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Research on China's Inter-Provincial Total Factor Productivity Under the Resources and Environment Constraints

Analysis Based on GML Index Method*

Qiong Zhao
School of Statistics and Mathematics
Zhongnan University of Economics and Law
School of Information Management and Statistics
Hubei University of Economics
Wuhan, China 430073

Zhanfeng Li
School of Statistics and Mathematics
Zhongnan University of Economics and Law
Wuhan, China 430073

Xiaoxue Guo
School of Statistics and Mathematics
Zhongnan University of Economics and Law
Wuhan, China 430073

***Abstract*—Based on the theory of total factor productivity, the directional distance function and the GML index were used to study the changes of total factor productivity in China's 30 provinces and cities from 2004 to 2016 under the constraints of resources and environment. The study found that after incorporating resources and environmental factors into the TFP research framework, the TFP in various regions was reduced to varied degrees. TFP growth in the eastern, central, and western regions decreased by 0.02, 0.29, and 0.1 per cent, respectively, and the national average decreased by 0.1 per cent; panel data regression results show that the level of economic development, endowment structure, resource factors, and foreign investment factors have a significant negative impact on total factor productivity, while industrial structure and technological factors have significant positive effects during the selected sample period. Among them, the largest effect on total factor productivity is the industrial structure and resource factors, and the smallest is the endowment structure.**

Keywords: resources and environment, constraints, total factor productivity, GML index

I. INTRODUCTION

In October 2017, the report of the 19th National Congress of the Communist Party of China pointed out that China's economy has shifted from high-speed growth to high-quality development. The report emphasized the need to insist on "promoting quality change, efficiency change, and power change of economic development, and increasing total factor productivity", as well, "building an ecological civilization, treating the ecological environment like life, and forming a green development approach" is taken as the basic strategy for upholding and developing socialism with Chinese characteristics in the new era.

In fact, from the first time that the "Eleventh Five-Year Plan" of China setting binding targets for energy conservation and emission reduction to the 18th National Congress of the Communist Party of China proposing the "beautiful China", the resources and environment have become not only endogenous variables of economic development, but also rigid constraints on the scale and speed of economic development. Since the "Twelfth Five-Year Plan", China's total investment in environmental pollution treatment has continued to increase each year. In 2013, China's total investment in environmental pollution treatment reached 951.65 billion yuan, an increase of 15.3% over the previous year's 825.35 billion yuan, accounting for 1.67% of GDP, reaching the highest in recent 10 years (National Bureau of Statistics). When socialism with Chinese characteristics enters a new era, how to reasonably add resources and environmental factors to the measurement framework of productivity growth, and study the impact of resource and environmental constraints on the growth of total factor productivity (TFP), have crucial practical significance on improving total factor productivity, achieving resource conservation and environmental protection, and implementing regional coordinated development and sustainable development strategies.

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In recent years, some scholars have tried to incorporate resources and environmental factors into the TFP analysis framework to conduct empirical research on the Chinese economy. Among them, the existing literature treats energy variables more consistently, that is, regards energy consumption as a new input factor and plays its role in sustainable growth. The treatment of pollution emissions is more complicated, and has gone through an evolutionary process of taking no account of and treating as an input element, as an expected output, and as an undesired output.

There are two general ways to measure the impact of pollution emissions on economic performance: one is to treat environmental pollution as a factor input, but there is not much literature. Chen Shiyi [1] introduced the energy consumption and carbon dioxide emissions as input factors to estimate the productivity of China's industrial sub-sectors by introducing a translog production function; Li Shengwen et al. [2] regarded environmental pollution as a harmful input, and adopted a factor synthesis method to classify the three types of pollution and combine into an environmental pollution indicator. It is estimated that China's level of environmental efficiency is low. The second is to treat environmental pollution as an unexpected output, and use the directional distance function and the exponential method to calculate the TFP size. Because this method considers the characteristics of multiple inputs and multiple outputs, it is more consistent with the actual production process and has been widely used. Fang Fuqian [3] used the Malmquist index method to calculate China's agricultural total factor productivity index, and explored the reasons for the difference in agricultural total factor productivity growth. It was found that technological progress in agricultural production is the main reason for the change in agricultural TFP. Pan Dan and Ying Ruiyao [4] used the ML index to measure the growth of China’s agricultural TFP under the constraints of resources and environment, and found that ignoring environmental factors would overestimate the growth of China ’s agricultural TFP. Yin Xiangfei, Liu Changshi [5] used a total factor productivity index (ISP) productivity index method based on input redundancy to measure the total factor productivity of China's manufacturing industry under the dual constraints of environment and mineral resources. It was found that the main driver of factor productivity growth for Chinese manufacturing industry is technical changes. Zheng Lilin, Zhu Qigui [6], etc. incorporated energy and environmental factors into the productivity research framework, and estimated the TFP of various provinces from 1995 to 2010. They believed that the TFP growth concerning environmental constraints was at a low level, and that the inter-provincial total factor productivity showed club-convergence characteristics. Qu Xiao'e [7] used a comprehensive environmental pollution assessment method to synthesize five major pollutants into a comprehensive environmental pollution index. The SBM model was used to examine the total factor productivity of all provinces and municipalities in China during 1996-2009, considering environmental constraints. Zhang Shaohua, Jiang Weijie [8] used the ISP index method to measure and decompose China's TFP from 1985 to 2009, and found that the contribution of TFP to China's economic growth is not low. The difference in TFP is also a key factor explaining the imbalance of regional economic development in China. Li Ping [9] measured the environmental and economic performance of 25 cities in the Yangtze River Delta and Pearl River Delta city clusters from 2000 to 2010 using the SBM model and the Luenberger productivity index method, and analyzed the differences between regions from three aspects: growth mode, environmental technology efficiency, and green productivity. The research found that the two indicators of pure technological progress and technological scale change contributed significantly to productivity growth, the contribution of scale efficiency change was small, and the contribution of pure efficiency change was small or even negative, which proposed two major reasonable suggestions for sustainable development of urban agglomerations. Wang Bing [10] studied the effect and mechanism of energy saving and emission reduction on China's green total factor productivity under the constraints of resources and environment during the period of 1999-2012, and made detailed calculations of energy saving and emission reduction performance. The study found that through promoting technological progress, green total factor productivity growth has been achieved, thereby achieving a win-win situation for the environment and the green economy.

The above mentioned studies that take into account resource and environmental factors have raised the research on total factor productivity to a new level. While teasing out domestic related literature on total factor productivity, it is found that:

From the point of view of index selection, there are not many factors that take into account energy and environmental factors, especially the undesired output index. The TFP values obtained from the same sample period are not consistent, and the results are not of reference significance. See, the DEA index method mostly uses the traditional M index and the ML index that only includes environmental constraints to measure TFP. It ignores the problems that linear programming has no feasible solution, the current ML index causes discontinuities in technological progress, and the sequence ML is not transitive. There are few literatures that use the global DEA linear programming model to further obtain the GML index to estimate the change in TFP. From the perspective of the research object, there have been a lot of studies on inter-provincial, inter-regional, and inter-industry TFP literature. However, due to the availability of data, Reasons such as availability and comparability make domestic research on TFP rarely support each other because of different sample periods. It can be seen that with the continuous enrichment of inspection perspectives and measurement methods, there is still huge space for exploration and research on total factor productivity under the constraints of resource and environment.

This article attempts to extend the existing research in the following three aspects: first, incorporating resources as input factors and environmental pollution as output factors into total factor productivity analysis; second, to avoid the shortcomings of the traditional ML index, combining the directional distance function with the GML index method to recalculate the total factor productivity under the constraints of resources and environment; third, as the uncoordinated regional economic development is mainly reflected in the large differences in the economic development levels of various provinces, the view is positioned in China's provincial regions. The sample period is selected from 2004 to 2016 to explore the influencing factors that cause the differences in total factor productivity growth in various provinces and cities in China impact mechanism to expand the existing literature on inter-provincial TFP.

II. ESTIMATION OF TOTAL FACTOR PRODUCTIVITY

This paper uses the data envelopment analysis (DEA) and index method to measure total factor productivity. This method first uses data envelopment analysis to build a global production possibility set for all decision-making units in the entire period; then constructs a directional distance function to measure the distance between each decision unit in each period to the production front of the production possibility set, and then use this distance to calculate the degree of efficiency change of the decision unit between different periods, expressing by the GML index.

A. GML productivity index

1) Directional distance function: The directional distance function including undesired outputs can reflect the distance between expected and undesired outputs from potential maximum and minimum values. YH Chung [11] and R. Fare [12] give directional distance functions that vary along different directions from the undesired output which reflected expected outputs.

$$\vec{D}_0(x,y,b;g_y,g_b)=\max\{\beta:(y+\beta g_y,b-\beta g_b)\in P(x)\} \quad (1)$$

Among them, $g=(g_y,-g_b)$ is the direction vector that reflects people's different preferences for expected output y and undesired output b. β reflects that compared with the frontier production side, it can maximize the expected output y and reduce the number of undesired outputs b.

2) Global Malmquist index method

The Global Malmquist model is a Malmquist index calculation method proposed by Pastor and Lovell [13]. It takes the sum of all the periods as a common reference set, that is, the common reference set for each period is $P^G=P^1\cup P^2\cup\cdots\cup P^T=\{(x^1,y^1)\}\cup\{(x^2,y^2)\}\cup\cdots\cup\{(x^T,y^T)\}$, because the unit being evaluated must be included in the global reference set, the global Malmquist index does not have the problem of no feasible solution for the VRS model. As the reference for periods is a common global frontier, the global Malmquist index is also transitive and multiplicative. The constructed Global Malmquist index can be decomposed into efficiency changes (EC) and technical changes (TC):

$$\begin{aligned}M_G(x^t,y^t,x^{t+1},y^{t+1})&=\frac{D^G(x^{t+1},y^{t+1})}{D^G(x^t,y^t)}\\&=\frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)}\times\left[\frac{D^G(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})}\times\frac{D^t(x^t,y^t)}{D^G(x^t,y^t)}\right]\\&=EC_G\times TC_G\end{aligned} \quad (2)$$

Among them, $\mathrm{EC_G}$ indicates the degree to which the decision-making unit catches up with the frontier of production during the two periods to reflect the change in relative efficiency. $\mathrm{TC_G}$ indicates the change of the frontier t + 1 compared with the frontier t to reflect the technical change.

Oh [14] combined the Global Malmquist index and the directional distance function, that is, using the global DEA linear programming technique to solve the directional distance function in the ML index. A Global Malmquist-Luenberger (GML) productivity index was constructed and decomposed into efficiency changes and technology changes.

$$\begin{aligned}GML^{t,t+1}(x^t,y^t,b^t,x^{t+1},y^{t+1},b^{t+1})&=\frac{1+D^G(x^t,y^t,b^t)}{1+D^G(x^{t+1},y^{t+1},b^{t+1})}\\&=\frac{1+D^t(x^t,y^t,b^t)}{1+D^{t+1}(x^{t+1},y^{t+1},b^{t+1})}\times\left[\frac{(1+D^G(x^t,y^t,b^t))/(1+D^t(x^t,y^t,b^t))}{(1+D^G(x^{t+1},y^{t+1},b^{t+1}))/(1+D^{t+1}(x^{t+1},y^{t+1},b^{t+1}))}\right]\\&=EC^{t,t+1}\times TC^{t,t+1}\end{aligned} \quad (3)$$

Different efficiency changes are obtained through variable returns to scale and constant returns to scale, which EC are decomposed into pure efficiency changes, scale efficiency changes, and TC are decomposed to pure technology changes and scale technology changes.

$$\mathrm{GML(CRS)=EC(CRS)*TC(CRS)=EC(VRS)*SEC*TC(VRS)*STC} \quad (4)$$

Among them, when $\mathrm{GML,EC,SEC,TC,STC}$ are greater than (less than) 1 indicate that total factor productivity is increased (decreased), pure efficiency is improved (deteriorated), scale efficiency is increased (decreased), pure technological progress (regression), and technological efficiency is increased (decreased).

B. Selection of samples and indicators in TFP calculation

Considering the comparability of input and output indicators and data availability in the process of total factor productivity measurement, excluding Tibet autonomous region and Hong Kong, Macao and Taiwan regions, this paper selects 30 provinces, municipalities and autonomous regions in China from 2004 to 2016 as decision-making units (DMUs) for comparative research. The main indicators involved in the calculation process include the input variables of labor and capital, energy input, expected output and undesired output. The basic data of the selected indicators are from the statistical yearbooks of the provinces, China Statistical Yearbook, China Environmental Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook, and the National Bureau of Statistics database.

1) Labor input: The labor factors are expressed in terms of the number of employees in each province and municipality over the years.

2) Capital input: As the data of capital stock cannot be obtained directly, this paper draws on Dan Haojie's (2008) extrapolated data and formulas to calculate the capital stock of each province from 2004 to 2016 by the perpetual inventory method. The calculation process is:

$$K_t = I_t + (1-\delta)K_{t-1} \quad (5)$$

Among them, K_t is the capital of the period t, I_t is the amount of investment t, and δ is the depreciation rate. Among them, the capital stock in the base period is calculated by dividing the total fixed capital formation in the base period by the average growth rate plus the depreciation rate[1]. In the process of calculating the capital stock of each province, Chongqing and Sichuan are merged.

3) Energy input: Due to the differences in the types of energy consumption in various provinces, the total energy consumption of various energy sources is converted into 10,000 tons by discounting the standard coal coefficient with 11 types of energy including coal energy, oil energy, liquefied petroleum gas and electricity, and then the total energy consumption is added as energy input.

4) Expected output: The expected output is the actual GDP of each province. To ensure comparability, the GDP deflator is used to adjust the actual GDP of each province to *a constant price in 2004.*

5) Unexpected output: As the main pollutants for which emission reduction targets were explicitly put forward during the "Eleventh Five-Year Plan" period were COD, SO2, ammonia nitrogen, and hydroxides, taking into account the availability of data, the COD and SO2 emissions of each province were used. "Table I" describes the basic statistical characteristics of annual labor, capital, energy, COD and SO2 emissions in the 30 provinces from 2004 to 2016.

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[1] Based on the theory of perpetual inventory method, the error in estimating the capital stock of the base period will affect the estimation of subsequent years. To reduce the impact, the earlier year of 1978 is used as the base period. Considering the availability of data, the total fixed capital formation in 1978 is divided by the sum of the average investment growth rate and depreciation rate of 0.1096 over a 5-year period. The capital stock in 1978 is calculated and then adjusted to the price parity based on 2004 based on the price index capital stock.

TABLE I. STATISTICAL CHARACTERISTICS OF ORIGINAL VALUES OF VARIABLES

	Unit	Sample number	Mean value	Standard deviation	Minimum value	Maximum value
Labor	10,000 people	390	2577.74	1699.44	290.42	6726.00
Capital	0.1billion yuan	390	31035.8	27017.35	1396.148	149689.2
Energy	10,000 tons of std coal	390	12369.96	7960.68	742.48	38899.25
Regional GDP	0.1billion yuan	390	12072.72	10882.15	466.1	62401.16
COD	10,000 tons	390	56.95	40.34	3.93	198.25
SO2	10,000 tons	390	71.52	43.87	1.70	200.20

C. The estimation and decomposition of TFP

The GM and GML productivity indexes of 30 provinces and autonomous regions from 2004 to 2016 were calculated in this paper. Both of them are the Malmquist index calculated under the same reference set. The difference is that the former is based on the energy input and the non-expected output. EC and TC represent two decomposition components: efficiency change and technology change. When GML index greater than 1 indicates an increase in productivity, less than 1 indicates a decrease in productivity, and so does the meaning of EC and TC. Because each decision-making unit calculates a corresponding index every two years, which is limited to space, this paper only makes a comparative analysis of its geometric mean value. The calculated results are shown in "Table II".

According to the GM and GML indexes and their decomposition results for provinces in "Table II", the characteristics are concluded as below.

1) The impact of resource and environmental constraints on productivity: The GML index considering energy input and non-expected output generally does not exceed GM index, among which the GML index of 27 provinces is less than or equal to GM index, and only 3 provinces have GML index more than GM index, indicating that the level of total factor productivity growth will be overestimated when the resource environment is not considered. The GML index of Heilongjiang, Liaoning and Shanxi provinces is larger than that of GM, which shows that the strong constraint of reducing energy consumption and pollution emission has a positive effect on the productivity growth of economic subjects. The mechanism of action is that, although taking up production resources and increasing the cost of environmental management will cause economic losses to economic subjects, this constraint can also stimulate economic subjects to invest more in R & D. It leads to technological innovation, which in turn promotes technological progress and efficiency improvement. In addition, considering the change of ML index, the growth of TFP in the east, middle and west region decreased by 0.02, 0.29 and 0.1 percentage points, respectively, and the national average decreased by 0.1 percentage points.

TABLE II. THE INDEXES AND DECOMPOSITION OF GM AND GML

Region	Does not consider resources and environmental factors			Consider resources and environmental factors		
	GM	*GMEC*	*GMTC*	*GML*	*GMLEC*	*GMLTC*
Anhui	0.998	0.998	1.001	0.994	0.992	1.002
Beijing	1.045	1.000	1.045	1.045	1.000	1.045
Fujian	0.993	0.985	1.008	0.992	0.984	1.007
Gansu	0.998	1.012	0.986	0.991	0.992	0.998
Guangdong	1.007	0.999	1.009	1.007	0.999	1.009
Guangxi	0.956	0.956	1.000	0.956	0.956	1.000
Guizhou	0.992	1.005	0.988	0.983	0.989	0.994
Hainan	0.982	0.974	1.008	0.978	0.968	1.010
Hebei	0.988	0.993	0.995	0.984	0.980	1.005
Henan	0.976	0.974	1.002	0.968	0.962	1.006
Heilongjiang	0.973	0.980	0.993	0.973	0.980	0.993
Hubei	0.992	0.992	1.000	0.989	0.988	1.001
Hunan	0.984	0.986	0.997	0.980	0.982	0.998
Jilin	0.964	0.964	1.000	0.964	0.964	1.000
Jiangsu	1.014	0.996	1.018	1.014	0.996	1.018
Jiangxi	1.002	0.998	1.005	1.002	0.998	1.005
Liaoning	0.979	0.978	1.001	0.980	0.973	1.007
Inner Mongolia	0.989	0.984	1.005	0.989	0.983	1.007
Ningxia	0.961	0.960	1.001	0.958	0.953	1.006
Qinghai	0.971	0.970	1.001	0.961	0.952	1.009
Shandong	1.003	0.998	1.005	1.001	0.989	1.012
Shanxi	0.981	0.984	0.997	0.982	0.980	1.001
Shannxi	0.982	0.980	1.002	0.980	0.977	1.003
Shanghai	1.020	1.000	1.020	1.020	1.000	1.020
Sichuan	1.028	1.030	0.998	1.027	1.027	1.000
Tianjin	1.004	0.996	1.008	1.004	0.996	1.008
Xinjiang	0.995	0.991	1.004	0.995	0.991	1.004
Yunnan	0.983	0.979	1.004	0.978	0.970	1.008
Zhejiang	1.020	1.001	1.019	1.020	1.000	1.020
Chongqing	1.065	1.015	1.049	1.065	1.015	1.049
The eastern area	1.008	0.998	1.009	1.008	0.994	1.014
The middle area	0.983	0.983	0.999	0.980	0.980	1.000
The western area	1.002	1.004	0.998	1.001	1.002	0.999
The nation	1.000	0.996	1.004	0.999	0.993	1.006

a. Data source: the data in the table is output using MaxDEA6.18 software.

2) From the perspective of sub-region: There is a significant difference in the growth of TFP in the eastern and western regions. The geometric mean of the GML indexes are 1.008, 0.980 and 1.001, respectively, indicating that the average productivity of the eastern and western regions has increased while that of the central regions has decreased, as shown in "Fig. 1".

As can be seen from "Fig. 1", the TFP of 11 provinces in the east is almost all above 0.98, the TFP of Hainan is 0.978, which is the smallest in the east. There are 6 of 8 provinces in the west are below 0.98, and 3 of 11 provinces in the middle are below 0.98. The GML indexes of Beijing, Guangdong, Jiangsu, Shandong, Shanghai, Tianjin, Zhejiang, Jiangxi, Sichuan and Chongqing are larger than 1, indicating that TFP is growing, while the GML indexes of Henan, Heilongjiang, Jilin, Guangxi, Ningxia, Qinghai and Yunnan are less than 1 and less than 0.98. It can also be seen that the TFP indexes of some areas with abundant resources are less than 1. For example, the GML indexes of Shanxi, Inner Mongolia and Henan, where are rich in coal resources, are between 0.96-0.99, which indicate that the over-use of energy and the reduction of environmental quality have an adverse effect on the regional TFP.

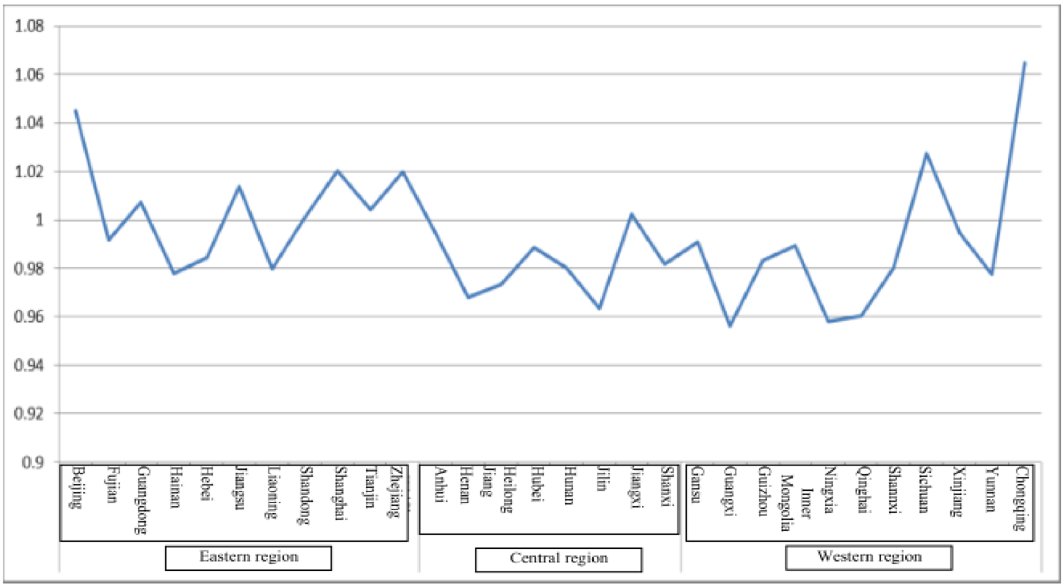

Fig. 1. Distribution of GML geometric mean of provinces and cities

3) From the point of view of the sources of TFP growth: The technological efficiency of the other nine provinces and cities except Sichuan is less than the value of technological progress in the 10 regions where TFP is growing. From the east, middle, west regions and the National GML index, only the western technical efficiency index is higher than the technical progress index, which indicates that the technological progress is the main driving force of the average TFP growth in these regions.

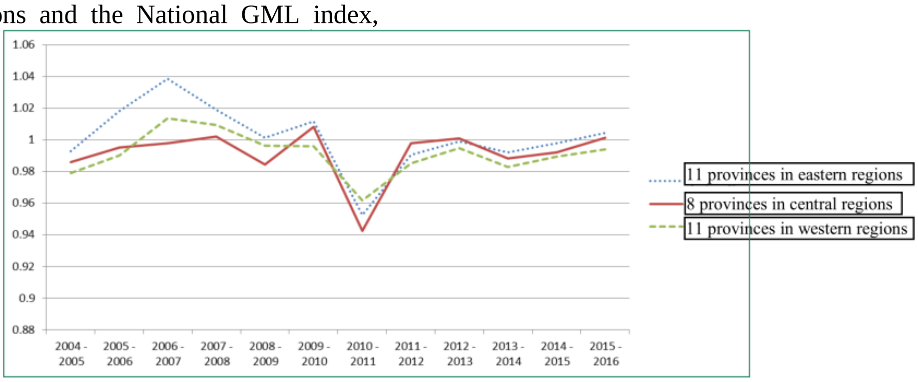

Fig. 2. The variation trend of GML geometric mean value in three major regions

4) In terms of time trend: The variation characteristics of TFP in East-West China during 2004-2016 are shown in "Fig. 2". It can be seen that the changes of TFP in the three regions show the common phase characteristics: the value of TFP increased steadily in 2004-2007, and roughly presented a decreasing trend in 2007-2011. After a slight rise in 2009, it fell to the lowest point in 2010, and recovered steadily after 2011, and fluctuated slightly in the range of (0.98,1). This trend change is closely related to the change of pollution emissions in corresponding years, the implementation of environmental protection policies, and the global economic environment. After the State Council issued the Decision on Implementing the Scientific Outlook on Development to Strengthen Environmental Protection in early 2005, the State Environmental Protection Administration and the Development and Reform Commission formulated the Eleventh Five-Year Plan for National Environmental Protection, which identified sulfur dioxide and chemical oxygen demand as the main environmental protection indicators, and explicitly put forward the major pollutant sulfur dioxide by 2010. The total amount of chemical oxygen demand (COD) emissions is 10% below the control target for 2005. Since then, the trend of rising pollution emissions has been alleviated, and the situation that the industrial structure is unreasonable, the mode of economic growth is extensive, and the environmental protection lags behind economic development has been reversed. With the emergence of the global financial crisis in 2007-2008, the growth rate of the domestic economy experienced a short-term decline, and only then recovered under the stimulus of active fiscal policy, which was relatively stable after 2011. The dynamic change of pollution emission is consistent with the fluctuation of TFP in three regions, which further shows that the non-expected output cannot be neglected in the measurement of TFP.

III. THE INFLUENCING FACTORS ANALYSIS OF TOTAL FACTOR PRODUCTIVITY

A. *Econometric model construction*

In economic growth theory, the input factors of production need are roughly divided into three categories: capital, labor and technical level. However, the factors that affect TFP vary from economy entities. First of all, economic scale is the basis of production. China is in the transition period of adjusting structure and promoting growth. The endowment structure and industrial structure of each region have direct influence on productivity. Secondly, the endogenous economic growth theory shows that the internal biochemistry of technological progress is an important factor affecting the long-term growth of economy, and the technological progress is characterized by the improvement of quality and the increase of product type. In Schumpeter (1934) quality ladder model, based on the positive or negative relationship between the current technology level and the highest quality level, it is concluded that the advanced R & D sector and the non-advanced sector have different expected growth rates, which will lead to the growth rate of the whole economy rising or falling, so R & D technology has an important effect on productivity. Third, the experience since reform and opening-up shows that FDI (FDI) is conducive to expanding production scale, bringing advanced management concepts and improving technical efficiency, so FDI is used to measure the degree of economic extroversion. Finally, the carrying capacity of resources and environment has become the rigid constraint of China's economic development. On the one hand, energy-saving and emission reduction will increase the cost, on the other hand, appropriate policy guidance and regulation may force enterprises to lead to technological innovation. In addition, resources and environmental factors should also be taken into account in productivity analysis based on the results of previous TFP measurements.

Referring to the previous research results and the relevant factors involved in the above economic growth theory, and considering the data availability and comparability, this paper divides the factors affecting the total factor productivity into two aspects: self-factor and foreign-factor, and analyzes the GML index which can directly measure the growth of the total factor productivity in 30 provinces, cities and regions of China.

Since the GML index is the ratio of the optimal solution of the adjacent two-phase linear programming calculated under the common reference set in each period, it is a relative variable, so all the variables involved are adopted to relative variables. The specific indicators are as follows.

Self-factor: (1) The level of economic development: in terms of per capita gross domestic product (PGDP), it is discounted to a constant price in 2004. (2) Structural factors: endowment structure is expressed as capital-labor ratio (KL); industrial structure is expressed as industrial added value as a percentage of GDP (INDY). (3) Resource and environment factors: resource factors are expressed as the percentage of provincial coal consumption to total energy consumption (COALE); environmental factors are expressed as the proportion of environmental pollution control investment to GDP (CY). (4) Science and technology factors: expressed as internal expenditure as a percentage of GDP of R & D funding of research and development institutions (RDY).

Foreign factors: Foreign capital factors are expressed as the percentage of actual foreign direct investment in GDP (FDIY).

The constructed regression equation is:

$$\mathrm{GML}_{it} = \alpha_1\mathrm{PGDP}_{it} + \alpha_2\mathrm{KL}_{it} + \alpha_3\mathrm{INDY}_{it} + \alpha_4\mathrm{COALE}_{it} + \alpha_5\mathrm{CY}_{it} + \alpha_6\mathrm{RDY}_{it} + \alpha_7\mathrm{FDIY}_{it} + \mathrm{u}_i + \varepsilon_{it} \quad (6)$$

Among them, u_i represents the intercept term of individual heterogeneity, ε_{it} is the disturbance term, and the regression result is shown in "Table III".

B. *Empirical analysis*

At first, the appropriate model is selected to analyze the influencing factors of GML according to the test results. For the mixed regression and fixed effect, because of the F-test result P = 0.000, the fixed effect model is superior to the mixed regression, and further using the least square virtual variable method, many individual virtual variables are significant at the level of 5%, indicating the existence of individual effect, and should not using the mixed regression. On this basis, considering the time effect, most of the annual virtual variables are significant at the 5% level, indicating that there is still a time effect. Because of the robust Hausman test result P = 0.0039, the null hypothesis of "the existence of individual random effects" was rejected, and a fixed effect model should be used. To sum up, the individual time bidirectional fixed effect model was eventually selected, and the regression results see "Table III".

TABLE III. REGRESSION RESULTS OF THE TWO-WAY FIXED-EFFECTS MODEL OF GML INFLUENCING FACTORS

Explanatory variable	**Coefficient**	**Explanatory variable**	**Coefficient**
PGDP	-0.366***	CY	-0.0129
	(0.000)		(0.150)
KL	-0.00687***	RDY	0.260***
	(0.000)		(0.000)
INDY	0.416***	FDIY	-0.0106**
	(0.003)		(0.042)
COALE	-0.373***	cons	-66.54***
	(0.001)		(0.000)
F-test		P=0	
Hausman Test		P=0.0039	

a. Note: P values in parentheses, *, **, *** means significant at 10%, 5%, 1% levels

Next is the analysis of model results. According to "Table III" and "Table IV", the influences of economic development level PGDP, endowment structure KL, industrial structure INDY, science and technology factor RDY, resource factor COALE, foreign capital factor FDIY on total factor productivity are statistically significant, while the environmental factor CY is not significant.

Per Capita GDP has significant negative effect on TFP increase. Taking into account of the constraints of resources and environment, the TFP growth is constrained. In fact, since the reform and opening up to the outside world, China has formed an economic development model which relies too much on factor input. While pursuing the economic growth rate, it is often accompanied by extensive use of factors of production, high consumption of resources and rapid increase of pollution, which leads to the decrease of TFP with the increase of GDP per capita and no substantial improvement of technical efficiency. With the increase of energy efficiency, the pollution emission control of TFP will be improved, which can be verified by the comparison of GM and GML indices in the eastern and western regions.

The effect of capital-labor ratio on the growth of TFP is negative. The capital-labor ratio is a specific index to measure the degree of capital intensity. To raise the capital-labor ratio means that the input of material capital is higher than the input of labor force, thus the capital composition of enterprises is improved. In production, as labor costs rise, companies purchase more machinery and equipment to replace labor. However, under the condition of the constant quality of the laborer, the efficiency of the production process will decrease due to the decrease of the coordination degree between man and machine, and thus the technical efficiency will be reduced. In addition, if the capital-labor ratio continues to rise and the excessive capital keeps deepen, that will cause the economic structure to shift towards the development of capital-intensive industries with high energy consumption and high pollution, thus negatively affects the growth of TFP.

The impact of industrial added value as a percentage of GDP on TFP growth was significantly positive. At the beginning of the process of industrialization, the economy depends on the increase of the added value of industry to develop rapidly. Its characteristics of high energy consumption and high pollution will inevitably aggravate the contradiction between energy supply and demand and environmental pollution, and then restrict the growth of total factor productivity. However, with the rapid advance of industrialization and urbanization, the total amount of energy consumption will continue to increase and the amount of pollutants produced will continue to increase. The environmental constraint of economic growth has been strengthened day by day. The Party Central Committee and the State Council will speed up the construction of a resource-conserving and environment-friendly society as an important part of the implementation of the Scientific Outlook on Development. This will fundamentally accelerate the transformation of the mode of economic development to "high efficiency, low energy consumption and low emissions", making TFP growth the main driving force for industrial development.

Coal as a percentage of total energy consumption has a significant negative effect on the change of TFP. Energy is an important input factor in the process of economic development, and coal, as the main primary energy, has a serious negative impact on the environment. Through market forces, enterprises can optimize energy structure independently, improve energy utilization efficiency and reduce the proportion of coal in total energy consumption, which can effectively improve the total factor productivity in resource environment. The statistical test shows the importance of optimizing energy consumption structure to economic growth.

The impact of the proportion of environmental pollution treatment investment to GDP on the change of TFP is negative, but not significant. Environmental pollution treatment will occupy production resources, raise management costs and lead to a certain degree of economic losses. It is detrimental to the growth of TFP by only increasing investment in environmental pollution control. Only when the productivity effect of energy saving and emission reduction is greater than the economic loss effect caused by it, can the economic subject be stimulated to strengthen the innovation of environment-friendly technology. Promote technological progress to achieve a productivity-driven development model.

The R&D internal expenditure of research and development institution as a proportion of GDP has a significant positive effect on the change of TFP. Increasing R & D input can raise the level of science and technology, and promote the technological progress in the field of production, making the output of a given factor input greater, and the most direct effect of the improvement of technical efficiency. Further, the improvement of R & D capacity and technological innovation capability in one region will have a positive spillover effect on other regions, thus promoting the continuous growth of TFP as a whole.

The actual use of foreign direct investment as a percentage of GDP has a significant negative effect on the change of TFP. The impact of foreign direct investment on productivity is shown in two aspects: technology spillover and environmental pollution. In the international trade market where international division of labor is conducted according to comparative advantage, higher standards and requirements for products from countries with technological progress will force export enterprises to improve their production technology and thus improve their efficiency, but at the same time, the introduction of foreign-funded enterprises with poor technology will lead to labor-intensive export. Low technology-intensive products will not only consume a large amount of resources in the host country, but also pollute the environment. Therefore, when the technology spillover effect of FDI cannot offset the resource and pollution effect of foreign-funded enterprises, it will restrain the growth of TFP instead. Although the statistical significance is obvious, we should select those foreign-funded enterprises that can really promote technological progress and improve productivity when introducing foreign capital.

IV. Conclusion

According to the expectancy of the theory, the inevitable way out for China to achieve sustainable development is to shift the pattern of economic growth to one based on increasing total factor productivity, especially those related to technological progress. Improving the allocation efficiency of resources such as labor, capital including material and human capital is one of the ways to improve the total factor productivity, while the technological progress brought by institutional factors, R & D and introduction technology can improve the micro-production efficiency of enterprises, which are the main components of the total factor productivity. Energy input and environmental factors are important factors that affect the improvement of total factor productivity.

Based on the panel data of 30 provinces and autonomous regions in China from 2004 to 2016 and using the global DEA model, this paper calculates the GML index and its decomposition components after considering resources and environmental factors, so as to measure the growth of total factor productivity in China's inter-provincial areas, and then makes an empirical analysis of the influencing factors, and draws the following conclusions.

First, the impact of resource and environment constraints on productivity is objective and cannot be ignored in the framework of total factor productivity research.

- The total factor productivity index when considering resources and environmental factors generally does not exceed the total factor productivity index when not considering resources and environment, so it is more in line with the reality of economic development to include resources and environmental factors;
- From the sub-region perspective, there are significant differences in TFP growth between eastern and western regions, and the over-use of energy and the reduction of environmental quality have adverse effects on TFP in resource-rich areas;
- From the point of view of the sources of TFP growth, technological progress is the main driving force of TFP growth, followed by technical efficiency in 10 regions with TFP growth trend of east, west and national GML index.

Secondly, there are some differences in the direction and size of total factor productivity growth affected by different factors.

- The level of economic development, endowment structure, resource factors and foreign capital factors are able to restrict the growth of total factor productivity.
- Industrial structure and scientific and technological factors can promote the growth of total factor productivity. Among them, the industrial structure has the greatest effect on the growth of total factor productivity, and the endowment structure is the smallest.
- The influence of environmental factors is not statistically significant, indicating that the impact of environmental governance investment on total factor productivity growth in the sample period selected in this paper is not clear, which is related to the limited access of environmental data.

Based on the above conclusions, this paper puts forward the following policy suggestions on how to improve China's total factor productivity, realize sustainable development and coordinate the development of economy, society and resources and environment.

First, in view of the difference between GM and GML, when evaluating the regional economic performance and social efficiency level of provinces and cities, we should give full consideration to the environmental factors of resources and attach great importance to the impact of resource input and environmental pollution on economic development.

Second, from the perspective of constraints, the improvement of the level of economic development may not necessarily improve the TFP. Under the environment of rapid industrialization and urbanization and increasingly strengthened environmental constraints of economic growth, the state should not blindly pursue the increase of GDP per capita, but take into account the requirements of the transformation of the mode of economic development. While, the state should rationally allocate the capital-labor ratio and increase the labor productivity of the labor force from the micro-level. In order to promote the growth of TFP, the energy structure should be optimized, increasing the use proportion of clean energy in total consumption, making full and effective use of energy, improving environmental pollution, taking a rational view of the role of foreign investment in economic growth, ensuring the quality of foreign investment, setting the threshold for entry of high energy consumption and high pollution industries, so as to bring into play the advanced production technology and management experience of Chinese enterprises and promote technological progress.

Third, from the perspective of TFP promoting factors, the industrial structure should be optimized, giving priority to the development of resource-conserving industries, accelerating the transformation of economic development mode to "high efficiency, low energy consumption and low emission", and stimulating the economic main body to strengthen the effective R & D force of science and technology, strengthening the innovation of environment-friendly technology, promoting technological progress and efficiency improvement.

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