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China's Green TFP Calculation Combining Energy Consumption and Environmental Pollution Emissions: 1981-2011

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Abstract

Building the non-radial, non-oriented, SBM super-efficiency model, this paper calculates China's green total factor productivity (GTFP) combining energy consumption and environmental pollution emissions during 1981-2011. It is found that the China's green TFP declined persistently since 1996, and significantly accelerated after 2008, transformation of economic development mode has been impeded.

JEL classification numbers: O33,Q56
Keywords: Green TFP; Pollution index; SBM Super-Efficiency Model; Sustainable economic development

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1 Introduction

China’s economy achieved rapid growth since the reform and opening up in 1978, the gross domestic product (GDP) has reached 47.22 trillion yuan, up by 9.9 percent over the previous year, more than Japan, Germany, Britain, France and other developed countries and jumped to second in the world. GDP per capita rose from \$98 to \$6100, falling into the category of “Upper-Middle-Income Countries”.

However, Deep-seated contradictions of economic development have become increasingly fierce, energy predicament and environmental pollution problems have become more apparent, the problem of natural and harmonious development is particularly prominent.

China’s economy is in the process of accelerated urbanization and industrialization. Deal to the simple level of industrial structure, the low level of production technology and management, irrational economic structure etc., about 70% of GDP relies on an increase in physical capital and labor input, which leads to too much material factor inputs and energy consumption while economic efficiency is low. By 2002 the growth rate of energy consumption was lower than the growth rate of the total economy, the gap had been gradually narrowing since 2003, and energy consumption growth exceeded 15% in 2003 and 2004, which, thereafter, remained higher than the growth rate of China's GDP. China's GDP accounted for 8.6% of the global amount, But it consumed 18% of the world's total energy, 44% of the total steel, and 53% of the total cement, in 2010 China's energy consumption was 3.25 billion tons of standard coal, surpassing the U.S. as the world's largest energy consumer, while China's GDP accounted for 40.6% of U.S. GDP in the same year. China’s oil, gas increased, while also vigorously developed hydropower and nuclear power to alleviate the problem of energy supply and demand during 1978-2011. However, due to the constraints of resource reserves and economic development needs, China still has to increase coal consumption to compensate for the lack of energy. The proportion of coal in China's total energy consumption fell from 70.70% to 68.4%, but the amount has increased by 4.89 times; oil imports abidingly rose in this period, the proportion of oil jumped from 10.92% to 18.60%, natural gas jumped from 3.20% to 5.00% during 1978-2011, indicating that the rise of oil consumption in the energy mix proportion with the economic development and improvement is an objective trend, and new energy in China's energy consumption structure can be ignored for the time being.

China's energy consumption structure is badly unbalanced compared with international standards. Clean energy shortage has become huge impact on the rapid development of China's economy and ecological environment protection. The industrial revolution, the change of productivity, social progress has brought brilliant material civilization to human beings while ecological civilization is in constant deterioration, which is particularly prominent in nearly 30 years of China’s development. “Carbon Dioxide Emissions Assessment Report” by Netherlands Environmental Assessment Agency showed that: China's carbon dioxide emissions totaled 6.72 billion tons in 2007, accounting for 24.3% of world emissions, became the world's largest emitter of carbon dioxide, China's carbon dioxide emissions in 2007 were twice as 2000’s, accounting for 64% of world emissions increase in the same period. the national total wastewater was 61.73 billion tons in 2010, industrial waste gas emissions were 51.9168 trillion cubic meters, industrial solid waste output was 2.41 billion tons, which were respectively 1.5 times, 3.8 times and 2.7 times as in 2000. According to statistics, 70% of the river water has been contaminated, 40% has lost the basic use functions; more than 95% of the river flows through the city has been of serious contamination; about 300 million peasants drink less than clean water, 400 million city dwellers breathe less than fresh air. World Environmental Performance Index (EPI) of 2010 showed that China ranked 121 in 163 countries and territories, 16 down compared to 2008, 27 down to 2006.

All along, China's economic growth mainly depends on factor inputs, highly on capital, raw materials, energy and labor, while technological growth or total factor productivity (TFP) makes less contribution to economic growth. In addition, under the influence of dual economy, which is called agriculture-nurturing-industry, China’s industry relies heavily on a large number of high-growth key elements, and the energy consumption is mainly dependent on coal resources. Economic growth overall shows the extensive characteristic of "high energy consumption, high pollution and low efficiency" and diversified and complicated tendencies in the inter-regional. Premier Wen Jiabao in his government work report in 2012 suggested that GDP growth target was 7.5%, which was lowered for the first time since 2005.

Seen that in the important period of strategic opportunities, facing energy constraints, environmental degradation constraints, how to obtain the new progress of economic development, new achievements about improving people's livelihood, breakthroughs of resource-saving and environment-friendly society have become national major problems in the economy. Therefore China needs discussions of changing the mode of economic development and sustainability.

2 Literature Review

Since the industrial revolution, the rapid economic growth promotes the change of society, people once made economic growth as a symbol of social civilization progress, but the brutal plundering of natural resources led to the double restriction that people have to face: energy and environment. Many scholars have realized that the natural environment influence in the economic development as an important constraint in the theoretical analysis has been underestimated for a long time, scholars began to redefine the stable economic development, and introduced natural resources into economic growth model through the exogenous growth model and endogenous growth model, which introduced the theory of sustainable development into economics, greatly enriched the theory of economic growth.

Dasgupta and Heal (1974) introduced resources as a production input in the Ramsey model, examining the role of economic growth and resource consumption; Rasche and Tatom (1977) assumed that elasticity of substitution remains unchanged between physical capital and energy, and energy was introduced in the C-D function; Pezzey and Withagen (1998) introduced technology into exogenous growth model; Stokey (1998) introduced environmental pollution into the economic growth model, found that per capita income and environmental quality existed the relationship of inverted "U"; Gradus and Smulders (1996) confirmed that the environment affected not only the production function but also the utility function of representative family; Bovenberg and Smulders (1996) proved the positive effect of environmental protection was enough to offset the blocking effect on economic growth by introducing environmental pollution into the Lucas model of human resource, and not only would the economic growth stop slowing, but also is likely to rise; Elasson and Turnovsky (2004) examined the influence of environmental policy on economic growth under the condition of the environmental pollution; Sweeney and Klavers (2007) studied RCK model which included energy, natural resources and environmental factors.

Sustainable development metrics include technological progress, energy conservation, income distribution, etc. However, total factor productivity (TFP) is the most important indicator to determine sustainable development from the economic point of view, only the continuous improvement of productivity intensive growth can be sustainable.

Solow (1957) published the "Technical change and the aggregate production function", integrated the theory of production function and the accounting system of national production method, and introduced technical factors into production function for the first time, establishing the famous "Solow model". Solow defined total factor productivity as the difference of labor productivity and capital productivity which couldn’t be explained by capital and labor in productivity growth, also known as “Solow residual”. Solow confirmed that this residual value originated in technological progress. On this basis, economists Denison (1967) extended the calculation method of Solow residual value through a detailed classification of the different types of input elements and assigned to different weights to calculate the total input index. This method developed by Solow, Denison and others still occupies a very important position until today. However, Solow model is an exogenous growth model which cannot explain the relationship between physical capital accumulation and per capita output.

Data envelopment analysis (DEA) approach, an important measure of total factor productivity, was presented by Charnes and other scholars in 1978 which could contain the endogenous variable to conform to reality. It promotes the concept of single-input and single-output efficiency to the multi-input and multi-output in particular, and evaluates the effectiveness of the same type of decision-making units (DMU) through the mathematical programming models. Currently, studies on China’s TFP through the utilization of DEA are: Yan Peng-fei, Wang Bing(2004) measured the technical efficiency in 30 provinces of China during 1978-2001 with the DEA method; Jiang Dian-chun, Huang Jing (2007) examined the domestic and foreign technical level and development trend in Chinese industrial sector through DEA; Wang Bing, Yan Peng-fei (2007) calculated the technical efficiency of 17 countries and regions belonging to APEC during 1960-2004 with the methods of contemporaneous DEA and sequential DEA.

The brutal plundering of natural resources led to the double restriction that people have to face: energy and environment. Many scholars have realized that the natural environment influence in the economic development as an important constraint in the theoretical analysis has been underestimated for a long time, scholars began to redefine the stable economic development, and introduced natural resources into economic growth model through the exogenous growth model and endogenous growth model, which introduced the theory of sustainable development into economics, greatly enriched the theory of economic growth. Hu An-gang, Zheng Jing-hai and Gao Yu-ning (2008) and Yue Shu-jing, Liu Fu-hua (2009), etc. used traditional DEA output directional distance function model to investigate pollution impact on productivity; the evaluation by Wei Chu, Du Li-min, Shen Man-hong (2010) based on DEA and simulation examined the possibilities of achieving emission reduction targets; Lei Ming, Zhao Xin-na, Zhang Ming-xi (2012) established a dynamic energy-pollution Malmquist productivity index based on DEA; Zhang Hong-feng, Chang Chao-zhong (2013) used DEA-Malmquist index calculation and decomposition of 30 industrial sectors’ TFP, and analyzed the impact of ownership structure on TFP.

China's current economic development situation is still in the extensive stage, requires a large number of inputs to ensure economic growth, and the resulting energy consumption conflicts and environmental pollution problems are very prominent. A substantial increase in energy prices and a sharp deterioration in the quality of the environment is bound to a profound impact on China’s economy. The main reasons for this situation is from irrational industrial structure, energy structure and pollution treatment mechanism, therefore, for the energy consumption and pollution emissions in the process of economic growth, exploring the situation of China's energy, environment and sustainable development as economic research objectives, and study China's economic problems as well as sustainable growth drivers of economic growth through combining both the energy and pollution factors into the production function and total factor productivity framework, undoubtedly has a certain practical guidance and significance for a correct understanding of China's current stage of development and China’s strategy of sustainable economic development, leads to the development of sound macroeconomic policies, scientific, rational energy consumption and environmental protection policies to achieve sustained economic growth gradually.

Overall, while China has conducted a lot of research on TFP, most of them had ignored the factors of environment and energy until recent years. Moreover, studies that take these two factors into consideration are likely to just select one single, independent indicator to represent the data on environment factor, thus failing to fully reflect the pollution impact on TFP.

In summary, this paper differs from previous research in that:

First, although China has a lot of researches on TFP currently, most of them ignored the environment and energy factors’ impact on TFP, and China’s TFP may be overrated. Therefore, TFP combining energy consumption and environmental pollution emissions should be more accurate and significative;

Second, this paper establishes a comprehensive pollution index with four major pollutant emissions integrated, reducing single or independent indicators’ accounting error, reflecting a more accurate impact of economic development and sustainability;

Third, the efficiency value is biased with the method of the radial, oriented DEA model for not adequately considering the problem of input-output slack, and the traditional DEA models require effective value of DMUs to be 1, resulting in efficient DMUs cannot be compared. The non-radial, non-oriented SBM super- efficiency model overcomes these two shortcomings and combines the involved indicators into a more complete and comprehensive system for green TFP estimations, and with cointegration analysis, impulse response analysis and variance decomposition method of VAR model to study TFP green affecting factors, designed to enrich the sustainability of China's economic development and transformation of the theoretical and empirical researches.

3 Model Specification

3.1 Traditional DEA Model

With the sample input and output data and linear programming model for each efficient production frontier to calculate the distance of each DMU actual production point between the production frontier, the closer the distance is, the higher its efficiency is , so as to evaluate the efficiency of each DMU. This paper starts from a traditional DEA model developed by Fare、Grosskopf and Lovell (1994)to choose and construct the appropriate theory model, combing with the actual situation of the research.

Define a production possibility set with $n\left(n=1,\cdots,N\right)$ kind of input x_n^k of $DMU_k\left(k=1,\cdots,K\right)$ to produce $m\left(m=1,\cdots,M\right)$ kind of output y_m^k:

$$P=\left\{\left(x,y\right)\left|\begin{array}{l}\sum_{k=1}^{K} z_k y_m^k \ge y_m^k, m=1,\cdots,M; \sum_{k=1}^{K} z_k x_n^k \le x_n^k, n=1,\cdots,N; \\ z_k \ge 0, k=1,\cdots,K\end{array}\right.\right\} \tag{1}$$

z_k: Weight of DMU_k

$DMUs'$ efficiency could be calculated through the following linear programming:

$$\begin{aligned} & F_o\left[y,x\left|C,S\right.\right]=\max h^k \\ & s.t.\sum_{k=1}^{K} z_k y_m^k \ge h^k y_m^k, m=1,\cdots,M; \sum_{k=1}^{K} z_k x_n^k \le x_n^k, n=1,\cdots,N; z_k \ge 0, k=1,\cdots,K \end{aligned} \tag{2}$$

h^k is the enlarging degree of $DMUs'$ output, if and only if $h^k=1$, DMU_k is efficient.

3.2 DEA Model with Undesirable Output

Pollution emissions is not very conform as inputs to the actual production process, and pollution emissions as the undesirable output is more suitable with the analysis of the multiple input multiple output of DEA model, thus this paper regards pollution emissions as undesirable output, energy consumption as new inputs and introduce them into the production function.

Constructing both the desirable output and the desirable output production possibility set is known as environmental production technology. Assume a production unit produces M kind of desirable outputs $y=\left(y_1,\cdots y_n\right)\in R_+^M$ and I kind of undesirable outputs $b=\left(b_1,\cdots b_n\right)\in R_+^I$ with N kind of inputs $x=\left(x_1,\cdots x_n\right)\in R_+^N$, the possibility set P is a bounded closed set with properties: First, jointly weak disposability of desirable and undesirable output, if $\left(x,y,b\right)\in P$ and $0\le\theta\le 1$, $\left(x,\theta y,\theta b\right)\in P$, explaining that To reduce the cost of undesirable outputs must reduce the undesirable output at the same time under the given input. Second, strong or free disposability of desirable outputs and inputs, if $x^{'}\le x$ then $P\left(x^{'},y,b\right)\subseteq P\left(x,y,b\right)$; and if $y^{'}\le y,\left(x,y,b\right)\in P$, then $\left(x,y^{'},b\right)\in P$. Third, null-jointness of desirable outputs and undesirable outputs, if $\left(x,y,b\right)\in P$, $b=0$, then $y=0$, explaining that desirable outputs are produced with undesirable outputs.

According to those characters, DEA model with undesirable outputs is as follows.

Assume $k\left(k=1,\cdots,K\right)$ DMUs produces $m\left(m=1,\cdots,M\right)$ kind of desirable outputs y_m^k and $i\left(i=1,\cdots,I\right)$ kind of undesirable outputs b_i^k with $n\left(n=1,\cdots,N\right)$ kind of inputs x_n^k, P, under preconditions of CRTS and free disposal of inputs, should be:

$$P=\left\{\left(x,y\right)\left|\begin{array}{l}\sum_{k=1}^{K}z_k y_m^k \geq y_m^k, m=1,\cdots,M;\sum_{k=1}^{K}z_k b_i^k = b_i^k, i=1,\cdots,I;\\ \sum_{k=1}^{K}z_k x_n^k \leq x_n^k, n=1,\cdots,N; z_k \geq 0, k=1,\cdots,K\end{array}\right.\right\} \tag{3}$$

z_k is weight of DMU, and assume:

$$\sum_{k=1}^{K}b_i^k \succ 0,, i=1,\cdots,I;\sum_{i=1}^{I}b_i^k \succ 0,, k=1,\cdots,K \tag{4}$$

It shows that every undesirable output is produced by at least one DMU, and every MU produces at least one undesirable output.

3.3 The Non-radial, Non-oriented, DEA Model with Undesirable Output

There are generally four kind of DEA models: the radial, oriented DEA model; the radial, non-oriented DEA model; the non-radial, oriented DEA model and non-radial, the non-oriented DEA model. "Radial" presents equal proportion of input or output in order to achieve effective. "Oriented" presents input-oriented or output-oriented. The radial DEA cannot deal with non-zero slack sufficiently so as to overate DMU's efficiency. The oriented DEA ignores the one aspect of input or output, thus the result is biased. Tone(2001) proposed the non-radial, non-oriented Slack-Based Measure(SBM) model. It effectively solved the defects of traditional DEA model by introducing the input and output slacks into objective function. Under preconditions of CRTS and free disposal of inputs, the non-radial, non-oriented, DEA model with undesirable output should be:

$$\rho_{k'}^{*}=\min\rho=\min\frac{1\text{-}\frac{1}{\mathrm{N}}\sum_{n=1}^{N}s_n^x\Big/x_n^{k'}}{1+\frac{1}{\mathrm{M}+\mathrm{I}}\left(\sum_{m=1}^{M}s_m^y\Big/y_m^{k'}+\sum_{i=1}^{I}s_i^b\big/b_i^{k'}\right)}$$

$$s.t.\sum_{k=1}^{K}z_k y_m^k \text{-} s_m^y = y_m^{k'}, m=1,\cdots,M;\sum_{k=1}^{K}z_k b_i^k + s_i^b = b_i^{k'}, i=1,\cdots,I; \tag{5}$$

$$\sum_{k=1}^{K}z_k x_n^k + s_n^x = x_n^{k'}, n=1,\cdots,N; z_k \geq 0, s_m^y \geq 0, s_i^b \geq 0, s_n^x \geq 0, k=1,\cdots,K$$

The numerator of $\rho_{k'}^{*}$ is input inefficiency degree by evaluating the average distance between actual input and production frontiers. Analogously, the denominator of $\rho_{k'}^{*}$ is output inefficiency degree. s_m^y、s_i^b、s_n^x, as input and output slacks, are introduced into function $\rho_{k'}^*$ to consider surplus input and inadequate output effectively so as to solve the defects of traditional DEA model. If and only if $\rho_{k'}^* = 1$, $s_m^y = s_i^b = s_n^x = 0$, DMU is totally efficient without excess input or output shortage.

3.4 The Non-radial, Non-oriented, SBM Super-efficiency Model with Undesirable Output

There is likely to be more than one efficient (equal to 1) DMUs in most of the DEA model estimations. In this case, the non-radial, non-oriented, SBM super-efficiency model with undesirable output proposed by Tone (2004) is used, of which main idea is to remove the limitation that the DMU's efficiency value must be equal to 1. Genuine efficiency difference can be obtained through Super-efficiency model, and thus the efficient DMUs may be further sorted.

Based on formula (3-4), if $\rho_{k''}^* = 1$ then DMU $k''\left(x^{k''}, y^{k''}, b^{k''}\right)$ is efficient, further constructs a limited production possibility set $P \setminus \left(x^{k''}, y^{k''}, b^{k''}\right)$ excluding DMU k'', which should be:

$$P\setminus\left(x^{k''},y^{k''},b^{k''}\right) = \left\{ \left(x,y,b\right) \left| \begin{array}{l} \sum\limits_{\substack{k=1 \\ k\neq k''}}^{K} z_k y_m^k \geq y_m^k, m = 1,\cdots,M; \sum\limits_{\substack{k=1 \\ k\neq k''}}^{K} z_k b_i^k = b_i^k, i = 1,\cdots,I; \\ \sum\limits_{\substack{k=1 \\ k\neq k''}}^{K} z_k x_n^k \leq x_n^k, n = 1,\cdots,N; z_k \geq 0, k = 1,\cdots,K\left(k \neq k''\right) \end{array} \right. \right\} \tag{6}$$

$$\pi_{k'}^* = \min \pi = \min \frac{1 - \frac{1}{\mathrm{N}} \sum\limits_{n=1}^{N} s_n^x \Big/ x_n^{k''}}{1 + \frac{1}{\mathrm{M+I}} \left(\sum\limits_{m=1}^{M} s_m^y \Big/ y_m^{k''} + \sum\limits_{i=1}^{I} s_i^b \Big/ b_i^{k''} \right)}$$

$$s.t. \sum_{\substack{k=1 \\ k\neq k''}}^{K} z_k y_m^k - s_m^y = y_m^{k''}, m = 1,\cdots,M; \sum_{\substack{k=1 \\ k\neq k''}}^{K} z_k b_i^k + s_i^b = b_i^{k''}, i = 1,\cdots,I; \tag{7}$$

$$\sum_{\substack{k=1 \\ k\neq k''}}^{K} z_k x_n^k + s_n^x = x_n^{k''}, n = 1,\cdots,N; z_k \geq 0, s_m^y \geq 0, s_i^b \geq 0, s_n^x \geq 0, k = 1,\cdots,K\left(k \neq k''\right)$$

In conclusion, the non-radial, non-oriented, SBM super-efficiency model with undesirable output is constructed by formula(3-4) and (3-6). Compared with other DEA models, DMUs' efficiency are not limited to 1 below in SBM super-efficiency model, providing a more accurate evaluation.

3.5 Variable Setting and Data Processing

This study aims to investigate changes of China's green TFP combining energy consumption and pollution emissions, the sample period is from 1981 to 2011, sets fixed capital, human capital, energy as the inputs, and turns out desirable output - GDP and undesirable outputs - pollution emissions.

1) Capital input. There is currently no available official Chinese capital stock or capital services in statistics. Most scholars directly or indirectly conducted their research with the capital stock data estimated by Zhang Jun (2004). Shan Haojie (2008) calculated the base-period capital stock and depreciation rate in a more rigorous way, and re-estimated the capital stock of China during 1952-2006. The research production is applied and updated in this paper.
2) Human capital investment. The product of the average schooling and social workforce counts as human capital stock in this paper. The calculation method of the average schooling consults the calculation formula by WANG YAO (2003) which segments years of education and educated population at all levels, ensures the accuracy of the data, but the advanced period (3 years) of data is needed to calculate the current level of human capital (the average schooling). Therefore, the average years of schooling from 2009 to 2011 are calculated in a more simple algorithm, the level of education is only divided into elementary, junior high, high school and college or above, years of education at all levels are valued 6,9, 12,16 respectively. The data comes from statistical yearbooks.
3) Energy inputs. Energy consumption has become an important issue of China's economic development impacted by energy supply contradiction and energy structural problems in recent years, this paper also puts annual total energy consumption as one of the factors of economic growth.
4) Desirable output - GDP. Nominal GDP longitudinal comparison will contain the factor of price changes, unable to reflect the actual output of economic activities. Therefore, GDP is deflated as 1991 fixed price from 1981 to 2011.
5) Undesirable output-pollution emissions. The traditional pollution emissions are indicated singly or separately by most scholars. Referencing Yang Wanping's thoughts, industrial wastewater emissions, industrial waste gas (including sulfur dioxide, smoke & powder) emissions, industrial solid waste production and carbon dioxide emissions are integrated into a comprehensive pollution emissions index by improved entropy method to make up for error caused by empirical research using the traditional environmental pollution indicators.

3.6 The Calculation Results of China's Green TFP.

On the basis of formula (4), China's green TFP is calculated from 1981 to 2011 using MaxDEA6.0. The results are shown in figure 1. Thus the transformation mode of China's economic development and economic sustainable development can be evaluated.

Table 1: China's green TFP from 1981 to 2011

Year	Green TFP	Growth rate	Year	Green TFP	Growth rate	Year	Green TFP	Growth rate
1981	0.6771		1992	0.7852	1.46%	2003	0.8592	-1.57%
1982	0.6723	-0.71%	1993	0.8512	8.41%	2004	0.8461	-1.52%
1983	0.6660	-0.94%	1994	0.9313	9.41%	2005	0.8310	-1.78%
1984	0.6602	-0.87%	1995	1.0359	11.23%	2006	0.8223	-1.05%
1985	0.6693	1.38%	1996	1.0125	-2.26%	2007	0.8227	0.05%
1986	0.6608	-1.27%	1997	1.0049	-0.75%	2008	0.8261	0.41%
1987	0.6703	1.44%	1998	0.8930	-11.14%	2009	0.8114	-1.78%
1988	0.6901	2.95%	1999	0.9005	0.84%	2010	0.7996	-1.45%
1989	0.7178	4.01%	2000	0.8961	-0.49%	2011	0.7691	-3.81%
1990	0.7360	2.54%	2001	0.8881	-0.89%			
1991	0.7739	5.15%	2002	0.8729	-1.71%			

4 Conclusion

China's green TFP down after rising first, and shows a declining trend, and was only more than 1 during 1995-1997, belonging to the stage of super efficiency, the rest are below 1, belonging to the stage of efficiency loss.

China's green TFP could be generally divided into three stages from the trend:

1981-1987: The government tried to combine central planning and market-oriented reform and carried out a series of measures to encourage state-owned enterprises more independent and improve the marker competitiveness. However, they lacked the experience of improving impacts and results. There was no significant change of China's green TFP in this period, fluctuated up and down around 0.67.

1988-1995: The 14th National Congress of China supported the proposition of re-introducing market reforms by Deng Xiaoping in 1992, and declared that establishing the socialist market economy was the primary mission of China's economy during the 1990s, thus, the economic system reform became the focus of the ten-year development plan, and China's economy was re-invigorated. China's green TFP made a sustained growth with a large growth amplitude (from 0.6901 to 1.0359).

1996-2011: China's green TFP sharply declined to 0.7691 in this period, gently after 1998 but increasingly after 2008 which is noteworthy.

The continuous declination of green TFP may indicate that the contribution of technological advance is going down, and economic development relies on factor input too much, ignoring environmental carrying capacity. Therefore, transformation of economic development patterns is urgently needed.

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