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RESEARCH ARTICLE

Analysis of the impact of foreign direct investment on urbanization in China from the perspective of "circular economy"

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Abstract

Persisting in opening up and achieving coordinated development of economy, society, and ecology is China's major strategies for achieving sustainable urbanization. Ecological efficiency is a reasonable indicator to measure the development level of a circular economy. Therefore, using the statistical data of 30 provinces in China from 2004 to 2016, this paper uses the super-efficiency SBM model that considers undesired output to measure the eco-efficiency value, which is used to measure the level of circular economy development in each province. Based on this, a panel model is constructed to test the impact of circular economy and FDI on urbanization. The empirical results show that (1) there is a complex nonlinear relationship between the development of circular economy and the advancement of urbanization, and the shape of the curve varies with areas; (2) FDI under environmental regulation is conducive to promoting China's urbanization to achieve green, effective, and sustainable development; and (3) the development of the tertiary industry, human resources, innovation capabilities, and employment situation is conducive to promoting China's urbanization. Finally, based on the empirical results, this paper puts forward policy recommendations to achieve green, efficient, and intelligent development of Chinese cities by promoting the development of a circular economy and strengthening FDI screening.

Keywords Urbanization · Circular economy · Ecological efficiency · Foreign direct investment · Environmental regulation

Introduction

Urbanization is an important form in the development of human society. With the continuous deepening of industrialization reform, the process of urban industrialization in China has gradually realized the transition from the initial stage of development to the accelerated stage of development. High-quality urban resources attract a large number of rural surplus labor to move to cities and promote the further improvement of urban economic development (Jin 2015). However, as the scale of urban population agglomeration expands, "urban diseases" such as traffic congestion, waste of resources, and environmental pollution have emerged one after another. In addition, problems such as the decline of the "demographic dividend" and overcapacity in the industry have also restricted the further improvement of the scale of the city and the level of economic development. The marginal attractiveness of cities to population gradually declines. At present, there are two opposing views on the development speed of Chinese cities: "lag theory" and "non-lag theory." "Lagging theorists" believe that China's urbanization level is still lagging behind other countries at the same level through the measurement of industrial indicators, chaners, purchasing power, and other indicators, so the development of urbanization in China should be accelerated (Jian and Huang 2010; Liu and Shi 2015). However, the "non-lag theory" people questioned the measurement standards and conclusions of the "lag theory," believing that China's current urbanization is developing so fast that there are serious situations such as resource shortages and environmental destruction (Du et al. 2018; Zhao and Zhang 2018). Therefore, as China's industrialization has

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entered a period of deepening development, it is particularly important to explore the continuous driving force that promotes the development of urbanization and realize the coordinated and sustainable development of the economy, society, and ecology in China's urban areas.

As a new type of economic growth, the core content of circular economy is to weigh the relationship between "economy," "society," and "environment" (Ye and Gan 2009). In 2006, the Chinese government included the development of circular economy as a major task of the "Eleventh Five-Year Plan" into the national economic and social development plan, and pointed out that the development of a circular economy is a major strategic decision for China to build a resource-saving and environment-friendly society and achieve sustainable development. In the report of the 19th National Congress of the Communist Party of China, General Secretary Xi Jinping issued a solemn promise to the world to build an ecological civilization in China. In order to achieve the coordinated development of economy, society, and ecology, circular economy advocates maintaining sustained regional economic growth with minimal resource consumption and environmental pollution. Obviously, circular economy does not solely emphasize the "quantity" issues such as output or cost in the economic production process, but comprehensively evaluates all aspects of economic development and emphasizes the "quality" issues such as economic development efficiency. It can be seen that the circular economy can alleviate the contradiction between the "lag theory" and the "non-lag theory" of China's urban. While ensuring the quantity of development, reduce the pressure on resources and environment and improve the quality of development and ecological efficiency, so how to scientifically measure and evaluate the level of circular economy development? Can vigorously developing a circular economy inspire a new round of urbanization in China?

Since the reform and opening up, while actively promoting the reform of urban industrialization internally, China has also implemented an opening-up policy of "bringing in and going out." Foreign direct investment (FDI) is an important form of opening up. By introducing foreign resources to invest and build factories in China, FDI can promote the upgrading of industries in the host country, provide employment opportunities, improve wage levels, and optimize the employment structure, thereby improving the economic development level of the host country's urban areas and increasing the incentives for population to enter cities (Clark 1998; Chen 2018). At present, FDI has a huge impact on the economic development and urbanization of developing countries, which has become the consensus of scholars from all over the world (Rafael et al. 2003). However, whether FDI has caused and aggravated the environmental pollution in the host country has always been controversial, and has formed two views of "pollution refuge" and "pollution halo" (Guo and Han 2008). The "pollution refuge" hypothesis holds that developed countries transfer high-polluting and high-energy-consuming industries to developing countries, which intensifies environmental pollution in the host country, but the "pollution halo" hypothesis believes that FDI can improve the environmental conditions of the host country through technology spillover effects (Antweiler et al. 2001; Xu and Deng 2012; Li et al. 2017; Daniel et al. 2019;). Considering the impact of FDI on China's environmental pollution, the Chinese government has adopted environmental regulatory policies such as increasing environmental protection investment and environmental information disclosure. Many scholars have found that loose environmental regulatory policies can create a "pollution refuge" effect, and increasing environmental policy control over FDI can accelerate the exit of polluting foreign-funded enterprises and increase investment in clean foreign-funded enterprises, thereby optimizing the structure of FDI in China (Guo et al. 2008; Shi et al. 2019), so is FDI conducive to the coordinated development of China's urban economy, society, and ecology? Can FDI enhance the attractiveness of Chinese cities and promote a new round of urbanization in China? Will environmental regulations affect the effect of FDI on the promotion of urbanization by restricting FDI? In addition, the existing literature is mostly limited to the discussion on the "quantity" level of development, that is, unilateral research on the impact of FDI on economic levels, urbanization, or environmental conditions. However, based on the perspective of development "quality," research on the impact of FDI on urbanization with circular economy as the starting point is still insufficient.

In view of this, drawing on the practice of Ren Mei et al. (2019), this paper, based on the panel data of 30 provinces in China from 2004 to 2016, constructs an input-output model and uses the super-efficiency SBM model to measure the level of ecological efficiency to evaluate the level of circular economy development in each province. Based on this, a panel measurement model was constructed to test the impact of circular economy and FDI on China's urbanization. The marginal contribution of this paper mainly includes the following three aspects: (1) measure and evaluate the development level of China's regional circular economy with ecological efficiency, and examine the impact of the development level of the circular economy on the promotion of urbanization based on the calculation results; (2) taking the development level of circular economy as the starting point, examine the impact of FDI and FDI under environmental regulations on the promotion of China's urbanization, and the intermediary role of circular economy in this process; (3) considering the differences in China's regional development, examine the regional heterogeneity of the impact of circular economy and FDI on China's urbanization.

The structure of this paper is as follows: the second part is model construction and data description, which mainly include the introduction of China's circular economy

development level evaluation indicators and evaluation methods, the construction of the panel test model for the impact of circular economy and FDI on China's urbanization, and the intermediary effect test model of the circular economy; the third part is the empirical analysis, which mainly includes the evaluation of China's regional circular economy development level, the impact of circular economy and FDI on the promotion of China's urbanization, the analysis of regional heterogeneity, and the test results of the intermediary effect of circular economy; the last part is the conclusion and discussion, including the main research conclusions, corresponding policy recommendations, and the limitations of this paper.

Model construction and data description

Eco-efficiency measurement model

Ecological efficiency is a reasonable measure of circular economy (Zhu and Qiu 2006). Eco-efficiency was proposed by Schaltegger and Stum in (1990) to measure the pressure on the ecological environment during economic development. In 1998, the OECD officially defined ecological efficiency as the efficiency of ecological resources meeting human needs, usually expressed as the ratio of economic output value to resource consumption and environmental pressure. Based on this, many scholars have measured the China's regional ecological efficiency (OECD 1998). Yang and Zhang (2018) and Ren et al. (2019), by incorporating environmental pollution indicators such as waste gas and solid waste emissions as undesired outputs into output indicators, constructed an input-output indicator system and evaluated the level of my country's inter-provincial ecological efficiency. Different from Ren et al., there are also many scholars constructing an eco-efficiency evaluation system by incorporating environmental pollution and resource consumption factors into input indicators (Cheng et al. 2014).

Taking into account the process of economic production and output, this paper draws on the practice of Ren et al. and constructs a regional eco-efficiency evaluation index system with 5 inputs and 5 outputs by regarding environmental pollution indicators as output indicators. Four input types including capital input, natural input, labor input, and energy input are selected to reflect the input status. Among them, capital input is measured by total fixed investment (10,000 yuan); natural input is measured by total water consumption (10^4 t) and urban construction land area (km^2); labor input is measured by the number of employees (10,000 people); energy input is measured by the total energy consumption (10,000 t of standard coal). At the same time, the expected output and the undesired output are selected to reflect the output status. Among them, the expected output is measured by the regional GDP (100 million yuan) and the public financial budget revenue (100 million yuan); the undesired output is measured by SO_2 emissions (10^4 t), wastewater emissions (10^4 m^3), and industrial solid waste emissions (10^4 t). The raw data of the above indicators are mainly from the China Statistical Yearbooks, National Environmental Statistics Bulletins, China Science and Technology Statistics Yearbooks, China Environmental Statistics Yearbook, China Population, Employment Statistics Yearbook and yearbooks of corresponding provinces (municipalities, districts) published from 2005 to 2017.

Most of the existing efficiency evaluation models are developed and extended based on data envelopment analysis (DEA). DEA, a non-parametric efficiency evaluation method based on the relative comparison between evaluation pairs, was first proposed by Charnes and Cooper in 1978. The principle of DEA is to use mathematical programming to determine the production frontier composed of the best-performing decision-making units (DMUs), and then calculate the efficiency score of each DMUs by calculating the distance between each DMU and the production frontier. However, the radial DEA does not consider the slack variable, which will lead to the "slack" or "crowding" of the input elements. Therefore, a non-radial DEA model was proposed by Tone in 2002, that is, a method for measuring the efficiency of DMUs based on relaxation variables, and then, he proposed a super-efficiency SBM model to achieve an economic explanation of profit maximization, instead of only focusing on maximizing relative benefits. Besides, S-SBM model not only can make up for the shortcomings of effective DMUs that cannot be further compared when evaluating relative efficiency but also can effectively deal with the problem of undesired output, so that more effective evaluation of DMUs (Xing et al. 2018; Mei et al. 2019). Therefore, this paper constructs a super-efficient SBM model that considers undesired output as follows:

$$\min \rho = \frac{\frac{1}{m}\sum_{i=1}^{m}\left(\frac{\bar{x}}{x_{ik}}\right)}{\frac{1}{r_1+r_2}\left(\sum_{s=1}^{r_1}\overline{y^d}/y^d_{sk} + \sum_{q=1}^{r_2}\overline{y^u}/y^u_{qk}\right)} \tag{1}$$

$$\text{Subject to}\begin{cases} \bar{x} \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j & i = 1,2,\cdots,m \\ \overline{y^d} \leq \sum_{j=1,\neq k}^{n} y^d_{sj}\lambda_j & s = 1,2,\cdots,r_1 \\ \overline{y^u} \geq \sum_{j=1,\neq k}^{n} y^u_{qj}\lambda_j & q = 1,2,\cdots,r_2 \\ \lambda_j \geq 0 & j = 1,2,\cdots,n \\ \bar{x} \geq x_k & k = 1,2,\cdots,m \\ \overline{y^d} \leq y^d_k & q = 1,2,\cdots,r_1 \\ \overline{y^u} \geq y^u_k & u = 1,2,\cdots,r_2 \end{cases} \tag{2}$$

ρ represents the value of eco-efficiency, and n represents the number of decision-making units (DMUs). Each DMU is composed of three parts: input index (m), expected output (r_1), and undesired output (r_2). x, y^d, and y^u are the elements of the corresponding input matrix, expected output matrix, and undesired output matrix. The matrix representation is the elements $\boldsymbol{x}\in\boldsymbol{R}^{\boldsymbol{m}}, \boldsymbol{y}^{\boldsymbol{d}}\in\boldsymbol{R}^{\boldsymbol{r}_1}, \boldsymbol{y}^{\boldsymbol{u}}\in\boldsymbol{R}^{\boldsymbol{r}_2}$, and the corresponding matrix is $\boldsymbol{X}=[\boldsymbol{x}_1,\cdots,\boldsymbol{x}_n]\in\boldsymbol{R}^{\boldsymbol{m}\times\boldsymbol{n}}$, $\boldsymbol{Y}^{\boldsymbol{d}}=\left[\boldsymbol{y}_1^{\boldsymbol{d}},\cdots,\boldsymbol{y}_n^{\boldsymbol{d}}\right]\in\boldsymbol{R}^{\boldsymbol{r}_1\times\boldsymbol{n}}, \boldsymbol{Y}^{\boldsymbol{u}}=\left[\boldsymbol{y}_1^{\boldsymbol{u}},\cdots,\boldsymbol{y}_n^{\boldsymbol{u}}\right]\in\boldsymbol{R}^{\boldsymbol{r}_2\times\boldsymbol{n}}$.

The model of the impact of circular economy and FDI on urbanization

Based on the panel data of 30 provinces in China from 2004 to 2016, this paper uses eco-efficiency to evaluate the development level of China's inter-provincial circular economy. Based on this, in order to further explore the role of the development of circular economy and FDI in promoting China's urbanization, this paper constructs a panel measurement model as follows:

$$urb_{it}=\alpha_0+\alpha_1 eco_{it}+\alpha_2(eco_{it})^2+\alpha_3(eco_{it})^3+\alpha_4 fdi_{it}+\psi\boldsymbol{X}+\delta_i+\varepsilon_{it}$$
$$\mathrm{urb}_{it}=\beta_0+\beta_1\mathrm{eco}_{it}+\beta_2(\mathrm{eco}_{it})^2+\beta_3(\mathrm{eco}_{it})^3 \quad (3)$$

$$+\beta_4\,\mathrm{fdi}_{it}+\beta_5\,\mathrm{reg}_{it}+\beta_6\,\mathrm{fdi}_{it}\mathrm{reg}_{it}+\beta_7\,\mathrm{fdi}_{it}\mathrm{reg}_{i,t-1}+\boldsymbol{\Omega}\mathbf{X}+\sigma_i+\mu_{it} \quad (4)$$

Formula (3) is the test model for the impact of circular economy and FDI on urbanization without considering environmental regulations, and Formula (4) is the test model with considering the constraints of environmental regulations; i is the province, t is the year; the explanatory variable urb_{it} indicates the level of urbanization of the province i in year t, measured by the proportion of urban population; eco_{it} indicates the level of circular economy development of the province i in year t, measured by the eco-efficiency value; fdi_{it} indicates the degree of opening of the province i in year t, measured by the ratio of foreign direct investment to GDP. In Formula (4), reg_{it} represents the environmental regulation level of province i in year t, measured by the ratio of government environmental protection investment to GDP; the interaction term of fdi_{it} and reg_{it} is used to measure the impact of FDI on the promotion of urbanization under the constraints of environmental regulations. Considering that there may be a certain time lag in environmental regulation, this paper selects an interaction term of fdi_{it} and reg_{it-1} to measure the impact of FDI on urbanization under the constraints of the lag period of environmental regulation. Finally, α_i, β_i represent the parameter to be estimated, δ_i, σ_i represent the urban fixed effect of each model, and ε_{it}, μ_{it} represent the random error term.

Considering that there are many other factors that affect the process of urbanization, this paper introduces a set of control variables ($\boldsymbol{X}$), including industrial structure (*ter*), human capital level (*edu*), unemployment rate (*uem*), and technological innovation level (*rd*). The specific contents of the variables are as follows:

(1) Industrial structure (*ter*). It is measured by the proportion of the added value of the tertiary industry in GDP. On the one hand, the tertiary industry has a wide variety of industries and strong labor capacity, and the effect of scale economies can attract the labor to move to cities. On the other hand, the tertiary industry is dominated by the service industry, with a higher level of digitization and informatization, and compared to the secondary industry; it is less destructive to resources and the environment (Xu and Wang 2020). From this point of view, the development of the tertiary industry can achieve population urbanization by providing employment resources and improving the quality of urban living environment. Therefore, this paper expects its coefficient sign to be positive.

(2) Human capital (*edu*). It is measured by the number of persons with a higher education degree per 10,000 people. Urban economics proposes that human capital accumulation can have an impact on the advancement of urbanization through knowledge spillovers and optimization of industrial structure (Duncan and Vernon 1999). High-quality resources in urban areas can better match the skill level of highly educated workers, and the working and living environment in urban areas can meet the higher demands of highly educated labor for capital returns and living environment (Ma 2014). From this point of view, the higher the education level, the higher the incentive for labor to enter the city. Therefore, this paper expects its coefficient sign to be positive.

(3) Employment status (*uem*). It is measured by urban registered unemployment rate. An important incentive for urban areas to attract population is that cities can provide better and more stable resources and opportunities to meet people's daily needs and self-worth realization. Therefore, a higher unemployment rate will cause urban migration of the population by increasing income risks. Inhibition, thereby restricting the increase in the level of urbanization in China. A higher unemployment rate will inhibit the urban migration of the population by increasing income risks, thereby restricting the improvement of China's urbanization level (Hare 1999). Therefore, this paper expects its coefficient sign to be negative.

(4) Innovation level (*rd*). It is measured by the number of patents owned by every 100 scientific researchers. Scientific and technological innovation not only can promote industrialization reform but also can be a powerful driving force for urbanization. Technological innovation can improve the overall employment structure of society,

raise wages, and improve the living environment by optimizing industrial structure, improving industrial layout, and promoting the development of digital intelligent service-oriented infrastructure (Wang and Yang 2014). Therefore, this paper expects its coefficient sign to be positive.

Except for the value of eco-efficiency indicators, the original data of other indicators come from the 2005–2017 China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Trade and Foreign Economic Statistics Yearbook, China Environment Statistical Yearbook, and China Population and Employment as well as yearbooks of the corresponding years in each province. Among them, currency indicators are deflated at constant prices in 2000.

The intermediary effect test model of circular economy

Taking into account the two-sided effects of FDI on the output level of economic development and the pressure on resources and environment, this paper intends to construct a model with the development level of circular economy as an intermediary variable to test the intermediary effect of circular economy in the process of FDI affecting China's urbanization. Considering the influence of an explanatory variable X on the explained variable Y, if X has an effect on Y through the variable M, then M is called an intermediate variable. During the whole process, the process in which X does not affect Y through the intermediate variable M is called a direct effect, and the process in which X affects Y through an intermediate variable M is called an indirect effect. The direct effect plus the indirect effect is equal to the total effect (Wen et al. 2004) (Fig. 1). The traditional step is to test the coefficients of each formula in the model in turn. In other word, Formulas (5)–(7) are tested in turn. If $H_0 : c = 0$ in Formula (5) is rejected, $H_0 : a = 0$ in Formula (6) is rejected, and $H_0 : b = 0$ in Formula (7) is also rejected, it means there is a mediation effect, otherwise there is no significant mediation effect.

$$Y = cX + e_1 \tag{5}$$

$$M = aX + e_2 \tag{6}$$

$$Y = c'X + bM + e_3 \tag{7}$$

According to the research content of this paper, based on the principle of the intermediary model, this paper selects the urbanization level urb_{it} as the explained variable, the development level of regional circular economy eco_{it} as the intermediation variable, the FDI intensity fdi_{it} as the explained variable to construct a mediation effect model as shown in Formulas (8)–(10) which respectively corresponds to formulas (5)–(7).

$$urb_{it} = \rho_0 + \rho_1 fdi_{it} + \boldsymbol{\Phi X} + v_i + \zeta_{it} \tag{8}$$

$$eco_{it} = \eta_0 + \eta_1 fdi_{it} + \boldsymbol{\Theta X} + \vartheta_i + \tau_{it} \tag{9}$$

$$\mathrm{urb_{it}} = \gamma_0 + \gamma_1 \mathrm{eco_{it}} + \gamma_2 fdi_{it} + \boldsymbol{\Upsilon X} + \pi_\mathrm{i} + \xi_\mathrm{it} \tag{10}$$

Empirical results and discussions

The estimation results of the development level of the circular economy

Based on the super-efficiency SBM model (Formulas (1)–(2)) that considers undesired output, this paper uses MaxDEA 7.0 to calculate the eco-efficiency of China's 30 provinces year by year to measure the level of circular economy development in each province. Considering that the eastern region is in a leading position in terms of economy, society, ecology, and foreign trade compared with the central and western regions, this paper divides the region into the eastern region and other regions (i.e., the central and western regions) for comparative analysis.

Figure 2 shows the average development level of the circular economy of the whole country, the eastern region and other regions from 2004 to 2016. Table 1 lists the average annual development level of circular economy in each province during the observation period. From the results of Fig. 2 and Table 1, we can see that there are obvious differences in the development level and trend of circular economy in the whole country and in various regions from 2004 to 2016. From the perspective of absolute development level over the same period (Fig. 2), the development level of circular economy in the eastern region is the highest and higher than the overall level of the country. The overall level of circular economy development in other regions is about half of that of the eastern region and lags behind that of the whole country. From the perspective of the time-series trend of the development level (Fig. 2), from 2004 to 2016, the development trend of the circular economy in the country and the eastern region was basically the same. Before 2011, it showed a fluctuating upward trend, but after 2012, it declined. However, the level of circular economy development in other regions shows a downward trend in fluctuations. From the analysis of the difference in the annual average level of circular economy development in each province during the observation period (Table 1), the circular economy of 13 provinces includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, Inner Mongolia, Qinghai, and Ningxia The average development level is higher than the national average. Obviously, most of these provinces are

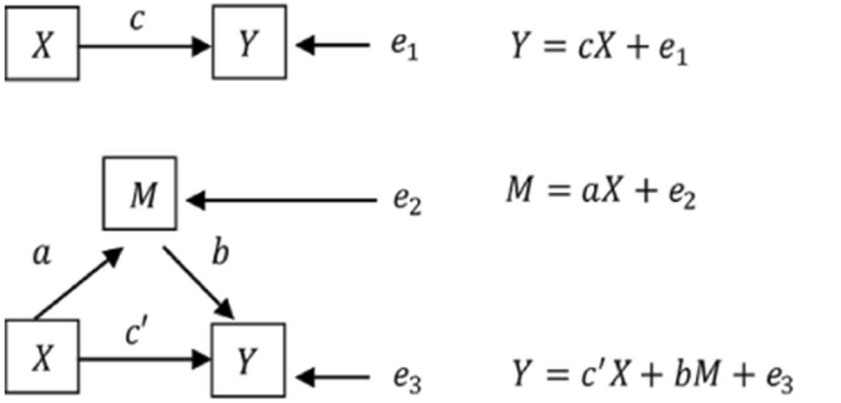

Fig. 1 The steps of mediating effects

eastern coastal areas, with developed economies and strong environmental protection capabilities, and they are also superior to other parts of the country in terms of green production and pollution control technologies.

The estimation results of the impact of circular economy and FDI on urbanization

Table 2 lists the test results of the model for the impact of circular economy and FDI on urbanization. Among them, columns (1)–(2) are the regression results of the panel model (Formula (3)) without considering environmental regulations, and columns (3)–(4) are the regression results of the panel model (Formula (4)) considering environmental regulations and their time lag. Columns (1) and (3) are the results of fixed effects (FE) regression, and columns (2) and (4) are the results of random effects (RE) regression. The Hausman test results show that each model rejects the null hypothesis that "the fixed effect is not different from the random effect" at the significance level of 1%, which means that the FE regression of each model is better than the RE regression. Therefore, this paper focuses on the FE regression results, namely columns (1) and (3) of Table 2.

There is a complicated linear relationship between the development of circular economy and the advancement of urbanization (Fig. 3). It can be seen from columns (1) and (3) of Table 2 that the circular economy has a significant positive impact on the advancement of urbanization, the coefficient of the second power is significantly negative, and the coefficient of the third power is significantly positive. This shows that with the development of circular economy, the level of urbanization presents a trend of first rising, then falling and then rising, that is, there is a significant positive "*N*" relationship between circular economy and urbanization. This shows that with the development of a circular economy, urbanization will experience three stages of development. In the first stage, the total economic output and environmental pressure are at a relatively low level, and the growth rate of economic output

Table 1 Descriptive statistics of ecological efficiency

Province	Mean	SD	Min	Max	Province	Mean	SD	Min	Max
Beijing	1.602	0.117	1.349	1.711	Hunan	0.482	0.251	0.268	1.005
Tianjin	1.149	0.035	1.093	1.216	Inner Mongolia	0.817	0.308	0.362	1.024
Hebei	0.815	0.299	0.281	1.010	Guangxi	0.285	0.050	0.218	0.410
Shanghai	1.143	0.051	1.081	1.238	Chongqing	0.441	0.080	0.358	0.674
Jiangsu	0.978	0.112	0.715	1.041	Sichuan	0.352	0.029	0.295	0.391
Zhejiang	1.018	0.009	1.006	1.038	Guizhou	0.386	0.023	0.346	0.413
Fujian	1.024	0.019	1.007	1.073	Yunnan	0.456	0.255	0.263	1.030
Shandong	1.049	0.015	1.030	1.075	Shannxi	0.588	0.254	0.328	1.015
Guangdong	1.217	0.020	1.186	1.260	Gansu	0.326	0.037	0.273	0.370
Hainan	2.664	0.341	2.074	3.270	Qinghai	1.315	0.290	0.365	1.488
Shanxi	0.388	0.072	0.244	0.493	Ningxia	0.998	0.111	0.638	1.070
Anhui	0.269	0.028	0.233	0.343	Xinjiang	0.302	0.042	0.248	0.377
Jiangxi	0.312	0.033	0.269	0.382	Liaoning	0.403	0.063	0.287	0.486
Hainan	0.431	0.054	0.340	0.522	Jilin	0.295	0.044	0.250	0.417
Hubei	0.299	0.043	0.231	0.355	Heilongjiang	0.417	0.341	0.184	1.020

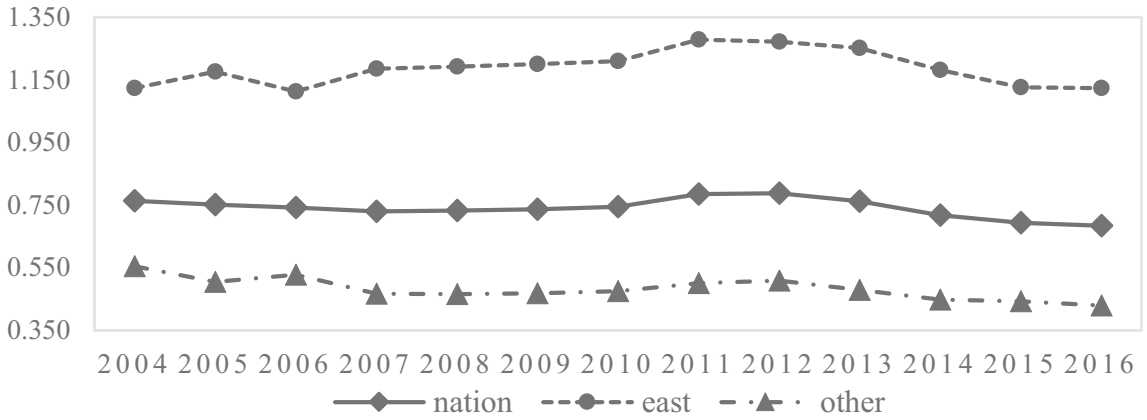

Fig. 2 The level of regional circular economy (average value of ecological efficiency) change trend chart

is faster than the growth rate of environmental pressure. Cities have greater development potential and employment opportunities at this stage, so there are more incentives for people to enter cities. Therefore, with the development of the circular economy, urbanization is also on the rise. In the second stage, with the continuous economic and social development, the scale of the city expanded rapidly. However, the traditional extensive development model has also led to the emergence of problems such as resource congestion and environmental degradation. The happiness of urban human settlements has gradually declined, and the incentives for the population to enter cities have gradually decreased. People are more inclined to choose to live in areas with a good environment such as suburbs, which restricts the progress of urbanization. In the third stage, with the further development of the economy and society, the environmental protection awareness and environmental protection capabilities of the government and the people have gradually increased. Green industries are competing to rise, and green production technologies and pollution control technologies have been widely used. In addition, as tertiary industries such as digital information gradually dominate, the pressure on resources and the environment has been eased. While the capacity of the labor market has expanded, urban service-oriented infrastructure has also been improved. Urban work and living environment have been optimized, and the level of urbanization has begun to steadily increase. Urbanization at this stage can achieve green, efficient, and sustainable development.

Table 2 Results of the impact of circular economy and FDI on urbanization at the national level

Variables	(1)	(2)	(3)	(4)
eco	33.331***	18.981**	28.598**	18.040**
	(12.39)	(8.36)	(12.62)	(8.14)
eco^2	−29.893***	−11.52	−24.669**	−10.55
	(11.01)	(7.11)	(11.17)	(6.85)
eco^3	4.703**	1.205	3.732*	1.059
	(2.13)	(1.46)	(2.12)	(1.38)
ter	0.311***	0.363***	0.289***	0.362***
	(0.10)	(0.08)	(0.09)	(0.08)
edu	0.004***	0.007***	0.004***	0.006***
	(0.00)	(0.00)	(0.00)	(0.00)
uem	−3.794***	−2.036**	−3.137***	−1.675*
	(1.05)	(0.96)	(1.02)	(0.96)
rd	0.120**	0.151***	0.146***	0.156***
	(0.06)	(0.05)	(0.05)	(0.05)
fdi	−0.880***	−0.655***	−0.975***	−0.768***
	(0.11)	(0.10)	(0.28)	(0.29)
reg			−0.107	−0.213
			(0.65)	(0.65)
regfdi			−0.372**	−0.392**
			(0.17)	(0.18)
reg1fdi			0.615***	0.586***
			(0.17)	(0.18)
Hausman test	41.75***		39.86***	

******, , and represent the 10%, 5%, and 1% significance levels, respectively; the standard error is shown in ()

According to the results in column (3) of Table 2, this paper calculates the inflection point of the positive "*N*" curve

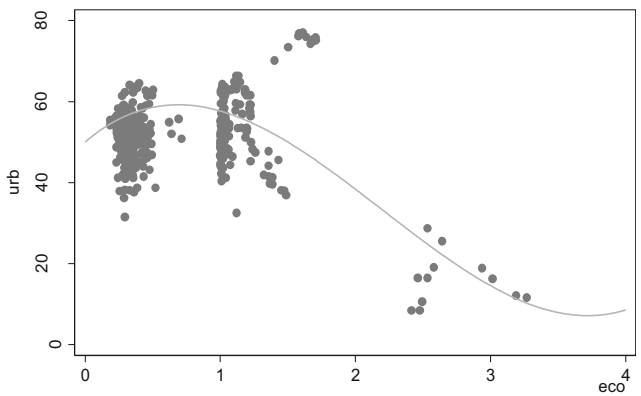

Fig. 3 Nonlinear scatter plot of *urb* and *eco*

between the circular economy and urbanization. It is found that the development level of circular economy in all provinces is less than the second inflection point value (3.7201), that is, no province has reached the third stage, so as to realize the sustainable development of urbanization, green, and efficient. In order to present this result more intuitively, this paper draws a scatter plot of urbanization level and ecological efficiency value and the corresponding fitting curve (Fig. 2). Obviously, all points are before the second inflection point. Provinces including Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan exceeded the first turning point (0.687) in the development of circular economy during 2004–2016. These provinces are all economically developed areas along the eastern coast. Although Hainan has a relatively high level of circular economy development due to the characteristics of its industrial structure, its urbanization is still at a relatively low level. Other provinces are in the early stage of the second stage, with a high level of urbanization but a relatively low level of circular economy development. According to 2018 statistics, the total GDP of the eastern region accounts for almost half of the country. However, high development under the extensive development model is also accompanied by high pollution and high energy consumption, resulting in the level of circular economy development failing to cross the second inflection point. Therefore, from the overall national level, China's overall urbanization development has not achieved green, efficient, and sustainable development.

Environmental regulations are conducive to the realization of FDI's promotion of urbanization. Column (1) of Table 2 shows that without considering environmental regulations, FDI has a significant negative impact on the advancement of urbanization, indicating that the increase in FDI will inhibit the advancement of urbanization into cities. This may be due to the fact that most of China's FDI imports are pollution-based investments, and the "pollution refuge" effect is greater than the "pollution halo" effect, leading to a decline in urban environmental conditions and further hindering the progress of urbanization. Column (3) of Table 2 shows that considering environmental regulations, although FDI and the interaction between FDI and environmental regulations have a significant negative impact on the advancement of urbanization, the interaction term between FDI and environmental regulations lags behind for a period has a significant positive effect on the promotion of urbanization. This shows that there is a time-lag effect in the impact of environmental regulations on FDI, and screening the quality of FDI through environmental regulations is conducive to promoting the development of urbanization. Therefore, China should strengthen the screening and supervision of FDI, raise the threshold for foreign investment, and introduce more clean foreign investment with high technology, low energy consumption, and low pollution, so as to realize the green, efficient, and sustainable development of China's urbanization.

From the results in Table 2, the control variable symbols are consistent with the expected symbols. The proportion of tertiary industry has a positive impact on the promotion of urbanization at a significant level of 1%, indicating that the development of the tertiary industry is conducive to the advancement of urbanization. This is mainly because the tertiary industry is mostly labor-intensive industries, which can create a large number of employment opportunities and accommodate a large number of surplus laborers transferred from the countryside, and the tertiary industry has less pressure on the resources and environment. In addition, the development of the digital information-based service industry is conducive to the improvement of the intelligent level of urban human settlements, and therefore is conducive to the promotion of the level of urbanization. Human capital has a positive impact on the promotion of urbanization at a significant level of 1%, indicating that the improvement of the human capital level is also conducive to the advancement of urbanization. Generally speaking, people with higher levels of education are more inclined to abandon the traditional rural lifestyle and relatively backward values, and pursue urban modern lifestyles and advanced ideological impact. At the same time, cities also provide corresponding resources and employment opportunities for people with higher education and higher skills, which in turn attracts those with higher education degrees to migrate to economic and social developed cities. The level of innovation all has a positive impact on the promotion of urbanization at a significant level of 1%. Innovation is the first driving force for development. The continuous improvement of the level of innovation is conducive to promoting the upgrading of the industrial structure, promoting the development of green industries, optimizing the allocation of urban space resources, and improving the efficiency of resource utilization. Therefore, the improvement of the level of innovation has expanded the potential space for urban development and guided the development of cities in a more informatized, digital, and intelligent direction. Thus, by providing more employment opportunities and optimizing the quality of life, a green, efficient, and sustainable urbanization process can be steadily advanced. The unemployment rate has a negative impact on the promotion of urbanization at a significant level of 1%, indicating that the increase in the level of unemployment will inhibit the progress of urbanization. This shows that the decline of the urban labor market is not conducive to the development of urbanization. Obviously, good job opportunities and high income levels are important factors in attracting the transfer of population from rural to urban areas. Therefore, an unstable job

market, accompanied by an increase in the unemployment rate, will inevitably inhibit the incentives for population progress.

The estimation results of the intermediary effect of circular economy

Table 3 reports the test results of the intermediary effect of circular economy, in which column (1) corresponds to the regression result of Formula (8), column (2) corresponds to the regression result of Formula (9), and column (3) corresponds to the regression result of Formula (10). It can be seen from the regression coefficient and the significance level that the coefficient of FDI is significantly negative in the regression result of Formula (8), and is also significant in the regression result of Formula (9), and the estimated coefficient of FDI in Formula (10) is (8) compared with some decline. Therefore, it can be concluded that circular economy has an intermediary effect in the process of FDI affecting urbanization. On the one hand, the introduction of FDI can have a direct effect on population urbanization by optimizing the employment structure, absorbing labor, and increasing wage levels. On the other hand, the introduction of FDI can affect the development of urbanization by influencing the development of circular economy. The development level of circular economy is measured by ecological efficiency. From the perspective of development quantity, eco-efficiency is the comparison between the expected and undesired output of economic development and the total input of the production process. FDI, by investing in the construction of factories in China, will inevitably affect the total resource consumption, total economic output, and total environmental pollution of the host country's production process. From the perspective of development efficiency, ecological efficiency includes environmental efficiency and resource efficiency. The introduction of foreign green and efficient advanced production technology and pollution control technology through FDI can promote the development of green economy in the host country. Therefore, this paper believes that FDI can increase the incentives for the population process, and then promote the process of urbanization, by directly expanding the capacity of the labor market, promoting the level of urban economic development, and improving the urban living environment.

Table 3 Regression results of mediating effect test

Variables	(1)	(2)	(3)
eco			3.477***
			(0.915)
fdi	−0.189*	0.024***	−0.272**
	(0.111)	(0.006)	(0.111)

******, , and represent the 10%, 5%, and 1% significance levels, respectively; the standard error is shown in (); due to space limitations, the parameter estimation results of other control variables are omitted

The estimation results of regional heterogeneity

China's economic development shows huge regional differences. It can be seen from Table 1 and Fig. 2 that the development level of circular economy in the eastern region differs greatly from other regions. In addition, considering that the eastern region is significantly more open to the outside world, and the eastern region accounts for a relatively large proportion of FDI, this paper divides China into eastern regions and other regions for regional heterogeneity analysis. Table 4 lists the regional heterogeneity analysis results of the impact of circular economy and FDI on urbanization. Columns (1) and (2) are the regression results of the eastern region, and columns (3)–(5) are other regions in China regression results. Columns (1), (3), and (4) are the regression results of the model without considering environmental regulations (Formula (3)), and columns (2) and (5) are the regression results of the model considering environmental regulations and their lag effects (Formula (4)). The Hausmann test result of the regression in the eastern region shows that the null hypothesis is rejected, so FE is more appropriate, while the Hausmann test result of the regression in other regions shows that the null hypothesis cannot be rejected, that is, RE is more appropriate. Due to space limitations, this paper only reports the FE regression results of the core explanatory variables in the eastern region and the RE regression results of the core explanatory variables in other regions.

The impact of circular economy on the advancement of urbanization has obvious regional differences. From the regression coefficients of the circular economy development level in columns (1)–(2) of Table 4, it can be seen that the regression results of the eastern region are basically consistent with the regression results of the national overall sample (Table 2). The development of the circular economy and the advancement of urbanization present a positive "N" nonlinear relationship at the level of 1%. Under the current development situation, with the development of a circular economy in the eastern region, green, efficient, and sustainable urbanization can finally be realized. However, according to the regression results in column (2) to calculate the inflection point value of the "*N*" curve, it is found that most provinces in the eastern region are in the second stage, and only Hainan exceeded the second inflection point (3.0542) and entered the third stage in 2011 and 2012. Different from the results of the whole country and the eastern region, there is an insignificant positive "*N*" relationship between the development of circular economy and urbanization in other regions (column (3) in Table 4). Therefore, this paper removes the three items of the level of circular economy development and returns to

Table 4 Results of the impact of circular economy and FDI on urbanization at the regional level

Variables	East region		Other regions		
	(1)	(2)	(3)	(4)	(5)
eco	84.545***	86.087***	35.364**	14.395**	5.772
	(22.396)	(24.724)	(16.900)	(7.012)	(6.460)
eco^2	−75.544***	−79.593***	−38.649*	−9.486**	−4.262
	(19.751)	(22.231)	(22.090)	(4.733)	(4.296)
eco^3	13.362***	14.297***	12.170		
	(3.805)	(4.213)	(9.040)		
fdi	−0.832***	−1.382**	−0.745***	−0.744***	−0.912***
	(0.193)	(0.615)	(0.101)	(0.101)	(0.229)
reg		−3.137*			0.602
		(1.748)			(0.426)
regfdi		−0.164			−0.0830
		(0.294)			(0.290)
reg1fdi		0.686**			0.287
		(0.286)			(0.287)
Hausman test	53.16***	51.77***	10.94	10.86	14.47

******, , and represent the 10%, 5%, and 1% significance levels, respectively; the standard error is shown in (); due to space limitations, the parameter estimation results of other control variables are omitted

column (4). Obviously, there is a significant inverted U-shaped curve between the development of a circular economy and the promotion of urbanization in other parts of China. This shows that under the current development situation, with the development of the circular economy, the level of urbanization in other areas of China has shown a trend of first rising and then falling. By calculating the turning point value, it can be seen that only Qinghai Province has passed the turning point value (1.318), and the overall level of urbanization in other provinces is still low. As mentioned above, China still has a long way to go to achieve green, efficient, and sustainable urbanization.

The impact of FDI on the promotion of urbanization also has obvious regional differences. From the regression results of the coefficients of environmental regulations and FDI in columns (1)–(2) of Table 4, it can be seen that FDI in the eastern region has a significant hindrance to the advancement of urbanization without considering environmental regulations. However, considering the environmental regulation and its time-lag effect, the interaction between the lag phase of environmental regulation and FDI can promote urbanization at a significant level of 5%. The eastern region attracts more foreign investment, and FDI accounts for a larger proportion. The FDI introduction structure can be optimized by strengthening the screening and supervision of FDI. On the one hand, expanding the inflow of cleaner production FDI can give full play to the "pollution halo" effect of FDI to offset the negative impact of the "pollution refuge" effect on the social economy of Chinese cities. On the other hand, expanding the inflow of FDI in digital information services can optimize the urban employment structure, raise wages, improve the living environment, and ultimately promote the green, efficient, and sustainable development of urbanization in the eastern region. From the regression results of the coefficients of environmental regulations and FDI in columns (4)–(5) of Table 4, it can be seen that FDI in other regions of China also has a significant hindering effect on the advancement of urbanization, but the interaction between the lag phase of environmental regulation and FDI has an insignificant role in promoting urbanization considering environmental regulation and its time-lag effect. This may be because, on the one hand, China's FDI is mainly concentrated in the eastern coastal areas, while the central and western regions account for a relatively small proportion of FDI, so the regression results are not statistically significant; on the other hand, the supervision of FDI in other regions of China is still not in place, resulting in the insignificant effect of FDI on the promotion of urbanization under the constraints of environmental regulations. This shows that China should fully consider the regional differences in China's economic development when introducing FDI, and introduce FDI in a targeted manner based on the level and mode of local economic development, so as to give full play to the positive externalities of FDI to local economic and social development.

Conclusions and policy implications

Based on the original data of 30 provinces in China from 2004 to 2016, this paper constructs input-output indicators, and uses

the super-efficiency SBM model that considers undesired output to measure the eco-efficiency of 30 provinces to measure the level of circular economy development in each province, and build a panel measurement model based on this to test the impact of circular economy and FDI on urbanization. The empirical results show that (1) between 2004 and 2016, there were large regional differences in the development level of China's circular economy. The development level of the circular economy in the country as a whole and in the eastern region showed a trend of rising first and then falling. The development level of the eastern region is obviously higher than the national average level, while the development of the central and western regions is relatively backward and shows a trend of decline in fluctuation. (2) The development of China's circular economy and the advancement of urbanization present a complex non-linear relationship, and there are regional differences. There is a positive "*N*"-shaped relationship between the country as a whole and the development of circular economy and urbanization in the eastern region, while the relationship between circular economy development and urbanization in the central and western regions is in an inverted "*U*" shape. (3) On the one hand, FDI directly affects the advancement of urbanization in China; on the other hand, it can have an indirect effect on the advancement of urbanization by affecting the level of circular economy development. FDI has a restraining effect on the advancement of urbanization without considering environmental regulations, while FDI can promote the advancement of urbanization under the influence of environmental regulations and their time-lag effects. (4) The development of the tertiary industry, the accumulation of human capital, the improvement of innovation capabilities, and a stable employment environment are all conducive to the continuous advancement of urbanization.

Based on the above conclusions, in order to realize the coordinated development of China's economy, society, and ecology, and realize the green and efficient sustainable development of China's urbanization, this paper proposes corresponding policy recommendations: (1) constructing a cultural environment for circular economy, forming a trend for the whole society to pursue circular economy, so as to promote the development of green cities. The Chinese government should incorporate economic development, environmental pollution, and resource consumption indicators into the evaluation system of governments at all levels, and adhere to the "3R" principles of reduction, reuse, and recycle for daily life and produce. In terms of production, the government can encourage companies to research and develop or introduce clean technologies for production, and rectify and remediate companies with serious pollution through improving and refining laws and regulations on resource consumption and environmental pollution, taxation systems, and reward and punishment systems. In terms of life, the government and social welfare organizations can cultivate residents' awareness of protecting the environment, saving resources, and developing a circular economy through media campaigns, community popularization, and school education. In addition, the construction of public transportation infrastructure should be improved, and green public transportation should be encouraged. (1) Purifying FDI inflows and optimizing the FDI structure to promote the development of efficient cities by strengthening the screening and supervision of FDI inflows. On the one hand, a variety of environmental regulatory measures, such as resource taxes, pollution fees, carbon emissions trading, and environmental information disclosure, should be combined to screen FDI inflows. The introduction of clean and efficient foreign investment should be encouraged, and the introduction of pollution-consuming foreign investment should be reduced. On the other hand, the introduction of FDI should not blindly follow the trend. Local governments at all levels should combine the local economic development level and industrial structure characteristics to introduce targeted and selective FDI that can drive the development of local industries. (3) Optimize the industrial structure to promote the development of smart cities by giving play to the powerful driving force of innovation. Combining emerging technologies such as big data and artificial intelligence to build a "politics-industry-academy-research" integrated innovation achievement conversion platform can fully stimulate the positive externalities of human capital and drive enterprise innovation and production. Eventually, it can promote the development of the information service-oriented tertiary industry and improve the construction of digital infrastructure, so that the urban human settlement environment can develop towards intelligence and convenience. (4) Through strengthening regional exchanges, the overall level of urbanization in China can be improved. On the one hand, the promotion of urbanization should be combined with regional characteristics. There are significant regional differences between eastern China and other regions in terms of economic and social development level, industrial structure, and social structure. The advancement of urbanization is not something that can be achieved overnight. It should be carried out slowly on the basis of a national overall plan in light of the local conditions. On the other hand, the links between regions should be strengthened. First, we should give full play to the role of driving radiation in the eastern region. Promote the development of the central and western regions through innovative technology spillovers, excellent talent exchanges, and high-tech industry transfers in the eastern region. Second, we must also attach importance to the self-development of the central and western regions. Improve the ability of the central and western regions to absorb and transform the spillover effects of the eastern region through the foundation of unique industries and natural resources.

The limitations of this paper are mainly reflected in the following two aspects: (1) limitations of the definition of

urbanization. This paper focuses on the factors influencing China's urbanization progress from the perspective of population process incentives. In fact, population is only an important manifestation of urbanization, and it is inevitable that there are some limitations to measuring the level of urbanization by population alone. However, due to the difficulty of obtaining measurement indicators and data, this paper did not consider it, and scholars are waiting for follow-up research. (2) Limitations in the selection of environmental regulations. This paper only considers one type of environmental regulation of government investment in environmental protection. In fact, in addition to formal environmental regulations at the government level, informal environmental regulations such as social-environmental awareness are also types of environmental regulations. However, due to the strong subjectivity of informal environmental regulations, measurement indicators are difficult to determine. Therefore, it is not considered in this paper, and scholars are waiting for follow-up research.

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Compliance with ethical standards

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References

Antweiler W, Copeland BR, Taylor MS (2001) Is free trade good for the environment? Am Econ Rev (4):877–908

Chen HM (2018) Foreign trade, foreign direct investment and urbanization—analysis based on the spatial panel dubin method. J Int Trade 10:147–161

Cheng JH, Sun Q, Guo MJ, Xu WX (2014) Research on regional differences and dynamic evolution of eco-efficiency in China. China Popul Resour Environ 24(1):47–54

Clark D (1998) Interdependent urbanization in an urban world: an historical overview. Geogr J 164(1):85

Daniel BL, Korhan KG, Nigar T, José María CC (2019) An approach to the pollution haven and pollution halo hypotheses in MINT countries. Environ Sci Pollut Res 26:23010–23026

Du YY, Sun TS, Peng J, Fang K, Liu YX, Yang Y, Wang YL (2018) Direct and spillover effects of urbanization on PM2.5 concentrations in China's top three urban agglomerations. J Clean Prod 190(7):72–83

Duncan B, Vernon H (1999) The theory of urban growth. J Polit Econ 107(2):252–284

Guo HY, Han LY (2008) Foreign direct investment, environmental regulation and environmental pollution. J Int Trade 8:111–118

Hare D (1999) "Push" versus "pull" factors in migration outflows and returns: determinants of migration status and spell duration among China's rural population. J Dev Stud 35(3):45–72

Jian XH, Huang K (2010) Empirical analysis and prospect forecast of China's urbanization level and speed. Econ Res 3:28–39

Jin B (2015) Research on the new normal of China's economic development. China Ind Econ 1:5–18

Li JK, Cheng LY, Zhang TB (2017) Does foreign direct investment have a "polluting halo" effect? China Popul Resour Environ 27(10):74–83

Liu RM, Shi L (2015) The ownership basis of China's urbanization delay: theory and empirical evidence. Econ Res 4:107–121

Ma XX (2014) Analysis of the key influencing factors and effects of China's urbanization. China Popul Resour Environ 24(12):117–124

OECD (1998) Eco-efficiency Pairs, pp7–11

Rafael EP, Wei L, Tridib B (2003) Agencies of globalization and third world urban form: a review. J Plan Lit 18:111–130

Ren M, Wang XM, Liu ZM, Liu L, Zhang WX (2019) Analysis of spatio-temporal changes and influencing factors of regional eco-efficiency in China. East China Econ Manag 33(9):71–79

Schaltegger S, Sturm A (1990) Ökologische rationalit t: ansatzpunktezur ausgestaltung von ökologieorientierten management instrumentent. Die unternehmung 44(4): 273–290

Shi BB, Feng C, Kang R (2019) Environmental information disclosure and optimization of foreign direct investment structure. China Ind Econ 4:98–116

Wang LY, Yang F (2014) Innovation-driven development strategy and China's future urbanization. China Popul Resour Environ 24(9): 163–169

Wen ZL, Zhang L, Hou JT, Liu HY (2004) Intermediary effect test procedure and its application. Acta Psychol Sin 5:614–620

Xing ZC, Wang JG, Zhang J (2018) Research on China's regional total factor eco-efficiency and its influencing factors. China Popul Resour Environ 28(7):119–126

Xu HL, Deng YP (2012) Has foreign direct investment caused the country's environmental pollution?—spatial measurement research based on China's provincial panel data. Manag World 2:30–43

Xu HF, Wang XD (2020) Does modern service industry help promote urbanization?—analysis of PVAR model based on the perspective of industry-city integration. Chin J. Manag Sci 28(4):195–206

Yang L, Zhang X (2018) Assessing regional eco-efficiency from the perspective of resource, environmental and economic performance in China: a bootstrapping approach in global data envelopment analysis. J Clean Prod 173(1):100–111

Ye WH, Gan H (2009) Current status and prospects of circular economy research. China Popul Resour Environ 19(3):102–106

Zhao PJ, Zhang MZ (2018) The impact of urbanisation on energy consumption: a 30-year review in China. Urban Clim 24(6):940–953

Zhu DJ, Qiu SF (2006) Ecological efficiency is a suitable measure of circular economy. China Popul Resour Environ 16(5):1–6