Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1–16
DOI: *10.15244/pjoes/195774* ONLINE PUBLICATION DATE: 2025-01-27

Original Research

Identifying Synergies between Industrial Agglomeration and Ecological Environment in New-Type Urbanization: A Collaborative Perspective from the Yangtze River Economic Belt, China

Zuoming Zhang[1], Yang Yi[2]*, Nannan Zhang[3], Ruoxin Lu[4]

[1]Accounting College, Wuhan Textile University, 430200 Wuhan, China
[2]School of Economics and Management, China University of Geosciences, 430074 Wuhan, China
[3]Wuhan Railway Vocational College of Technology, 430205 Wuhan, China
[4]School of Economics, Wuhan Textile University, 430200 Wuhan, China

Received: 29 July 2024
Accepted: 10 November 2024

Abstract

Managing environmental problems invited by industrial agglomeration has become a crucial issue at this stage of the new-type urbanization process. Based on the panel data of prefecture-level cities in China's Yangtze River Economic Belt from 2006 to 2018, we used location entropy and dynamic factor analysis to measure industrial agglomeration and the level of new-type urbanization, respectively. Then, we used the System Generalized Method of Moments model to examine the dynamic effect of industrial agglomeration on the ecological environment and synergies between industrial agglomeration and the ecological environment in new-type urbanization. The findings show that (1) industrial agglomeration in the current period significantly deteriorates the ecological environment. Conversely, industrial agglomeration in a lagging period significantly improves the ecological environment. (2) Population size in a lagging period contributes more to environmental quality than in a current period. Additionally, technological progress in both current and lagging periods contributes to improving the quality of the ecological environment. (3) There is a significant synergistic effect between industrial agglomeration and ecological environment quality in the lagging period of high-level new-type urbanization compared to the low-level new-type urbanization stage. Meanwhile, regardless of the level of new-type urbanization, the synergy between industrial agglomeration and ecological quality is not significant in the current period.

Keywords: industrial agglomeration, ecological environment, STIRPAT model, new-type urbanization, dynamic factor analysis

*e-mail: yiyang0671@cug.edu.cn

Introduction

According to UN projections, by approximately 2050, more of the world's population will be moving from rural to urban areas, demonstrating the far-reaching impact of cities on human development [1]. Climate change, public health, resource sustainability, and the development of traditional industries are heavily dependent on the level of urban development and urban functioning [2]. With rapid urbanization and growing demand for infrastructure, the future path of urban development will have a significant impact on social and natural systems.

China is currently undergoing a period of rapid development of new-type urbanization and industrialization, yet the environmental problems that accompany economic activity have not been well addressed. At the same time, new-type urbanization, namely urbanization with higher requirements for agriculture and ecology, will inevitably attract a continuous agglomeration of industries. The higher the degree of agglomeration, the greater the impact on the environment. The environmental damage in cities will become a barrier to industrial agglomeration [3, 4].

Given the complex sustainability challenges facing urban areas today, urban development requires creative solutions, particularly in the context of growing new-type urbanization and increasing industrial agglomeration. Towns and cities are gradually and increasingly exploring various forms of urban development [5, 6]. With this background, how to address the environmental problems brought about by industrial agglomeration has become a vital issue that cannot be ignored in the process of new-type urbanization. In addition, China's Yangtze River Economic Belt, one of the world's largest inland economic belts in terms of the volume of freight, spans 11 provinces in east, west, and central China and has distinctive industrial clustering characteristics [7].

The development of the Yangtze River Economic Belt is a powerful force in China's economic development, also having a significant impact on the construction of urban agglomerations in economic regions globally. Therefore, this paper selects prefecture-level cities in China's Yangtze River Economic Belt as the research unit to study the ecological and environmental impacts of industrial agglomeration in the context of new-type urbanization.

This paper has reviewed the types of scenarios proposed in the existing literature based on ecological change during the urbanization of natural ecosystems [1]. Although specific scenarios are proposed, the existing literature does not subsequently analyze the specific impacts of the research options available. At the same time, few studies offer specific conclusions on the impact of interventions in the social, ecological, or combined spheres in the urbanization process [8]. Moreover, a lack of spatial and temporal analysis appears in the literature regarding the cultural and climatic factors that cause urbanization to develop [9–11].

Whether the sustainability of urbanized ecosystems in a given region has sufficient impact remains unknown [12]. Given the limited resources, the heterogeneity of town environments, and the challenges, there is considerable variation in the content and research methods of different scholars. Current approaches to assessing the impact of urbanization on ecosystems are mainly drawn from urban ecology and the ecosystem approach [13, 14]. However, existing approaches to urbanization do not adequately consider the environmental impacts of industrial agglomeration.

The question remains whether industrial agglomeration impacts the environment and to what extent. In addition, research is needed on how the environmental effects of industrial agglomeration differ at various levels of new-type urbanization and whether there are synergies between industrial agglomeration and the ecological environment. To answer the above questions, this paper uses a panel data sample of 86 prefecture-level cities in China's Yangtze River Economic Belt from 2006–2018, with analysis conducted using the system generalized method of moments (SYS-GMM). The stochastic impacts by regression on population, affluence, and technology (STIRPAT) model was used to analyze the interaction mechanism between industrial agglomeration and eco-environmental quality. Based on this assessment, an empirical examination of the eco-environmental quality of industrial agglomerations was conducted. It also specifically measures new-type urbanization and identifies and compares the differences in the ecological and environmental effects of new-type urbanization at different stages of industrial agglomeration to provide a decision basis for the effective implementation and optimal adjustment of regional industrial and urbanization-related policies based on scientific evaluation of new-type urbanization to improve regional ecological and environmental quality.

The remainder of the paper is organized as follows: The second part is "Material and Methods," which attempts to identify the marginal contribution of this paper by reviewing previous research results, followed by a theoretical analysis of the mechanism of the role of industrial agglomeration on ecological and environmental quality. In addition, we have constructed the empirical model of this paper based on the measurement of new-type urbanization and introduced the selection of variables and data in this paper. The third part is devoted to "Results and Discussion," which is divided into baseline regression analysis, robustness tests, and a discussion of the heterogeneous effects of industrial agglomeration on ecological and environmental quality under different stages of new-type urbanization. Finally, "Conclusions" presents policy implications in the context of the main findings of this paper and the actual situation.

Materials and Methods

Literature Review

Industrial agglomeration is a process of continuous convergence of industrial capital elements in the spatial scope. The causes and effects of agglomeration have received much attention from scholars. According to

Krugman [15], the equilibrium of regional economic development is governed by the interaction of attractive and repulsive forces, with industries clustering when attractiveness is the dominant force and spreading when it is not. The intrinsic economic mechanism of industrial agglomeration for its development in the new-type urbanization process lies in the agglomeration economy generated by industrial agglomeration. The agglomeration effect of industry is reflected in two main types of agglomeration: economies and diseconomies, which act together in the spatial agglomeration and dispersion of social activities. Agglomeration economies act as major forces driving urban development, attracting a further concentration of socio-economic activities in cities, while agglomeration diseconomies act as exclusionary forces, hindering and limiting further concentration of social activities in cities, resulting in unsustainable urban development [16].

The existing literature mainly explores the economic and environmental effects of industrial agglomeration from the perspective of positive or negative externalities. The externalities of industrial agglomeration manifest themselves in the form of economies of scale, a specialization of the division of labor, and convenient technological spillovers. In his discussion of industrial agglomeration, Marshall attributed the creation of agglomeration economies to external economies of scale caused by externalities arising from the concentration of firms within an industry. The regional specialized division of labor brought about by industrial agglomeration has improved production efficiency, maximizing the use of resources, and improved pollution control technology, thus reducing the cost of pollution control for the industry overall [17].

The concentration of scientific research, training institutions, and more within the geographical space makes it easier for technology to spill over between enterprises. The increased level of innovation plays a greater role in reducing environmental pollution in the region to some extent [18, 19], which is a reflection of the positive externalities of industrial agglomeration. However, industrial agglomeration, particularly the large concentration of industry, also exhibits some negative externalities.

The increase in the agglomeration effect is depicted as an inverted U-shaped curve [20]. When agglomeration crosses the turning point of the inverted U-curve, the benefits follow the law of diminishing marginal effects. Excessive agglomeration is likely to cause too many environmental problems. Studies have shown that industrial agglomeration is one of the main causes of environmental concerns such as regional water and air pollution [21, 22]. Wang and Zhou reviewed the issue of whether agglomeration leads to environmental pollution, concluding that both positive and negative externalities of industrial agglomeration on the environment occur. The authors proposed a research project on whether an industrial structure and industrial association can internalize the negative externalities of industrial agglomeration on the environment [23]. Feng et al. argue that industrial agglomeration pollutes the environment through capacity expansion; that is, agglomeration leads to capacity expansion and thus increases environmental pollution [3].

At the same time, there are three main views on the ecological effects of industrial agglomeration in existing studies. First, industrial agglomeration can have a positive impact on the quality of the ecological environment. These studies explain the ecological effects of industrial agglomeration in terms of clean technology spillovers, economies of scale, and reduced pollution control costs. Industrial agglomeration can generate technological spillover effects through cooperation and exchange between enterprises, enabling them to reduce the production of pollutants during production and operation, thereby improving regional environmental quality [24]. Chen et al. [25] show that the scale effect of industrial agglomeration can effectively reduce pollutant emissions per unit of economic output. In addition, industrial agglomeration can also reduce the cost of pollution by centralizing the treatment of pollutants, thus reducing the cost of environmental management and improving the quality of the ecological environment [26, 27].

Second, some scholars have found that industrial agglomeration does not really improve the quality of the ecological environment [28]. These studies mainly confirm the negative impact of industrial agglomeration on the ecological environment in terms of increased production capacity, increased energy consumption, increased emissions from enterprises, and competition from local governments [22, 29, 30]. Specifically, industrial agglomeration can contribute to labor productivity and the productive capacity of firms, resulting in increased resource consumption and pollutant emissions [31]. Coupled with the relaxation of environmental regulations by local governments, this has exacerbated the release of pollutants [32]. By studying the impact of industrial agglomeration on the surrounding water environment, Wang and Nie [33] found that biological oxygen demand, ammonia nitrogen, and other pollutants in river water increased significantly after the establishment of industrial development zones. In addition, Hong et al. [34] argue that industrial agglomeration patterns exacerbate environmental pollution through competitive interactions with local governments. Moreover, the process of industrial agglomeration by local governments may lead to the overexploitation of resources in the area, destroying the ecological environment [35].

Third, some scholars point out that the ecological effects of industrial agglomeration are uncertain. There is a nonlinear relationship between industrial agglomeration and pollution; that is, the impact of industrial agglomeration on environmental pollution shows U-shaped, inverted U-shaped, and typical N-shaped trends [36]. Many studies point to a "U" shaped nonlinear correlation between industry clusters and environmental performance [37–39]. At the same time, the inverted "U" shaped relationship between industrial agglomeration and regional environmental pollution has been supported by many researchers [40, 41]. In addition, differences in resource endowments and environmental policies across regions have led to variations in the environmental effects of industrial agglomeration between regions [42].

The following points describe the main contributions of this paper. (1) The literature on the ecological effects of industrial agglomeration presents inconsistent findings. In addition, few studies simultaneously consider the dynamic nature of the effects of industrial agglomeration as well as the endogeneity between industrial agglomeration and ecological quality. Therefore, this paper uses the SYS-GMM method in dynamic panel models to revalidate the ecological effects of industrial agglomeration. (2) Few scholars have considered the impact of new-type urbanization on the ecological effects of industrial agglomeration, which is a critical issue to be considered for some countries, particularly developing countries like China. In addition, this paper not only starts from the perspective of new-type urbanization but also adopts dynamic factor analysis (DFA) to measure the level of new-type urbanization to solve the problem of vertical incomparability in the traditional objective weighting method for dynamic evaluation and to objectively analyze the ecological and environmental effects brought about by industrial agglomeration in various urbanization contexts. (3) Although there is rich literature on the ecological effects of industrial agglomeration, there remains less literature on the construction of clearer theoretical models. This paper incorporates industrial agglomeration into the STIRPAT model and attempts to construct a theoretical model of the ecological effects of industrial agglomeration.

Mechanism Analysis

Industrial agglomeration is usually accompanied by externalities in economics, especially positive and negative externalities. Positive externalities refer to the fact that when agglomeration brings favorable factors such as technological innovation, resource sharing, and economies of scale, the surrounding environment and economy can benefit from it and enhance the environmental efficiency of the region. Positive externalities are mainly reflected in the technological progress, information sharing, infrastructure optimization, and other effects brought by industrial agglomeration, which help to improve resource utilization efficiency and reduce environmental pollution [43]. For example, industrial agglomeration can effectively reduce the resource consumption and pollution emissions of individual enterprises by promoting the application of cleaner production technology and enhancing the environmental protection capability of enterprises. On the other hand, negative externalities are manifested in pollutant emissions, excessive consumption of resources, etc., which adversely affect the ecological environment [44]. According to the Coase Theorem, negative externalities can only be effectively controlled through the market mechanism if there are clear property rights [45]. However, in practice, enterprises often lack sufficient incentives to reduce pollution on their own, thus leading to environmental degradation. Therefore, the impact of industrial agglomeration on ecological quality may vary in different stages of new-type urbanization. When viewed statically, the effect of industrial agglomeration is more of a positive externality. When placed in a dynamic time trajectory, industrial agglomeration will spontaneously form a shift between positive and negative externalities, the former being called a static agglomeration economy and the latter a dynamic agglomeration economy [46]. Regarding new-type urbanization, the process is inevitably lengthy. From this perspective, industrial agglomeration should be considered more dynamically. For example, with the concentration of population and industry in the early stages of urbanization, a rational urbanization layout brings greater convenience to people's lifestyles, an improved sanitary environment, effective disposal of domestic waste, effective use of land, and increasing accessibility to transport. These changes drive up the level of urban productivity. However, as the level of urbanization increases, the concentration of urban elements can invite negative externalities such as increased costs of living and transport, increased pollution, and social problems such as crime [47]. Guo et al. show that there is a serious lag in this negative externality [48], while Liu et al. directly show that industrial agglomeration in China has crossed the inverted U-shaped inflection point at the current level of urbanization [49], that is, a negative externality appears in the environmental effects of industrial agglomeration. Northam and von Rosenberg Jr. [50] studied the urbanization process from the perspective of its stages, remarking that the ecological environment is variably affected at different stages of urbanization. Moreover, the ecological environment also undergoes a similar U-shaped evolutionary process as urbanization moves from the nascent to the final stage of development [50].

In the study of the interaction between industrial agglomeration and the ecological environment, the synergistic effect plays a key role. The theory of synergistic effect refers to the fact that the overall effect produced by the synergistic cooperation of each part of the system is greater than the sum of the individual effects of each part [51]. In the context of this study, specifically, the synergistic effect is manifested in resource sharing, technological innovation, pollution control, etc. Cooperation and coordination among enterprises can effectively reduce resource consumption, optimize the production process, and improve the ecological environment. The generation of a synergistic effect not only enhances the overall efficiency of the region but also forms a virtuous cycle between different fields, thus promoting the sustainable development of the economy, society, and the environment. It is worth mentioning that new-type urbanization plays an important role in the synergy between industrial agglomeration and the ecological environment, and its mechanism of action includes: First, optimizing the industrial layout. New-type urbanization encourages the rational layout of towns and cities and optimizes industrial layout by guiding the transfer of industries to areas around towns and cities [52]. This layout helps to form the agglomeration effect of industrial chains, supply chains, and value chains, increase the degree and scale of industrial agglomeration, and enhance the industrial competitiveness

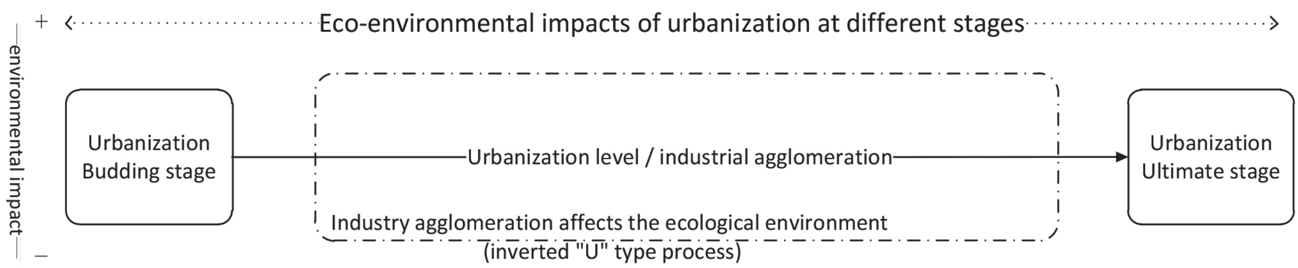

Fig. 1. Ecological and environmental mechanisms of industrial agglomeration in the context of new-type urbanization.

Note: + and − represent the positive and negative effects of environmental impacts, respectively.

of cities and regions. Second, promote the development of green industries. New-type urbanization encourages the development of green industries and eco-tourism and promotes a virtuous cycle of industrial development and ecological protection [53]. Green industries have lower resource and environmental requirements and are conducive to the realization of the synergistic development of industrial agglomeration and ecological environment. Third, promoting scientific and technological innovation. New-type urbanization will pay more attention to scientific and technological innovation and green development and encourage the promotion of industrial upgrading. Towns provide a better environment for scientific research and innovation, attracting more high-tech enterprises and talents. Scientific and technological innovation drives industrial upgrading and optimization, which helps promote the development of green industries, reduce dependence on resources, and lower environmental pressure [54]. Overall, new-type urbanization has promoted synergy between industrial agglomeration and the ecological environment through efforts to optimize industrial layout, develop green industries, and promote scientific and technological innovation. This synergy has made the new-type urbanization process no longer simply the pursuit of economic growth and urban expansion but more focused on the harmonious coexistence of human beings and nature, achieving sustainable economic, social, and environmental development.

In sum, the mechanism of the ecological role of industrial agglomeration in the context of new-type urbanization is shown in Fig. 1.

Construction and Measurement of a New-Type Urbanization Level Index

Based on a profound understanding of the connotation of new-type urbanization and based on the design idea of Fig. 2, this paper refers to the research results of Zhang [55], Siciliano [56], and Adebayo and Ullah [57] on the index system for measuring urban development and systematically integrates from different dimensions. Then, the new-type urbanization comprehensive evaluation index system is established, which consists of 4 criteria and 13 index levels, namely the new-type urbanization basic construction level, the new-type urbanization economic development level, the new-type urbanization social investment level, and the new-type urbanization environment-friendly level (see Table 1).

Unlike most scholars who use static analysis methods such as hierarchical analysis, factor analysis, entropy, and gray correlation analysis [58], this paper chooses to use DFA to measure the level of new-type urbanization. The DFA method, proposed by Anderson [59] and further refined by Corazziari [60], is a multivariate statistical analysis method that combines the results of cross-sectional analysis, obtained from principal component analysis, and the results of time series analysis obtained from a linear regression model, which can solve the problem of longitudinal incomparability of the traditional objective weighting method in the dynamic evaluation and is more suitable for trend analysis and evaluation of a large number of evaluation units over different periods. A composite score for the level of new-type urbanization was measured, as shown in the table, for the negative scores obtained from the dynamic factor approach. This paper adopts the approach of Cai [61]: when the level of development in the base period is positive, growth rate = level in the reporting period/level in the base period − 1. When the base period data is negative, the growth rate = 1 − reporting period level/base period level, and the results of the measurement are shown in Fig. 3. Taking into account changes in the exchange rate, the actual amount of foreign direct investment utilized is converted into RMB at the current year's exchange rate and deflated to the 2000 price level; the amount of fixed asset investment is deflated to the 2003 price level using the fixed asset investment price index.

Model Construction

Dietz and Rosa [62] developed the STIRPAT model based on the Environmental Impact = Population × Affluence × Technology (IPAT) to support the analytical framework proposed by Ehrlich and Holdren [63], with some refinements. The main idea of the model is to represent

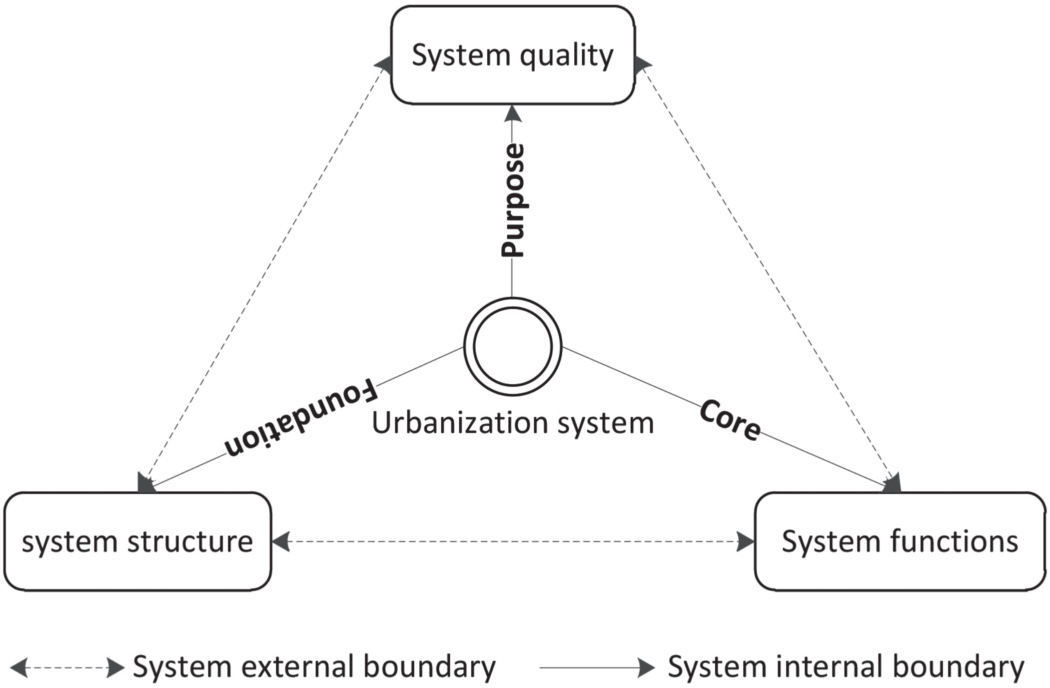

Fig. 2. Criteria for evaluating the level of the new-type urbanization phase.

Table 1. Industrial digitization level evaluation index.

Objective	Criteria level	Indicator level	Description of indicators	Unit	Property
the level of the new-type urbanization	new-type urbanization basic construction level	Urban population	Urban population density	10000 persons/km²	+
		Urban income	Average wage of urban workers	RMB	+
		Economic growth	GDP per capita	RMB	+
	new-type urbanization economic development level	Industrial development	Share of tertiary sector in GDP	%	+
		Economic openness	Actual Utilization of Foreign Investment	10000 RMB	+
		Investment level	Investment in fixed assets	10000 RMB	+
		Employment	Ratio of population employed in secondary and tertiary sectors	%	-
	new-type urbanization social investment level	Road traffic	Urban road area per capita	m^2/person	+
		Education level	Number of students in general higher education	10000 persons	+
		Level of medical care	Number of beds in health care facilities	-	+
		Informatization	Number of people using the Internet	10000 households	+
	new-type urbanization environment-friendly level	Environmental quality	Harmless disposal rate of domestic waste	%	+
		Environmental pollution	Industrial wastewater discharge	10000 tonnes	-
		Ecological construction	Green space coverage in built-up areas	%	+

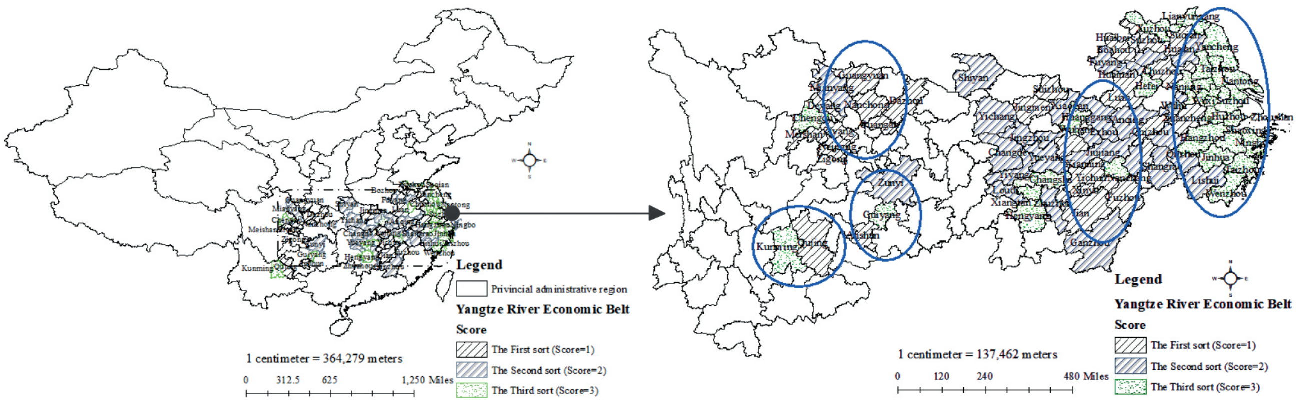

Fig. 3. Changes in urbanization levels in the Yangtze River Economic Belt at various levels.

Note: The map on the left is a map of China excluding the South China Sea and the Ten-Dashed Line (for the sake of the overall brevity of the picture display), and the map on the right is a map of the Yangtze River Economic Belt.

Table 2. Descriptive statistics of variables.

Variables	Symbols	Mean	Std. dev	Min	Max
State of the Environment (I)	$I_{i,t}$	4.579	4.578	0.217	25.934
Industrial Agglomeration (C)	$C_{i,t}$	0.874	0.293	0.107	2.239
Size of population (P)	$P_{i,t}$	470.390	218.859	70.910	1188.000
Affluence (A)	$A_{i,t}$	26580.580	12808.650	7950.660	73034.500
Technical level (T)	$T_{i,t}$	19054.880	47809.310	7.000	413314.000

the interaction between population size (P), affluence (A), technology level (T), and environmental impact (I). Based on this framework, Wang and Wang [64] added industrial agglomeration (C) to the model for the exploration of industrial agglomeration and urban environmental issues, and the basic equation of the STIRPAT model incorporating industrial agglomeration variables is:

$$I_{it} = \alpha C_{it}^{\omega} P_{it}^{\beta} A_{it}^{\gamma} T_{it}^{\delta} e_{it} \quad (1)$$

Where I_{it} is the state of the environment, P_{it}, A_{it}, T_{it}, C_{it}, denote population, affluence, technology level, and industrial agglomeration, respectively. The econometric model obtained by taking the logarithm of both sides of it is as follows:

$$ln(I_{it}) = \alpha + \omega ln(C_{it}) + \beta ln(P_{it}) + \gamma ln(A_{it}) + \delta ln(T_{it}) + e_{it} \quad (2)$$

According to Malmberg et al. [46], industrial agglomeration not only leads to static efficiency gains in inter-firm trade but also to dynamic knowledge and technology spillovers, with the former reflecting efficiency and the latter a learning process, which is the dynamic nature of the agglomeration effect [65]. Dynamic agglomeration economies develop from knowledge creation and learning, a process that requires an extended period for firms to come together. Moreover, endogenous problems are often present in terms of industrial agglomeration and ecology [3, 65]; ignoring this endogeneity problem biases the estimation results.

The relationship between industrial agglomeration and the ecological environment may be bidirectional; that is, industrial agglomeration may promote the continuous improvement of the ecological environment, while the improvement of the ecological environment may attract a large number of enterprises to gather and promote the formation of industrial agglomeration, which also gives rise to the problem of endogeneity. Based on this, the GMM proposed by Bun and Windmeijer [66] is used in this paper. Not only does the SYS-GMM capture dynamic effects, but its greatest advantage is also that it can address the endogeneity problem arising from the interaction between industrial agglomeration and environmental pollution [67], which can effectively isolate non-time-varying regional effects by using lags of internal variables as instrumental variables.

Based on the above considerations, the industrial agglomeration and the one-period lagged industrial agglomeration in the model are set as endogenous explanatory variables, and the one-period lags of other explanatory variables are used as instrumental variables, which transforms the model based on the IPAT analysis framework into the following econometric model:

$$ln(I_{i,t}) = \alpha_0 + \omega_0 ln(C_{i,t}) + \omega_1 ln(C_{i,t-1}) + \beta_0 ln(P_{i,t}) + \beta_1 ln(P_{i,t-1}) + \gamma_0 ln(A_{i,t}) + \gamma_1 ln(A_{i,t-1}) + \delta_0 ln(T_{i,t}) + \delta_1 ln(T_{i,t-1}) + e_{i,t} \quad (3)$$

Wang et al. [68] showed that environmental pollution has significant autocorrelation in time and space. In other words, environmental pollution itself has a time effect, and the current period's environmental pollution problem is also influenced by the previous period's environmental conditions. Therefore, this paper draws on both the modeling approach of Liang and Goetz [69] in the model by selecting a lagged period of environmental impacts and using the ADL(1,1) model to construct the model for this paper. The ADL(1,1) model is one of the main models used to study the dynamics. Combined with the previous choice of variables, the final model in this paper takes the form of:

$$ln(I_{i,t}) = \alpha_0 + \omega_0 ln(C_{i,t}) + \omega_1 ln(C_{i,t-1}) + \alpha_1 ln(I_{i,t-1}) + \beta_0 ln(P_{i,t}) + \beta_1 ln(P_{i,t-1}) + \gamma_0 ln(A_{i,t}) + \gamma_1 ln(A_{i,t-1}) + \delta_0 ln(T_{i,t}) + \delta_1 ln(T_{i,t-1}) + e_{i,t} \quad (4)$$

Variable Selection and Data Description

The data in this section are obtained from the 2007–2019 China Urban Statistical Yearbook, the China Environmental Statistical Yearbook, and the statistical yearbooks of various provinces in China, taking into account the completeness and continuity of the statistical data as well as the adjustment of individual administrative regions; 86 prefecture-level cities in the Yangtze River Economic Belt of China were finally selected. For the sample time horizon, the selection is based on the following: First, China's 11th Five-Year Plan included the urbanization rate for the first time as an expected indicator to be accomplished in that period, and the starting year of China's 11th Five-Year Plan was 2006. Second, in 2012, new-type urbanization was first proposed in the report of the 18th National Congress, and the promotion of new urbanization construction has become the focus of attention of all parties. Third, compared with 2006, the first six months of 2012, and the second six months of 2012, new urbanization has made positive progress in 2018. The "Network of the Development of the Yangtze River Economic Belt" report shows that the new urbanization of the Yangtze River Economic Belt has made positive progress in 2018 and has made public the completion of the new urbanization indicators of the Yangtze River Economic Belt before 2018. Therefore, the sample time of this paper is selected as the data from 2006 to 2018. This involves output indicators such as GDP and gross industrial output, which are deflated utilizing the GDP index and the ex-industrial price index, respectively, and adjusted to constant 2000 prices.

State of the Environment $I_{i,t}$: Quantitative analysis using the Relative Environmental Damage Index (RDI). The RDI is calculated using the following formula:

$$RDI = \frac{\left(\frac{RD}{CD}\right)}{\left(\frac{RC}{CC}\right)} = \frac{\left(\frac{RD}{CD}\right)}{\left(\frac{RA}{CA}\right)} = RD_A/CD_A \quad (5)$$

Where RA is the area of the region, CA is the overall area of the study area of the Yangtze River Economic Belt; RD is the regional pollutant emissions, CD is the total regional pollutant emissions of the Yangtze River Economic Belt, RD_A is the regional average pollutant emissions, and CD_A is the regional average pollutant emissions of the Yangtze River Economic Belt. In the selection of pollutants, this paper considers three different forms of pollutants, namely industrial wastewater, industrial sulfur dioxide, and industrial dust, from the perspective that different pollutants have different impacts on industrial agglomeration, and these three pollutants can reflect the environmental pollution situation of the region more appropriately than carbon dioxide [70].

Industrial Agglomeration $C_{i,t}$: Location entropy was used to measure. Location entropy is a basic analysis method for evaluating regional advantageous industries, but since there are large differences in the advantageous industries of each of the 11 provinces (municipalities directly under the central government) involved in the Yangtze River Economic Belt, considering the operability of the evaluation and the availability of data, this paper uses the location entropy measurement of manufacturing industries at the prefecture-level uniformly. It is calculated as the ratio of the "total industrial output value above the scale" to the "total industrial output value of the Yangtze River Economic Belt" and the ratio of the "total output value of the secondary industry" to the "total output value of the secondary industry of the Yangtze River Economic Belt".

Technical level $T_{i,t}$: Expressed using regional scientific expenditures. Industrial agglomeration influences the economies of scale of regional industries by affecting the scale and spatial distribution of regional economic activities on the one hand and the rate of technological change by influencing the rate at which new technologies are developed, the rate at which new technological knowledge enters and diffuses throughout the region, and the incorporation of new technologies into the production processes of manufacturers on the other [71]. Taken together, the technological and knowledge spillover effects of industrial agglomeration have contributed to technological progress to a certain extent. However, the impact of technological progress on the environment is two-sided. On the one hand, improvements in production and environmental technologies can reduce the emission of environmental pollutants to a certain extent. On the other hand, the increase in technology may only increase the efficiency and scale of production but not the environmental technology in the production process, thus causing an increase in the level of environmental pollution rather than an improvement.

Size of population $P_{i,t}$: The total urban population is used. In general, there is a positive correlation between the number of people in a region and the level of environmental pollution [64]. The size of the population determines the size of the demand for resources and the most basic impact it can have on the environment, and there is a reasonable regression between the gradient of population concentration and the change in the course of the industrial structure [72].

Affluence $A_{i,t}$: The average wage of an employee is used as a proxy. The average wage of an employee represents the income level of a region. As the income level of urban residents continues to rise, the amount of urban household waste is growing rapidly, adding great pressure to urban environmental management [73, 74]. There are differences in income levels between regions, which have a significant impact on industrial agglomeration. The variables and symbolic representation, as well as descriptive statistics, are shown in Table 2.

Results and Discussion

Baseline Regression Analysis

Based on the aforementioned theoretical framework and sample description, this paper uses STATA software for SYS-GMM estimation. It should be noted that to obtain more robust estimates, the "two-step" option has been included in the empirical analysis, and the time effect has been taken into account to control for the possible effects of economic cycles, and the corresponding estimation results are finally obtained as shown in Table 3.

From the regression model tests, the results of the second-order serial correlation AR(1) in the main model SYS-GMM regression showed rejection of the original hypothesis, indicating that the random error term of the model is not serially correlated, indicating that the model we have set up is reasonable, and the results of the Sargan over-identification test also indicated that there is no over-identification of the instrumental variables used in the regression (the p-values of the Sargan statistics are all greater than 1%).

The results of the industrial agglomeration variable in the regression analysis show that industrial agglomeration has a dynamic effect on the ecological environment in the case of a SYS-GMM regression of the city as a whole. Specifically, in the current period, industrial agglomeration has a positive and significant effect on the ecological environment, with a regression coefficient of 0.036. This suggests that the current industrial agglomeration has not significantly improved the ecological environment but has only positively contributed to the emission of pollutants in urban areas, which is not conducive to the construction of urban ecological quality. In the lagged period, industrial agglomeration has a significant "negative" impact on the ecological environment, with a regression coefficient of -0.097, i.e., industrial agglomeration lagging helps cities to clean up their environmental pollution emissions. At the same time, this also indicates that the impact of industrial agglomeration in the Yangtze River Economic Belt on the regional ecological environment varies from one period to another, which proves to a certain extent that there may be an inverted U-curve development trend between industrial agglomeration and its ecological environment effects. The lagging results of industrial agglomeration also indicate that there is strong inertia in the quality of the ecological environment and that the quality of the ecological environment in the current period is largely influenced by the previous period's pollution emissions. This is, in general, consistent with the findings of Chen et al. and Hao et al. [75, 76].

Table 3. Regression results of the impact of industrial agglomeration on the environment.

Variables	SYS-GMM
$I_{i,t-1}$	0.670^{***}
	(104.299)
$C_{i,t}$	0.036^{***}
	(3.367)
$C_{i,t-1}$	-0.097^{***}
	(-11.098)
$P_{i,t}$	0.512^{***}
	(6.639)
$P_{i,t-1}$	-0.744^{***}
	(-9.657)
$A_{i,t}$	0.046^{***}
	(2.783)
$A_{i,t-1}$	0.029
	(1.151)
$T_{i,t}$	-0.010^{***}
	(-5.535)
$T_{i,t-1}$	-0.005^{***}
	(-2.651)
Constant	1.085^{***}
	(7.635)
Year	Control
N	860
AR(1)-Test	36.000^{***}(p=0.00)
AR(2)-Test	1.286(p=0.1986)
P(Sargan Test)	0.80151

Note: Standard errors of coefficient estimates are in parentheses; *** indicates a 1% significance level. The AR(2) test is mainly used to test the autocorrelation of random errors in dynamic panels, and the Sargan test is for the overidentification of dynamic panels.

From the results of the other variables in the regression analysis, the significant estimates of the variable P

Table 4. Robustness test results.

Variables	OLS	FE
$I_{i,t-1}$	0.937***	0.553***
	(77.099)	(8.081)
$C_{i,t}$	-0.011	-0.028
	(-0.289)	(-0.640)
$C_{i,t-1}$	0.030	-0.014
	(0.886)	(-0.367)
$P_{i,t}$	0.814***	0.952***
	(3.597)	(3.454)
$P_{i,t-1}$	-0.866***	-0.207
	(-3.838)	(-0.837)
$A_{i,t}$	-0.035	0.004
	(-0.257)	(0.027)
$A_{i,t-1}$	0.037	0.032
	(0.277)	(0.250)
$T_{i,t}$	0.004	-0.001
	(0.430)	(-0.108)
$T_{i,t-1}$	-0.001	-0.009
	(-0.070)	(-0.709)
Constant	0.338	-4.291***
	(0.964)	(-3.016)
Year	-	Control
F/WALD	1097.119***	240.666***
N	860	860
Adjusted-R^2	0.928	0.918

Note: Standard errors of coefficient estimates are in parentheses, and *** indicates a 1% level of significance, respectively.

indicate that the current population is not conducive to the improvement of the quality of the urban ecosystem, but the lagged period contributes to the improvement of the quality of the environment. The SYS-GMM estimate of the variable T is -0.010, which passes the significance test at the 1% level. The estimated coefficient of the variable T lagged by one period is still significantly negative, and the degree of impact is reduced compared to the current period, which indicates that technological progress helps improve the ecological quality of cities in the Yangtze River Economic Belt and the effect of such improvement becomes more obvious over time. The regression estimate of variable A is significantly positive and passes the test at the 1% level of significance with an effect level of 0.046. The estimate of variable A with one period lag does not pass the significance test; that is, affluence does not improve the ecological quality of cities in the Yangtze River Economic Belt. This finding shows that under today's crude development model, the increase in per capita wealth has a negative effect on the ecological environment, and as people's living standards increase, they consume more material resources and place a greater burden on the ecological environment.

Robustness Test

In the baseline regression, we used the Sargan test to identify the validity of the instrumental variables; however, the Sargan test can only assess over-identification of the instrumental variables and cannot test whether the instrumental variables are underidentified. According to Bun and Windmeijer [58], if the instrumental variables in the SYS-GMM regression are not sufficiently identified, the assessment can result in biased estimates in the case of small samples. Bond [77] proposes a more intuitive test that the autoregressive coefficients estimated by OLS tend to overestimate, while the autoregressive coefficients of the FE model have a tendency to underestimate.

If the values of the autoregressive coefficients obtained from the SYS-GMM regression are exactly between the OLS and FE autoregressive coefficients, the instrumental variables used in the SYS-GMM regression can be considered to be appropriate, and there is no under-identification problem. Therefore, the robustness of the baseline regression results is further tested by OLS and FE models in this paper. The results of the robustness tests are shown in Table 4. From the regression model tests, the F (Wald) test values pass the tests at the 1% significance level in both OLS and FE, and the adjusted R^2 for OLS and FE are 0.93 and 0.92, respectively, making the model significant overall. From Tables 3 and 4, we observe that in the same model, the autoregressive coefficient estimated by SYS-GMM is 0.670, which lies exactly between the OLS autoregressive coefficient of 0.937 and the FE autoregressive coefficient of 0.553. Thus, the choice of instrumental variables for the econometric model is appropriate; that is, the results of the baseline regression are robust.

Heterogeneity Analysis Based on Different Stages of New-type Urbanization

In order to further identify whether there is a synergistic effect between industrial agglomeration and the ecological environment at different stages of new-type urbanization, i.e., whether there is a difference in the impact of industrial agglomeration on the ecological environment, this paper further analyzes the heterogeneity of the baseline regression model from the perspectives of the level of urbanization and synergy. Table 3 reports the results of the regression of the impact of industrial agglomeration on the ecological environment, but based on the previous analysis, it can be seen that the impact of industrial agglomeration on the ecological environment may differ between regions. Considering the impact of population, technology level, and income disparity on industrial agglomeration, the difference in the level and scale of urbanization between regions may be an important source of the difference in the impact of industrial agglomeration on the ecological environment. When the level of urbanization is still relatively low, the scale of the city is not large, and conditions such as labor supply, environmental technology, and consumption are in a mildly rising stage, industrial agglomeration is not yet rapidly increasing. At this stage, industrial development and the ecological environment are still in a relatively harmonious state, likely due to improvements in environmental technology. From the analysis in the theoretical part of the article, the impact of industrial agglomeration on the ecological environment is positive at this time. Based on the results in Fig. 2, cities with a score of 3 are classified as high urbanization stages (High), and those with scores of 1 and 2 are classified as low urbanization stages (Low). The cities with a score of 3 are mainly located in the lower reaches of the Yangtze River, with a sample size of 28, while the cities with scores of 1 and 2 are mainly located in the upper and middle reaches of the Yangtze River, with a sample size of 58.

Table 5 uses the same approach as Table 3 and the SYS-GMM method to estimate the ecological and environmental effects of industrial agglomeration under phased urbanization levels. The results show that the SYS-GMM statistic F is significant enough to pass the 1% significance level test, and the model is significant overall. The results of the estimation of high-stage urbanization and low-stage urbanization show that the second-order serial correlation AR(2) test in the model indicates that the random error terms of the model are not serially correlated, indicating that it is reasonable to estimate the model using SYS-GMM. The results of the Sargan overidentification test also indicated that the instrumental variables used in the regressions were not overidentified (all p-values of the Sargan statistic were greater than 1%).

The regression results show that there is dynamism in the impact of industrial agglomeration on the ecological environment in the case of SYS-GMM regression for high-stage urbanization. Specifically, there is a negative effect of lagging industrial agglomeration on the ecological environment, with a regression coefficient of -0.001, but the regression result is not significant. This indicates that industrial agglomeration does not have an effective impact on the ecological environment in the current period when the urbanization level is high, while in the lagged period, industrial agglomeration has a significant negative impact on the ecological environment with a regression coefficient of -0.208. This indicates that the lag of industrial agglomeration in the high stage of urbanization in the Yangtze River Economic Belt contributes to the improvement of urban ecological environment quality. Its lagged estimated coefficient is -0.208, indicating that for every 1% increase in the level of new-type urbanization, the ecological quality will improve by 0.208%, which is not prominent among the factors affecting ecological quality compared to other explanatory variables. Compared to the high stage of urbanization, the low urbanization development shifted from 0.19 in the current period to -0.107 in the lagged period, and their estimated coefficients passed the test at the 1% level. Industrial agglomeration in the low stage of urbanization did not effectively reduce environmental pollution emissions, but the lagged industrial agglomeration helped reduce pollution emissions to a lesser extent than in the high stage of urbanization. It is worth noting that there is a significant synergistic effect between industrial agglomeration and the ecological environment under high levels of urbanization, which is consistent with the study of Zhu and Xia, who point out that as the level of urbanization rises, the improvement of infrastructure and the wide application of clean technology make the positive effect of industrial agglomeration on the environment more obvious [40]. The negative effects of industrial agglomeration on the ecological environment are also significant at the stage of low-level urbanization. Wang et al. support this conclusion by pointing out that insufficient infrastructure and environmental protection measures in low-level urbanization areas lead to more serious environmental pollution problems [78]. The environmental burden of low-level urbanization is heavier, while the high-level urbanization stage shows stronger synergistic effects. This is consistent with the study of Liang et al., who found that socio-economic factors have a significant impact on environmental pollution in rapidly growing cities, which further supports the findings of this paper [79]. This may be mainly due to the following reasons: firstly, compared with traditional urbanization, the new type of urbanization has undergone significant changes in both development thinking and development methods, emphasizing ecological civilization and green low-carbon in development thinking, proposing that ecological civilization should be integrated with urbanization, focusing on promoting green development, circular development, and low-carbon development, emphasizing the economical use of land, water, energy and other resources in development methods, focusing on environmental protection and ecological restoration, reducing interference with and damage to nature, and promoting the formation of green low-carbon lifestyles and urban construction and operation modes. Secondly, there are significant differences in urban size between the high and low stages, and existing studies generally support the idea that Chinese cities have significant economies of scale. The increase in production efficiency due to urban expansion varies between stages, and the division of labor and specialization leads to more pronounced per capita pollution emissions at different stages. Thirdly, the concentration of population and industry in higher stages of urbanization makes pollution relatively concentrated and allows companies to share cleaner production technologies through joint payments, thereby improving environmental quality; however, lower stages of urbanization do not have such facilities, and the mismatch between their technological and economic structures leads to a certain threshold for the efficiency of some pollution control technologies.

The estimated coefficients of the current technology level T and affluence A do not change after taking into account the different stages of urbanization, while the estimated

Table 5. Regression results by stage of urbanization level.

Variables	High	Low	Overall
$I_{i,t-1}$	0.802***	0.418***	0.670***
	(21.995)	(28.346)	(104.299)
$C_{i,t}$	-0.001	0.190***	0.036***
	(-0.027)	(6.060)	(3.367)
$C_{i,t-1}$	-0.208***	-0.107***	-0.097***
	(-8.842)	(-3.616)	(-11.098)
$P_{i,t}$	0.917***	-1.128***	0.512***
	(7.601)	(-2.815)	(6.639)
$P_{i,t-1}$	-1.154***	0.769*	-0.744***
	(-8.859)	(1.844)	(-9.657)
$A_{i,t}$	1.188***	0.073	0.046***
	(5.210)	(1.602)	(2.783)
$A_{i,t-1}$	-0.993***	0.052	0.029
	(-4.346)	(1.194)	(1.151)
$T_{i,t}$	-0.010	-0.036***	-0.010***
	(-1.328)	(-11.221)	(-5.535)
$T_{i,t-1}$	-0.028***	0.001	-0.005***
	(-4.304)	(0.173)	(-2.651)
Constant	-0.021	1.546***	1.085***
	(-0.043)	(3.673)	(7.635)
Year	Control	Control	Control
N	280	580	860
AR(1)-Test	44.594***(p=0.00)	16.000***(p=0.00)	36.000***(p=0.00)
AR(2)-Test	1.176(p=0.240)	1.190(p=0.234)	1.271(p=0.204)
P(Sargan-Test)	0.32248	0.35379	0.80151

Note: Standard errors of coefficient estimates are in parentheses, and *, **, and *** denote 10%, 5%, and 1% significance levels, respectively. The AR(2) test is mainly used to test the autocorrelation of random errors in dynamic panels, and the Sargan test is for overidentification in dynamic panels.

coefficients of the remaining variables are all inconsistent across the different stages of urbanization. The main reason for the variation in the estimated coefficients of these two variables is that there are inherent spillovers from the level of technology and affluence in the current period, and there may be multicollinearity between these two variables and the spillovers from new-type urbanization. The estimates of the other variables are broadly consistent with those of the dynamic panel data model.

As can be seen from Table 5, the coefficients on the lagged level of population $P_{i,t-1}$, the level of technology $T_{i,t}$, $T_{i,t-1}$ and the lagged level of affluence $A_{i,t-1}$ are all negative in the higher stage of urbanization models. The coefficients of population level $P_{i,t}$ and technology level $T_{i,t}$ in the urbanization model at the low stage of urbanization are negative, indicating that new-type urbanization does have a certain degree of impact on ecological and environmental quality while promoting rapid economic development. For a long time, China has been promoting urbanization with an emphasis on quantitative changes: estimates of urbanization at a low stage, in terms of population, indicate that the urbanization of the population has been characterized by the promotion of the citizenship of peasants and the transfer of agricultural labor to the cities, but that the cities have not kept pace with the development of infrastructure to absorb this transferred agricultural population, resulting in problems such as “urban villages” and “slums”. From the estimates of the level of technology, China is still in the accelerated stage of industrialization, i.e., in the left half of the environmental Kuznets curve, and as the level of industrialization increases, it will inevitably put some pressure on the ecological environment. The expansion of agglomeration from the spatial scale of the city and the massive agglomeration of economy and population to the city can reduce the unit pollution emission level through the scale effect, but the huge increment not only offsets this scale effect but also causes more pollution.

Conclusions

Based on the improved STIRPAT model, this paper measures the new-type urbanization index by constructing a theoretical model of the ecological and environmental effects of industrial agglomeration and uses the SYS-GMM model to robustly analyze the ecological and environmental effects of industrial agglomeration and synergies between industrial agglomeration and the ecological environment in new-type urbanization in 86 prefecture-level cities in China's Yangtze River Economic Belt from 2006–2018, and the results of the study show that:

Firstly, the impact of industrial agglomeration on the ecological environment is dynamic. Industrial agglomeration has a positive impact on the ecological environment in the current period, while industrial agglomeration has a negative impact on the ecological environment after a lag, i.e., industrial agglomeration in the Yangtze River Economic Belt has different impacts on the ecological environment in different periods. The lagging results of industrial agglomeration also indicate that there is a strong inertia in the quality of the ecological environment, and the quality of the ecological environment in the current period is largely influenced by the pollution emissions in the previous period.

Second, the current population is not conducive to the improvement of urban ecological quality, but the lagged term helps to improve environmental quality. The results of technological progress and its lags show that current technological progress helps cities in the Yangtze River Economic Belt to improve the quality of the ecological environment. Under today's crude development model, the growth of per capita wealth has a negative effect on the ecological environment, and as people's living standards increase, they consume more material resources and impose a greater burden on the ecological environment.

Thirdly, the lag of industrial agglomeration in the Yangtze River Economic Belt at the high stage of urbanization contributes to the improvement of urban ecological and environmental quality, while the industrial agglomeration in the low stage of urbanization does not effectively reduce environmental pollution emissions, but the lag of industrial agglomeration helps reduce pollution emissions to a lesser extent than the high stage of urbanization. There is a significant synergistic effect between industrial agglomeration and ecological environment quality in the lagging period of high-level new-type urbanization compared to the low-level new-type urbanization stage. At the same time, regardless of the level of new-type urbanization, the synergy between industrial agglomeration and ecological quality is not significant in the current period, indicating that the new-type urbanization does affect synergies between industrial agglomeration and the ecological environment while promoting rapid economic development.

Our results suggest some policy implications. First, guide the long-term sustainable development of industrial agglomeration. In response to the negative impacts of current industrial agglomeration on the environment identified in the study, it is recommended that the government prioritize the long-term sustainable development of industries in the agglomeration area in its policy-making and avoid excessive pursuit of short-term economic benefits. Specific measures include, on the one hand, the implementation of strict environmental access standards to limit the excessive agglomeration of highly polluting industries in sensitive ecological zones. On the other hand, promote green industrial agglomeration and encourage the development of eco-friendly industries, such as renewable energy and environmental protection technology industries, to ensure that industrial agglomeration has a positive effect on the ecological environment. Second, promote technological innovation and clean production. According to research findings on the role of technological progress in improving the ecological environment, the government should strongly support technological innovation by enterprises, especially the research, development, and application of green technologies. Specific policies include providing financial subsidies or tax breaks to support the transformation and upgrading of highly polluting industries and the adoption of cleaner production technologies. Promote low-carbon technologies and circular economy models to reduce energy consumption and pollution emissions and enhance resource utilization efficiency. Third, promote the synergistic development of high-level new urbanization and ecological protection. Research shows that there is a significant synergistic effect between high-level new urbanization and industrial agglomeration. Therefore, the government should focus on promoting the high-quality development of new urbanization, and specific measures include: Promoting the construction of eco-towns and green infrastructure, ensuring the positive interaction between industrial agglomeration and urbanization, and enhancing ecological carrying capacity. Formulating differentiated urbanization policies, giving priority to the promotion of high-level industrial agglomeration in areas with sound infrastructure and strong environmental carrying capacity, so as to avoid the excessive consumption of resources and environmental degradation brought about by low-level urbanization, thereby reducing environmental pollution and achieving sustainable urban development.

Acknowledgments

The authors gratefully acknowledge the editor and the anonymous referees for their valuable comments on this paper.

Conflict of Interest

The authors declare no conflict of interest.

References

1. KEELER B.L., HAMEL P., MCPHEARSON T., HAMANN M.H., DONAHUE M.L., MEZA PRADO K.A., ARKEMA K.K., BRATMAN G.N., BRAUMAN K.A., FINLAY J.C., GUERRY A.D. Social-ecological and technological factors moderate the value of urban nature. Nature Sustainability. **2** (1), 29, **2019**.
2. SETO K.C., GOLDEN J.S., ALBERTI M, TURNER B.L. Sustainability in an urbanizing planet. Proceedings of the National Academy of Sciences of the United States of America. **114** (34), 8935, **2017**.
3. FENG T., DU H., LIN Z., ZUO J. Spatial spillover effects of environmental regulations on air pollution: Evidence from urban agglomerations in China. Journal of Environmental Management. **272**, 110998, **2020**.
4. YU B. Ecological effects of new-type urbanization in China. Renewable & Sustainable Energy Reviews. **135**, 110239, **2021**.
5. NESSHÖVER C., ASSMUTH T., IRVINE K.N., RUSCH G.M., WAYLEN K.A., DELBAERE B., HAASE D., JONES-WALTERS L., KEUNE H., KOVACS E., KRAUZE, K. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. Science of the Total Environment. **579**, 1215, **2017**.
6. CHENG Z., LI X., ZHANG Q. Can new-type urbanization promote the green intensive use of land. Journal of Environmental Management. **342**, 118150, **2023**.
7. XIE F., LI Y., ZHANG B. Threshold effect of industrial agglomeration on carbon productivity in China's Yangtze River economic belt: a perspective of technical resourcing. Environmental Science and Pollution Research. **29**, 64704, **2022**.
8. YU B. Ecological effects of new-type urbanization in China. Renewable and Sustainable Energy Reviews. **135**, 110239, **2021**.
9. BAI X., MCPHEARSON T., CLEUGH H., NAGENDRA H., TONG X., ZHU T., ZHU Y.G. Linking urbanization and the environment: Conceptual and empirical advances. Annual Review of Environment and Resources. **42** (1), 215, **2017**.
10. LUMENG L.I.U., JIANGUO W.U. Scenario analysis in urban ecosystem services research: Progress, prospects, and implications for urban planning and management. Landscape and Urban Planning. **224**, 104433, **2022**.
11. SHARIFI A. The resilience of urban social-ecological-technological systems (SETS): a review. Sustainable Cities and Society. **99**, 104910, **2023**.
12. ZHANG X., LI H. Urban resilience and urban sustainability: What we know and what do not know? Cities. **72**, 141, **2018**.
13. YUSHANJIANG A., ZHOU W., WANG J., WANG J. Impact of urbanization on regional ecosystem services-a case study in Guangdong-Hong Kong-Macao Greater Bay Area. Ecological Indicators. **159**, 111633, **2024**.
14. LUEDERITZ C., BRINK E., GRALLA F., HERMELINGMEIER V., MEYER M., NIVEN L., PANZER L., PARTELOW S., RAU A.L., SASAKI R., ABSON D.J. A review of urban ecosystem services: Six key challenges for future research. Ecosystem Services. **14** (14), 98, **2015**.
15. KRUGMAN P. Increasing returns and economic geography. Journal of Political Economy. **99** (3), 483, **1991**.
16. ZHANG Y., FAN J., CHEN S., LI T., YU Z. A quantitative evaluation on ecological city construction level of urban agglomeration in the middle reaches of Yangtze river. Journal of Coastal Research. **98** (SI), 300, **2019**.
17. COPELAND B.R., TAYLOR M.S. North-South trade and the environment. Quarterly Journal of Economics. **109** (3), 755, **1994**.
18. DONG F., WANG Y., ZHENG L., LI J., XIE S. Can industrial agglomeration promote pollution agglomeration? Evidence from China. Journal of Cleaner Production. **246**, 118960, **2020**.
19. REN Y., TIAN Y., ZHANG C. Investigating the mechanisms among industrial agglomeration, environmental pollution and sustainable industrial efficiency: A case study in China. Environment, Development and Sustainability. **24** (11), 12467, **2022**.
20. FENG M., LI D.D., WU S. How did China maintain macroeconomic stability during 1978–2018? China & World Economy. **29** (3), 55, **2021**.
21. LI L., LEI Y., WU S., HE C., CHEN J., YAN D. Impacts of city size change and industrial structure change on CO_2 emissions in Chinese cities. Journal of Cleaner Production. **195**, 831, **2018**.
22. WANG M., LIU R., CHEN W., PENG C., MARKERT B. Effects of urbanization on heavy metal accumulation in surface soils, Beijing. Journal of Environmental Sciences. **64**, 328, **2018**.
23. WANG X., ZHOU D. Spatial agglomeration and driving factors of environmental pollution: A spatial analysis. Journal of Cleaner Production. **279**, 123839, **2021**.
24. CHEN J., HU C. The agglomeration effect of industrial agglomeration – A theoretical and empirical analysis of the Yangtze River Delta sub-region as an example. Management World. **6**, 68, **2008** [In Chinese].
25. CHEN D., CHEN S., JIN H. Industrial agglomeration and CO_2 emissions: Evidence from 187 Chinese prefecture-level cities over 2005–2013. Journal of Cleaner Production. **172**, 993, **2018**.
26. COPELAND B.R. Trade and the environment. Palgrave handbook of international trade. pp. 423, **2013** [In Chinese].
27. WANG Z., JIA H., XU T., XU C. Manufacturing industrial structure and pollutant emission: An empirical study of China. Journal of Cleaner Production. **197**, 462, **2018**.
28. TIAN Y., ZHANG Y., ZHANG T., ZHU Y. Co-agglomeration, technological innovation and haze pollution: An empirical research based on the middle reaches of the Yangtze River urban agglomeration. Ecological Indicators. **158**, 111492, **2024**.
29. VERHOEF E.T., NIJKAMP P. Externalities in urban sustainability: Environmental versus localization-type agglomeration externalities in a general spatial equilibrium model of a single-sector monocentric industrial city. Ecological Economics. **40** (2), 157, **2002**.

30. CHENG Z., LI L., LIU J. Identifying the spatial effects and driving factors of urban $PM_{2.5}$ pollution in China. Ecological Indicators. **82**, 61, **2017**.
31. RAWLEY E., SEAMANS R. Internal agglomeration and productivity: Evidence from microdata. Strategic Management Journal. **41** (10), 1770, **2020**.
32. JIANG S., TAN X., HU P., WANG Y., SHI L., MA Z., LU G. Air pollution and economic growth under local government competition: Evidence from China, 2007–2016. Journal of Cleaner Production. **334**, 130231, **2022**.
33. WANG B., NIE X. Industrial agglomeration and environmental governance: the power or resistance-Evidence from a quasi-natural experiment of establishment of the development zone. China Industrial Economics. **12**, 75, **2016** [in Chinese].
34. HONG Y., LYU X., CHEN Y., LI W. Industrial agglomeration externalities, local governments' competition and environmental pollution: Evidence from Chinese prefecture-level cities. Journal of Cleaner Production. **277**, 123455, **2020**.
35. LIU S., ZHU Y., DU K. The impact of industrial agglomeration on industrial pollutant emission: Evidence from China under New Normal. Clean Technologies and Environmental Policy. **19** (9), 2327, **2017**.
36. SONG Y., ZHU J., YUE Q., ZHANG M., WANG L. Industrial agglomeration, technological innovation and air pollution: Empirical evidence from 277 prefecture-level cities in China. Structural Change and Economic Dynamics. **66**, 240, **2023**.
37. PEI Y., ZHU Y., LIU S., XIE M. Industrial agglomeration and environmental pollution: based on the specialized and diversified agglomeration in the Yangtze River Delta. Environment, Development and Sustainability. **23**, 4061, **2021**.
38. SHEN N., PENG H. Can industrial agglomeration achieve the emission-reduction effect? Socio-Economic Planning Sciences. **75**, 100867, **2021**.
39. GUO S., MA H. Does industrial agglomeration promote high-quality development of the Yellow River Basin in China? Empirical test from the moderating effect of environmental regulation. Growth and Change. **52** (4), 2040, **2021**.
40. ZHU Y., XIA Y. Industrial agglomeration and environmental pollution: Evidence from China under New Urbanization. Energy & Environment. **30** (6), 1010, **2019**.
41. CHEN C., SUN Y., LAN Q., JIANG F. Impacts of industrial agglomeration on pollution and ecological efficiency-A spatial econometric analysis based on a big panel dataset of China's 259 cities. Journal of Cleaner Production. **258**, 120721, **2020**.
42. ZHANG K., XU D., LI S. The impact of environmental regulation on environmental pollution in China: an empirical study based on the synergistic effect of industrial agglomeration. Environmental Science and Pollution Research. **26** (25), 25775, **2019**.
43. ZHAO Y., LIANG C., ZHANG X. Positive or negative externalities? Exploring the spatial spillover and industrial agglomeration threshold effects of environmental regulation on haze pollution in China. Environment, Development and Sustainability. **23**, 11335, **2021**.
44. ANTOCI A., BORGHESI S., GALEOTTI M., RUSSU P. Maladaptation to environmental degradation and the interplay between negative and positive externalities. European Economic Review. **143**, 104023, **2022**.
45. VATN A., BROMLEY D.W. Externalities-a market model failure. Environmental and Resource Economics. **9**, 135, **1997**.
46. MALMBERG A., SÖLVELL Ö., ZANDER I. Spatial clustering, local accumulation of knowledge and firm competitiveness. Geografiska Annaler: Series B, Human Geography. **78** (2), 85, **1996**.
47. ZHAO C., WANG B. How does new-type urbanization affect air pollution? Empirical evidence based on spatial spillover effect and spatial Durbin model. Environment International. **165**, 107304, **2022**.
48. GUO X., DENG M., WANG X., YANG X. Population agglomeration in Chinese cities: is it benefit or damage for the quality of economic development? Environmental Science and Pollution Research. **31** (7), 10106, **2024**.
49. LIU X., ZHANG X., SUN W. Does the agglomeration of urban producer services promote carbon efficiency of manufacturing industry? Land Use Policy. **120**, 106264, **2022**.
50. NORTHAM D.B., VON ROSENBERG JR C.W. Coal gasification in steam at very high temperatures. Fuel. **58** (4), 264, **1979**.
51. LIU X., REN T., GE J., LIAO S., PANG L. Heterogeneous and synergistic effects of environmental regulations: Theoretical and empirical research on the collaborative governance of China's haze pollution. Journal of Cleaner Production. **350**, 131473, **2022**.
52. Li H., Song W. Evolution of rural settlements in the Tongzhou District of Beijing under the new-type urbanization policies. Habitat International. **101**, 102198, **2020**.
53. SHAO J., WANG L. Can new-type urbanization improve the green total factor energy efficiency? Evidence from China. Energy. **262**, 125499, **2023**.
54. ZHANG Y., CHEN X. Spatial and nonlinear effects of new-type urbanization and technological innovation on industrial carbon dioxide emission in the Yangtze River Delta. Environmental Science and Pollution Research. **30** (11), 29243, **2023**.
55. ZHANG L. Conceptualizing China's urbanization under reforms. Habitat International. **32** (4), 452, **2008**.
56. SICILIANO G. Urbanization strategies, rural development and land use changes in China: A multiple-level integrated assessment. Land Use Policy. **29** (1), 165, **2012**.
57. ADEBAYO T.S., ULLAH S. Towards a sustainable future: The role of energy efficiency, renewable energy, and urbanization in limiting CO_2 emissions in Sweden. Sustainable Development. **32** (1), 244, **2024**.
58. YANG S., LIU S., WU T., ZHAI Z. Does new-type urbanization curb haze pollution? A case study from China. Environmental Science and Pollution Research. **30** (8), 20089, **2023**.
59. ANDERSON T.W. The use of factor analysis in the statistical analysis of multiple time series. Psychometrika. **28** (1), 1, **1963**.
60. CORAZZIARI I. Dynamic factor analysis. Classification and Data Analysis. Springer, Berlin, Heidelberg. pp.171, **1999**.
61. CAI Z. Exploring the calculation of profit growth rates for loss-making enterprises. Journal of Yanbian University (Social Science Edition). **26** (1), 74, **2000** [In Chinese].
62. DIETZ T., ROSA E.A. Effects of population and affluence on CO_2 emissions. Proceedings of the National Academy of Sciences of the United States of America. **94** (1), 175, **1997**.
63. EHRLICH P.R., HOLDREN J.P. Impact of population growth. Science. **171** (3977), 1212, **1971**.

64. WANG Y., WANG J. Does industrial agglomeration facilitate environmental performance: new evidence from urban China? Journal of Environmental Management. **248**, 109244, **2019**.
65. LI W., SUN B., ZHANG T. Spatial structure and labour productivity: Evidence from prefectures in China. Urban Studies. **56** (8), 1516, **2019**.
66. BUN M.J.G., WINDMEIJER F. The weak instrument problem of the system GMM estimator in dynamic panel data models. Econometrics Journal. **13** (1), 95, **2010**.
67. ELBERS C., WITHAGEN C. Environmental policy and international trade: Are policy differentials optimal? In: Marsiliani L, Rauscher M, Withagen C (eds) Environmental Policy in an International Perspective. Economy & Environment, volume **26**. Springer, Dordrecht, **2003**.
68. WANG J., WANG R., ZHU Y., LI J. Life cycle assessment and environmental cost accounting of coal-fired power generation in China. Energy Policy. **115**, 374, **2018**.
69. LIANG J., GOETZ S.J. Technology intensity and agglomeration economies. Research Policy. **47** (10), 1990, **2018**.
70. CRIADO C.O., VALENTE S., STENGOS T. Growth and pollution convergence: Theory and evidence. Journal of Environmental Economics & Management. **62** (2), 199, **2011**.
71. CHENG Z., JIN W. Agglomeration economy and the growth of green total-factor productivity in Chinese Industry. Socio-Economic Planning Sciences. **83**, 101003, **2022**.
72. ZHANG H., ZHANG J., SONG J. Analysis of the threshold effect of agricultural industrial agglomeration and industrial structure upgrading on sustainable agricultural development in China. Journal of Cleaner Production. **341**, 130818, **2022**.
73. RAJU K.V., RAVINDRA A., MANASI S., SMITHA K.C., SRINIVAS R. Urban environmental governance: Global experience. Urban Environmental Governance in India. Springer, Cham, **2018**.
74. SINGH P., JAECKEL A. Future prospects of marine environmental governance. Switzerland: Springer, **2018**.
75. CHEN Y., ZHU Z., CHENG S. Industrial agglomeration and haze pollution: Evidence from China. Science of the Total Environment. **845**, 157392, **2022**.
76. HAO Y., SONG J., SHEN Z. Does industrial agglomeration affect the regional environment? Evidence from Chinese cities. Environmental Science and Pollution Research. **29**, 7811, **2022**.
77. BOND S.R. Dynamic panel data models: a guide to micro data methods and practice. Portuguese Economic Journal. **1** (2), 141, **2002**.
78. WANG Y., YAO L., XU Y., SUN S., LI T. Potential heterogeneity in the relationship between urbanization and air pollution, from the perspective of urban agglomeration. Journal of Cleaner Production. **298**, 126822, **2021**.
79. LIANG L., WANG Z., LI J. The effect of urbanization on environmental pollution in rapidly developing urban agglomerations. Journal of Cleaner Production. **237**, 117649, **2019**.