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Original Research

The Impact of Economic Agglomeration on Green Total Factor Productivity: An Empirical Analysis from China's Yellow River Basin

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Abstract

The process of pursuing high-quality economic development involves many moving parts, and economic agglomeration (EA) is an essential element that can significantly affect green total factor productivity (GTFP). This study uses SBM and GML models to calculate GTFP of 99 cities in the Yellow River Basin from 2004 to 2017. Then, based on the panel data of these cities, the SYS-GMM and the mediating effect model are used to empirically test the influence and action path of EA on GTFP. The conclusions are as follows: There is an evident inverted U-shaped link between EA and GTFP in the YRB. The development level of the upper and middle reaches of the YRB is lower than the “ agglomeration inflection point ” (CNY 1.231 billion/KM^2), while the downstream region has crossed this inflection point and has a crowding effect. In addition, EA affects GTFP through labor pool, intermediate input sharing and knowledge technology spillover. This study concludes that, in order to boost GTFP in the YRB, diversified strategies based on regional development are required to avoid the crowding impact.

Keywords: green total factor productivity, economic agglomeration, mediating effect, Yellow River Basin

Introduction

After the financial crisis, countries around the world are facing the dual test of economic recession and environmental deterioration. Therefore, how to alleviate the relationship between economic development, energy consumption and resource utilization has become the focus of governments and international organizations to consider. In October 2008, the United Nations Environment Programme (UNEP) launched the Green Economy Initiative to promote investment and policy support by Governments for the Green Economy [1]. The Organisation for Economic Cooperation and Development (OECD) proposed a ‘green development strategy’ in 2009, claiming that green development entails ensuring that natural resources continue to produce resources and environmental services that are beneficial to national prosperity while also implementing actions that promote economic growth and development [2]. China is simultaneously aggressively pursuing

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the coordinated development of its resources, ecology, and economy. In the 14th Five-Year Plan, it is proposed to accelerate the green transformation of development mode, adhere to ecological priority and green development, promote the total amount of resources management, scientific allocation, comprehensive conservation and recycling, and jointly boost economic growth and high standards of environmental protection. Thus, green development has become the world's economic development process needs to achieve the core goal. In this context, green total factor productivity (GTFP) which may represent economic progress and the natural environment, deserves special attention. Some scholars put resources and environmental factors into the analysis framework of total factor productivity, and then put forward the concept of GTFP [3]. Many sources have confirmed from theoretical analysis and practice that improving GTFP is helpful to solve resource supply crisis and environmental pollution, and is the fundamental way to achieve green economic transformation and sustainable development [4].

Another typical fact that accompanies economic development is the rapid advancement of urbanization. As the number and size of cities continue to grow, the relationship between economic agglomeration (EA), economic growth, and environmental pollution has attracted widespread attention from scholars [5]. On the one hand, EA can exert its promoting effect to gradually transform and upgrade economic development to an environment-friendly and resource-friendly green development model [6]. On the other hand, with the increase of agglomeration degree, the congestion effect brought by EA has exerted certain pressure on green development [7]. Thus, EA may be one of the important ways to improve GFTP. Therefore, it is of vital importance to determine the influencing mechanism between EA and GTFP and study the characteristics of this influencing process for the realization of urban sustainable development.

As an important regional economic plate and densely populated area in China, the Yellow River Basin (YRB) is a vital energy chemistry base and food production base, and has a prominent position in China's economic growth pattern. On the one hand, most provinces in the YRB belong to the underdeveloped areas in the central and western regions, and the industrial level is relatively low, especially the development of technology-intensive manufacturing and modern producer services is weak, and the degree of EA is low [8, 9]. On the other hand, the industrial structure dominated by energy and chemical industry and the excessive scale of energy development have caused the low GTFP in the YRB [10]. In 2019, ecological conservation and high-quality development in the YRB became an important national policy. Therefore, exploring the impact of EA on green development in the YRB is conducive to deepening the understanding of the relationship between EA, economic growth and environmental pollution in the YRB, better formulating development plans, achieving energy conservation and emission reduction goals, and providing theoretical basis and policy basis for regional ecological protection and high-quality development.

This paper focuses on three questions: What are the current situation and trends of EA and GTFP in the YRB ? What is the mechanism of EA affecting GTFP? How to improve GTFP through EA?

To address these issues, this paper first evaluates EA and GTFP of 99 cities in the YRB from 2004 to 2017; secondly, the relationship between EA and GTFP is tested theoretically and empirically. Finally, the action path of EA on GTFP is verified, which provides decision basis for industrial agglomeration and sustainable development strategy in the YRB. Finally, the effect path of EA on GTFP is verified, which provides decision-making basis for industrial agglomeration and sustainable development strategy in the YRB.

Specifically, the marginal contribution of this paper is reflected in the following three aspects: Firstly, energy factor and GTFP are added to the production function, and the impact of EA on GTFP is deduced mathematically. Secondly, CO2 is included in the undesirable output, and the index system of GTFP is constructed from capital, labor, energy input, expected output and undesirable output, and the GTFP of the YRB is systematically calculated. Compared with previous studies, the index is more comprehensive. Finally, this paper makes a quantitative analysis of the EA effect from the three aspects of labor pool effect, intermediate goods sharing effect and knowledge spillover effect. Additionally, this study uses the system GMM method to control the time lag effect of GTFP in order to address the endogenous issue brought on by the potential two-way causal relationship between EA and GTFP. This study's results provide the foundation and potential implementation strategies for the advancement of GTFP research in the future.

Literature Review

Research on Green Total Factor Productivity

Green total factor productivity (GTFP) has become an important indicator for balancing energy consumption, economic development and environmental protection [11]. At the moment, the index system, evaluation procedures, and influencing factors are the key areas of GTFP study.

Numerous academics have broadened the definition of "green development" to encompass economic growth, the preservation of natural resources, environmental protection, and human well-being, as well as the establishment of a multi-index comprehensive assessment system [12, 13]. The analysis framework of total factor productivity has also been attempted by some academics to take resource and environmental issues into account [14]. It is important to note that while calculating GTFP, the majority of scholars only consider the traditional industrial "three wastes" (wastewater, waste gas, and waste), failing to account for carbon dioxide emissions when determining undesirable outputs. However, a key component of the idea of "green development" is the conservation of energy, the reduction of emissions, and the safeguarding of low-carbon environments. Carbon dioxide emissions must therefore be considered an undesirable output in the input-output system for calculating the level of green development.

The evaluation methods mainly include Malmquist-Luenberger (ML) index evaluation [15], instrumental variable estimation [16], life cycle analysis (LCA) etc. [17]. According to Chung's proposed Activity Analysis Model (AAM) for environmental regulation behavior, which is based on the Directional Distance Function (DDF), pollutants are seen as undesirable outputs with negative externalities, and the expected outputs are simultaneously added to the production process. The limitations of environmental factors in the production process are finally adequately accounted for in technique. The factors impacting GTFP then differ depending on research topics and methodologies, and it is important to note that this method is extensively used [18]. In general, GTFP in various locations and industries is influenced by technical level [19], industrial structure [14], environmental regulation [20], openness [21], and urbanization [22].

Research on Economic Agglomeration

The process of national spatial reorganization goes hand in hand with the growth and improvement of industry. The evolving EA has emerged as a key element of the dynamics of the national industrial landscape [23]. Numerous studies have demonstrated that EA has advantages that cannot be disregarded, including lower costs of living and production for people and businesses [24], increased information transmission efficiency [25], promotion of R&D innovation activities [25], improved energy consumption structures while increasing productivity [26], decreased intensity of pollutant emissions [20], and support for urban green development. The calculating method, study angle, and influencing factors are currently the key areas of interest for EA research. Data envelopment analysis (DEA) [19], spatial analysis [27], gravity model [28], distance analysis, and hybrid method [29] are the main approaches used for EA calculations.

Scholars also examine EA's exterior implications from a variety of perspectives. EA can, from a regional standpoint, increase economic growth and lessen the intensity of local carbon emissions [24]. Digital EA can foster economic growth to result in a non-spatial carbon emission reduction effect from an industrial standpoint [30].

Relationship between EA and GTFP

EA and GTFP also demonstrated three distinct potential correlations in other studies. First, EA may actively support the expansion of GTFP. Through the three mechanisms of sharing, matching, and learning, externalities of EA have an impact on green economic efficiency [31]. Urban green development may be fueled by the innovation impact, agglomeration effect, and reaction force effect [32]. Second, EA and GTFP are not correlated positively. Growing larger results in pollution, traffic jams, increased land prices, etc. [33]. The positive externalities of agglomeration are somewhat offset by the congestion effect [34]. Third, EA has a non-linear effect on GTFP, meaning it first manifests its advantageous externalities in the early stages of the sector's development. The negative externality of EA starts to limit the growth of GTFP once it reaches a certain level [35].

The majority of the studies, however, ignored how EA affected GTFP. Since the agglomeration advantage of the city creates the labor pool impact, intermediate good sharing effect, and knowledge spillover effect, we attempt to quantitatively investigate the relationship between EA and GTFP from these three perspectives.

Materials and Methods

Theoretical Analysis

EA and GTFP

EA can lower the cost of living and production for people and businesses, increase the effectiveness of information transmission, and encourage businesses to engage in R&D and innovation activities. While increasing corporate productivity, it can also change how businesses use energy, lessen the intensity of pollutant emissions, and encourage cities to increase their gross domestic product (GDP). The excessive concentration of production components would, however, drive up the city's transportation and renting costs as well as its energy use and environmental impact. Additionally, unhealthy competition between businesses will result from an excessive concentration of producers, and the adverse effects of agglomeration will manifest. It will prevent the city from developing sustainably. Additionally, excessive agglomeration will fuel fierce business rivalry. Businesses will use low-price competition as a tactic to capture the market, but doing so will significantly reduce their margins, force them to invest less in product innovation research and development, which lowers their chances of successful research and development, and put them in the position of being unable to diversify. In addition to hindering the advancement of businesses' technology for treating pollution, the development of new products, new knowledge, and new technology also adds to the environmental burden brought on by business operations. This leads this paper to suggest the following hypothesis:

H1: EA and GTFP have a nonlinear relationship, and there is a certain threshold between them.

The Mechanism via which EA Affects GTFP

The positive externalities of EA can be summarized into three aspects: labor pool, intermediate input sharing and knowledge and technology spillovers [36].

First, from the standpoint of the labor force, EA contributes to the development of a labor market with a largely steady labor supply. It is possible to increase the effectiveness of matching between manufacturers and labor as well as the effectiveness of manufacturers and labor in the labor market by lowering the information asymmetry in the labor market. the capacity to withstand shocks from the outside world, increasing manufacturers' production efficiency and decreasing their manufacturing costs. Manufacturers can alter their demand for labor in response to variations in the demand for their own products thanks to the enormous labor market, which can also offer a diverse labor reserve [37] . On the basis of this, this study suggests the following hypothesis:

H2a: EA affects GTFP through labour pool effects.

From the standpoint of intermediate input sharing, on the one hand, the agglomeration between various industries may cause the wastes or byproducts produced by one enterprise to become the intermediate inputs needed by another enterprise, increasing the overall resource utilization efficiency and decreasing the enterprise's availability. Agglomeration amongst industries, on the other hand, can also give rise to specialized producer services, allowing manufacturers to outsource pollution control work to specialist businesses to increase their energy usage efficiency and level of pollutant control to attain green production. The combination of numerous producers of final goods also raises the demand for intermediate goods, creates the circumstances for those suppliers to benefit from economies of scale, and lowers the cost of production for those suppliers. The variety of intermediate products that final product manufacturers can select and employ can be expanded as a result of economies of scale among intermediate product producers, increasing the final product manufacturers' production efficiency. On the basis of this, this study suggests the following hypothesis:

H2b: EA affects GTFP through intermediate input sharing effects.

The migration of numerous talents from various knowledge backgrounds to metropolitan regions serves as a requirement for knowledge sharing from the perspective of knowledge and technology spillovers. The production and commercial innovation of manufacturers have been strongly supported by knowledge spillovers within the municipal borders. Technology and information transfer between businesses and industries decreases innovation risks, accelerates business technological innovation cycles, and boosts business production efficiency. Sharing environmental protection expertise, pollution control know-how, and pollution treatment technology across industries and businesses can also help to spur the development of new eco-friendly production techniques, boost businesses' energy efficiency, and raise the technical bar for pollutant removal. On the basis of this, this paper proposes:

H2c: EA affects GTFP through knowledge and technology spillovers.

Model Elaboration

The following model is built from the output density models of Ciccone & Hall [38] and Ciccone [39] by factoring energy consumption into the production function:

If we assume that the non-agricultural output in a region with land area S in a country C is q, then its production function can be written as:

$$q = f(l, k, e, Q_{SC}, A_{SC}, \Omega_{SC}) \tag{1}$$

Among these, l stands for the number of workers employed per unit of land area, k for capital input, and e for the amount of energy used in economic output per unit of land area, and e or the amount of energy used in economic output per unit of land area. The GTFP, which is the subject of this study, is represented by Ω_{SC} which also stands for capital, economic output of labor, energy, "good" output, and "bad" output. Q_{SC} stands for non–agricultural production, and A_{SC} stands for the region's total land area.

For the convenience of empirical research, the production function is written in the functional form of Cobb Douglas:

$$q = f(l, k, e, Q_{SC}, A_{SC}, \Omega_{SC}) = \Omega_{SC}\left(l^{\beta} k^{\gamma} e^{1-\beta-\gamma}\right)^{\alpha} \left(\frac{Q_{SC}}{A_{SC}}\right)^{\frac{\lambda-1}{\lambda}} \tag{2}$$

Among these, α indicates the share of output per unit area of labor, capital, and energy ($0<\alpha\leq1$); β represents the contribution rate of output per unit area of labor input relative to capital input ($0<\beta<1$); γ represents the contribution rate of capital input to output per unit area ($0<\beta + \gamma<1$); λ is the output density coefficient ($\lambda>1$).

The region's overall output can be expressed as follows, assuming that labor, capital, and energy are spread equally across the land area:

$$Q_{SC} = qA_{SC} = \Omega_{SC}\left(l^{\beta} k^{\gamma} e^{1-\beta-\gamma}\right)^{\alpha} \left(\frac{Q_{SC}}{A_{SC}}\right)^{\frac{\lambda-1}{\lambda}} A_{SC} \tag{3}$$

Correspondingly, the output density is expressed as:

$$\frac{Q_{SC}}{A_{SC}} = \Omega_{SC}\left(l^{\beta}k^{\gamma}e^{1-\beta-\gamma}\right)^{\alpha}\left(\frac{Q_{SC}}{A_{SC}}\right)^{\frac{\lambda-1}{\lambda}} \tag{4}$$

The marginal output of each factor of production in equilibrium is equal to its price, so assuming that capital can move freely between areas, we can obtain:

$$k_{SC} = \frac{K_{SC}}{A_{SC}} = \frac{\alpha\gamma}{r_C} \times \left(\frac{Q_{SC}}{A_{SC}}\right) \tag{5}$$

$$e_{SC} = \frac{E_{SC}}{A_{SC}} = \frac{\alpha(1-\beta-\gamma)}{P_C} \times \left(\frac{Q_{SC}}{A_{SC}}\right) \tag{6}$$

Among these, r_C and P_C indicate the cost of capital and energy, respectively. Replace (4) with (5) and (6) to obtain:

$$\left(\frac{Q_{SC}}{A_{SC}}\right)^{\frac{1-\alpha(1-\beta)\lambda}{\lambda}} = \Omega_{SC}\left(\frac{Q_{SC}}{N_{SC}}\right)^{\alpha\beta}\left(\frac{\alpha\gamma}{r_C}\right)^{\alpha\gamma}\left[\frac{\alpha(1-\beta-\gamma)}{P_C}\right]^{\alpha(1-\beta-\gamma)} \tag{7}$$

Therefore, the GTFP can be obtained as:

$$\Omega_{SC} = \Lambda\left(\frac{Q_{SC}}{A_{SC}}\right)^{\frac{1-\alpha(1-\beta)\lambda}{\lambda}}\left(\frac{Q_{SC}}{N_{SC}}\right)^{-\alpha\beta} \tag{8}$$

Among these, $\boldsymbol{\Lambda} = \left[\left(\frac{\alpha\gamma}{r_C}\right)^{\alpha\gamma}\left[\frac{\alpha(1-\beta-\gamma)}{P_C}\right]^{\alpha(1-\beta-\gamma)}\right]^{-1}$, is a constant term, taking the logarithm of both sides to get:

$$ln\Omega_{SC} = ln\Lambda + \frac{1-\alpha(1-\beta)\lambda}{\lambda}\ln\left(\frac{Q_{SC}}{A_{SC}}\right) - \alpha\beta ln\frac{Q_{SC}}{N_{SC}} \tag{9}$$

Among these, Ω_{SC} is the explanatory factor that this research concentrates on, GTFP; $\frac{Q_{SC}}{A_{SC}}$ is AGG, measured in terms of non-agricultural output per kilogram of land (CNY 100 million /KM^2); $\frac{Q_{SC}}{N_{SC}}$ is the productivity of labor, expressed in terms of non-agricultural output per unit of labor (CNY 100 million/10,000 people).

The improvement of EA is correlated with the improvement of the level of green development, according to formula (9), when $1 < \lambda < \frac{1}{\alpha(1-\beta)}$ the positive externality of EA is still quite important at this point, but when $\lambda > \frac{1}{\alpha(1-\beta)}$, the negative externality of EA starts to show, and the improvement of EA prevents cities from developing sustainably, indicating that the relationship between EA and GTFP is non-linear. The quadratic term for EA is added to the model, taking into account the nonlinear link between EA and GTFP, and an econometric model is generated, as illustrated in Equation (10):

$$\ln(GTFP)_{it} = \alpha_0 + \alpha_1\ln(agg)_{it} + \alpha_2\ln(\text{agg})^2{}_{it} + \alpha_3\ln(labor)_{it} + \alpha_4 X_{it} + \varepsilon_{it} \tag{10}$$

Among these, i represents a component of a municipal section. (city), t represents time (year), $\ln(GTFP)_{it}$ is the logarithm of the city's GTFP, $\ln(agg)_{it}$ is the logarithm of EA, $\ln(labor)_{it}$ is the logarithm of labor productivity, x_{it} represents a series of related control variables, ε_{it} is a random error term.

Study Area

Nine provinces in the YRB are the subject of this paper's investigation. With a total of 99 cities, the top reaches are made up of Sichuan, Qinghai, Gansu, Ningxia, and Inner Mongolia, the middle reaches are made up of Shanxi and Shaanxi, and the lowest reaches are made up of Henan and Shandong (Table 1). [1]

Measurement of Variables

Explained Variable:GTFP

To determine total factor productivity, some researchers employ the Malmquist-Luenberger (ML) index approach based on data envelopment analysis (DEA) [39]. Given that the typical radial DEA efficiency measure will overstate the efficiency value of the research object when there is too much input or not enough output, or when there is a non-zero slack (Slack) of input or output. To address this issue, this article makes use of Tone By including non-radial and non-angular slack variables, the super-efficient SBM model put out by [40, 41] successfully resolves the issue of proportionate growth and decrease of input and output in the conventional DEA model. Assume that each city inside the YRB functions as a DMUj (j = 1, 2,..., n). I input vectors, S expected output vectors, and Q unwanted output vectors are all present in each decision-making unit. On the basis of undesirable outputs, the kth decision-making unit's super-efficient SBM model is built as.

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[1] The areas excluded are Haidong City, Haibei Tibetan Autonomous Prefecture, Huangnan Tibetan Autonomous Prefecture, Hainan Tibetan Autonomous Prefecture, Guoluo Tibetan Autonomous Prefecture, Yushu Tibetan Autonomous Prefecture, Haixi Mongolia Tibetan Autonomous Prefecture, Linxia Hui Autonomous Prefecture, Gannan Tibetan Autonomous Prefecture, and Liangshan Yi Autonomous Prefecture due to missing.

Table 1. Study area and division of the YRB.

Region	Province	City
Upper reaches	Qinghai, Gansu, Ningxia, Inner Mongolia	Xining, Lanzhou, Jiayuguan, Jinchang, Baiyin, Tianshui, Wuwei, Zhangye, Pingliang, Jiuquan, Qingyang, Dingxi, Longnan, Yinchuan, Shizuishan, Wuzhong, Guyuan, Zhongwei, Hohhot, Baotou, Wuhai, Ordos, Bayannur, Ulanqab
Middle reaches	Shanxi, Shaanxi, Sichuan	Xi'an, Tongchuan, Baoji, Xianyang, Weinan, Yan'an, Hanzhong, Yulin, Ankang, Shangluo, Taiyuan, Datong, Yangquan, Changzhi, Jincheng, Shuozhou, Jinzhong, Yuncheng, Xinzhou, Linfen, Lvliang, Chengdu, Zigong, Panzhihua, Luzhou, Deyang, Mianyang, Guangyuan, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guang'an, Dazhou, Ya'an, Bazhong City, Ziyang City
Lower reaches	Henan, Shandong	Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Sanmenxia, Nanyang, Shangqiu, Xinyang, Zhoukou, Zhumadian, Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Weifang, Jining, Tai'an, Weihai, Rizhao, Laiwu, Linyi, Dezhou, Liaocheng, Binzhou, Heze

efficiency measure will overstate the efficiency value of the research object when there is too much input or not enough output, or when there is a non-zero slack (Slack) of input or output. To address this issue, this article makes use of Tone By including non-radial and non-angular slack variable [40], the suggested super-efficiency SBM model successfully resolves the issue of proportionate growth and reduction of input and output in the conventional DEA model. Assume that each city inside the YRB functions as a DMUj (j = 1, 2,..., n). I input vectors, S expected output vectors, and Q unwanted output vectors are all present in each decision-making unit. On the basis of undesirable outputs, the kth decision-making unit's super-efficient SBM model is built as

$$\rho = \min_{\lambda,\bar{x},\bar{y}^d,\bar{y}^u} \frac{\frac{1}{m}\sum_{i=1}^{m}\left(\frac{\bar{x}}{x_{ik}}\right)}{\frac{1}{r_1+r_2}\left(\frac{\sum_{s=1}^{r_1}\overline{y^d}}{y_{sk}^d}+\frac{\sum_{q=1}^{r_2}\overline{y^u}}{y_{qk}^u}\right)} \quad (11)$$

$$st.\begin{cases} \bar{x} \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j;\ \overline{y^d} \leq \sum_{j=1,\neq k}^{n} y_{sj}^d\lambda_j;\ \overline{y^d} \geq \sum_{j=1,\neq k}^{n} y_{qj}^d\lambda_j; \\ \bar{x} \geq x_k;\ \overline{y^d} \leq y_k^d;\ \lambda_j \geq 0;\ i = 1,2\cdots m; \\ j = 1,2,\cdots n;\ s = 1,2,\cdots r_1;\ q = 1,2,\cdots,r_2 \end{cases} \quad (12)$$

In the formula, among the n DMUs, each corresponds to input m, expected output r_1 and undesired output r_2; x, y^d, y^u are elements in the matrix corresponding to input, expected output and undesired output; ρ is green economic efficiency.

This paper establishes the input-output indicators as follows, based on the current literature [42, 43], 1) Input indicators, construct input indicators from three elements of capital, labor, and energy, and use capital stock, respectively. (CNY 100 million), the total number of employees in the society at the end of the year (10,000 employees), and the total amount of power used by the society (10,000 kilowatt-hours). One of them uses the perpetual archiving method to calculate capital stock data, and the base period capital stock is set at the local level in 2000. According to the asset investment amount, the depreciation rate was 10.96%. 2) Output indicators include both expected and undesired output. Expected output is calculated using the city's actual gross domestic product (CNY 100 million), deflated using 2000 as the base period; undesired output is calculated using industrial SO_2 emissions (10,000 tons), industrial wastewater discharge (10,000 tons), industrial smoke and dust emissions (10,000 tons), and CO_2 emissions (10,000 tons). Except for the CO_2 emissions, which were taken from the China Carbon Accounting Database (CEAD) (https://www.ceads.net/data/county/) [49], all of the aforementioned data come from the China Urban Statistical Yearbook for the years 2003 to 2017.

When measuring the intertemporal distance function, the classic Malmquist-Luenberger (ML) productivity index has the issue that it cannot solve linear programming [44]. This issue is successfully avoided by the Global Malmquist-Luenberger (GML) index. The GML index can simultaneously take into account actual production and historical production by using the total of all eras as a reference set. The advantage of being comparable over time is that the relative relationship between the production frontier (change in efficiency) and the change in the bounds of the production frontier for each unit. This work creates a non-angular, non-radial GML index based on the super-efficiency SBM efficiency assessment paradigm. The formula is:

$$GML_0^{T,T+1} = \frac{\rho_0^{T+1}\left(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1}\right)}{\rho_0^{T}\left(x_0^{T}, y_0^{d,T}, y_0^{u,T}\right)} \times \left[\frac{\rho_0^{d}\left(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1}\right)}{\rho_0^{T+1}\left(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1}\right)} \times \frac{\rho_0^{T}\left(x_0^{T}, y_0^{d,T}, y_0^{u,T}\right)}{\rho_0^{d}\left(x_0^{T}, y_0^{d,T}, y_0^{u,T}\right)}\right] \quad (13)$$

where: $GML_0^{T,T+1}$ Measure the change of city GTFP from T to T+1 period. $\rho_0^T(x_0^T, y_0^{d,T}, y_0^{u,T})$, $\rho_0^{T+1}(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1})$, represent the green economic efficiency value of the city in T and T+1 periods, respectively; $\rho_0^d(x_0^T, y_0^{d,T}, y_0^{u,T})$ is based on the overall production technology of each period and the efficiency value of input and output in period T; $\rho_0^d(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1})$ is based on the overall production technology of each period and the efficiency value of input and output in the T+1 period. $\frac{\rho_0^d(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1})}{\rho_0^{T+1}(x_0^{T+1}, y_0^{d,T+1}, y_0^{u,T+1})}$ reflects the proximity of frontier T+1 to the global frontier, $\frac{\rho_0^T(x_0^T, y_0^{d,T}, y_0^{u,T})}{\rho_0^d(x_0^T, y_0^{d,T}, y_0^{u,T})}$ reflects the proximity of frontier T to the global frontier. If $GML_0^{T,T+1} = 1$, it means that GTFP does not change from T to T+1 period, if $GML_0^{T,T+1}<1$, it means that GTFP regresses, if $GML_0^{T,T+1}>1$, indicating that GTFP increased. Since the GML index reflects the growth rate of GTFP in the period from T to T+1 rather than the GTFP itself, this paper assumes that the GTFP in 2003 is 1, and then multiplies the calculated GML index to obtain the 2004-2017 YRB at various levels City's GTFP.

Core Explanatory Variable: EA

While output density (carrying capacity per unit area) is regarded as a good indicator for measuring EA at the regional level [45], other commonly used indicators to characterize EA include the spatial Gini coefficient, Herfindahl index, Theil index, etc. These indicators ignore the spatial bias caused by relatively small differences in geographical units. In order to determine the level of EA in a particular location, this study uses the output density, and the precise calculation method is presented in formula (14):

$$Agg_c = \frac{Non - farm\ output_c}{S_c} \tag{14}$$

Among them, Agg_c is the EA degree of a city c in the YRB (CNY 100 million /KM^2); $Non - farm\ output_c$ s expressed by the added value of secondary and tertiary industries; S_c is the built-up area of city c (KM^2).

Mediating Variable: Aggregation Effects

1) Labor pool effect (Labor): According to the method used by Rusiawan W. et al. [4], the total number of laborers at the end of the year is equal to the sum of the total number of private employees and the number of employees per unit. It represents the total of secondary and tertiary industries' added value.

2) Intermediate input sharing effects (Inform, Road): Considering the availability of city-level data, referring to the practice of Lin et al. [17], the urban infrastructure construction level is used to measure the utilization efficiency of intermediate products. Among them, the urban per capita telephone users are used to measure the information transmission efficiency (Inform), and the urban per capita road area is used to measure the transportation efficiency (Road).

3) Knowledge and technology spillovers (Spill): Considering the accessibility of city-level data, referencing Lin et al. 's method [17], the knowledge spillover effect is measured by the proportion of the labor force in the education and technology industries to the total labor force.

Control Variables

4) Per capita GDP (PGDP). The level of the city's economic development is determined by looking at its per capita GDP. The relationship between economic development and pollutant emissions can be visualized as an inverted U-shaped curve using the environmental Kuznets curve hypothesis [46]. The control variable additionally contains the GDP per capita quadratic. to prevent an inverse or U-shaped link between the GTFP and the amount of economic progress.

5) Degree of openness (FDI). Through the effect of technological diffusion, a city's degree of openness to the outside world may increase its level of green development [47], but it may also follow the "pollution paradise" hypothesis and prevent the realization of green development in cities [30], using the ratio of the actual turnover of foreign direct investment to the region's GDP to calculate a region's degree of opening.

6) Industrial structure (Indus). Generally speaking, the more manufacturing there is in an area, the more severe the pollution will be, which will have a negative effect on the area's green development [42]. The industrial makeup of the area is evaluated using the secondary industry's contribution to GDP as a percentage.

7) Urbanization (Urban). The process of urbanization will, on the one hand, result in a high demand for energy, which will increase pollution emissions; on the other hand, when the rate of urbanization exceeds a certain threshold, the use of new technologies and the enhancement of energy utilization efficiency are advantageous to cities. green development to be achieved [32]. The urbanization level of a city is determined by the year-end population per unit area because the "China Urban Statistical Yearbook" has not published the urbanization rate since 2015.

8) Energy consumption structure (EN). In order for the city to achieve green development, the energy consumption structure, specifically the percentage of coal consumption in total energy consumption, is crucial [48]. Coal consumption would cause major air pollution as well as solid waste contamination. Analyze the city's energy consumption pattern.

9) Environmental regulation (Envir). According to the "Porter Hypothesis," effective environmental legislation can encourage businesses to implement technological innovation, increase energy efficiency, and lower pollutant emissions, all of which will support green development [49]. Environmental legislation may also raise production costs for businesses, which is counterproductive to increasing their economic efficiency and thwarting the level of green development of cities, according to certain studies [50]. This study

measures the extent of urban environmental regulation using the comprehensive solid waste utilization rate.

10) Policy for energy efficiency and emissions reduction (Dum). Since the "11th Five-Year Plan" period (2006-2010), China has proposed the indicator of decreasing energy intensity as a binding indicator, and in the "12th Five-Year Plan" (2011-2015), a binding indicator of carbon emission intensity has been added. The aforementioned two indicators have significantly impacted changes in carbon emissions in various regions. This study incorporates them into the model as control variables based on Shao's [51] method.

Data Sources

This paper chooses the panel data of 99 prefecture-level cities in the YRB from 2003 to 2017 as the research sample based on the data's availability and consistency of quality, "China Labor Statistics Yearbook," and provincial statistical yearbooks. To increase the reliability of the data, the variables with time value (capital stock, GDP, per capita GDP) are converted to 2000 as the base period, because when calculating GTFP, these variables are used. The empirical period of this study is from 2004 to 2017, since the GTFP value in 2003 is given a value of 1. Table 2 displays the descriptive statistics for each variable.

Model Design

Benchmark Model

This paper employs SYS-GMM to assess the relationship between GTFP and EA in order to reduce the potential endogeneity issue between GTFP and EA. SYS-GMM has the ability to account for unobservable factors that may affect the explained variable and may correct the synchronization discrepancy between core explanatory variables and control variables, producing estimates that are accurate and reliable [52]. The final benchmark econometric model of this paper is as follows after including the lag period of GTFP and the relevant control variables in the model:

$$ln(GTFP)_{it} = \alpha_0 + \alpha_1 \, ln(GTFP)_{i,t-1} + \alpha_2 \, ln(Agg)_{it} + \alpha_3 \, ln(Agg)^2{}_{it} + \alpha_4 \, ln(Labor)_{it} + \alpha_5 X_{it} + \varepsilon_{it} \quad (15)$$

Among them, $\ln(GTFP)_{i,t-1}$ is the lagged 1-period GTFP value of city i, $X_{i,t}$ is a set of control variables, including per capita GDP and its quadratic term, level of opening to the outside world, industrial structure, urbanization, energy consumption structure, environmental regulation, etc. In order to ensure the accurate identification of the relationship between EA and urban green development, this paper refers to the practice of Meng F. [53], and adds labor productivity, knowledge and technology spillovers, information transmission efficiency, and transportation cost as control variables in the benchmark regression.

Mediation Effect Model

According to the preceding theory, the labor pool effect, intermediate product sharing effect, and knowledge spillover effect are three ways in which EA may affect the degree of green development. carry out empirical research. Examine whether the mediation effect exists in accordance with the sequential approach suggested by Baron and Kenny [54]:

Table 2. Descriptive statistics of variables.

Variable name	Symble	Unit	Obs	Mean	Std. Dev.	Min	Max
GTFP	GTFP		1386	1.117	0.443	0.166	4.803
EA	Agg	CNY billion /KM^2	1386	1.916	0.651	-0.871	3.306
Labor productivity	Labor	10,000 people / KM^2	1386	2.204	0.575	-2.114	4.402
Per capita GDP	PGDP	CNY 10,000	1386	3.114	2.645	0.189	21.549
Degree of openness	FDI	%	1386	1.807	5.783	0	83.023
Industrial structure	Indus	%	1386	49.88	11.62	9.753	82.235
Urbanization	Urban	10,000 people / KM^2	1386	6.798	5.789	0.291	42.1
Energy consumption structure	EN	%	1386	78.894	10.429	48.896	93.089
Policy for energy efficiency and emissions reduction	Dum		1386	0.857	0.35	0	1
Environmental regulation	Envir	%	1386	74.687	26.379	0.24	100
Knowledge and technology spillovers	Spill	%	1386	0.036	0.019	0.001	0.141
Information transmission efficiency	Inform		1386	0.738	0.56	0.019	5.935
Transportation cost	Road	Per people/M^2	1386	3.729	3.871	0.143	32.352

$$\ln(GTFP)_{it} = \alpha_0 + \alpha_1 \ln(GTFP)_{i,t-1} + \beta_1 \ln(Agg)_{it} + \beta_2 \ln(\text{Agg})^2{}_{it} + \beta_4 X_{it} + \varepsilon_{it} \quad (16)$$

$$M_{it} = \gamma_0 + \gamma_1 M_{i,t-1} + \gamma_2 \ln(Agg)_{it} + \gamma_3 \ln(\text{Agg})^2{}_{it} + \gamma_4 X_{it} + \varepsilon_{it} \quad (17)$$

$$\ln(GTFP)_{it} = \alpha_0 + \alpha_1 \ln(GTFP)_{i,t-1} + \beta_1 \ln(Agg)_{it} + \beta_2 \ln(\text{Agg})^2{}_{it} + \beta_3 M_{it} + \beta_4 X_{it} + \varepsilon_{it} \quad (18)$$

Among them, $M_{i,t}$ is the mediation effect, which represents the labor pool effect (lnLabor), intermediate goods sharing effect (Inform, Road) and Knowledge and technology spillovers effect (Spill) in this paper. There is a mediation effect if at least one of the γ_2 or γ_3 in formula (17) and the β_3 in formula (18) is substantial. Furthermore, a partial mediation effect exists if at least one of β_1 and β_2 is significant. There was a full mediating effect because β_1 and β_2 were not significant.

Results and Discussion

EA Level in the YRB

Fig. 1 depicts the YRB 's EA trend from 2004 to 2017. The figure illustrates that, overall, from 2004 to 2017, the YRB 's level of EA increased steadily. The YRB 's lower reaches have the highest level of EA, followed by the middle reaches, while the higher reaches have the lowest level. Additionally, the disparity in EA across various locations has been expanding. This is due in part to the YRB 's middle and upper reaches covering a larger area than its lower reaches and, in part, to their distance from developed coastal markets, where local technology and capital accumulation are weak and economic development is overly dependent on resource-based industries due to a lack of low-energy and high-productivity industries to support them. As a result, they are unable to achieve further rapid accumulation of ecological capital [10].

GTFP in the YRB

Fig. 2 depicts the GTFP's shifting pattern in the YRB. Figures (a)-(d) show that in 2004, the YRB 's green development level was very concentrated, with a median value of roughly 1, and that it was essentially the same throughout the entire region. From 2011 to 2017, the YRB 's green development level gradually increased, and the median GTFP of each watershed was higher than 1. The watershed's green development level started to diverge. Figure (a) demonstrates that, between 2006 and 2011, the GTFP in the YRB experienced a large decline, which is consistent with the restrictions on energy intensity and carbon emissions indicated in China's "11th Five-Year Plan" and "12th Five-Year Plan" noted above. restrictions on emission intensity. On the one hand, it illustrates the thoughtful and successful choice of the control variables in this study. On the other hand, it also reflects the distinctive feature of the YRB 's industrial structure, which is intensively

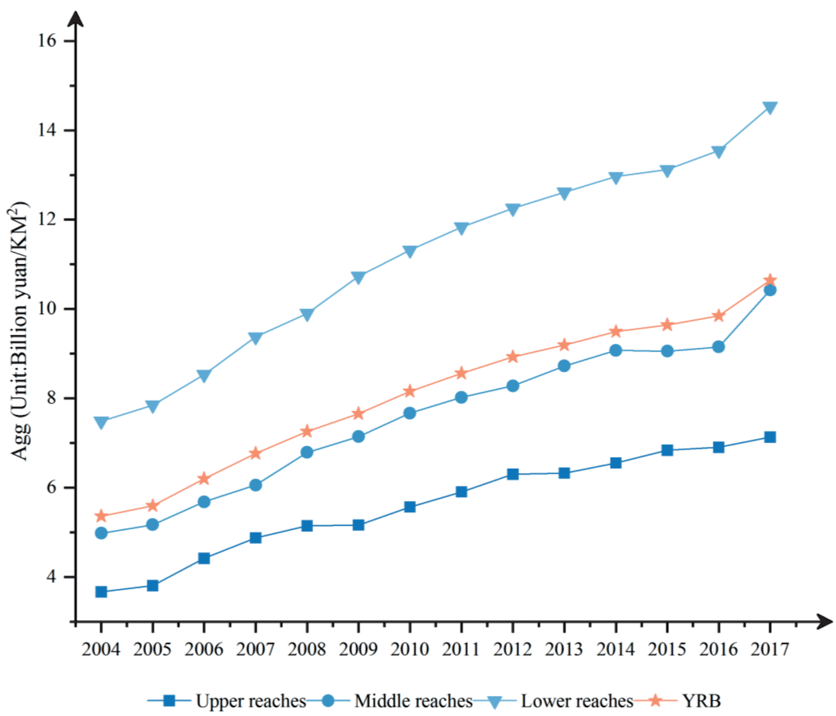

Fig. 1. EA trends in the YRB from 2004 to 2017.

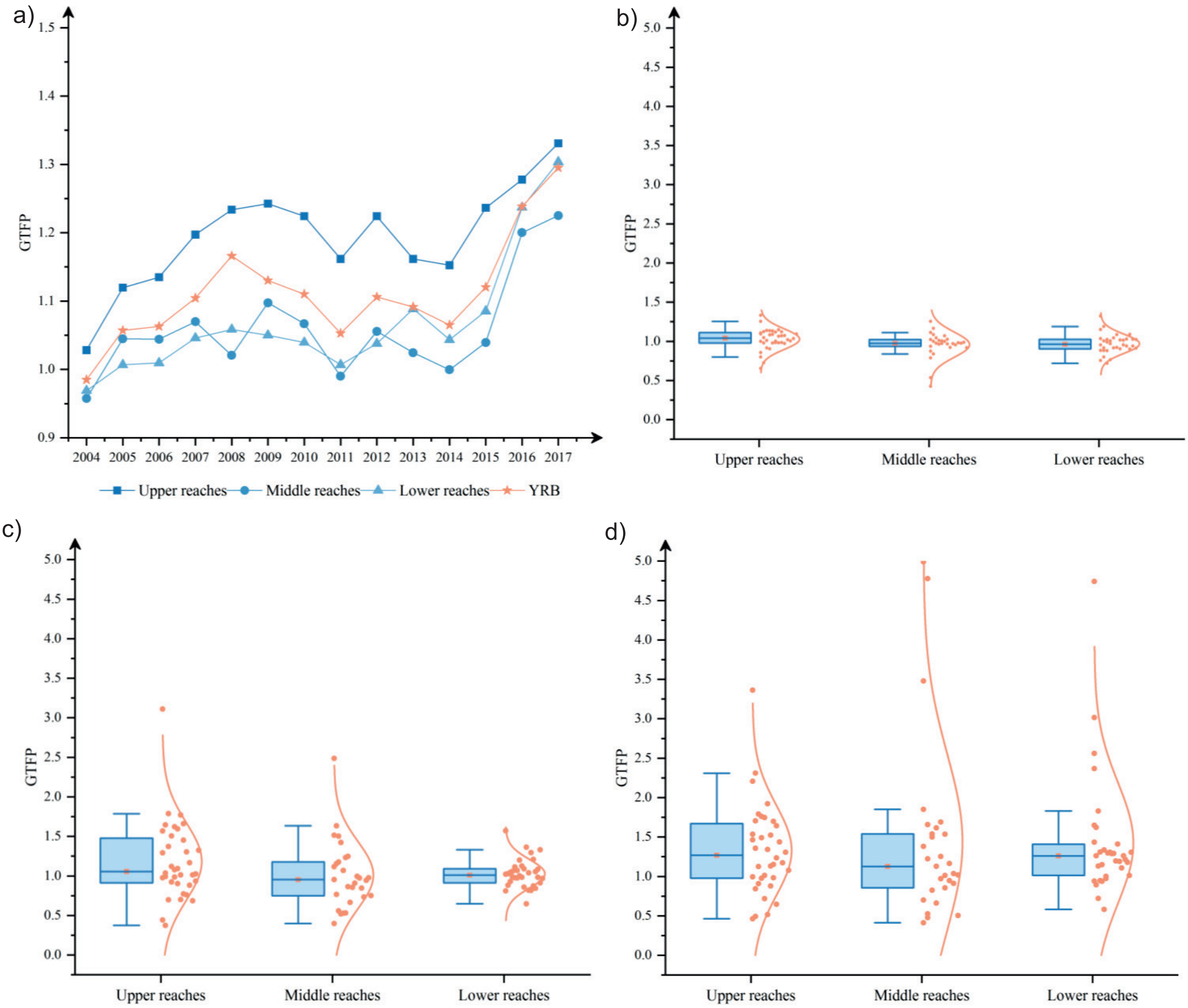

Fig. 2. The trend and decomposition of GTFP in the YRB from 2004 to 2017. a) The changing trend of GTFP in the YRB from 2004 to 2017; b) Sub-basin GTFP box diagram for 2004; c) Sub-basin GTFP box diagram for 2011; d) Sub-basin GTFP box diagram for 2017.

industrialized. Two major occurrences in 2006 and 2011, respectively, had an impact on the growth of companies that are largely dependent on energy and resources. External shocks have limited the YRB 's traditional economic development model at the price of the environment and hindered economic development effectiveness. Prior to 2011, the YRB 's lower reaches had the lowest amount of green development in the entire basin in terms of basins.

Measurement Results

Benchmark Regression

The estimation results of the OLS model (column 1), the two-way fixed-effects model (column 2), and the SYS-GMM model (column 3) are presented in Table 3 for ease of comparison. Table 3 shows that, without taking into account the endogeneity issue, the estimated coefficient of column 1 is high, the estimated coefficient of column 2 is low, and the quadratic term of EA 's sign has altered. As a result, disregarding the endogeneity issue will probably result in skewed estimation results. Additionally, the fact that most of the control variables in columns 1 to 3 have consistent coefficient signs suggests that the main source of endogeneity for this study's EA, which is another indication that the endogeneity problem is taken into account. In light of this, the discussion that follows concentrates on the estimation outcomes of the dynamic panel model based on the SYS-GMM model (column 3). Column 3's AR1 and AR2 demonstrate that the model only contains first-order correlation and no second-order correlation, proving that serial correlation is not present in the data. The Hansen test findings demonstrate that there is no over-identification issue, making the SYS-GMM estimation reliable and credible. It is clear from the data in column 3 that GTFP exhibits a sizable time lag

Table 3. Benchmark regression.

	(1) OLS	(2) FE	(3) SYS-GMM
VARIABLES	lnGTFP	lnGTFP	lnGTFP
L.lnGTFP			0.8019***
			(23.40)
lnAgg	0.7131***	-0.4034***	0.6433***
	(9.55)	(-4.16)	(2.80)
$lnAgg^2$	-0.1644***	0.0930***	-0.1277**
	(-8.05)	(4.04)	(-2.18)
lnLabor	0.4676***	0.1696***	0.1156*
	(9.82)	(3.56)	(1.86)
PGDP	0.0091	-0.0037	-0.0040
	(0.68)	(-0.52)	(-0.30)
$PGDP^2$	-0.0008	0.0003	0.0004
	(-0.81)	(0.55)	(0.34)
FDI	-0.0002	-0.0005	-0.0012
	(-0.07)	(-0.36)	(-0.87)
Indus	-0.0000	0.0011	0.0016**
	(-0.03)	(1.46)	(2.27)
Urban	0.0293***	0.0156***	-0.0055
	(7.88)	(3.62)	(-1.08)
Dum	0.0002	-0.0004	-0.0002
	(0.14)	(-0.57)	(-0.06)
Envir	-0.2913***	-0.0003	-0.1115**
	(-6.09)	(-0.72)	(-2.35)
Spill	-0.0014**	0.6713	-0.0028***
	(-2.52)	(0.62)	(-3.82)
Inform	0.5912	-0.0469*	2.3743**
	(0.66)	(-1.86)	(2.13)
Road	-0.1394***	0.0232***	-0.1850***
	(-3.73)	(4.34)	(-3.91)
Constant	0.0099*	-1.2478***	0.0219***
	(1.84)	(-8.39)	(2.68)
Obs.	1386	1386	1,287
Hansen			0.365
AR1			0.000
AR2			0.677

Note: *, * * and * * * * represent the significance levels of 10%, 5% and 1%, respectively, and the t-statistic value is in brackets.

impact as well as strong path dependence properties in the time dimension. The conclusions of the existing literature are consistent [55], indicating that the time-locking effect cannot be ignored in the study of GTFP. This further demonstrates that the model setting in this paper is reasonable and credible. If the GTFP of the previous period is at a high level, the GTFP of the next period will continue to rise. The primary term of EA is significantly positive at the 1% level, and the quadratic term is significantly negative at the 5% level, indicating that EA has an inverted U-shaped relationship with GTFP, which is consistent with the conclusion of Wu et al. [56], hypotheses H1 is validated. EA has a driving influence on the fulfillment of green development of the city when the agglomeration level is lower than the inflection point value of 2.51 (CNY 1.231 billion/KM^2). Right now, EA 's positive externality – which includes an adequate labor supply and a solid foundation – plays a prominent role. Building new facilities and the knowledge transfer impact encouraged by the influx of personnel from many industries work together to advance urban sustainability [17]. The adverse effects of agglomeration start to show up when the amount of agglomeration exceeds 2.51 (CNY 1.231 billion/KM^2). A city's transportation costs and rent will continue to rise as a result of an excessive concentration of economic activity, which will also lead to issues like traffic congestion and environmental degradation. As a result, both the cost of production for manufacturers and the cost of living for people both rise. At this point, the expansion of EA will obstruct cities' efforts to develop sustainably [57]. The average level of EA in the YRB as a whole was CNY 1.064 billion/KM^2 in 2017, remaining below the inflection point of 2.51 (1.231 billion/KM^2) at that time. That is to say, on an average level, EA 's positive externality continues to have a significant impact on how sustainably the YRB develops. The YRB can keep concentrating on enhancing its EA in the future to support the basin's overall transition to a greener economy. In terms of river basins, the lower reaches EA of the YRB reached CNY 1.453 billion/KM^2 in 2017 compared to the upper and middle reaches, which had EA levels of CNY 713 million/KM^2 and CNY 1.042 billion/KM^2, respectively, that is to say, the negative externalities of EA in the YRB 's lower reaches have already started to become apparent, and their level will only continue to rise, which will harm the sustainable growth of cities further upstream. In order to achieve the sustainable and coordinated development of the entire basin, resource-intensive businesses will be moved to the middle and upper reaches that still have the capacity to take on new projects.

The impact of labor productivity on the control variables is strongly favorable. The GTFP grows by 0.1156% for every 1% increase in labor productivity, showing that the increase in labor productivity promotes urban economic growth while accomplishing resource conservation and environmental protection. Environmental control and energy conservation and emission reduction regulations had a major negative impact, showing that in the YRB, these rules mostly increased the cost of production for businesses rather than encouraging them to innovate with green technology. The industrial structure is overwhelmingly favorable. On the one hand, it demonstrates that the YRB ‘s industrial sector can produce economic gains that can have a bigger influence on environmentally friendly development. decreased emissions of pollutants.

Robustness Test

Change Metering Model

This article utilizes the differential GMM (DIF-GMM) method to re-examine the association between EA and green development in order to validate the robustness of the regression results [58]. The empirical findings from the estimation using DIG-GMM are displayed in Column 1 of Table 4. The Hason test is not significant, indicating that there is no weak instrumental variable question, while AR1 is significant at the 1% level and AR2 is not significant, demonstrating that the model does not have serial correlation issues. The primary component of the benchmark regression is significantly positive whereas the quadratic term of EA is notably negative, showing that the connection between EA and GTFP is inverted U-shaped, indicating that the benchmark regression is robust and further verifies the hypothesis H1.

Replace the Explained Variable

In order to do regression using the SYS-GMM approach, this research employs green economic efficiency (Green) as the explanatory variable. It makes reference to the way some scholars use green economic efficiency to measure urban green development [42]. The outcomes are displayed in Table 4’s column 2. The relationship between green economic efficiency and EA is also inverted U-shaped, as seen in column 2, and it has passed both the serial correlation test and the weak instrumental variable test, demonstrating the robustness of the estimated benchmark regression results in this study. In the YRB, there is an inverted U-shaped relationship between EA and environmentally friendly growth.

Mediation Test

Table 5 displays the test results for the mediation effect between EA and environmentally friendly growth. The SYS-GMM approach was used to evaluate each model in Table 5, and the estimated results passed both the serial correlation test and the Hansen test, proving that the mediation effect model was properly calibrated.

Table 4. Robustness test.

	(1) FD-GMM	(2) SYS-GMM
VARIABLES	lnGTFP	lnGreen
L.lnGTFP	0.8950***	0.7734***
	(52.20)	(18.50)
lnAgg	0.0516*	0.4837*
	(1.78)	(1.97)
$lnAgg^2$	-0.0110*	-0.1037*
	(-1.67)	(-1.78)
lnLabor	0.0738***	0.0043
	(2.76)	(0.03)
Controls	YES	YES
Obs.	1,287	1,386
Hansen	0.210	0.277
AR1	0.000	0.000
AR2	0.751	0.987

Note: *, * * and * * * * represent the significance levels of 10%, 5% and 1%, respectively, and the t-statistic value is in brackets.

In particular, the coefficient of the first term of EA in column (2) is strongly positive, demonstrating the effectiveness of EA in boosting worker productivity. There are two plausible explanations: on the one hand, a concentration of laborers and manufacturers improves labor productivity by allowing workers to switch employment from organizations with poor economic benefits to organizations with greater economic benefits and by encouraging pay growth [59]. On the other hand, the labor market’s skill requirements and division of labor classification will be more streamlined and distinct, which will enhance the effectiveness of matching labor with manufacturers and raise labor productivity [60]. When columns (1), (2), and (6) are combined, it is clear that EA raises the amount of green development in cities due to the labor pool effect. The relationship between information communication efficiency and EA is an inverted U shape, as can be seen in column (3). The corresponding inflection point is 2.82 (CNY 1.677 billion /KM^2), meaning that the information communication efficiency rises with a decrease in EA. When the agglomeration level above the inflection point, the efficiency of information communication starts to decline as it rises. One explanation is that there won’t be enough base stations left to effectively cover all people and manufacturers if it exceeds the inflection point. Stage at which the YRB is currently at In a situation where the degree of agglomeration increases the efficiency of information transfer. The improvement of the level of EA can greatly increase the city’s commuting effectiveness, as can be shown from column

Table 5. Mediation test.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnGTFP	lnLabor	Inform	Road	Spill	lnGTFP
L. lnGTFP	0.8393***					0.8019***
	(24.80)					(23.40)
L.lnLabor		0.2498***				
		(3.32)				
L.Inform			0.2476***			
			(6.51)			
L.Road				0.8309***		
				(11.81)		
L.Spill					0.1790***	
					(2.63)	
lnAgg	0.3629**	0.6707***	1.7277***	0.5624**	0.0286*	0.6433***
	(2.42)	(8.29)	(2.99)	(2.48)	(1.77)	(2.80)
$lnAgg^2$	-0.0837*		-0.3054**			-0.1277**
	(-1.77)		(-2.34)			(-2.18)
lnLabor			-0.7037***	0.4294*	0.0194***	0.1156*
			(-2.90)	(1.89)	(2.91)	(1.86)
Inform		-0.1412		1.2393***	0.0000	2.3743**
		(-1.55)		(5.37)	(0.01)	(2.13)
Road		0.0147	0.0880***		0.0002	-0.1850***
		(0.44)	(3.38)		(0.15)	(-3.91)
Spill		13.117***	0.1601	-5.6121**		-0.0028***
		(5.26)	(0.05)	(-2.16)		(-3.82)
Controls	YES	YES	YES	YES	YES	YES
Obs.	1,287	1,287	1,287	1,287	1,287	1,287
Hansen	0.227	0.285	0.326	0.355	0.461	0.338
AR1	0.000	0.000	0.000	0.000	0.000	0.000
AR2	0.828	0.320	0.420	0.363	0.340	0.634

Note: *, * * and * * * * represent the significance levels of 10%, 5% and 1%, respectively, and the t-statistic value is in brackets.

(4). This is due to the fact that as urban EA levels rise, accompanying infrastructure investment becomes more finished, effectively increasing the carrying capacity of manufacturers and saving money as well as reducing travel times for inhabitants [61]. By combining columns (3) and (4), it is possible to conclude that an increase in EA can lower the price of intermediate shared goods and increase their usage efficiency. EA has greatly raised the proportion of practitioners in education and technology in the total number of employees since the first term in column (5) of the equation is notably positive. The agglomeration of many businesses can encourage the spread of knowledge and the development of new technologies, which may explain why locations with higher EA tend to have more diverse industries [62]. The information spillover effect can be employed as a part of the mediating effect of EA affecting urban green growth, according to a further comparison with column (6).

EA can influence urban green development through the labor pool impact, intermediate product sharing effect, and knowledge spillover effect, according to a thorough analysis of columns (1) to (6). The H2a, H2b, and H2c hypotheses are supported. Inflection point between EA and green development is shifted by the combined force of the three from 216 (CNY

867 million/KM^2) in column (1) to 251 (CNY 1.231 billion/KM^2) in column (6), which significantly raises the cost per unit area. The time it takes for EA to impose its beneficial externalities is greatly lengthened by the maximum economic activity limit that can be carried.

Conclusions

EA is a key driver of economic progress, but it can also result in environmental degradation. This study first measures GTFP, which includes CO2, and then, using panel data from 99 prefecture-level cities in the YRB from 2004 to 2017, employs the SYS-GMM model and the mediation model to investigate the mechanism of EA's influence on GTFP. It is found that EA can promote GTFP through labor pool effect, intermediate goods sharing effect and knowledge spillover effect. In the later stage, with the increase of agglomeration, the improvement of GTFP is inhibited. This study provides a systematic summary of the mechanism of EA on GTFP, which is useful for the development and improvement of the GTFP evaluation system and the EA research scope. The results of this study can provide suggestions for the creation of industrial development and environmental protection policies in the YRB, which is beneficial for the long-term, high-quality expansion of China's urban economy. The following conclusions can be drawn from the research results:

(1) The impact of EA on GTFP considering economic growth, resource conservation and environmental protection is non-linear. When the degree of EA is low, it mainly promotes GTFP, and when the degree of EA is greater than a certain value, it mainly inhibits GTFP. The corresponding turning point of EA in the YRB is CNY 1.231 billion/KM^2. In 2017, the average degree of EA in the whole basin was CNY 1.064 billion/KM^2, and the average degree of EA in the upper, middle and lower reaches was CNY 7.13 billion/KM^2, CNY 1.042 billion/KM^2 and CNY 14.53 billion/KM^2, respectively. Except for the lower reaches of the YRB, none of them have passed this turning point.

(2) The inverted U-shaped effect of EA on GTFP is mainly transmitted through three paths : labor pool effect, intermediate goods sharing effect and knowledge spillover effect. Specifically, EA can improve the carrying capacity of economic activities per unit area by improving labor productivity, reducing the cost of intermediate goods use, improving the utilization efficiency of intermediate goods and promoting knowledge spillover. In terms of the YRB, EA expands the carrying capacity of economic activities per unit area of the YRB from CNY 867 million/KM^2 to CNY 1.231 million/KM^2 through the above three positive externalities. It effectively extends the time for EA to exert its positive externalities to promote urban green development.

Based on the above findings, we propose the following policy implications:

(1) The majority of cities in the YRB can use preferential policies and regional resource advantages to improve EA by attracting more firms to concentrate, which will further promote GTFP, especially in the upper and middle reaches of the Yellow River. In addition, EA levels can be properly controlled in some cities that have already crossed the EA bending point, particularly in the downstream regions, to direct urban industry toward high-quality development rather than quantitative agglomeration. Low-end industries, for example, with outdated technologies and high energy use can be eliminated. Focusing on the rationality of industrial structure layout can boost industrial structure modernization, eliminate congestion effect, and devise distinctive development plans.

(2) Given the mediating influence of EA on GTFP, GTFP in the YRB can be improved further by stimulating practical technical innovation, strengthening regional infrastructure construction, raising the level of public services, and increasing professional accumulation. Promote the rational flow and efficient agglomeration of regional factors, construct a modern economic corridor dominated by advanced manufacturing and driven by innovation, participate actively in the national and international economic division, and encourage the green and low-carbon development of the YRB.

Although this study has some new discoveries in the mechanism between EA and GTFP, it also has some limitations. In terms of indicators, the selection of indicators affecting GTFP is not perfect. Other factors such as openness and human capital level may also affect GTFP. Secondly, the spatial spillover mechanism of EA on GTFP is not clear, which also provides space for future research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, Y.H. and X.W.; methodology, Y.H. and C.Z.; resources, Y.H. and X.W.; formal analysis, X.W. and C.Z.; writing – original draft preparation, X.W. and Y.H.; writing – review and editing, Y.H., X.W.. All authors have read and agreed to the published version of the manuscript.

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Appendix

Table A1. Index System of GTFP.

Target Layer	First-Level Indicators	Second-Level Indicators	Index Definition	Unit	Mean	Standard deviation	Minimum value	Maximum value
Input	Capital elements	Fixed capital stock	Total social investment in fixed assets	CNY 10 million	2559.493	3320.167	49.394	29496.027
	Labour factor	Number of employees per unit	Number of employees at the end of the year, number of employees in the private sector	Thousands	670244.1	771463.5	55830	8684634
	Resource elements	Energy input	Electricity consumption of the whole society	Million kWh	605641.8	779911	8055	10353925
Output	Expected output	Economic benefits	Gross Domestic Product (GDP)	CNY Billion	921.559	1154.824	8.331	9756.679
	Unexpected output	Environmental pollution	Sulphur dioxide emissions	Tons	6.372	5.226	0.063	33.716
			Wastewater discharge	Tons	5349.239	5630.41	99	53421
			Industrial smoke emissions	Tons	4.031	18.318	0.045	516.881
			CO_2 emissions	Tons	2483.52	1898.13	163.321	10847.946

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