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Study on Spatiotemporal Features and Factors Influencing the Urban Green Total Factor Productivity in the Yellow River Basin under the Constraint of Pollution Reduction and Carbon Reduction

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Abstract: Whether cities can attain a win-win situation with simultaneous environmental protection and economic growth is a compelling issue in current urban development. It will be of great practical significance to comprehensively evaluate the implementation effect of the multi-dimensional goals of an urban development from the perspective of a green total factor productivity (GTFP) evaluation. The paper places pollution reduction and carbon reduction into the research framework of GTFP, introduces the SBM-DDF model to evaluate the urban GTFP of 58 cities in the Yellow River Basin (YRB) from 2006 to 2020, and employs the panel regression model to empirically study the factors influencing the urban GTFP of the region. The results are obtained as follows: (1) from the perspective of time range, the urban GTFP in the basin displays an evolutionary trend of first declining and then mounting, demonstrating the highest GTFP in the downstream, the second-highest in the midstream and the lowest in the upstream; (2) regarding the spatial distribution characteristics, the urban GTFP in the basin presents obvious spatial differences, showing the regional differences by increasing from the upstream to the downstream; (3) from the perspective of the whole basin, the advancement of economic development, urbanization processes, environmental regulations and the ecological background have significantly positive effects in improving the urban GTFP, while the improvement of the industrial structure, opening-up and energy intensity affects the urban GTFP of the basin negatively; and (4) from the perspective of the regional heterogeneity of the effects of the various influencing factors, the improvement of the opening-up and industrial structure expedites the growth of the urban GTFP of the downstream, the advancement of urbanization process restrains the urban GTFP in the upstream and the impact of the ecological background on the urban GTFP in different regions is relatively complex. This study is of great importance to improve the urban GTFP and boost the high-quality development of the cities in the basin.

Keywords: urban green total factor productivity; pollution reduction and carbon reduction; SBM-DDF model; the Yellow River Basin

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1. Introduction

As urbanization and industrialization increasingly accelerate, China has made great achievements in urban development. Urban development has become the key engine of regional economic growth, employment creation and technological innovation [1]. However, China's urban development also faces multiple pressures from climate change, resource shortage and ecological security. China's urban areas contribute approximately 80% of the country's total emissions of CO_2, which mainly come from human activities in the urban industry, construction industry, transportation industry and agriculture [2]. Additionally, cities are areas with relatively concentrated emissions of various pollutants. China's urban ambient air quality and its impact on health have attracted growing attention. Over the past few years, serious environmental pollution such as haze, water pollution, garbage siege and others have appeared in the basin. The increasingly severe resource and environmental pressure cause people to worry about the sustainability of China's urban development [3]. Studies have revealed that coal and other fossil fuels emit air pollutants such as particulate matter and SO_2 during combustion, discharging greenhouse gases such as CO_2 and black carbon as well [4,5]. Considering that the emissions of greenhouse gases and major air pollutants share characteristics of the same root, source and process, corresponding measures should be taken to simultaneously reduce the emissions of urban pollutants and greenhouse gas emissions to improve the urban GTFP [6].

The rapid development of cities has aroused great attention in academic circles centered on urban GTPF research. The traditional research on urban total factor productivity (TFP) has not considered energy consumption or the environmental costs paid by urban economic growth, disregarding the resources and adverse environmental impact and leading to the distortion of social welfare changes and the evaluation of GTFP; it is apt to offer misleading policy recommendations [7,8]. GTFP is an amendment to the traditional TFP that incorporates energy and environmental factors into the economic growth analysis framework. It emphasizes low resource consumption and low pollutant emissions and is the chief force in transforming the economic development mode restricted by resources and the environment. [9]. Some scholars have conducted research on the GTFP in recent years, including economic sectors such as industry [10], agriculture [11,12], construction [13] and tourism [14]. The existing research mainly focuses on GTFP measurement methods, spatiotemporal features, affecting factors and others. Regarding measuring methods for the GTFP, scholars introduce factors such as the consumption of resources and environment pollution into the production function, which develops into GTFP to inspect regional economic development based on the TFP. Most scholars employ a data envelopment analysis (DEA) model to evaluate the relationship between the input and output. For example, Tone propounded the slacks-based model (SBM) and first included the slack variable in the analysis, eliminating the radial and angular defects of the distance function [15]. On the basis of the existing research, Fukuyama and Weber united the improved SBM model and the directional distance function to further reduce the calculation error [16]. Regarding the spatiotemporal characteristics of GTFP, some scholars introduced the Theil coefficient, coefficient of variation, kernel density estimation, Gini coefficient, spatial autocorrelation and other methods to study the spatial and temporal variations of GTFP [17–21]. In terms of factors that influence GTFP, scholars' research results focused on the following aspects: the improvement of the economic development level is generally favorable for improving GTFP [22]; the industrial structure over which the secondary industry predominates is the chief factor affecting GTFP [23]; energy intensity can effectively affect GTFP by improving the efficiency of energy utilization [24]; the effect of population agglomeration caused by urbanization on GTFP is uncertain [25] and how the level of opening-up indirectly affects GTFP by influencing technological innovation and industrial structure, etc. [26]. In addition, environmental regulations and the ecological background are also proven to be important factors affecting GTFP [27,28].

According to the relevant literature, scholars have carried out relatively rich explorations on the measurement, spatial–temporal characteristics and the identification of factors that influence GTFP. However, the possible limitations of the existing research are as follows: firstly, many studies reviewed the urban GTFP under the constraint of reducing air pollution or greenhouse gases and did not consider the urban GTFP constrained by the double aims of pollution reduction and carbon reduction; secondly, the research on the factors affecting GTFP mainly focused on testing the relationship between GTFP and a specific factor and seldom comprehensively analyzed the interaction of multiple factors on GTFP; finally, because the regional resource endowment and economic development models are different and the urbanization process has promoted the structural transformation of an urbanization spatial form, the evolution law of the urban GTFP is complex and demonstrates regional heterogeneity. However, there is little further explanation for the heterogeneity of the influencing factors in current research.

The Yellow River Basin (YRB) has been a region with fragile ecological security and a vulnerable climate in China and even in the world. It is also a significant production center of energy and of the chemical and heavy industries in China. The region is characterized by concentrated pollution and carbon emissions. The current environmental problems, such as resource over-exploitation and ecological deterioration, are ultimately economic development problems [29,30]; improving the urban GTFP under the constraints of pollution reduction and carbon reduction could balance resource conservation, ecological environment improvement and economic development [31]. Therefore, this paper brings the dual constraints of pollution reduction and carbon reduction into the research framework. This paper intends to study 58 cities in the basin to measure the urban GTFP level and answer the following three questions: what is the trend of evolution for the urban GTFP in the basin under the constraints of pollution reduction and carbon reduction? Are there any spatial differences among regions? What factors influence the differences between the regional urban GTFPs? This paper provides an interpretation for the formation of spatial differences in the urban GTFP and the heterogeneity of the affecting factors in the basin. With a comparison to the existing literature, the chief contribution of this paper consists of two points: the paper measures the real level and dynamic evolution tendency of the urban GTFP in the YRB under the dual constraints of pollution reduction and carbon reduction; and the paper establishes a panel regression model to explore the factors influencing the urban GTFP, providing data and theoretical support for effectively improving the urban GTFP in the YRB.

The rest of the paper is laid out as follows: Section 2 presents the materials and methods. Section 3 measures the spatial–temporal features and regional differences of the urban GTFP in the YRB, and explores the extent to which different factors influence the urban GTFP, and Section 4 offers conclusions and suggestions.

2. Materials and Methods

2.1. Study Areas

The YRB is an important ecological region and economic belt in China which covers nine provinces (Qinghai, Sichuan, Gansu, Inner Mongolia, Ningxia, Shaanxi, Shanxi, Henan and Shandong). It connects Northwest China and North China, including various geomorphic units—the Qinghai–Tibet Plateau, Qilian Mountains, Helan Mountains, the Loess Plateau, Qinling mountains, Taihang mountains and the North China Plain. Due to the complex and diverse ecology, the relatively dry climate, the simple energy structures, the large population, severe human–land conflicts, high ecological pressure, serious environmental pollution and large internal economic differences, the layout of productivity and ecological security is not coordinated in the YRB. Considering the availability and systematic nature of the data, this paper excluded some regions of Qinghai, Gansu, Inner Mongolia and Sichuan, finally determining 58 cities as the research objects. Referring to the division method of Guo Han [32], this paper grouped these 58 cities into the upper stream, the midstream and the downstream of the YRB. The upstream area spreads from Xining City of Qinghai Province to Hohhot of Inner Mongolia (including Hohhot), the midstream area ranges from Hohhot to Zhengzhou of Henan Province (including Zhengzhou) and the downstream area extends from Zhengzhou to Dongying of Shandong Province.

2.2. Research Methods

Supposing that there are k decision-making units (DMU) in the period t, each DMU utilizes n inputs $x = (x_1, x_2 \cdots x_n) \in R_n^+$ to yield m desired outputs $y = (y_1, y_2 \cdots y_m) \in R_m^+$ and i undesired outputs $b = (b_1, b_2 \cdots b_i) \in R_I^+$. When the input x and the desired output y meet strong disposability and the undesired output b meets weak disposability, the function is constructed as follows [33]:

$$P^t\left(x^t\right)\left\{\begin{array}{l}\left(y^t, b^t\right): \sum_{k=1}^{K} \lambda_k^t y_{km}^t \geq y_{km}^t \forall m \\ \sum_{k=1}^{K} \lambda_k^t b_{ki}^t \forall i \\ \sum_{k=1}^{K} \lambda_k^t x_{kn}^t \leq x_{kn}^t, \forall n \\ \sum_{k=1}^{K} \lambda_k^t = 1, \lambda_k^t \geq 0, \forall k\end{array}\right\} \tag{1}$$

In this formula, λ is the weight vector of k dimensions $\lambda = (\lambda_1, \lambda_2 \cdots \lambda_k)$. If λ is equal to 1, the sum of weights being 1 expresses a variable scale reward. When the sum of weights is not 1, it signifies a constant scale reward. In order to reduce input–output slack, we constructed a directional SBM model, including slack variables, as follows:

$$\begin{array}{l}\vec{S}_V^t\left(x^{t,k'}, y^{t,k'}, b^{t,k'}, g^x, g^y, g^b\right) = \max\limits_{s^x, s^y, s^b} \frac{\frac{1}{N}\sum\limits_{n=1}^{N}\frac{s_n^x}{g_n^x} + \frac{1}{M+1}\left[\sum\limits_{m=1}^{M}\frac{s_m^y}{g_m^y} + \sum\limits_{i=1}^{I}\frac{s_i^b}{g_i^b}\right]}{2} \\ s.t. \sum_{k=1}^{K} \lambda_k^t x_{kn}^t + s_n^x = x_{k'n}^t, \forall n; \sum_{k=1}^{K} \lambda_k^t y_{km}^t - s_m^y = y_{k'm}^t \forall m; \\ \sum_{k=1}^{K} \lambda_k^t b_{ki}^t + s_i^b = b_{k'i}^t \forall i; \sum_{k=1}^{K} \lambda_k^t = 1, \lambda_k^t \geq 0, \forall k; s_i^b \geq 0, \forall i; \\ s_n^x \geq 0, \forall n; s_y^m \geq 0, \forall m;\end{array} \tag{2}$$

where $\vec{S}_v^t$ indicates SBM under the variable scale return, $\left(x^{t,k'}, y^{t,k'}, b^{t,k'}\right)$ denote the production input, the desired output and the undesired output of the k DMU in the period t, respectively, $\left(g^x, g^y, g^b\right)$ represents direction vectors and $\left(s_n^x, s_m^y, s_i^b\right)$ expresses slack variables.

2.3. Variables Selection

2.3.1. Input and Output Variables

In this study, capital, energy and labor were selected as input indicators. GDP was selected as the desired output indicator. Moreover, in order to signify the two target constraints of pollution reduction and carbon reduction in the urban GTFP, this paper added two key environmental constraints of carbon emissions and air pollution to the research framework, establishing the indicator system of the urban GTFP in the basin constrained by pollution reduction and carbon reduction. The descriptive statistics of the data are demonstrated in Table 1.

Table 1. Descriptive statistics of inputs and outputs from 2006 to 2020.

Indicators	Scales	Unit	Number of Observed Values	Mean	Std. dev.	Min.	Max.
Input	Capital input	CNY 1 billion	870	122.71	118.58	2.93	703.51
	Energy input	10 thousand tons of standard coal	870	135.99	78.08	7.97	435.13
	Labor input	10 thousand individuals	870	47.08	36.45	4.84	213.99
Desired output	Real GDP	CNY 1 billion	870	922.02	772.24	75.01	4237.12
Undesired output	$PM_{2.5}$ concentration	$\mu g/m^3$	870	51.77	20.31	14.47	103.90
	CO_2 emissions	Million tonnes	870	33.88	19.50	1.99	108.48

(1) Input variables. The capital input was evaluated by the city capital stock over the years according to the perpetual inventory method. The energy input was represented by the total energy consumption, and the labor input was represented by the total employment of three industries.

(2) Output variables. Output variables were further grouped into the desired output and the undesired output, in which the desired output was the regional GDP of each city over the years. Additionally, in order to remove the price factor effect, the study used the GDP index to deflate the regional nominal GDP by taking 2006 as the base period. Moreover, we took the $PM_{2.5}$ concentration as the proxy variable for the pollution constraint and CO_2 emissions as the proxy variable for the carbon emission constraint so as to simultaneously examine the double undesired constraints of environmental pollution and climate change accompanied by economic development.

2.3.2. Influencing Mechanism and Explanatory Variable Selection

Combining the previous research results and the features of the cities in the basin, we selected the economic development [34,35], urbanization process [36], industrial structure [37,38], opening-up [39–41], environmental regulation [42,43], energy intensity [44,45] and ecological background [46–48] as the explanatory variables.

Economic development (ED): Cities with a high economic development can promote the aggregation of high-level knowledge and talent, improve the technology and means of pollution control, boost the utilization efficiency of resources and energy and provide a material basis and technical support for the urban GTFP. Additionally, high economic development can upgrade individuals' living standards and enhance their environmental protection consciousness. Individuals' pursuit of a green quality life can positively affect the improvement of the urban GTFP. Therefore, there may be a positive connection between the urban GTFP and the economic development level. This study employed GDP per capita to evaluate the economic development level of the YRB cities.

Industrial structure (IS): Industrial structure is a crucial factor for explaining the development of an urban GTFP, and the city industrial structure determines the mode of economic development. Generally, in comparison to the tertiary industry, the secondary industry tends to consume more resources and produce more waste. At present, the quality of industrial development in the YRB is not high, and enterprises in industries with a high energy consumption, serious pollution and heavy emissions still account for the main part. In this study the ratio of added value of the secondary industry to the GDP was selected to symbolize the industrial structure.

Urbanization process (UP): In the early and middle stages of urbanization, with the labor force in the primary industry transferring to the secondary industry, the heavy chemical industry, enterprises develop rapidly, energy and resource consumption increases, the emissions of the three industrial wastes rise and the problems of environmental pollution and traffic congestion become prominent. In this period, the development of urbanization tends to negatively impact the urban GTFP. Nevertheless, with the further acceleration of urbanization, the upgrade of the industrial structure, the advancement in the efficiency of resource utilization and the enhancement of population quality, the growth of urbanization will promote the improvement of the urban GTFP. In this study, the percentage of the non-agricultural population in the total population was adopted to represent the urbanization process.

Opening-up (OU): In an open economic environment, foreign exchange contributes to the introduction of innovative factors such as high-quality foreign talents, high-level foreign technology, foreign direct investment (FDI) and more. Expanding the opening-up can make it easier for the region to gain international spillover effects and promote its own innovation ability. At the same time, according to the "pollution paradise" hypothesis, some developed countries tend to move industries which are seriously polluted and consume more energy to developing countries. Foreign capital introduction can cope with the capital shortage issue in developing countries and bring technological spillovers, but it is also likely to bring pollution-intensive industries in the foreign countries to the host country and cause consequent environmental degradation; this may also increase the cost of environmental governance of the country. The economy of many cities in the basin, especially upstream cities, is relatively backward, where local governments are liable to reduce environmental standards to introduce foreign capital. Improving the opening-up level may reduce the urban GTFP in the YRB. In this study, the ratio of the amount of foreign capital utilized in the current year to the GDP was adopted as an alternative indicator of the level of opening-up.

Environmental regulation (ER): The influence exerted on the urban TFCP by environmental regulations includes two categories: "compliance costs" and the "Porter hypothesis". At the initial stage of implementing environmental policies, the low environmental cost makes it difficult to motivate the urban GTFP promotion. The people who hold the "compliance costs" believe that the added costs of environmental regulations may occupy the development space, which is unfavorable for improving the urban GTFP. As the environmental regulation intensity grows further, the rise of pollution costs compels enterprises to fulfill technological innovations and make upgrades. The "Porter hypothesis" holds that rational, external environmental regulation is apt to counterbalance the environmental governance cost in the long term, thus achieving the win-win effect of economic and environmental benefits in the YRB and promoting the urban GTFP. This paper adopted the percentage of environmental governance investment in the GDP as an alternative indicator.

Energy intensity (EI): China has a large structure gradient of energy conservation technology which boasts not only world-class advanced technologies with high efficiencies and low energy consumption but also has many backward technologies. The indicator of energy economic efficiency, represented by the energy consumption per GDP, is a crucial measure for evaluating green development. The indicator reflects the extent to which economic development depends on energy, industrial structure, energy consumption composition and the effects of policies and measures in conserving energy and reducing consumption. In this study, energy consumption per GDP was employed as an alternative indicator.

Ecological background (EB): Ecological environment construction, economy and societal development complement each other. An excellent ecological environment is crucial for improving green transformation and development. This is particularly essential for the basin, where ecological governance is at the critical stage. This paper adopted the percentage of green coverage of the built-up area to represent the ecological background.

In this study, a regression model was constructed to estimate the urban GTFP in the YRB according to random effects (RE), fixed effects (FE), mixed effects (ME) and common correlated effects (CCE). The equation is symbolized as follows:

$$\begin{gathered}\ln GTFP_{i,t} = \beta_0 + \beta_1 \ln ED_{i,t} + \beta_2 \ln IS_{i,t} + \beta_3 \ln UR_{i,t} + \beta_4 \ln FDI_{i.t} + \beta_5 \ln ER_{i,t} + \\ \beta_6 \ln EI_{i,t} + \beta_7 \ln EB_{i,t} + \mu_{i,t}\end{gathered} \tag{3}$$

In the equation, i represents the 58 cities of the basin, t indicates the years from 2006 to 2020, μ_0 denotes the intercept and $\varepsilon_{i,t}$ refers to a random disturbance term (Table 2).

Table 2. Selection of the influencing factor indicators.

Indicator Attribute	Indicator Name	Indicator Interpretation
The explained variable	GTFP	GTFP value
Explanatory variables	ED	GDP per capita
	IS	Percentage of secondary industry added value to GDP
	UP	Proportion of non-agricultural population in the total population
	OU	Ratio of the foreign capital utilized in the current year in GDP
	ER	Proportion of environmental governance investment to GDP
	EI	Ratio of energy consumption to GDP
	EB	Percentage of green coverage of the built-up area

2.4. Data Collection

The data in this paper were obtained from the China City Statistical Yearbook, China Energy Statistical Yearbook and China Statistical Yearbook from 2006 to 2020, some statistical yearbooks of cites and the statistical bulletins on the websites of municipal governments. Additionally, the $PM_{2.5}$ original concentration meteorological grid data were collected from Dalhousie University, and the carbon emissions data were collected from the CEADs database. At the same time, we referred to the research results of some scholars and research institutions. Although we tried to collect data from many sources, some data were still incomplete. Therefore, we conducted a supplementary treatment of the missing data as follows: (1) for the aggregate data, we first calculated the average proportion of the city in the province in the last two years and used the provincial data to multiply the proportion to obtain the data for the city; (2) for horizontal data, we first calculated the ratio of the city to the provincial average level over the last two years and then multiplied the provincial data by the ratio to obtain the city data and (3) the average value of adjacent years was used to supplement deficient data for individual years.

3. Results and Analysis

3.1. Features of Spatiotemporal Evolution of the Urban GTFP in the YRB

According to the Super-SBM model, the GTFP of the 58 cities in the YRB from 2006 to 2020 was estimated. Since the YRB is spread over three chief regions of China—the east, the middle and the west—the economic base and resource endowment of the provinces in the basin are different. In order to demonstrate the regional differences in the urban GTFP of the YRB, this paper used a trend chart to show the change in trends from the perspectives of the whole basin, the upstream, the midstream and the downstream (as are displayed in Figure 1).

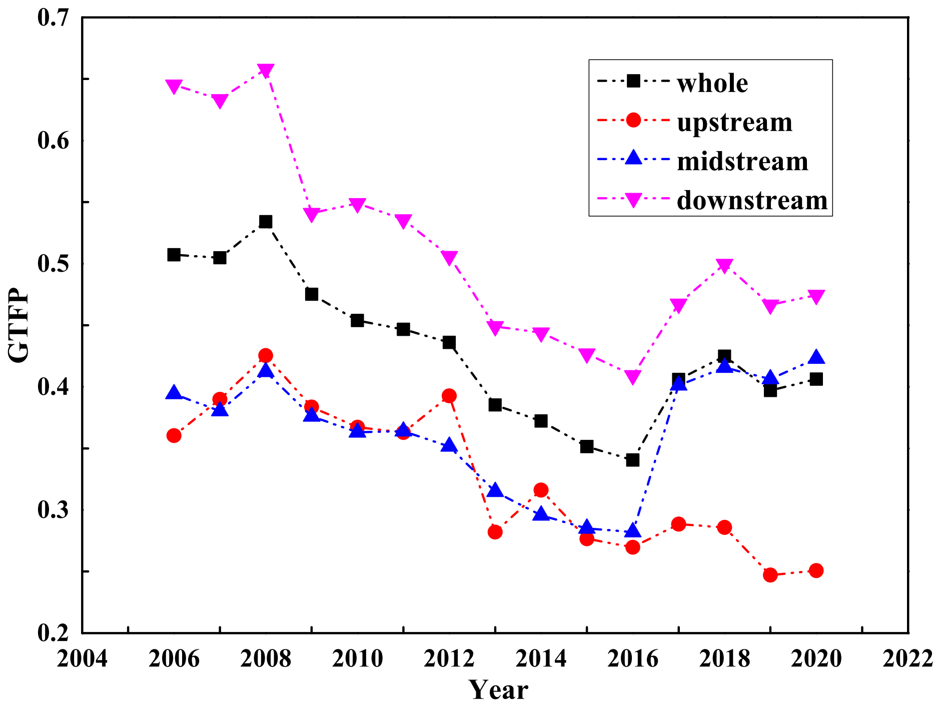

Figure 1. Trend of the urban GTFP in the YRB from 2006 to 2020.

From the perspective of the whole basin, the urban GTFP can be divided into two stages: 2006–2015 and 2016–2020. From 2006 to 2015, the overall urban GTFP of the YRB demonstrated a downward fluctuating trend with a slow increase from 2006 to 2008 and a sharp decrease from 2009 to 2015. From 2016 to 2020, the overall urban GTFP of the basin was on the rise. Impacted by the 2008 financial crisis, overall economic development slowed down in China. In order to drive the economy to develop rapidly, local governments put many resources into infrastructure projects and urban leading industries and relaxed the intensity of environmental regulations and foreign access conditions, which resulted in a large consumption of energy and resources and serious environmental pollution. Emphasizing only the GDP also drove some locations to pursue short-term benefits excessively and disregard the cost to the environment, causing the urban GTFP to decrease. To stimulate the economy, China began to implement a fiscal stimulus plan that focused on promoting industrial development in 2009. However, the plan had a limited effect on boosting the economic development level of the basin and was accompanied with substantial resource consumption and grave environmental pollution, making the urban GTFP decline further. In 2014, China advocated for the green, circular and low-carbon development mode and called for environmental conservation and ecological restoration. Meanwhile, China required that the GDP assessment be diluted and that the quality of economic development be emphasized more. An increasing number of local governments cancelled the GDP assessment and replaced it with the assessment guidance of the environment and peoples' livelihoods. Therefore, since 2016, the entire urban GTFP of the basin has gradually increased. From 2016 to 2020, the economy of the basin gradually shifted from the rapid growth stage to a stage of more intensive and sustainable high-quality development. Energy structure and industrial structure were in transition, technologies of energy development, cleaner production and pollution control were gradually promoted, and the regional urban GTFP was steadily on the rise.

From the perspective of the upstream, the midstream and the downstream of the YRB, the change in trend of the urban GTFP in the three reaches was basically consistent with that of the overall urban GTFP in the basin. The GTFP of the downstream cities was the highest, followed by the midstream cities. It was the lowest in the upstream cites. The overall urban GTFP of the downstream cities remained at a high level mainly because the cities in that region possessed a high economic development level, a high efficiency in transformation and upgrading industry, the relatively complete growth of emerging technological industries and a modern service industry and outstanding performance in the efficient application of resources, energy and environment pollution treatment. The midstream cities are rich in energy resources and fragile in their ecological environment. Due to a heavy emphasis on traditional and resource-consuming industries and the low level of industrialization, these cities are still at a development stage and demonstrate substantial energy consumption, serious carbon emissions, grave pollution discharge and a low income. In addition to having a weak economic foundation, the upstream cities also stress the energy industry. This is a situation in which the economic growth of some cities comes at the cost of ecological environment, resulting in a generally low urban GTFP.

According to the natural breakpoint method, the urban GTFP can be divided into five levels. The spatial evolution patterns of the urban GTFP in 2006, 2010, 2015 and 2020 were drawn by the aid of ArcGIS software to explore the spatial pattern characteristics of the urban GTFP in the YRB. The study revealed that the spatial characteristics of the urban GTFP in the YRB were significantly different from 2006 to 2020, showing a spatial differentiation pattern in which the urban GTFP of the downstream was higher than that of midstream, and that the upstream had the lowest GTFP in the YRB (revealed in Figure 2).

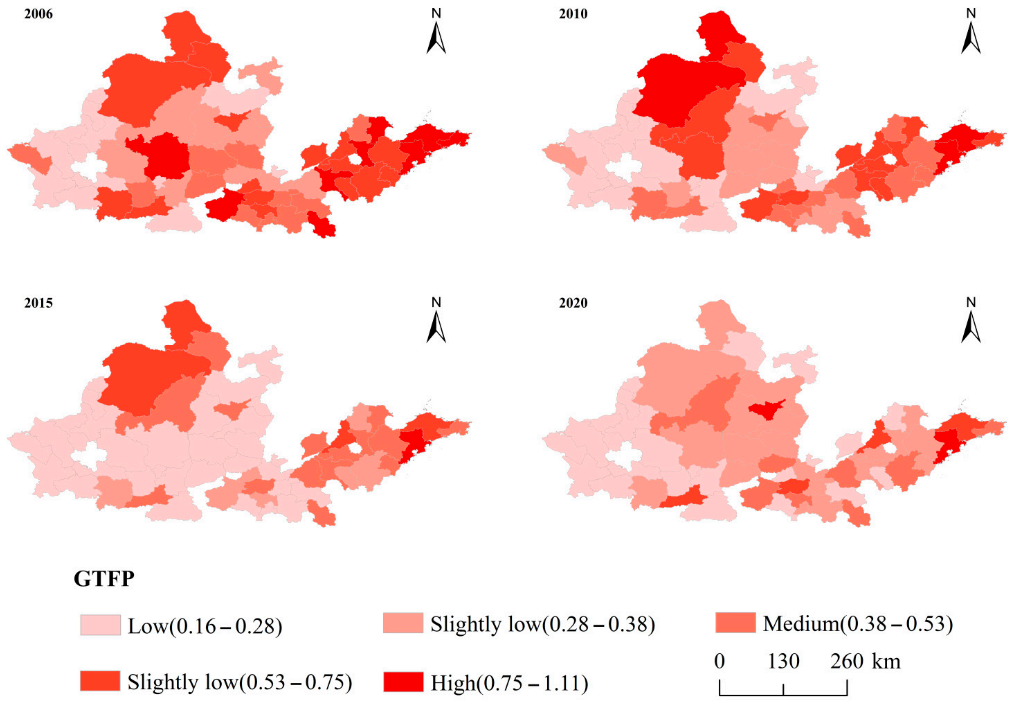

Figure 2. Spatial differentiation of the urban GTFP in the YRB.

3.2. Analysis of Factors Affecting the Urban GTFP in the YRB

3.2.1. Descriptive Statistics and Stability Test

This study conducted a descriptive statistics test on the urban GTFP and the affecting factors to intuitively demonstrate the general information of the sample data from the basin (Table 3). When the panel data model is used for quantitative analysis there would be a strong correlation between sections in some cases, resulting in biased and inconsistent estimators from the usual FE and RE models. Therefore, this paper used a Lagrange multiplier (LM) test and a cross-sectional dependence (CD) test to analyze the cross-sectional dependency [49,50], the results showed that all statistics were below a significant level of 1%, which rejected the original assumption that the cross-section units were independent from each other; that is, there was cross-sectional correlation between each series' cross-section (Table 4). In order to guarantee the validity of the regression estimation and avoid spurious regressions, and in view of the cross-sectional correlation of each series, this paper employed the cross-sectionally augmented Dickey–Fuller (CADF) test and the seemingly unrelated regressions augmented Dickey–Fuller (SURADF) test to examine the stationarity of each variable series to verify whether there would be homogeneity and a heterogeneity panel unit root [51,52]. The results demonstrated that all variables were stable under the 5% significance level and that there were no spurious regressions due to a unit root, which could be estimated by the panel data model (Table 5).

Table 3. Descriptive statistics of variables.

Variables	Min	Max	Mean	Std. Dev
GTFP	0.108	1.127	0.396	0.198
ED	0.276	10.328	2.154	1.433
IS	0.158	0.806	0.505	0.106
UP	0.023	1.612	0.243	0.182
OU	0.000	0.413	0.032	0.049
ER	0.007	0.107	0.035	0.024
EI	0.168	4.609	1.040	0.672
EB	0.000	0.718	0.380	0.074

Table 4. Test for cross-sectional dependence.

Test	Statistics	*p* Value
Breusch–Pagan LM	5273.176	0.000
Pesaran scaled LM	62.962	0.000
Bias-corrected scaled LM	60.891	0.000
Pesaran CD	2.797	0.005

Table 5. Stationarity test of panel data.

Variables	CADF Statistics	*p* Value	SURADF Statistics	*p* Value	Results
GTFP	−6.112	0.000	−6.052	0.000	stationary
ED	−5.136	0.000	−4.177	0.026	stationary
IS	−4.375	0.023	−5.008	0.000	stationary
UR	−4.068	0.028	−3.702	0.038	stationary
FDI	−4.827	0.015	−3.691	0.039	stationary
ER	−6.116	0.000	−3.332	0.045	stationary
EI	−7.483	0.000	−8.105	0.000	stationary
EB	−4.233	0.025	−6.436	0.000	stationary

3.2.2. The Overall Sample Regression of the Basin

A regression analysis was carried out on the factors influencing the GTFP of 58 cities in the YRB from 2006 to 2020. To remove the impact of heteroscedasticity on the regression results, we conducted a logarithmic processing of the sample data and a regression analysis of the influencing factors by adopting the RE, FE, ME and CCE models, respectively. Due to the existence of a cross-sectional correlation, the estimation results of the CCE are more reasonable [53]. From the value of the root mean square error (RMSE) of each regression equation, the RMSE of CCE was the smallest; regarding the cross-sectionally augmented Im–Pesaran–Shin (CIPS) test on the stationarity of the residual sequence, the regression results of the four equations only showed that the residual sequence estimated by the CCE was stationary, while the other three equations did not consider the correlation between sections. This resulted in non-stationary residual sequence (shown in Table 6).

Table 6. Estimation results of factors influencing the GTFP in the YRB.

Variables	RE	FE	ME	CCE
ED	0.095 *** (14.006)	0.094 *** (13.251)	0.073 *** (24.258)	0.086 *** (12.193)
IS	−0.312 *** (−4.991)	−0.233 *** (−5.519)	−0.225 *** (−6.185)	−0.207 *** (−5.426)
UR	0.021 * (1.726)	0.028 ** (2.201)	0.023 ** (2.095)	0.026 ** (2.192)
FDI	−0.493 *** (−4.733)	−0.117 * (−1.692)	−0.123 ** (−1.993)	−0.113 ** (−2.187)
ER	0.866 ** (2.213)	0.750 *** (5.164)	0.863 ** (2.137)	0.806 ** (2.172)
EI	−0.111 *** (−4.051)	−0.154 ** (−2.105)	−0.142 *** (−10.357)	−0.163 * (−1.705)
EB	0.103 * (1.713)	0.181 * (1.695)	0.208 ** (2.168)	0.176 ** (2.099)
cons	0.178 (0.517)	0.307 (1.019)	0.364 (0.962)	0.312 (1.125)
RMSE	0.225	0.142	0.187	0.063
CIPS (*p* value)	0.265	0.126	0.263	0.000

Note: ***, ** and * signify significance on levels 1%, 5% and 10%, respectively.

The overall regression results regarding factors affecting the urban GTFP of the YRB are manifested in the following aspects:

(1) Economic development: the regression coefficient in terms of economic development was positively significant and below a 1% confidence level (CL), suggesting that improving the economic development can advance the urban GTFP in the YRB. Cities with a high level of economic development are inclined to expand capital investments in reducing carbon emissions. By establishing special fund for conserving energy, reducing CO_2 emissions and conducting clean development, they can provide financial support for emerging industries such as renewable energy power generation, advanced energy storage and green, zero-carbon buildings, steadily improving the enterprise capacity of technological research and innovation. Additionally, regions with a high level of economic development have obvious advantages in achieving the radical transformation from factor-driven economic growth to innovation-driven economic growth. This will contribute to the optimization and upgrade of industrial structure, thus improving the urban GTFP.

(2) Industrial structure: the regression coefficient regarding the industrial structure was negatively significant and below a 1% CL, expressing that the increase in the ratio of the secondary industry tends to inhibit the urban GTFP. The basin is governed by petroleum processing, nonferrous metal smelting, mining and other heavy chemical industries, and the internal structures concerning the secondary industry in some cities are not reasonable in the YRB. Therefore, it is particularly important for the cities in the basin to conduct an active adjustment of the industrial structure, remove backwards technologies and production capacities and optimize the industrial layout and process structure to improve the urban GTFP. Labor, capital, technology and other production factors should be shifted from the production sectors with low efficiencies and high consumption to the advanced manufacturing industry, modern service industry and other production sectors with high efficiencies and low consumption. The drift and reorganization of production factors among various sectors can impel the development of an industrial structure oriented toward rationalization, upgrading and cleaning and urge the transformation of the economic growth mode from extensive to intensive.

(3) Urbanization process: the coefficient of urbanization process was positively significant and below a 5% CL, showing that improving the urbanization process can improve the urban GTFP. Improving the urbanization process can increase the labor force supply, contributing to the accumulation of high-quality talents and an increase in the level of human capita. This brings a huge innovation effect and a spatial spillover effect for regional economic development, motivating an urban green economy to develop. In addition, as new urbanization develops and transforms, urban residents' ideas of low-carbon and environmental protection gradually deepen. The transition of the public governance model of cities can promote the low carbonization of technology, the energy structure industry, lifestyles and patterns of consumption, thus improving the urban GTFP.

(4) Opening-up: the opening-up coefficient was negatively significant and below a 5% CL, demonstrating that the "pollution paradise" hypothesis exists in the basin. The economic development level of the YRB is relatively low; therefore, some local governments tend to reduce environmental standards and induce foreign investment by making the basin a "pollution refuge" for multinational enterprises. The introduction of foreign investment may restrain the urban GTFP in the basin.

(5) Environmental regulations: the regression coefficient for environmental regulation was significantly positive and below a 5% CL, revealing that environmental regulation influences the urban GTFP positively. As the problems resulting from resources and the environment become increasingly obvious in the basin, the governments of cities have strengthened their investment in environmental governance. Additionally, the reasonable agglomeration of various resource elements into the domain of green technology innovation has promoted technological research and development industries with respect to energy saving and environmental conservation, cleaner production and green intelligence and the

collaborative cooperation and innovation between enterprises and industries. The active effect of environmental regulations on the urban GTFP in the YRB has become prominent.

(6) Energy intensity: the regression coefficient of energy intensity was significantly negative and below a 10% CL, revealing that the increase in energy consumption per GDP tends to inhibit the urban GTFP. The industrial structure in the basin, which is governed by the heavy chemical industry, is difficult to change. To some extent, the energy consumption per GDP can express technological progress in reducing pollution and carbon. In the future, cites in the basin should reduce the energy consumption per GDP by altering their economic growth patterns, industrial production patterns and social consumption patterns.

(7) Ecological background. The ecological background coefficient was significant positive and below a 5% CL, revealing that an improvement in green coverage in the built-up area can significantly improve the urban GTFP. The local government should improve the coverage of urban vegetation, build protective forest belts, optimize the layout of green space, enhance the storage capacity of carbon sink and strengthen the control of ecological space, actions which can bring good ecological protection benefits to the cities in the basin.

3.2.3. The Respective Sample Regression of Influencing Factors in Downstream, Midstream and Upstream Cities

In order to explore the factors influencing the respective urban GTFPs in the downstream, midstream and upstream cities in the YRB, this study introduced the CCE to carry out a regression analysis on the panel data from the upstream, midstream and downstream cities in the YRB (as shown in Table 7). The estimated results were reasonable. The RMSE values of cities in the YRB upstream, midstream and downstream were relatively small, and the residual sequence was stationary.

Table 7. CCE estimation results of cities in the YRB upstream, midstream and downstream.

Variables	Upstream Cities	Midstream Cities	Downstream Cities
ED	0.076 *** (12.108)	0.112 *** (8.735)	0.058 *** (4.163)
IS	−0.085 *** (−7.015)	−0.078 *** (−6.193)	0.026 *** (7.432)
UR	−0.015 ** (−2.206)	0.016 * (1.895)	0.195 *** (4.432)
FDI	−0.116 * (−1.707)	−0.158 ** (−2.268)	0.628 ** (2.109)
ER	0.458 ** (2.127)	1.272 *** (4.506)	0.693 *** (5.736)
EI	−0.065 ** (−2.182)	−0.086 * (−1.872)	−0.287 ** (−2.283)
EB	−0.069 * (−1.813)	0.079 ** (2.272)	0.086 ** (2.246)
cons	0.258 (0.726)	−0.383 * (−1.873)	−0.802 (−0.863)
RMSE	0.082	0.075	0.063
CIPS (p value)	0.000	0.000	0.000

Note: ***, ** and * signify significance on levels 1%, 5% and 10%, respectively.

The respective regression results of the factors impacting the urban GTFP of the downstream, midstream and upstream cites in the YRB are demonstrated as follows: (1) the economic development positively influenced the urban GTFP of the upstream, midstream and downstream cites in the basin, which were significantly below 1% CL. These results coincide with those of the overall estimation of the YRB. Improving the regional economic development can significantly advance the regional production technology and energy structure, etc., verifying the importance of economic growth in improving the urban GTFP. (2) The industrial structure went through the significance test below a 1%

CL. The urban GTFP of the upstream and midstream cities was negatively significant, while the industrial structure exerted a remarkably positive effect on the urban GTFP in the downstream, reflecting that the downstream cities have developed a better "light" and "clean" industrial structure and that the common problems resulting from the heavy industrial structure of the upstream and midstream cities were not fundamentally changed. (3) The urbanization process passed the significance test at different levels. The urbanization process had a significantly negative correlation with the urban GTFP of upstream cities but it a significantly positive correlation with the urban GTFPs of midstream and downstream cities, indicating that the improvement of the urbanization process in the midstream and downstream cities advanced the factor agglomeration, thus promoting the urban GTFP. (4) Opening-up was significant, scoring below 1% and 5% CLs, respectively. The impact of opening-up on the GTFPs of upstream and midstream cities was significantly negative, while the impact on the GTFP of downstream cities was significantly positive. This demonstrates that the "pollution paradise" hypothesis exists in upstream and midstream cities, and that the attraction of foreign investment had not brought about an increase in the urban GTFP of this region. (5) Environmental regulation was significant and below 1% and 5% CLs, respectively. All the estimated coefficients were positive in the upstream, midstream and downstream cites, which is in line with the overall evaluation of the basin. This reveals that strengthening environmental regulations may increase the urban GTFP of the basin. (6) The energy intensity exerted a remarkably negative effect on the GTFP of upstream, midstream and downstream cites, and was significant below 5% and 10% CLs, respectively. This is in agreement with the overall estimated results of the basin. Reducing the energy intensity can improve the urban GTFP. (7) The ecological background had a negative correlation with the urban GTFP of the upstream but a notably positive correlation with the urban GTFP of the midstream and downstream cities. The regression coefficients of ecological background were significant and below 5% and 10% CLs, respectively, demonstrating that the impact of the ecological background on the urban GTFP of different regions in the YRB is relatively complex. Due to the intensification of urbanization in the new era and the deep-rooted pollution caused by traditional industries, the improvement of environmental conditions through increasing the coverage of green space in a single dimension was gradually weakened. At present, local governments should coordinate economic development with ecological environment in an all-round way from the sources, channels and terminals of governance.

Considering that there might be a heterogeneity of individuals, missing variables and measurement errors affecting the stability of the regression results, the mean value of the group (MG) and CCE were combined, and the common correlation effect group mean estimation (CCEMG) was used to test the robustness of the urban GTFP in the YRB upstream, midstream and downstream cites. The results demonstrated that the nature and significance of the influence of each factor are basically in agreement with the original regression results, and that the empirical results are reliable (shown in Table 8).

Table 8. Robustness test results.

Variables	Upstream Cities	Midstream Cities	Downstream Cities
ED	0.081 ***	0.107 ***	0.061 ***
	(13.732)	(8.846)	(4.863)
IS	−0.079 ***	−0.069 ***	0.031 ***
	(−8.126)	(−6.792)	(7.684)
UR	−0.012 ***	0.012 *	0.206 **
	(−8.473)	(1.936)	(2.279)
FDI	−0.109 *	−0.147 **	0.583 **
	(−1.726)	(−2.208)	(2.194)

Table 8. *Cont.*

Variables	Upstream Cities	Midstream Cities	Downstream Cities
ER	0.503 **	1.136 ***	0.713 ***
	(2.158)	(5.701)	(5.007)
EI	−0.058 **	−0.076 *	−0.316 **
	(−2.195)	(−1.887)	(−2.247)
EB	−0.071 **	0.082 **	0.079 **
	(−2.116)	(2.209)	(2.185)
cons	0.302 *	−0.327	−0.787
	(1.872)	(0.982)	(−1.006)
RMSE	0.072	0.063	0.049
CIPS (*p* value)	0.000	0.000	0.000

Note: ***, ** and * signify significance on levels 1%, 5% and 10%, respectively.

4. Discussion

4.1. Summary

In accordance with the panel data from 58 cities in the YRB from 2006 to 2020, this paper adopted the Super-SBM model to calculate the urban GTFP, constrained by pollution reduction and carbon reduction, and analyzed its spatiotemporal evolution law, revealed that factors that influence the urban GTFP in the basin and examined the regional heterogeneity of each influencing factor from the perspectives of the upstream, midstream and downstream cities in the YRB. The following findings were obtained:

Firstly, the overall urban GTFP in the YRB is relatively low, showing an evolutionary tendency of first declining and then mounting within the study time range. This was obviously different among regions, with the GTFP being the highest in the downstream, the second highest in the midstream, and the lowest in the upstream. Obvious differences exist with respect to spatial distribution in the urban GTFP in the YRB, demonstrating an increasing trend from the upstream cities to the downstream cities. Secondly, from the perspective of the overall basin, the economic development level, urbanization process, environmental regulations and ecological background have significant positive effects on promoting the urban GTFP, while the industrial structure, opening-up and energy consumption constrain the increase of the urban GTFP of the basin. Finally, from the perspective of the regional heterogeneity of the affecting factors, certain differences exist regarding the influence of diverse factors on the urban GTFP in the YRB downstream, midstream and upstream cities. The improvement of the opening-up and industrial structure can induce the growth of the urban GTFP in the downstream and the improvement of the urbanization process can restrain the urban GTFP in the upstream, while the influence of the ecological background on the urban GTFP of different regions in the YRB is relatively complex.

4.2. Recommendations

Due to the above findings, we offer the following specific recommendations for further promoting the urban GTFP in the basin.

(1) On the basis of the current situation in which the urban GTFP in the basin is generally low, the local governments should promote the dual control of the total amount and intensity of pollution reduction and carbon reduction according to the development stages, natural conditions and resource endowment structure of each city. They should appropriately reduce the proportion of secondary industries concerning petroleum, coal and chemicals, promote the green transformation of key industries regarding petroleum, coal and cement and, in an orderly manner, arrange emerging industries related to new material and electronic information technology according to local conditions in the basin, such as intelligent manufacturing, photovoltaic energy storage, new energy vehicles and bioenergy power generation, etc.

(2) On the basis of the regression results and in terms of the factors influencing the urban GTFP in the YRB, in the current situation of slowdown in economic growth, the local

governments should emphasize the size, structure and functional layout of the urban populations, and the urban population capacity at different development stages and sizes should be scientific and appropriate. Based on the spatial planning of urban agglomerations, economic circles and metropolitan areas, local governments should take measures to accelerate the interconnection of the infrastructure between cities and reduce administrative barriers and transaction costs by promoting the development of urban and regional integration. They should give full play to environmental governance measures such as emissions trading, environmental taxes, environmental damage compensation, environmental resource prices and green procurement, and they should avoid the crowding-out effect resulting from excessive pollution control investment or pollution control intervention. Moreover, they should carry out ecological restoration projects in urban parks, green spaces, wetlands and water areas, improve the urban living environment, increase the carbon sink capacity of ecosystems and help cities to reduce their pollution and carbon emissions.

(3) Based on the regional heterogeneity of the urban GTFP and the affecting factors in the basin, the local governments should, when formulating relevant policies, not only take the basin as a whole and establish a coordinated development mechanism, paying attention to the systematic nature, integrity and coordination of ecological environment conservation and regulation, but also take into account the differences in the YRB's downstream, midstream and upstream cities and implement policies according to local conditions. Furthermore, they should take maximum advantage of the multiple dynamic combination means of the economy, industry, system, innovation, finance and foreign capital, lay emphasis on the time period, strength, rhythm, priority, difference and cooperation between the regulation and control methods, and accurately implement policies according to the specific cities, locations, times and situations.

4.3. Limitations

Although this paper provides some insight into the spatiotemporal features and factors affecting the urban GTFP in the YTB basin under the constraints of pollution reduction and carbon reduction, there were still some deficiencies. This study selected CO_2 and $PM_{2.5}$ emissions as undesired outputs to account for the GTFP without considering other types of pollutants, such as SO_2, wastewater and solid emissions, which might affect the accuracy of accounting for the urban GTFP. In the future, we can expand the data collection channels, optimize data processing and other methods, improve the relevant statistical data, and make the research and analysis more accurate.

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