ATLANTIS PRESS

Advances in Economics, Business and Management Research, volume 159

Fifth International Conference on Economic and Business Management (FEBM 2020)

Empirical Research of China's Environmentally Adjusted Total Factor Productivity

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ABSTRACT

Total factor productivity is a key indicator for achieving sustainable economic growth and high-quality development in China. Traditional TFP calculations do not include natural resources and environmental pollution into the accounting framework, and the calculated TFP is usually overestimated. This paper calculates the environmentally adjusted total factor productivity (EATFP). The results showed that from 2001 to 2007, the unadjusted TFP growth rate was relatively high, mainly due to the technological progress brought about by China's institutional reforms such as opening up and joining the WTO. Since 2008, in response to the international financial crisis, China has implemented a four trillion stimulus policy, which has led to a reduction in the efficiency of resource allocation, a low effective investment ratio, and a large decline in total factor productivity growth. The total factor productivity adjusted for environmental factors maintained a low growth rate even during the period 2001-2007 when the reform dividend was continuously released, indicating that China's economy has always been extensively developed, and the rapid economic growth is at the cost of environmental damage.

Keywords: *Total factor productivity, environmental factor adjustment, slow growth accounting*

1. INTRODUCTION

The report of the 19th National Congress of the Communist Party of China included "improving total factor productivity" in the report of the Party Congress for the first time. At the same time, the report of the 19th National Congress of the Communist Party of China no longer clearly defines the goal of economic growth, but puts more emphasis on high-quality growth. It clearly takes the supply-side structural reform as the main line to promote changes in economic development quality, efficiency and dynamics, and improve total factor productivity. The total factor productivity is a key indicator for achieving sustainable economic growth and high-quality development in China. The main reason for the slowdown in economic growth since 2012 is the decline in the growth rate of the working population and total factor productivity. In fact, China's total factor growth rate has declined since the financial crisis, and the better growth performance of China's economy compared with other economies during 2009-2011 has benefited to a certain extent from the large-scale stimulus plan implemented in response to the financial crisis. Although the stimulus measures have alleviated the negative impact of the financial crisis and the European debt crisis in the short term, they have not reversed the long-term trend of declining economic growth. Moreover, after the gradual withdrawal of stimulus measures, the effect of "stabilizing growth" is difficult to sustain, but the negative impact on productivity still exists. When the phased tasks of "three removals, one reduction and one subsidy" are completed, the elimination of backward production capacity will provide space for the development of new kinetic energy, the real estate bubble will be effectively resolved, and financial risks will be effectively controlled. Next is the medium and long-term task to optimize the allocation and combination of production factors such as technology, capital, and labor, improve the utilization efficiency of production factors, promote the increase of total factor productivity, and continuously strengthen the endogenous growth momentum of the economy. Therefore, in the medium and long term, supply-side structural reforms will increase the potential growth rate of China's economy and promote sustainable economic development by increasing total factor productivity.

Total factor productivity (TPP) accounting methods can be divided into two categories: one is the growth accounting method, and the other is the frontier function method based on technical efficiency. Among them, the growth accounting method is mainly the Solow growth accounting method, and the frontier function method mainly includes data envelopment analysis (DEA), malmquist index method and Stochastic Frontier Analysis (SFA). China's research on total factor productivity started later than developed countries, with fewer innovations in theoretical research and measurement methods, and mainly relied on mature foreign models. Liu Jianguo et al. [1] combed the TFP from two aspects: theoretical development and empirical research, and believed that theoretical research still has shortcomings, and at the same time, there is a lack of empirical research at the national level and the policy system is relatively weak. Yu Kang et al. [2] reviewed the literature of empirical research on China's agricultural total factor productivity from 1989 to 2009, and found that the measurement methods concentrated on the production function method, the growth accounting index method, the DEA-Malmquist method and the SFA method. Ye Gui et al. [3] believe that there are many types of evaluation methods used in TFP measurement in the construction industry, and DEA-Malmquist and transcendental logarithmic production function methods are most used. Su Weihua [4] used TFP as a measure of the quality of economic growth, measured the difference in the quality of economic growth between the Yangtze River Delta and the three northeastern provinces, and found that whether capital accumulation can achieve a positive interaction with TFP is the key to the quality of economic growth. Traditional TFP calculations do not include natural resources and environmental pollution into the accounting framework, which obviously cannot fully describe the development of the entire society. The TFP calculated by this method is usually overestimated. If this is used to guide the formulation of China's sustainable development policy, it may once again embark on the old path of emphasizing economy, neglecting environmental protection, emphasizing speed and neglecting quality. Therefore, it is necessary to develop a new indicator that is superior to traditional TFP calculations to measure China's economic development more scientifically.

2. EATFP CALCULATION METHOD

In 2018, the OECD [5] released the Environmentally Adjusted Total Factor Productivity (EATFP), which is its latest research result in the field of total factor productivity measurement, and has been included in the OECD Green Development Indicator System. This indicator incorporates a variety of natural resources and environmental pollution into the traditional TFP growth accounting framework, and uses econometric regression methods to conduct a more comprehensive, scientific, and green total factor productivity calculation for 51 countries and regions. From the perspective of research methods, compared with the methods based on data envelopment analysis (DEA) and stochastic frontier analysis (SFA) used in most domestic documents, the method of measuring EATFP adopted by the OECD is based on the growth accounting framework of Solow residuals. The research ideas of total factor productivity obtained from the growth accounting framework are more concise, and the research conclusions are more comparable.

2.1. Theoretical Basis

According to the transfer function $H(Y,R,K,L,t) \geq 1$, H represents the combination of input and output when production is efficient, where Y represents expected output, R represents undesirable output, K represents capital, L represents labor, and t represents time. Take the logarithmic form of the transfer function H and differentiate t, we get:

$$\frac{d\ln H(Y,R,K,L,t)}{dt} = \frac{\partial \ln H}{\partial Y}\frac{\partial Y}{\partial t} + \frac{\partial \ln H}{\partial R}\frac{\partial R}{\partial t} + \frac{\partial \ln H}{\partial K}\frac{\partial K}{\partial t} + \frac{\partial \ln H}{\partial L}\frac{\partial L}{\partial t} + \frac{\partial \ln H}{\partial t} = 0 \quad (1)$$

According to $\partial \ln U = \frac{\partial U}{U}$ to organize formula (1), we get

$$\frac{\partial \ln H}{\partial t} = -\frac{H_Y Y}{H}\frac{\partial \ln Y}{\partial t} - \frac{H_R R}{H}\frac{\partial \ln R}{\partial t} - \frac{H_K K}{H}\frac{\partial \ln K}{\partial t} - \frac{H_L L}{H}\frac{\partial \ln L}{\partial t} \quad (2)$$

Among them, $H_U = \frac{\partial H}{\partial U}$, so $\frac{H_U U}{H}$ is the elastic coefficient, expressed by ε_{HU}, and the formula (2) can be expressed as:

$$\frac{\partial \ln H}{\partial t} = -\varepsilon_{HY}\frac{\partial \ln Y}{\partial t} - \varepsilon_{HR}\frac{\partial \ln R}{\partial t} - \varepsilon_{HK}\frac{\partial \ln K}{\partial t} - \varepsilon_{HL}\frac{\partial \ln L}{\partial t} \quad (3)$$

According to the existing research results, under the premise of maximizing the profit of the producer (or minimizing the cost), the elastic coefficient of output is equal to the proportion of output value of various types of output, and the elastic coefficient of input is equal to the proportion of cost of various inputs. Formula (3) can be rewritten as:

$$\frac{\partial \ln H}{\partial t} = \frac{p_Y Y}{\rho}\frac{\partial \ln Y}{\partial t} + \frac{p_R R}{\rho}\frac{\partial \ln R}{\partial t} - \frac{p_K K}{\gamma}\frac{\partial \ln K}{\partial t} - \frac{p_L L}{\gamma}\frac{\partial \ln L}{\partial t} \quad (4)$$

Among them, p_Y is the price of expected output, p_R is the price of undesirable output ($p_R < 0$), $\rho = p_Y Y + p_R R$; p_K represents the price of capital, p_L represents the price of labor, $\gamma = p_K K + p_L L$.

Define the calculation formula of TFP growth rate as:

$$\frac{\partial \ln EATFP}{\partial t} \equiv \frac{\partial \ln Y}{\partial t} - \varepsilon_{YR}\frac{\partial \ln R}{\partial t} - \varepsilon_{YK}\frac{\partial \ln K}{\partial t} - \varepsilon_{YL}\frac{\partial \ln L}{\partial t} \quad (5)$$

Shifting the term of formula (5) to obtain:

$$\frac{\partial \ln Y}{\partial t} - \varepsilon_{YR}\frac{\partial \ln R}{\partial t} = \frac{\partial \ln EATFP}{\partial t} + \varepsilon_{YK}\frac{\partial \ln K}{\partial t} + \varepsilon_{YL}\frac{\partial \ln L}{\partial t} \quad (6)$$

The left side of formula (6) represents the growth of adjusted output, and the right side represents the contribution of EATFP, K, and L growth to the adjusted growth.

2.2. Data Processing

(1) Capital input

This article uses capital stock to measure capital input. The specific method for calculating capital stock is the perpetual inventory method. The calculation formula is:

$$K_t = K_{t-1}(1 - \delta_t) + I_t \quad (7)$$

Among them, δ_t is the depreciation rate, and I_t is the investment amount. Because when using the perpetual inventory method to measure the capital stock, the earlier the start time is selected, the more accurate the later capital stock measurement results will be. Therefore, this article only needs to use the capital stock data after 1991, but for more accurate considerations, still use 1952 as the base year for calculation. The capital stock in the base year uses the value adopted by Zhang Jun [6], the depreciation rate is 9.6% (When calculating the depreciation rate, the investment in fixed assets is divided into three categories: construction and installation engineering, purchase of equipment and tools, and other expenses. According to their respective life periods, the depreciation method of declining geometric efficiency is used to calculate the depreciation rates of the three types of fixed asset investments, and then weighted by the proportions of the three types of investments to obtain the total fixed capital formation depreciation rate.), and the investment amount is the total amount of capital formation, which is converted by the actual growth rate of total capital formation in 1952 as the base year.

(2) Labor input

Considering the availability of data, this article uses the labor force. That is, the number of employees in three industries.

(3) Expected output

Refer to the practice of OECD (2018) and most domestic research documents, and use constant price GDP as the expected output indicator.

(4) Undesirable output

Considering the availability of data, this paper only considers CO_2 emissions when measuring undesirable output. The specific data directly uses China's CO_2 emissions over the years in the World Bank's WDI database.

(5) Coefficient of elasticity

When calculating the coefficient of elasticity of capital input and labor input, this paper assumes that the return to scale is constant, the ratio of labor compensation to GDP is used as the labor elasticity coefficient, and the proportion of the difference between GDP and labor compensation in GDP is used as the capital elasticity coefficient.

When calculating the elastic coefficient of undesirable output, because p_R is unknown, this paper uses quantitative regression to determine the elastic coefficient of pollution emissions.

Define X as the total investment combination of K and L:

$$\frac{\partial \ln X}{\partial t} = \varepsilon_{HK}\frac{\partial \ln K}{\partial t} + \varepsilon_{HL}\frac{\partial \ln L}{\partial t} \qquad (8)$$

By shifting and adjusting formula (9), we get: Combine formulas (4) and (8) to get the required model equation, define $U = \frac{\partial \ln U}{\partial t}$, then formula (4) can be expressed as:

$$H = \frac{p_Y Y}{\rho} Y + \frac{p_R R}{\rho} R - X \qquad (9)$$

Shift and adjust the formula (9) to get:

$$Y - X = \alpha' + a(R - X) \qquad (10)$$

In this paper, formula (10) is used as a model for regression analysis, and the elastic coefficient of pollution emission is 0.342.

3. CALCULATION AND APPLICATION OF EATFP IN CHINA

According to formula (6), the GDP growth rate after excluding CO_2 emissions (hereinafter referred to as adjusted GDP) is calculated. The adjusted average GDP growth rate of China from 1991 to 2017 is 7.8%, which is 2.0% lower than the average GDP growth rate. According to formula (5), the EATFP growth rate is calculated. The average growth rate of EATFP in China from 1991 to 2017 is 0.6%, which is a relatively low growth rate overall. From 1991 to 2017, China's adjusted GDP growth rate and EATFP growth rate are shown in Table 1.

Comparing the environmentally adjusted GDP growth rate (EATFP) with the unadjusted TFP (as shown in Figure 1), from 2001 to 2007, the unadjusted TFP growth rate was relatively high, mainly due to the technological progress brought about by China's institutional reforms such as opening up and joining the WTO. Since 2008, in response to the international financial crisis, China has implemented a four trillion stimulus policy, which has led to a reduction in the efficiency of resource allocation, a low effective investment ratio, and a large decline in total factor productivity growth. Even during the 2001-2007 period when the reform dividends continued to be released, EATFP maintained a low growth rate, indicating that China's economy has always been extensively developed, and the rapid economic growth is at the cost of environmental damage.

From 1991 to 2017, the average contribution rate of TFP to GDP growth was 31.4%. In phases, since the financial crisis, the average contribution rate of TFP to GDP growth has fallen sharply to 18.6%. Economic growth is mainly driven by investment. The contribution rate of labor, capital and TFP to GDP growth are shown in Table 2.

From 1991 to 2017, the average contribution rate of EATFP to environmentally adjusted GDP growth rate was 14.3%. In stages, since the financial crisis, the average contribution rate of TFP to GDP growth has dropped sharply to 1.6%. Economic growth is mainly driven by investment. The contribution rate of labor, capital and EATFP to environmentally adjusted GDP growth are shown in Table 3.

4. CONCLUSION

We calculates the environmentally adjusted total factor productivity. The results showed that from 2001 to 2007, the unadjusted TFP growth rate was relatively high, mainly due to the technological progress brought about by China's institutional reforms such as opening up and joining the WTO. Since 2008, in response to the international financial crisis, China has implemented a four trillion stimulus policy, which has led to a reduction in the efficiency of resource allocation, a low effective investment ratio, and a large decline in total factor productivity growth. The total factor productivity adjusted for environmental factors maintained a low growth rate even during the period 2001-2007 when the reform dividend was continuously released, indicating that China's economy has always been extensively developed, and the rapid economic growth is at the cost of environmental damage.

Table 1 China's adjusted GDP growth rate and EATFP growth rate from 1991 to 2017(%)

Year	GDP growth rate	Environmentally adjusted GDP growth rate	TFP growth rate	EATFP growth rate
1991	9.26	7.54	4.06	2.33
1992	14.20	12.53	8.56	6.89
1993	13.90	11.51	6.35	3.95
1994	13.00	10.86	5.21	3.08
1995	11.00	8.07	2.98	0.04
1996	9.90	8.43	2.16	0.69
1997	9.20	9.14	2.23	2.17
1998	7.80	9.23	1.37	2.80
1999	7.70	7.76	1.75	1.82
2000	8.50	7.60	2.94	2.04
2001	8.30	7.47	2.48	1.65
2002	9.10	5.54	3.16	-0.40
2003	10.00	3.86	3.44	-2.70
2004	10.10	4.87	3.21	-2.01
2005	11.40	7.06	4.62	0.28
2006	12.70	9.03	5.73	2.06
2007	14.20	11.57	6.94	4.31
2008	9.70	7.16	2.59	0.05
2009	9.40	7.37	1.57	-0.46
2010	10.60	7.28	2.85	-0.47
2011	9.50	5.77	2.07	-1.66
2012	7.90	6.86	0.97	-0.07
2013	7.80	7.02	1.08	0.29
2014	7.30	7.19	0.93	0.82
2015	6.90	6.77	0.95	0.83
2016	6.70	7.31	1.07	1.69
2017	6.80	5.60	1.25	0.06

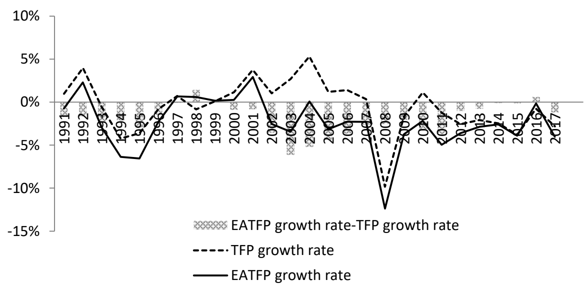

Figure 1 Comparison of EATFP growth rate and the TFP growth rate

Table 2 The contribution rate of labor, capital and TFP to GDP growth in different time periods(%)

Variable	Index	Total time period	Sub-period		
		1991-2017	**1991-2000**	**2001-2007**	**2008-2017**
GDP	Average annual growth rate	9.74	10.45	10.83	8.26
Capital	Average annual growth rate	10.68	10.42	10.58	11.01
	Contribution rate	65.83	59.87	58.64	79.96
Labor force	Average annual growth rate	0.68	1.08	0.63	0.30
	Contribution rate	2.77	4.13	2.33	1.47
TFP	Average annual growth rate	3.06	3.76	4.23	1.53
	Contribution rate	31.40	36.00	39.03	18.57

Table 3 The contribution rate of labor, capital and EATFP to environmentally adjusted GDP growth in different time periods(%)

Variable	Index	Total time period	Sub-period		
		1991-2017	**1991-2000**	**2001-2007**	**2008-2017**
GDP	Average annual growth rate	7.79	9.27	7.06	6.83
Capital	Average annual growth rate	10.68	10.42	10.58	11.01
	Contribution rate	82.24	67.48	89.96	96.66
Labor force	Average annual growth rate	0.68	1.08	0.63	0.30
	Contribution rate	3.47	4.66	3.57	1.78
TFP	Average annual growth rate	1.11	2.58	0.46	0.11
	Contribution rate	14.29	27.86	6.47	1.56

ACKNOWLEDGMENT

This work was supported by the Science and Technology Project of State Grid Corporation of China (Research and Development of Comprehensive Analysis and Forecasting Model System for Multi-regional Energy Supply and Demand in China) and the Young Talents Programme of State Grid Energy Research Institute Co., Ltd. (Research on the new urbanization development indicators of energy and electricity supply and demand analysis based on night lighting remote sensing data for smart grid, No. XM2018020037579).

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