



Exploring the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control in China

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Abstract

Based on the perspective of government-dominated and market-driven industrial co-agglomeration mode, the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control is explored by using spatial Durbin model, and the mediating effect of technological innovation is further tested. The results show that: (1) At the national level, the government-dominated industrial co-agglomeration only significantly promotes the local ecological environment pollution control, while the market-driven industrial co-agglomeration also can promote the ecological environment pollution control in the surrounding region through its spatial spillover effect. Moreover, there is a significant inverted “U-shaped” curve relationship between the economic development level and ecological environment pollution. Additionally, the environment regulation is also conducive to promoting the ecological environment pollution control, while the industrial structure and foreign direct investment will lead to more serious ecological environment pollution; (2) In the east region, the government-dominated and market-driven industrial co-agglomeration can promote the ecological environment pollution control in the local and surrounding regions, and the promotion effect and spatial spillover effect of market-driven industrial co-agglomeration are greater. However, in the central and west regions, the government-dominated industrial co-agglomeration and market-driven industrial co-agglomeration only promote the local ecological environment pollution control. (3) Technological innovation has partial mediating effect in the impact of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution control, namely that the government-dominated and market-driven industrial co-agglomeration not only can directly promote the ecological environment pollution control, but also can indirectly promote the ecological environment pollution control through the mediating effect of technological innovation.

Keywords Producer services and manufacturing industrial co-agglomeration · Ecological environment pollution control · China · Dynamic spatial Durbin model (SDM) · Spatial spillover effect · Mediating effect test

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Abbreviations

<i>EPI</i>	Ecological environment pollution index
<i>Gov_Coagg</i>	Government-dominated producer services and manufacturing industrial co-agglomeration
<i>Mar_Coagg</i>	Market-driven producer services and manufacturing industrial co-agglomeration
<i>Pgdp</i>	Economic development level
<i>Er</i>	Environment regulation
<i>Is</i>	Industrial structure
<i>FDI</i>	Foreign direct investment
<i>W</i>	Spatial weight matrix
ρ	Spatial lag coefficient
<i>LogL</i>	Log-likelihood
Obs.	Observation
VIF	Variance inflation factor
SDM	Spatial Durbin model
<i>TI</i>	Technological innovation level

1 Introduction

Since the founding of new China 70 years ago, China's economy has achieved a miracle of rapid development, which is largely due to the cheap labor and abundant natural resources. However, with China's economy entering the "new normal," the extensive economic growth model, which consumes too much energy resources and sacrifices the ecological environment, is difficult to sustain (Feng & He, 2020; Huo et al., 2018, 2020; Lin & Chen, 2019; Ouyang et al., 2019; Yang et al., 2020; Zhao & Li, 2020; Zhao & Lin, 2020). Problems such as resource shortage, environment pollution and ecological damage arise one after another, and the economic development mode needs to change into the intensive development of pursuing structural adjustment and environment efficiency. China has become one of the most polluted countries in the world; the worsening ecological environment pollution has gradually become the main bottleneck restricting the sustainable economic & social development and the economy green transformation and upgrading of China. According to the "China Environment Economic Accounting Research Report 2010," the cost of ecological environment degradation in China reached 1538.95 billion yuan in 2010, accounting for 3.5% of GDP in that year. At the same time, according to the "China's Economic and Ecological GDP Accounting Development Report 2018," the ecological destruction cost of China was 0.63 trillion yuan, the pollution loss cost was 2 trillion yuan, and the total cost of ecosystem destruction and pollution loss accounted for about 2.1% in 2015. In addition, due to the burning of fossil fuels, carbon dioxide (CO₂) emissions in the atmosphere have increased dramatically, which resulted in the destruction of ecological environment and the decline of ecological environment quality (Akram et al., 2019; Engo, 2020; Hossain et al., 2021). Therefore, how to strengthen the ecological environment pollution control and improve the ecological environment quality, so as to reduce environment pollution and ecological destruction, and realize the sustainable economic development, have become the key problem to be urgently solved for fighting the battle of pollution prevention and accelerating the construction of beautiful China.

In recent years, the energy crisis, greenhouse gas and wastewater emissions had led the world's nations to face higher production costs and serious ecological environment issues (Farahbod, 2020a, b; Taherizadeh et al., 2020). In order to solve the problem of simultaneously considering the economic development and environment protection, Chinese President of Xi Jinping repeatedly put forward "speeding up the transformation of economic development mode and strengthening the comprehensive control of ecological environment pollution." Based on the theory of industry co-agglomeration, on the one hand, the producer services and manufacturing industrial co-agglomeration can effectively solve the industrial mismatch problem, guide the optimal allocation of industrial resource, so as to further improve the resource utilization efficiency, reduce the energy consumption, and then reduce the pollution emissions and ecological damage through the collaborative labor division and resource integration (Liu et al., 2017; Wang et al., 2020; Yang et al., 2020); On the other hand, the producer services and manufacturing industrial co-agglomeration can also promote technological innovation through the mechanism of resource sharing effect, knowledge or technology spillover effect, as well as competition upgrading effect, so as to optimize the energy consumption structure, promote the energy conservation and emission reduction and green economic transformation and upgrading, then accelerate the environment pollution control and improve the ecological environment quality (Howard et al., 2016; Van Oort, 2017). Therefore, the producer services and manufacturing industrial co-agglomeration is undoubtedly an important breakthrough direction of economy green transformation and ecological environment pollution control in China. At present, the collaborative development of producer services and manufacturing industry has risen to China's national strategy level, and it has been steadily and orderly promoted all over the country. The "13th five year plan" of China clearly points out to "promote the transformation of manufacturing industry from production oriented to production service oriented, guide the manufacturing enterprises to extend service chain and promote service value-added," which indicates that the top-level design of producer services and manufacturing industrial co-agglomeration are getting more and more emphasis. Therefore, under the dual pressures of resource and environment constraint, in order to promote China's economic green transformation development and the comprehensive control of ecological environment pollution, so as to promote the ecological environment protection and ecological civilization construction, and then promote the continuous improvement of ecological environment quality, this paper will make in-depth analysis of the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control, and further explore the new path and policy focus of China's ecological environment pollution control.

With the upgrading of industrial structure, the refinement of social labor division and the improvement of specialization level, as well as the transformation from "industrial economy" to "service economy," the trend of collaborative development between producer services and manufacturing industry is increasingly apparent (Ke et al., 2014). The producer services & manufacturing industrial co-agglomeration and environment pollution control are important thrust and objective function of economic green transformation, there is an internal relation between them that cannot be ignored. However, the existing studies mainly focus on the impact of single industrial agglomeration, such as manufacturing industrial agglomeration or services industrial agglomeration, little has been studied on the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution. Moreover, their conclusions are still controversial. Among them, the most representative views are as follows: The first view is that, on the one hand, industrial agglomeration can effectively promote technological innovation through the knowledge or technology spillovers, so as to improve the energy utilization efficiency, reduce the environment pollution, then promote the ecological environment pollution control and

improve the ecological environment quality (Hosoe & Naito, 2006; Liu et al., 2017; Wang et al., 2020; Yang et al., 2020; Zeng & Zhao, 2009); On the other hand, enterprises in the industrial agglomeration area can effectively produce structural effects through the horizontal and vertical correlations, thus promote the formation of circular economy, reduce the energy consumption and pollutant emission (Enrenfeld, 2003). At the same time, according to the theory of new economic geography (NEG), technology spillover is the main driving force of industrial agglomeration, and the diffusion of clean technology can effectively reduce the ecological environment pollution control cost. The second view is that industrial agglomeration will not only lead to “race to the bottom line of environment standards” in policy making, so as to attract foreign backward enterprises with high pollution, high energy consumption and high emission, thus become a “paradise for enterprises of pollution refuge,” which results in rapid increasing of energy consumption and pollutant emission (Akbostanci et al., 2007; Shen et al., 2019; Verhoef & Nijkamp, 2002); But also, it will cause cross-regional mixed pollution of ecological environment and cross-regional superposition of pollutant through the negative environment externalization, so as to lead to the deterioration of ecological environment (Cheng, 2016). In addition, the excessive pursuit of “policy rent” (free rider) and intense homogeneous competition (crowding effect) caused by increasing agglomeration will lead to inefficient energy utilization and further aggravate the ecological environment pollution (De Leeuw et al., 2001; Han et al., 2018; Verhoef & Nijkamp, 2002). The third view is that there is a threshold effect in the impact of industrial agglomeration on the energy utilization efficiency, which leads to a nonlinear relationship between the industrial agglomeration and ecological environment pollution (He, 2006; He et al., 2014; Zhao & Lin, 2019; Zheng & Lin, 2018).

The existing studies provide some reference for us to explore the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control, but there are still spaces for further analysis: (1) Scholars have yet to reach an agreement on the effect of industrial agglomeration on the ecological environment pollution, and the producer services and manufacturing industrial co-agglomeration is quite different from the single industrial agglomeration previously studied. At the same time, the existing studies usually regard the industrial co-agglomeration as a “black box,” and relatively few studies have been conducted by analyzing the producer services and manufacturing industrial co-agglomeration from the perspective of government-dominated and market-driven industrial co-agglomeration mode. (2) The existing studies mainly analyze the effect of industrial agglomeration on the ecological environment pollution control in the local region, but there is no further research on its spillover effect on the surrounding region and rare investigation into the phenomenon that industrial co-agglomeration mode of producer services and manufacturing industry has stronger spatial spillover effect. (3) There is still a lack of delving into the heterogeneity of the impact of different industrial co-agglomeration modes (government-dominated and market-driven industrial co-agglomeration) on the ecological environment pollution control in different regions. Moreover, most of the literature rarely further analyzes the mediating effect of technological innovation in the impact of government-dominated and market-driven producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control.

In view of these, this paper attempts to make efforts in the following three aspects: (1) Different from the measurement model of single industrial agglomeration degree, this paper will construct the measurement model of producer services and manufacturing industrial co-agglomeration according to the differences of agglomeration indicators. Meanwhile, this paper will further divide the industrial co-agglomeration modes into government-dominated and market-driven industrial co-agglomeration, and construct the measurement

model of government-dominated and market-driven industrial co-agglomeration through introducing the interaction item between industrial co-agglomeration and government support & market-driven ability, so as to better reflect the behaviors choices of the government and the market in the producer services and manufacturing industrial co-agglomeration. (2) Different from the above literature that mainly analyzes the effect of industrial agglomeration on the local ecological environment pollution, this paper will introduce the spatial weight matrix to construct the spatial Durbin econometric model to explore the effect of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution control in the surrounding region, and further compares its spatial spillover effects, so as to analyze whether the government or the market plays a decisive role in the development of industrial co-agglomeration, and deal with the relationship between the government and the market in the “two-wheel drive” of manufacturing industry and producer services industry. (3) Different from the above literature which pays little attention to the effect of different industrial co-agglomeration modes on the ecological environment pollution control in different regions, this paper will explore the differences in the effect of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution control in the east, central and west regions, so as to provide a new development direction and route choice for each region to promote the effective ecological environment pollution control in China by combining its own industrial foundation and comparative advantages. Meanwhile, with the idea of mediating effect test, taking the technological innovation as the intermediary variable, this paper will further study the internal mechanism of the impact of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution control, so that these conclusions have more abundant policy connotation and practical significance.

2 Theoretical analysis, variables description, data source and model construction

2.1 Theoretical analysis

Generally speaking, the producer services industry plays the role of “middleman” for the manufacturing industry, while the manufacturing industry plays the role of “customer” for the producer services industry. In order to get closer to the “customer,” promote the information transmission and save the transaction cost as well as reduce the manufacturing cost, the producer services industry tends to be concentrated around the manufacturing industry, thus forming a phenomenon of industry division and cooperation (Ke et al., 2014). Therefore, producer services and manufacturing industry will show an obvious spatial co-agglomeration trend.

With the deepening of producer services and manufacturing industrial co-agglomeration, on the one hand, it not only can conduce to the formation of scale economy effect and resource sharing effect, so as to comprehensively improve the factor productivity, and effectively reduce the production cost and transaction cost, thus reduce the unit energy consumption and improve the energy utilization efficiency (Hosoe & Naito, 2006; Liu et al., 2017; Wang et al., 2020; Yang et al., 2020; Zeng & Zhao, 2009), then reduce the pollution emissions & ecological destruction, promote centralized governance of ecological environmental pollution. On the other hand, producer services and manufacturing industrial co-agglomeration is also conducive to strengthening the flow and diffusion of innovation elements such

as talent, capital, information and technology among regions, and then producing the technology spillover effects to accelerate the technological innovation, thus bringing about the energy-saving technology progress, producing the circular economy, promoting the green transformation and upgrading of economy and optimization of energy consumption structure, finally promoting the comprehensive control of ecological environment pollution and improving the environment quality (Enrenfeld, 2003; Howard et al., 2016; Van Oort, 2017).

In summary, producer services and manufacturing industrial co-agglomeration not only can directly promote the ecological environment pollution control, but also can indirectly promote the ecological environment pollution control through the mediating effect of technological innovation. The influence mechanism of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control can be illustrated by Fig. 1.

2.2 Variable description

2.2.1 Explained variable: ecological environment pollution index (EPI)

Considering that industrial pollution is the most important source of ecological environment pollution in China, with reference to Yang and Wei (2019) and Yang et al. (2020), this paper uses industrial waste gas emissions (100 million standard cubic meters), industrial wastewater emissions (10,000 tons), industrial solid waste (10,000 tons), industrial sulfur dioxide emissions (ton), industrial smoke and dust emissions (10,000 tons) to construct an ecological environment pollution index (EPI) to measure the ecological environment pollution degree of 30 provinces in China from 2003 to 2018. With reference to Yang et al. (2020), the entropy method is applied to calculate

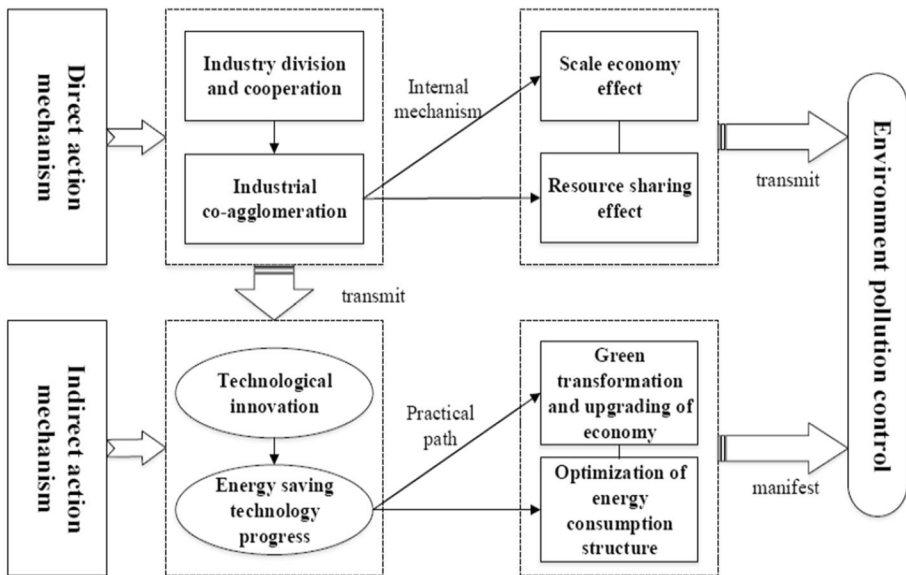


Fig.1 The influence mechanism of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control

the weight index ($w_{\text{poll}_{ijt}}$) of these industrial pollutants, and the formula of ecological environment pollution index (EPI) can be given as follows.

$$\text{EPI}_{it} = \sum_{j=1}^n w_{\text{poll}_{ijt}} \text{poll}_{ijt}, \quad (1)$$

where the larger the EPI, the worse the ecological environment pollution control.

2.2.2 Explanatory variable: government-dominated & market-driven producer services and manufacturing industrial co-agglomeration

With reference to the idea of co-agglomeration between industries proposed by Ellison et al. (2010), this paper mainly uses the difference of agglomeration indicators to construct the measurement model of producer services and manufacturing industrial co-agglomeration. Firstly, the location entropy method is used to measure the agglomeration degree of manufacturing industry (maagg) and producer services industry (seragg), respectively. The formula can be given as follows:

$$\text{LQ}_{ij} = \frac{q_{ij}/q_j}{q_i/q} \quad (i = \text{maagg}, \text{seragg}), \quad (2)$$

where q_{ij} denotes the number of employees of industry i in the province j , q_j denotes the number of employees of producer services and manufacturing industry in the province j , q_i denotes the national number of employees of industry i , and q denotes the national number of employees of producer services and manufacturing industry.

Then, the measurement model of producer services and manufacturing industrial co-agglomeration can be given as follows:

$$\text{Coagg} = 1 - \left| \text{LQ}_{\text{maagg}} - \text{LQ}_{\text{seragg}} \right| / (\text{LQ}_{\text{maagg}} + \text{LQ}_{\text{seragg}}). \quad (3)$$

Moreover, in order to better reflect the behaviors choices of the government and the market in the producer services and manufacturing industrial co-agglomeration, this paper further constructs the measurement model of government-dominated and market-driven industrial co-agglomeration by introducing the interaction item between industrial co-agglomeration and government support & market-driven ability, respectively. The formula can be given as follows:

$$\text{Gov_Coagg} = \text{Gover} \times \text{Coagg} \quad (4)$$

$$\text{Mar_Coagg} = \text{Market} \times \text{Coagg}, \quad (5)$$

where Gover denotes the government support, which is measured by the proportion of government funds in the amount of funds raised by enterprises activities; Market denotes the market-driven ability, which is measured by the proportion of non-state owned enterprises in the total number of producer services and manufacturing enterprises.

2.2.3 Control variables

Previous studies have shown that the ecological environment pollution can also be affected by other factors, such as economic development level (Akram et al., 2020; Zhang et al., 2017), environment regulation (Jin et al., 2019; Song et al., 2018), industrial structure (Freire-González et al., 2017; Gao & Zhang, 2019) and FDI (Pan et al., 2020; Wang et al., 2020). Therefore, this paper mainly takes the following variables as the control variables.

2.2.3.1 Economic development level (*Pgdp*) Ecological environment pollution is closely related to economic development level. Economic development will consume a lot of energy factors and aggravate ecological environment pollution, but economic development also can provide sufficient financial support for the prevention and control of ecological environment pollution. The per capita gross domestic product is used to denote the economic development level. At the same time, in order to further test whether Environment Kuznets Curve (EKC) hypothesis exists in China, this paper introduces the quadratic term of economic development level.

2.2.3.2 Environment regulation (*Er*) Environment regulation is an important tool to prevent and control ecological environment pollution (Jin et al., 2019; Song et al., 2018). With reference to Yang et al. (2020), this paper uses the ratio between the investment in pollution abatement and the gross output to denote the environment regulation intensity.

2.2.3.3 Industrial structure (*Is*) A large number of existing studies have shown that the industrial structure is a very important factor affecting the ecological environment pollution control (Freire-González et al., 2017; Gao & Zhang, 2019). This paper uses the proportion of the output of the secondary industry in GDP to measure the industrial structure.

2.2.3.4 Foreign direct investment (*FDI*) Foreign direct investment is also an important factor affecting the ecological environment pollution. On the one hand, compared with domestic enterprises, foreign-funded companies have relatively more advanced environment protection technology, which will improve the ecological environment quality; In addition, foreign-funded enterprises can also produce spillover effect to the enterprises in host country through the channels of demonstration imitation effect, competition effect, connection effect and training effect, so as to improve the energy utilization efficiency, and then reduce pollutant emissions. On the other hand, due to the technical blockade or intellectual property protection measures taken by foreign companies, it is difficult to obtain the technology spillover effect of utilizing foreign capital. Moreover, foreign direct investment will also lead to the transfer of backward industries with high pollution to developing countries with weak environment regulation, namely the famous hypothesis of “pollution paradise” exists (Akboanci et al., 2007), which is not conducive to the ecological environment pollution control in developing countries. The amount of foreign capital actually utilized is used as a proxy variable of foreign direct investment (FDI) in this paper.

2.3 Data sources

Considering the availability of data and the consistency of statistical caliber, this paper uses the panel data of 30 provincial regions (Tibet, Hong Kong, Macao, Taiwan are not included in the study sample) in China from 2003 to 2018 as the research sample. The

original data are mainly from China Statistical Yearbook (2004–2019), China Environment Yearbook (2004–2019), China Labour Statistical Yearbook (2004–2019), China Statistical Yearbook for Regional Economy (2004–2019), China Statistical Yearbook on Science and Technology (2004–2019) and Provincial Statistical Yearbook (2004–2019). With reference to Yang et al. (2020), “communications and transportation, warehousing and postal services industry,” “information transmission, computer service and software industry,” “wholesale and retail trades industry,” “financial intermediation industry,” “real estate industry,” “leasing and business services industry” and “scientific research, technical service and geological prospecting industry” are defined as the producer services industry. In order to eliminate the possible heteroscedasticity and large coefficient gap in the estimation results caused by the variable unit inconsistency, the natural logarithm is processed for each variable.

For testing the multi-collinearity, this paper has analyzed correlation between all logarithmic variables. As shown in Table 1, the explanatory variable and control variables exhibit a low correlation. Moreover, this paper has calculated the variance inflation factor (VIF) about the explanatory variable and control variables, and the results show that all the values of VIFs are lower than 5, which indicate the explanatory variable and control variables exhibit no multi-collinearity.

2.4 Model construction

In order to analyze the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control empirically, with reference to Musah et al. (2020), the benchmark econometric model of this paper is given as follows:

$$\ln EPI_{it} = \alpha_0 + \lambda \ln Coagg_{it} + \beta_1 \ln Pgd_{it} + \beta_2 \ln Er_{it} + \beta_3 \ln Is_{it} + \beta_4 \ln FDI_{it} + \mu_i + \nu_t + \varepsilon_{it}, \quad (6)$$

where EPI denotes the ecological environment pollution index; Coagg denotes the producer services and manufacturing industrial co-agglomeration degree; Pgd, Er, Is and FDI denotes the economic development level, environment regulation, industrial structure and foreign direct investment, respectively; α_0 is constant; λ, β is coefficient of related variables; ε_{it} denotes the random error term.

In order to further explore the different co-agglomeration modes between producer services and manufacturing industry, which is more conducive to promoting the ecological environment pollution control, this paper divides the producer services and manufacturing industrial co-agglomeration into two modes: government-dominated and market-driven industrial co-agglomeration. The benchmark econometric model can be changed as follows:

Table 1 Correlation analysis of all logarithmic variables

Variables	VIF	$\ln Coagg$	$\ln Pgd$	$\ln Er$	$\ln Is$	$\ln FDI$
$\ln Coagg$	1.22	1.0000				
$\ln Pgd$	4.35	0.1385	1.0000			
$\ln Er$	1.58	-0.1340	-0.3897	1.0000		
$\ln Is$	1.23	-0.3749	0.1642	-0.0231	1.0000	
$\ln FDI$	1.58	0.3445	0.0004	-0.4585	-0.1582	1.000

$$\ln \text{EPI}_{it} = \alpha_0 + \lambda_1 \ln \text{Gov_Coagg}_{it} + \lambda_2 \ln \text{Mar_Coagg}_{it} + \beta_1 \ln \text{Pgdp}_{it} + \beta_2 \ln \text{Er}_{it} + \beta_3 \ln \text{Is}_{it} + \beta_4 \ln \text{FDI}_{it} + \mu_i + \nu_t + \varepsilon_{it}, \quad (7)$$

where *Gov_Coagg* denotes the government-dominated producer services and manufacturing industrial co-agglomeration degree, *Mar_Coagg* denotes the market-driven producer services and manufacturing industrial co-agglomeration degree.

Considering that there is a strong spatial correlation between the co-agglomeration of producer services and manufacturing industry and the ecological environment pollution control, if the existence of spatial spillover effect is ignored, biased estimation results may be obtained. The spatial correlation may come from the explanatory variable, the explained variable and the error term, while the spatial Dubin model (SDM) can reflect the spatial correlation of different sources (Elhorst, 2003). In addition, the SDM is more general to use and it also can be changed into the spatial error and spatial lag model. Therefore, based on Eq. (7), the following spatial Dubin model is further constructed for empirical analysis.

$$\ln \text{EPI}_{it} = \alpha_0 + \rho \sum_{j=1}^n W_{ij} \ln \text{EPI}_{it} + \lambda_1 \ln \text{Gov_Coagg}_{it} + \lambda_2 \ln \text{Mar_Coagg}_{it} + k_1 \sum_{j=1}^n W_{ij} \ln \text{Gov_Coagg}_{it} + k_2 \sum_{j=1}^n W_{ij} \ln \text{Mar_Coagg}_{it} + \delta \sum \ln X_{it} + \eta \sum_{j=1}^n w_{ij} \ln X_{it} + \varepsilon_{it}, \quad (8)$$

where *W* is the spatial weight matrix, *X* is the control variable, which denotes other important factors affecting the ecological environment pollution. Combining the above analysis, this paper mainly considers following four variables as other important factors: economic development level (*Pgdp*), environment regulation (*Er*), industrial structure (*Is*) and foreign direct investment (*FDI*). According to the first law of geography, the closer the distance, the greater the impact on each other. Therefore, this paper selects the weight matrix of geographical distance to denote the spatial weight matrix. Meanwhile, considering the attenuation law of geographical distance, this paper uses the reciprocal of distance square to denote it. The formula can be given as follows:

$$W = \begin{cases} \frac{1}{d_{ij}^2} & i \neq j \\ 0 & i \equiv j \end{cases}. \quad (9)$$

3 Results analysis and discussion

3.1 Spatial correlation test

Before we carried out the spatial econometric analysis, the spatial correlation of variables is necessary to be tested. Referencing to Yang et al. (2020), this paper uses *Moran's I* index to conduct spatial correlation test of the variable of ecological environment pollution index. The formula can be given as follows.

$$Moran's I = \frac{\sum_{i=1}^n \sum_{j=1}^n W(EPI_i - \overline{EPI})(EPI_j - \overline{EPI})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W}, \tag{10}$$

where $\overline{EPI} = \frac{1}{n} \sum_{i=1}^n EPI_i$, $S^2 = \frac{1}{n} \sum_{i=1}^n (EPI_i - \overline{EPI})^2$. At the same time, the standard statistic Z is used to test the significance level of Moran's I index. The formula can be given as follows.

$$Z(Moran's I) = \frac{Moran's I - E(Moran's I)}{\sqrt{VAR(Moran's I)}} \tag{11}$$

$$E(Moran's I) = -\frac{1}{n-1}. \tag{12}$$

As shown in Table 2, although the Moran's I index of China's ecological environment pollution index (EPI) from 2003 to 2018 shows a wave-like trend, all of them have passed the significance test, which indicates that there is an obvious spatial correlation among the ecological environment pollution. Therefore, it is appropriate to use the spatial econometric model to analyze the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control.

3.2 Spatial econometric analysis at the national level

According to Eq. (8), based on the panel data of 30 provincial regions in China from 2003 to 2018, firstly, the static spatial Durbin model (SDM) is used for the regression estimation. However, considering that the static SDM may ignore the time dependence of the ecological environment pollution, which will lead to the error of spatial econometric estimation result, therefore, with reference to Feng and Wang (2020), this paper introduces the first-order lag term of the explanatory variable (EPI) into Eq. (8), and further constructs the dynamic SDM to carry out spatial econometric regression estimation at the national level, the results are reported in Table 3.

According to the estimation results of static SDM in Table 3, the effect of government-dominated and market-driven industrial co-agglomeration on the local ecological environment pollution is significantly negative, the coefficients are -0.2009 and

Table 2 Moran's I index of China's ecological environment pollution index (EPI) from 2003 to 2018

Year	2003	2004	2005	2006	2007	2008	2009	2010
<i>Moran's I</i>	0.121**	0.206**	0.180*	0.104*	0.193*	0.132**	0.152*	0.122*
Z values	2.261	1.979	1.816	1.706	1.714	2.038	1.670	1.725
Year	2011	2012	2013	2014	2015	2016	2017	2018
<i>Moran's I</i>	0.143**	0.135**	0.178***	0.166***	0.227**	0.118***	0.129**	0.213**
Z values	2.109	2.047	3.065	3.216	2.025	3.012	2.304	1.967

***, ** and * denote a significance of 1%, 5% and 10%, respectively

Table 3 Spatial econometric regression results at the national level

Variable	Static SDM		Dynamic SDM	
	Coefficient	<i>t</i> values	Coefficient	<i>t</i> values
<i>L.lnEPI</i>			0.4034***	9.78
<i>lnGov_Coagg</i>	-0.2009*	-1.83	-0.1723**	-2.25
<i>lnMar_Coagg</i>	-0.3246***	-3.12	-0.4998***	-4.10
<i>lnPgdp</i>	0.2892	0.98	0.3616*	1.81
$(\ln Pgdp)^2$	-0.1796**	-2.35	-0.0883*	-1.67
<i>lnEr</i>	-0.4904	-1.37	-0.6561***	-4.42
<i>lnIs</i>	0.3642	1.19	0.2980*	1.65
<i>lnFDI</i>	0.0230	0.72	0.0695**	2.30
<i>WlnGov_Coagg</i>	-0.0625	-1.36	-0.0388	-1.25
<i>WlnMar_Coagg</i>	-0.2112*	-1.90	-0.1009**	-2.18
<i>WlnPgdp</i>	-0.2078	-1.44	0.1770**	2.36
<i>WlnEr</i>	-0.1907	-0.69	-0.2246*	-1.80
<i>WlnIs</i>	0.4001	0.87	0.3012	0.94
<i>WlnFDI</i>	0.0886	1.38	0.1197*	1.75
ρ	0.1629***	3.99	0.0985***	2.87
<i>LogL</i>	-96.86		-105.23	
Obs	480		450	

L.lnEPI is the first-order lag term of logarithm of the explanatory variable (EPI)

-0.3246, respectively. Moreover, the absolute value of the influence coefficient of market-driven industrial co-agglomeration on the local ecological environment pollution is greater, which indicates that both the government-dominated and market-driven industrial co-agglomeration modes are conducive to promoting the ecological environment pollution control, and the promotion effect of market-driven industrial co-agglomeration is stronger. This is one of the novelties of this article, and it coincides with the Chinese government's proposal to give full play to the decisive role of the market in resource allocation. The thorough interpretations may be as follows: On the one hand, the producer services and manufacturing industrial co-agglomeration can effectively solve the problem of industrial mismatch, guide the optimal allocation of industrial resource through collaborative labor division and resource integration, so as to improve the resource utilization efficiency and reduce the energy consumption (Liu et al., 2017; Wang et al., 2020; Yang et al., 2020), and then reduce the pollution emissions and ecological damage; On the other hand, the producer services and manufacturing industrial co-agglomeration can also accelerate the technological innovation through the resource sharing effect, knowledge or technology spillover effect, and energy conservation & pollution reduction effect, so as to optimize the structure of energy consumption (Howard et al., 2016; Van Oort, 2017), promote the energy conservation & emission reduction and green economic transformation and upgrading, then accelerate the environment pollution control and improve the ecological environment quality. In addition, with the continuous promotion of global economic integration and the continuous development of China's market economy, compared with the government-dominated industrial co-agglomeration mode, as the core product of market economy, the market-driven industrial co-agglomeration through the formation of market division & cooperation

and competition selection mechanism not only can guide the allocation of industrial resource, so as to improve the comprehensive utilization efficiency of resource, promote the energy conservation & emissions reduction and industrial transformation and upgrading; But also, it can effectively avoid “race to the baseline of environment standards” in the policy making of industrial co-agglomeration, so as to avoid becoming a “paradise for pollution refuge enterprises” (Akboostanci et al., 2007; Shen et al., 2019; Verhoef & Nijkamp, 2002), and then optimize and improve the ecological environment quality, promote the centralized control of environment pollution. Therefore, China should give full play to the leading role of the market in the “two-wheel drive” collaborative development of producer services and manufacturing industry, so as to better promote the energy conservation and emission reduction, which is consistent with the current principle of dealing with the relationship between the government and the market in China.

Meanwhile, the influence coefficient of government-dominated industrial co-agglomeration on the ecological environment pollution in the surrounding region is negative, but it doesn't pass the significance test, which indicates that government-dominated industrial co-agglomeration only can promote the local ecological environment pollution control, while there is no spatial spillover effect on the ecological environment pollution control in the surrounding region. However, the influence coefficient of market-driven industrial co-agglomeration on the ecological environment pollution in the surrounding region is significantly negative (the coefficient is -0.2112), which indicates that the market-driven industrial co-agglomeration not only can promote the local ecological environment pollution control, but also can further promote the ecological environment pollution control in the surrounding region, it exhibits a significant spatial spillover effect. Therefore, at the national level, the government-dominated industrial co-agglomeration only significantly promotes the local ecological environment pollution control, and there is no spatial spillover effect on the ecological environment pollution control in the surrounding region, while the market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control, but also can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect.

According to the estimation results of dynamic SDM in Table 3, it can be concluded as follows: Firstly, the first-order lag coefficient of ecological environment pollution is significantly positive at 1% significance level (the coefficient is 0.4034), which indicates that there is an obvious time-dependent effect for the ecological environment pollution. Therefore, the dynamic SDM should be preferred to use when using the spatial econometric model to analyze the impact of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control. Secondly, both the influence coefficients of government-dominated and market-driven industrial co-agglomeration on the local ecological environment pollution are significantly negative, which are -0.1723 and -0.4998 , respectively. Thirdly, although the influence coefficient of government-dominated industrial co-agglomeration on the ecological environment pollution in the surrounding region is negative, it doesn't pass the significance test, while the influence coefficient of market-driven industrial co-agglomeration on the ecological environment pollution in the surrounding region is significantly negative (the coefficient is -0.1009). It shows once again that at the national level, the government-dominated industrial co-agglomeration only can significantly promote the local ecological environment pollution control, and there is no spatial spillover effect on the ecological environment pollution control in the surrounding region; on the contrary, the market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control, but also

can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect. It proves that the dynamic SDM is robust and reliable. Therefore, this paper will use the dynamic SDM in the following regression estimation.

In the control variables: (1) The quadratic coefficient of economic development level is significantly negative, which indicates that there is a significant inverted “U-shaped” curve relationship between the economic development level and ecological environment pollution. It further verifies the existence of Environment Kuznets Curve (EKC) hypothesis in China. Result of our study is similar to (Akram et al., 2020; Erdogan, 2020; Liu et al., 2019; Sarkodie & Ozturk, 2020; Sarkodie & Strezov, 2019; Yang et al., 2020) who prove the environment Kuznets hypothesis is valid. (2) The influence coefficient of environment regulation is significantly negative, which indicates that environment regulation is conducive to promoting the ecological environment pollution control. The result confirms the existence of the Porter hypothesis that appropriate environment regulation not only can make up for the “compliance costs,” but also can effectively promote the improvement of innovation ability (Feng et al., 2019; Porter & Linde, 1995), then to improve the ecological environment (Dou & Han, 2019; Mi et al., 2018; Wang et al., 2019). However, the result is dissimilar to (He et al., 2020; Wang et al., 2020) who propose that the Porter hypothesis is not supported in China’s manufacturing sector. (3) The influence coefficient of industrial structure on the ecological environment pollution is significantly positive, which indicates that the higher the proportion of the secondary industry, the more serious the ecological environment pollution, namely, it is less conducive to the ecological environment pollution control. The result is similar to (Gao & Zhang, 2019; Yu et al., 2020) who suggest that the increase in the proportion of secondary industry will aggravate the ecological environment pollution. (4) The influence coefficient of FDI is also significantly positive, which shows that it is not only difficult to obtain the technology spillover effect of utilizing foreign capital in China, but also it will lead to more serious ecological environment pollution due to the use of foreign capital, which verifies that the “pollution paradise” hypothesis is established in China. The similar results are obtained by (Shen et al., 2019; Yang et al., 2020). However, the result is dissimilar to (Akbostanci et al., 2007; Shao et al., 2019; Wang et al., 2020; Yilanci et al., 2020) who hold the view that the inflow of FDI may improve the environment quality rather than aggravate the ecological environment pollution. The reason why our study concludes that FDI could aggravate the ecological environment pollution may be that: Under the cadre assessment mechanism of “Only GDP is Hero” in China, in order to pursue economic growth and personal achievements, some local governments run to the bottom line of the environment standard on the policy making of attracting investment, even at the expense of expensive resources and environment, which leads to the introduction of the foreign investment projects with low-end, high pollution, high energy consumption and high emission, then resulting in the aggravation of ecological environment pollution, and causing the “pollution refuge” effect.

3.3 Spatial econometric analysis at the east, central and west regions levels

In order to further explore the effect of different co-agglomeration modes of producer services and manufacturing industry in different regions of China on the ecological environment pollution and its spatial spillover effect, this paper divides 30 provincial regions into the east, central and west regions, and adopts the dynamic spatial Dubin panel model to estimate the effect of government-dominated and market-driven industrial

Table 4 Spatial econometric regression results of east, central and west regions

Variable	East region		Central region		West region	
	Coefficient	<i>t</i> values	Coefficient	<i>t</i> values	Coefficient	<i>t</i> values
<i>L.lnEPI</i>	0.3696***	9.28	0.3729***	8.95	0.4063***	11.21
<i>lnGov_Coagg</i>	-0.3305**	-2.00	-0.3188**	-2.32	-0.2947**	-2.19
<i>lnMar_Coagg</i>	-0.5009***	-4.37	-0.2446*	-1.75	-0.1620*	-1.83
<i>lnPgdp</i>	2.3618***	4.44	3.0357***	3.25	1.9810	1.62
$(\ln Pgdp)^2$	-0.6198***	-3.91	-0.1966***	-4.37	-0.1119**	-2.31
<i>lnEr</i>	-0.3754*	1.80	-0.2831***	4.93	-0.4645***	-6.27
<i>lnIs</i>	0.2125*	1.73	0.1981	1.27	0.2501	1.14
<i>lnFDI</i>	-0.0835***	-4.46	0.0695**	2.16	0.0842***	3.15
<i>WlnGov_Coagg</i>	-0.1534**	-1.99	-0.2420	-1.18	-0.1399	-0.92
<i>WlnMar_Coagg</i>	-0.3728***	-3.28	-0.3272	-0.79	-0.3394	-0.56
<i>WlnPgdp</i>	0.1331***	3.14	0.0847**	2.30	0.1070	0.84
<i>WlnEr</i>	-0.6025	-0.95	-0.2608	-1.58	-0.4892	-0.25
<i>WlnIs</i>	-0.0589	-1.31	0.0432	0.49	0.0093	0.76
<i>WlnFDI</i>	-0.0801**	-2.29	0.0766	1.47	0.0792	1.08
ρ	0.1739***	3.38	0.1358***	2.96	0.1522***	4.21
<i>LogL</i>	-124.41		-200.09		-258.38	
Obs	165		120		165	

co-agglomeration on the ecological environment pollution control in different regions. The estimation results are reported in Table 4.

As shown in Table 4, all the first-order lag coefficients of ecological environment pollution are positive in the east, central and west regions, which are 0.3696, 0.3729 and 0.4063, respectively, and have passed the significance test of 1%. It indicates that the dynamic SDM is appropriate to use in this paper. According to the estimation results, there are obvious regional differences in the impact of different co-agglomeration modes of producer services and manufacturing industries on the ecological environment pollution and its spatial spillover effect. (1) In the east region, the influence coefficients of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution in the local and surrounding regions are significantly negative, which are -0.3305 and -0.5009, -0.1534 and -0.3728, respectively. Moreover, the absolute value of influence coefficients of market-driven industrial co-agglomeration on the ecological environment pollution in the local and surrounding regions are larger. This indicates that in the east region, the government-dominated and market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control, but also can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect, and the promotion effect and spatial spillover effect of market-driven industrial co-agglomeration are greater. Therefore, the eastern region of China should coordinate the relationship between the government and the market in the “two-wheel drive” collaborative agglomeration development of producer services and manufacturing industries, fully release the market potential, and give full play to the decisive role of the market in the ecological environment pollution control, so as to promote the energy conservation and emission reduction. (2) In the central and west regions, the influence coefficients of government-dominated and market-driven industrial

co-agglomeration on the local ecological environment pollution are significantly negative, which are -0.3188 and -0.2947 , -0.2446 and -0.1620 , respectively. Moreover, the absolute value of the influence coefficient of government-dominated industrial co-agglomeration on the local ecological environment pollution is larger. Meanwhile, the influence coefficients of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution in the surrounding region are negative, but they aren't significant. The results indicate that in the central and west regions, the government-dominated and market-driven industrial co-agglomeration only can promote the local ecological environment pollution control, and the government-dominated industrial co-agglomeration plays the most important role, but there is no spatial spillover effect on the ecological environment pollution control in the surrounding region. Therefore, different from the east region, the central and western regions of China should give full play to the government's macro-control role in the "two-wheel drive" collaborative agglomeration development of producer services and manufacturing industries, actively formulate the preferential policies for the producer services and manufacturing industrial co-agglomeration in the central and west regions, increase the government support and guidance, then promote the environment pollution control and the construction of ecological civilization.

In summary, there are obvious regional differences in the impact of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution and its spatial spillover effect: (1) In the east region, the government-dominated and market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control, but also can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect, and the promotion effect and spatial spillover effect of market-driven industrial co-agglomeration are stronger; (2) In the central and west regions, the government-dominated and market-driven industrial co-agglomeration only can promote the local ecological environment pollution control, and the promotion effect of government-dominated industrial co-agglomeration is greater, but there is no significant spatial spillover effect on the environment pollution control in the surrounding region. The main reasons may be as follows: Compared with the central and western regions, the eastern region of China has obvious advantages in capital, human capital, technological level, system policy and location, resources flow frequently, and most of them are technology-intensive and capital-intensive industries; meanwhile, it is a national technology transfer center with strong technological innovation ability. Therefore, on the one hand, it can promote the collaborative labor division and resource integration through the government-dominated and market-driven industrial co-agglomeration, generate scale economy effect, knowledge or technology spillover effect, centralized control effect and energy conservation & emission reduction effect, so as to accelerate the comprehensive control of local ecological environment pollution, and improve the local ecological environment quality; On the other hand, it also can form the infiltration radiation effect and spatial spillover effect on the surrounding region through the leading demonstration effect, resource sharing effect and technology sharing platform, so as to promote the energy-saving technology progress in the surrounding region, improve the energy utilization efficiency, then promote the environment pollution control in the surrounding region. In addition, the market economic system in the eastern region is becoming more and more sophisticated and the market is prosperous and active, which makes its market dominant in the resource allocation. The result in the market-driven industrial co-agglomeration in the eastern region has a greater promotion effect and spatial spillover effect on the ecological environment pollution control in the local and surrounding regions. However, the ecological environment pollution control in the central and western regions

depends more on the macro-control role of the government in the collaborative agglomeration development of producer services and manufacturing industries, and due to the existence of local protectionism barriers, it is difficult for the surrounding regions to obtain obvious radiation effect and spatial spillover effect.

3.4 Robustness test

In order to further enhance the robustness of the above regression estimation results, this paper adopts the following two methods:

- 1 Use per capita industrial SO₂ emissions to measure the EPI.

Considering that the industrial pollution is the main pollution source of ecological environment in China, the proportion of sulfur dioxide emissions in industrial pollutant emissions is also high. Therefore, with reference to Xin and Zhang (2020), Wang and Luo (2020) and Song et al. (2020), this paper uses per capita industrial SO₂ emissions to measure the ecological environment pollution index (EPI) in China. The result shows that Moran's I index of per capita industrial SO₂ emissions from 2003 to 2018 has passed the significance test, and its first-order lag coefficient is significantly positive at the 1% significance level, which indicates that it is appropriate to empirically analyze the impact of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution (per capital industrial pollution SO₂ emissions is used to measure the ecological environment pollution index) and its spatial spillover effect by using dynamic SDM. The estimation results are reported in Table 5.

- 2 Replace the geographical distance weight matrix by the spatial economic weight matrix.

With reference to Yang et al. (2020), this paper will use the spatial economic distance weight matrix to replace the geographical distance spatial weight matrix. The formula can be given as follows.

$$w_2 = w_1 \text{diag} \left(\frac{\bar{y}_1}{\bar{y}}, \frac{\bar{y}_2}{\bar{y}}, \dots, \frac{\bar{y}_n}{\bar{y}} \right), \quad (13)$$

where $\bar{y}_i = \frac{1}{t_1 - t_0 + 1} \sum_{t_0}^{t_1} y_{ij}$ is the average of GDP of the region i , $\bar{y} = \frac{1}{n(t_1 - t_0 + 1)} \sum_{i=1}^n \sum_{t_0}^{t_1} y_{ij}$ is the average of GDP in all regions during the period.

This paper calculates the Moran's I values of the ecological environment pollution index (EPI) in China under this matrix constraint, the result indicates that they have passed the significance test and their first-order lag coefficients are also significantly positive at the significance level of 1%. Therefore, an empirical analysis of the impact and its spatial spillover effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution under the economic spatial weight matrix by using dynamic SDM are carried out. The estimation results are also reported in Table 5.

As shown in Table 5, either use per capita industrial SO₂ emissions to measure the EPI in China or replace the geographical distance spatial weight matrix by the spatial economic weight matrix to analyze the impact and its spatial spillover effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution, the results are consistent with Tables 3 and 4. This further indicates that the results of this paper are robust. That is to say: (1) At the national level, the government-dominated

Table 5 Regression results of robustness test

Variable	National level	East region	Central region	West region	National level	East region	Central region	West region
	(1) Use per capita industrial SO ₂ emissions to measure the EPI							
<i>L.lnEPI</i>	0.4261*** (10.95)	0.4199*** (9.86)	0.3835*** (9.24)	0.3968*** (9.28)	0.3827*** (11.12)	0.4052*** (10.54)	0.3729*** (11.04)	0.4106*** (7.99)
<i>lnGov_Coagg</i>	-0.1616* (-1.80)	-0.3074** (-2.42)	-0.2745* (-1.73)	-0.2499** (-2.27)	-0.2582* (-1.77)	-0.3268** (-2.25)	-0.2833** (-2.41)	-0.3007*** (-6.08)
<i>lnMar_Coagg</i>	-0.3988** (-2.35)	-0.4989*** (-4.61)	-0.2280** (-2.44)	-0.1252* (-1.78)	-0.4738** (-2.46)	-0.5119** (-2.48)	-0.2047* (-1.80)	-0.1433** (-2.21)
<i>lnPgdp</i>	0.0987 (0.84)	2.7367*** (3.12)	11.2618* (1.75)	2.4901*** (2.48)	0.2163* (1.66)	1.3347*** (4.01)	2.4390** (2.45)	1.6077* (1.67)
<i>(lnPgdp)²</i>	-0.0941* (-1.92)	-0.6285*** (-3.98)	-0.1489*** (-4.07)	-0.1336*** (-3.65)	-0.1129* (-1.74)	-0.6198*** (-3.64)	-0.1173*** (-3.19)	-0.2022*** (-4.36)
<i>lnEr</i>	-0.3678** (-2.49)	-0.3106* (-1.73)	-0.3820** (-2.42)	-0.4044*** (-5.06)	-0.4981*** (-3.89)	-0.3537*** (-9.41)	-0.3724* (-1.77)	-0.5361*** (-5.34)
<i>lnIs</i>	0.4283* (1.66)	0.1841* (1.78)	0.0926 (1.02)	0.1219 (1.10)	0.3316** (2.02)	0.6212*** (2.71)	0.0760 (0.21)	0.2518 (0.85)
<i>lnFDI</i>	0.2068** (2.27)	-0.0661*** (-2.83)	0.0418 (1.61)	0.2005* (1.84)	0.0932* (1.91)	-0.1113*** (-3.04)	0.0645* (1.86)	0.0266*** (3.73)
<i>WlnGov_Coagg</i>	-0.0776 (-0.67)	-0.1618* (-1.70)	-0.1941 (-1.37)	-0.1982 (-0.46)	-0.0857 (-0.83)	-0.2115** (-2.46)	-0.1323 (-0.91)	-0.2019 (-0.72)
<i>WlnMar_Coagg ρ</i>	-0.2012* (-1.88)	-0.2977*** (-3.23)	-0.2536 (-0.94)	-0.1792 (-0.31)	-0.1284* (-1.79)	-0.4082*** (-3.65)	-0.2127 (-1.06)	-0.2717 (-0.29)
	0.1056*** (3.27)	0.1627*** (4.31)	0.1584*** (3.66)	0.1602*** (3.87)	0.0820*** (2.99)	0.2005*** (3.90)	0.1335*** (3.43)	0.1691*** (3.86)
<i>LogL</i>	-158.65	-201.09	-106.12	-69.99	-103.38	-195.18	-139.64	-98.76
Obs	450	165	120	165	450	165	120	165

Figures in parentheses are *t* values

industrial co-agglomeration only significantly promotes the local ecological environment pollution control, and there is no spatial spillover effect on the ecological environment pollution control in the surrounding region, while the market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control, but also can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect. (2) There are obvious regional differences in the impact of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution and its spatial spillover effect: In the east region, the government-dominated and market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control, but also can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect, and the promotion effect and spatial spillover effect of market-driven industrial co-agglomeration are stronger; However, in the central and west regions, the government-dominated and market-driven industrial co-agglomeration only can promote the local ecological environment pollution control, and the promotion effect of government-dominated industrial co-agglomeration is greater, but there is no significant spatial spillover effect on the environment pollution control in the surrounding region.

4 Mediating effect mechanism test

In order to test whether there is a mediating effect of technological innovation in the impact of producer services and manufacturing industrial co-agglomeration promoting the ecological environment pollution control, with reference to Yuan and Zhang (2020), Anis and Tarek (2020), Wang and Luo (2020), the number of patent (denoted by TI) is used as the proxy variable of the technological innovation level. Meanwhile, with reference to the mediating effect test method proposed by Baron and Kenny (1986), taking the technological innovation as an intermediary variable, this paper constructs the following mediating effect test model:

$$\begin{cases} \ln EPI_{it} = \alpha_1 + a \ln Coagg_{it} + \delta \sum \ln X_{it} + \varepsilon_{it} & (14) \\ \ln TI_{it} = \alpha_2 + b \ln Coagg_{it} + \delta \sum \ln X_{it} + \varepsilon_{it} & (15) \\ \ln EPI_{it} = \alpha_3 + c \ln Coagg_{it} + \varphi \ln TI_{it} + \delta \sum \ln X_{it} + \varepsilon_{it} & (16) \end{cases}$$

where EPI is the explained variable, which denotes the ecological environment pollution index; Coagg is the explanatory variable, which denotes the producer services and manufacturing industrial co-agglomeration degree; TI is the intermediary variable, which denotes the technological innovation level; X is the control variable, which is the same with Eq. (8). Firstly, if the estimated result of the coefficient a in Eq. (14) passes the significance test, it will indicate that there is a mediating effect in the impact of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control. Secondly, if the estimated result of the coefficient b and φ in Eqs. (15) and (16) passes the significance test, it will indicate that technological innovation has indirect effect on the producer services and manufacturing industrial co-agglomeration promoting the ecological environment pollution control. Finally, if the estimated result of the coefficient c in Eq. (16) passes the significance test, it will indicate that the producer services and manufacturing industrial co-agglomeration has direct effect on the ecological environment

pollution control, which also means that the technological innovation has partial mediating effect in the impact of producer services and manufacturing industrial co-agglomeration promoting the ecological environment pollution control; Otherwise, it will indicate that the technological innovation has a complete mediating effect in the impact of producer services and manufacturing industrial co-agglomeration promoting the ecological environment pollution control.

The paper is intended to make an in-depth exploration into whether there is a mediating effect of technological innovation in different co-agglomeration modes of producer services and manufacturing industries (government-dominated and market-driven industrial producer services and manufacturing industrial co-agglomeration) promoting the ecological environment pollution control. Consider that producer services and manufacturing industries present an obvious spatial co-agglomeration trend, and there is obvious spatial correlation and time dependence in the ecological environment pollution, therefore, this paper further modifies the above mediating effect test model into as follows:

$$\left\{ \begin{aligned} \ln EPI_{it} &= \alpha_1 + \beta_1 \ln EPI_{i,t-1} + \rho_1 \sum_{j=1}^n W_{ij} \ln EPI_{it} + \lambda_{11} \ln Gov_Coagg_{it} + \lambda_{12} \ln Mar_Coagg_{it} + \\ &k_{11} \sum_{j=1}^n W_{ij} \ln Gov_Coagg_{it} + k_{12} \sum_{j=1}^n W_{ij} \ln Mar_Coagg_{it} + \delta \sum \ln X_{it} + \eta \sum_{j=1}^n W_{ij} \ln X_{it} + \varepsilon_{it} \end{aligned} \right. \quad (17)$$

$$\left\{ \begin{aligned} \ln TI_{it} &= \alpha_2 + \rho_2 \sum_{j=1}^n W_{ij} \ln TI_{it} + \lambda_{21} \ln Gov_Coagg_{it} + \lambda_{22} \ln Mar_Coagg_{it} + \\ &k_{21} \sum_{j=1}^n W_{ij} \ln Gov_Coagg_{it} + k_{22} \sum_{j=1}^n W_{ij} \ln Mar_Coagg_{it} + \delta \sum \ln X_{it} + \eta \sum_{j=1}^n W_{ij} \ln X_{it} + \varepsilon_{it} \end{aligned} \right. \quad (18)$$

$$\left\{ \begin{aligned} \ln EPI_{it} &= \alpha_3 + \beta_2 \ln EPI_{i,t-1} + \rho_3 \sum_{j=1}^n W_{ij} \ln EPI_{it} + \lambda_{31} \ln Gov_Coagg_{it} + \lambda_{32} \ln Mar_Coagg_{it} + \lambda_{33} \ln TI_{it} + \\ &k_{31} \sum_{j=1}^n W_{ij} \ln Gov_Coagg_{it} + k_{32} \sum_{j=1}^n W_{ij} \ln Mar_Coagg_{it} + k_{33} \sum_{j=1}^n W_{ij} \ln TI_{it} + \delta \sum \ln X_{it} + \eta \sum_{j=1}^n W_{ij} \ln X_{it} + \varepsilon_{it} \end{aligned} \right. \quad (19)$$

On this basis, this paper uses the dynamic spatial Durbin panel (SDM) to carry out the econometric regression analysis for equations (17), (18) and (19), respectively. The estimation results are shown in Table 6.

As shown in Table 6, the first-order lag coefficients of the ecological environment pollution index in Eqs. (17) and (19) are significantly positive, which are 0.4034 and 0.2981, respectively, indicating that it is appropriate to use dynamic SDM to conduct the mediating effect test. The estimation result of Eq. (18) indicates that there is a mediating effect in the impact of government-dominated and market-driven producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control. The estimation result of Eq. (18) shows that the influence coefficients of government-dominated and market-driven producer services and manufacturing industrial co-agglomeration on the technological innovation are 0.1218 and 0.1962, respectively, which means that the government-dominated and market-driven producer services and manufacturing industrial co-agglomeration are significantly conducive to promoting the technological innovation, it is consistent with the previous influence mechanism analysis. The estimation result of Eq. (19) indicates that the coefficients of government-dominated and market-driven co-agglomeration modes are -0.1369 and -0.3595 , respectively, which still passes at least 5% of the significance test. At the same time, the coefficient of technological innovation is -0.0883 , which passes the significance test, indicating that the technological innovation has partial mediating effect in the different co-agglomeration modes of producer services and manufacturing industry (government-dominated and market-driven industrial co-agglomeration) promoting the ecological environment pollution control. That is to say, the government-dominated and market-driven industrial producer services and manufacturing industrial co-agglomeration not only can directly promote the ecological environment

pollution control, but also have indirect effect on the ecological environment pollution control through the intermediary variable of technological innovation. This is another novelty of this paper, the thorough interpretations may be as follows: Producer services and manufacturing industrial co-agglomeration is conducive to enhancing the relevance between industries, strengthening the flow and diffusion of innovation elements such as talent, capital, information and technology among regions, and then producing the technology spillover effects to accelerate the technological innovation (Howard et al., 2016; Van Oort, 2017), thus bringing about the energy-saving technology progress and the improvement of energy efficiency, promoting the green transformation and upgrading of economy and optimization of energy consumption structure (Liu et al., 2017; Wang et al., 2020; Yang et al., 2020), finally promoting the comprehensive control of ecological environment pollution and improving the environment quality.

In summary, there are two influence mechanisms for the government-dominated and market-driven producer services & manufacturing industrial co-agglomeration on the ecological environment pollution control, which are direct influence and indirect influence, respectively. On the one hand, the government-dominated and market-driven producer services and manufacturing industrial co-agglomeration directly promote the ecological environment pollution control; On the other hand, the government-dominated and market-driven producer services and manufacturing industrial co-agglomeration can also indirectly promote the ecological environment pollution control through the intermediary variable of technological innovation.

5 Conclusions and policy implications

5.1 Conclusions

Based on the perspective of government-dominated and market-driven industrial co-agglomeration mode, the effect of producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control is analyzed by using spatial Durbin model. Furthermore, the mediating effect of technological innovation in the industrial co-agglomeration promoting the ecological environment pollution control is tested. The results are as follows: (1) At the national level, the government-dominated industrial co-agglomeration only significantly promotes the local ecological environment pollution control (the coefficient is 0.1723), and there is no spatial spillover effect on the ecological environment pollution control in the surrounding region, while the market-driven industrial co-agglomeration not only can significantly promote the local ecological environment pollution control (the coefficient is 0.4998), but also can significantly promote the ecological environment pollution control in the surrounding region through its spatial spillover effect (the coefficient is 0.1009). Moreover, there is a significant inverted “U-shaped” curve relationship between the economic development level and ecological environment pollution, which further verifies the existence of Environment Kuznets Curve (EKC) hypothesis in China. Additionally, the environment regulation is also conducive to promoting the ecological environment pollution control, which confirms the existence of the Porter hypothesis, while the industrial structure and foreign direct investment will lead to more serious ecological environment pollution, which verifies that the “pollution paradise” hypothesis is established in China. (2) There are obvious regional differences in the impact

Table 6 Estimation results of mediating effect test

Variable	Equation (17): $\ln EPI$		Equation (18): $\ln TI$		Equation (19): $\ln EPI$	
	Coefficient	<i>t</i> values	Coefficient	<i>t</i> values	Coefficient	<i>t</i> values
$L.\ln EPI$	0.4034***	9.78			0.2981***	7.12
$\ln Gov_Coagg$	-0.1723**	-2.25	0.1218**	2.31	-0.1369**	-2.47
$\ln Mar_Coagg$	-0.4998***	-4.10	0.1962***	3.96	-0.3595***	-6.04
$\ln TI$					-0.0883***	-3.32
$\ln Pgdg$	0.3616*	1.81	2.8697***	6.48	1.0010	1.63
$(\ln Pgdg)^2$	-0.0883*	-1.67	-0.1712***	-5.99	-0.2204**	-2.16
$\ln Er$	-0.6561***	-4.42	0.2804***	8.73	-0.4827*	-1.88
$\ln Is$	-0.2980	-0.65	0.6330**	2.28	0.2478	0.29
$\ln FDI$	0.0695**	2.30	0.2676***	4.25	0.2316***	4.85
$Wln Gov_Coagg$	-0.0388	-1.25	0.3129	1.61	-0.1113	-1.05
$Wln Mar_Coagg$	-0.1009**	-2.18	0.1588***	3.08	-0.2028**	1.96
ρ	0.0985***	2.87	-0.2247***	-6.12	0.1701***	11.15
$LogL$	-105.23		-126.86		-102.91	
Obs	450		480		450	

of government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution and its spatial spillover effect: In the east region, both the government-dominated and market-driven industrial co-agglomeration can significantly promote the ecological environment pollution control in the local region and surrounding regions through its spatial spillover effect (the coefficients are 0.3305 and 0.5009, 0.1534 and 0.3728), and the promotion effect and spatial spillover effect of market-driven industrial co-agglomeration are greater. However, in the central and west regions, the government-dominated industrial co-agglomeration and market-driven industrial co-agglomeration only promote the local ecological environment pollution control (the coefficients are 0.3188 and 0.2947, 0.2446 and 0.1620), while there is no significant spatial spillover effect on the ecological environment pollution control in the surrounding region. (3) There are two influence mechanisms for the government-dominated and market-driven industrial co-agglomeration on the ecological environment pollution control, which are direct influence and indirect influence. On the one hand, government-dominated and market-driven industrial co-agglomeration directly promote the ecological environment pollution control (the coefficients are 0.1369 and 0.3595); On the other hand, government-dominated and market-driven industrial co-agglomeration can also indirectly promote the ecological environment pollution control through the intermediary variable of technological innovation (the coefficient is 0.0883). That is to say the technological innovation has partial mediating effect in the government-dominated and market-driven industrial co-agglomeration promoting the ecological environment pollution control.

5.2 Policy implications

The above conclusions provide following policy implications for promoting the “two-wheel” collaborative development of China’s producer services and manufacturing industries, and the economic green transformation and upgrading, so as to promote the energy

conservation & emission reduction and ecological environment pollution control, then accelerate the construction of ecological civilization. (1) The eastern region should make use of its advantages to gather more technology-intensive and capital-intensive producer services, focus on promoting the integration and development of the internal subdivision of producer services industry, and further promote the collaborative development of producer services and high-end manufacturing industries. At the same time, the eastern region should also coordinate the relationship between the government and the market in the “two-wheel drive” co-agglomeration development of producer services and manufacturing industries, and actively play the decisive role of the market in the ecological environment pollution control, so as to promote the energy conservation and emission reduction. (2) The central and western regions should combine the regional labor-intensive low-end manufacturing industry, which accounted for a relatively high proportion, actively introduce the relevant supporting producer services industries, promote the horizontal and vertical expansion of industrial chain, and effectively undertake the industrial gradient transfer from the eastern region, so as to enhance the industrial co-agglomeration degree. Moreover, the central and western regions should also give full play to the government’s macro-control role in the “two-wheel drive” collaborative development of producer services and manufacturing industries, and actively formulate the preferential policies for the producer services and manufacturing industrial co-agglomeration, increase the government support and guidance, so as to promote the ecological environment pollution control. (3) China should actively build a community of common destiny for the ecological environment pollution control, and further promote the formation of a win–win cooperation and benign interaction of the ecological environment pollution prevention and control system among the eastern, central and western regions. Moreover, China should continue to strengthen the control of ecological environment pollution, and make full use of the spatial spillover effect of “two-wheel drive” producer services and manufacturing industrial co-agglomeration on the ecological environment pollution control in the neighboring regions, strive to promote the cross-regional collaborative control of the ecological environment pollution, actively carry out cross-regional joint law enforcement of ecological environment protection, so as to form a layout of “joint prevention and control” regional ecological environment pollution collaborative control, then promote China’s ecological civilization construction to a new stage.

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Declarations

Conflict of interest The authors declare that there is no conflict of interests.

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