting that for every 1% increase in FDI during the previous period the current period increases by 0.446%. FDI shows an agglomeration effect because foreign investors tend to focus on location when choosing investments. To reduce the risks posed by uncertain factors such as culture, economy, market situation, and

TABLE 4 GMM estimation results for pollution, FDI, and economic growth.

Variable	Diff-GMM (1) *lny*	Sys-GMM (2) *lny*	Diff-GMM (3) *Lnfdi*	Sys-GMM (4) *lnfdi*	Diff-GMM (5) *lnp*	Sys-GMM (6) *lnp*
lny			1.1090*** (3.4500)	0.7740* (1.8700)	1.3420*** (3.4100)	0.5200** (2.7500)
lnfdi	0.2320*** (4.6500)	0.1490*** (3.5900)			−0.3450 (−0.9000)	0.2540* (1.9400)
lnp	0.1090*** (4.7800)	0.0410* (1.8100)	0.0610 (1.1300)	0.1410** (2.1000)		
lnk	0.8250*** (11.1600)	0.7100*** (9.0300)				
tec	0.0660 (1.0700)	0.0550* (2.0000)				
gov	−0.6160 (−1.0400)	1.0330*** (2.8200)				
lnpop	1.0370 (1.4600)	0.1370*** (3.7000)				
Open	−0.3540** (−2.1600)	0.0350 (0.5600)	0.3490 (0.9300)	0.4230 (1.4700)	1.7000** (2.1800)	0.1430 (0.8200)
reg			0.0080 (0.2100)	−0.2250** (−2.4500)	0.1430*** (2.9900)	0.1610* (1.9300)
Lnwage			−0.1200 (−0.4200)	−0.1520 (−0.6100)		
lnhum			−1.0870* (−1.8600)	0.9900** (2.3400)		
urb					−0.0930*** (−4.590)	−0.0310*** (−2.8100)
tec					0.1110 (0.5200)	0.0650 (0.4900)
str					0.0610*** (3.6300)	0.0100 (0.9600)
L.lny	0.3620* (1.9900)	0.1520** (2.0500)				
L.lnfdi			0.1710 (1.2400)	0.4460* (1.7500)		
L.lnp					0.4050 (1.6800)	0.8230*** (3.5000)
N	300	330	300	330	300	330
AR (2)	(0.1180)	(0.1380)	(0.6030)	(0.2750)	(0.7610)	(0.2760)
Hansen-J	(0.0810)	(0.9340)	(0.5660)	(0.8940)	(0.5010)	(0.6150)

Notes: The estimated *p*-values are enclosed in parentheses. The Hansen J-test refers to the over-identification test for GMM, estimation restrictions according to the original hypothesis that there is no over-identification of the equation perturbation terms. The AR(2) test refers to the Arellano–Bond test for the existence of a second-order autocorrelation in first differences. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

host country preferential policies, foreign investors tend to be drawn to those areas where foreign capital is relatively concentrated. Meanwhile, the flow of foreign capital into the high-emission manufacturing industry will increase industrial sulfur dioxide emissions and intensify environmental pollution. For the environment, pre-pollution will significantly aggravate the deterioration of current environmental levels. Timely population control measures, therefore, should be adopted to avoid ecosystem destruction.

5 Conclusion

By using a dynamic panel coefficient model, this paper analyzes the panel data of 30 provinces and cities in China between 2006 and 2017 with the aim of understanding whether introducing foreign investments produces a pollution-haven or pollution-halo effect on China's environment, whether economic growth and foreign investment inflow have a mutual promotion effect, and whether an EKC exists between economic growth and pollution.

On the one hand, FDI inflows promote China's economic growth, but economic growth also brings harm to the environment. Seeing that a high level of environmental pollution is conducive to FDI taking place, these inflows do pose a threat to China's environment, thereby validating the pollution-paradise hypothesis. So, despite the negative relationship between environmental regulations and FDI inflows, China's present environmental regulations do not actually benefit the country's environment. Moreover, foreign investors choose to invest in those areas with poor environmental standards, thereby exacerbating these complications. On the other hand, the scale of economic development positively affects FDI, indicating that economic growth and FDI inflows can promote each other. Actively introducing FDI while supervising and improving foreign investment access policy can promote China's economic growth yet deteriorate its environment at the same time. Green thresholds should be established, therefore, ensuring that the inflow of highly polluting foreign investment is strictly gated and managed, the industrial structure of FDI is balanced, and the development of high-tech industries accelerated. When foreign investors consider green industries, some preferential treatment may be advisable to encourage additional investments in sustainable development.

Economic growth harms the environment, whereas industrial pollution positively affects economic growth. In this case, China's economic development leans on the left side of the EKC curve, meaning that the country sacrifices its environment for the sake of economic development. Therefore, China needs to change its economic development model and emphasize the quality of economic growth. At the same time, the government should strengthen environmental supervision, introduce high-quality FDI, and play the role of foreign investment in improving the environment.

6 Limitations and future directions

Although this study supplements the research on the relationship between FDI, economic growth, and industrial pollution under the same framework, it still has shortcomings that need further improvement. First of all, due to the limitations of data availability and data processing methods, only *per capita* industrial sulfur dioxide emission is selected as the proxy variable of industrial pollution, which has certain defects in measuring industrial pollution. Subsequent studies can expand this based on data richness. Secondly, this study did not analyze the relationship mechanism among the three. In the follow-up study, more in-depth research should be carried out on the theoretical and specific effect mechanisms of the interaction between the three. Finally, the panel data of 30 provinces in China from 2006 to 2017 are studied in this paper. In future work, the scope of the study can be expanded to other regions with different economic and social conditions, which is conducive to the comparison and generalization of the research results.

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

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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