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Measuring Quality of Economic Growth Incorporating Environment and Social Welfare: a Total Productivity Approach with an Application on China

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Abstract: By extending the traditional productivity theory , a new concept total productivity (TP) is introduced. Using a directional distance function approach , the concept is applied to measuring economic growth of 8 economic regions of China covering an 18 years period(1997—2014) and test its convergence. Results showed that TP grew at an average rate of 6.6% per year led mainly by technical change(6.5%) . When environmental undesirable outputs are included , the Middle Yellow River , Northwest and Southwest regions of China witnessed higher productivity changes. Results of the convergence analysis revealed that China had made progress in reducing regional imbalance in growth. Inclusion of undesirable output showed that the energy-saving emission reduction policies had speed up the convergence rate of TP and environment oriented productivity. However , China's welfare oriented productivity is still very low.

Key words: undesirable output; directional distance function; total productivity (TP); Malmquist-Luenberger productivity index; quality of economic growth

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Introduction

Productivity is an important indicator in evaluating economic activities , because it reflects the efficiency and effectiveness of economic activities. The main weakness of traditional productivity theory is that it does not recognize the need to account for increasing environmental pollution and improvements in social welfare. It has now been proved that without sustainable development , human society will face destruction^[1]. This paper argues that it is necessary to rethink development from the viewpoint of productivity while taking into account environmental pollution and social welfare elements in order to find a better path to pursue sustainable growth successfully. Therefore , this paper extends the traditional productivity theory , which is a measure of output-input ratio) and introduces the concept of total productivity(TP) which is a measure of objective-means ratio. The concept of TP includes three aspects: economic growth (traditional productivity) , ecological environment(environment oriented productivity) and social welfare(welfare oriented productivity) .

Starting from the production theory and combining with three areas of sustainability , *i. e.* , economic growth , ecological environment and social welfare , this study integrates the elements of environment and social welfare into calculating TP. The dilemma faced by China is not only to maintain economic growth , but also to avoid ecological destruction and depletion of resources while pursuing economic growth. Given this backdrop , this study applies the concept TP to measure the level and quality of economic growth of 8 economic regions(*i. e.* , 30 districts) in China using a set of time-series panel data covering a period of 18 years(1997—2014) .

The reminder of this paper is organized as follows. Section

1 describes the theoretical framework of this study. Section 2 discusses the methodology and develops the directional distance function and Malmquist-Luenberger productivity index to measure the productivity indices; describes the data and construction of some variables. Section 3 presents the results including convergence analysis. Section 4 provides conclusions.

1 Theoretical Framework

1.1 An extended definition of productivity and the TP theory

In general , productivity is simply defined as the output-input ratio. However , implementation of this simple concept becomes complicated when the production process is characterised by multi-input or multi-output technologies^[2]. The practice and research on productivity respond to different demands of economic development stages , which in turn have moved on from just an exploration of inputs of labour and capital to sustainable development of society , economy and the environment. Hence , this paper divides the process of productivity development into three categories(Fig. 1) .

Firstly , the most important concept of productivity is labor productivity because only labor can create value. Therefore , labor input provided by workers is the main foundation of productivity because only materialized or physical labor can transfer value in the production process. The effects of scientific discovery , technological invention , and science administration on the production process are mainly realized through acts of physical labor.

Secondly , after the second world war , technology and other factors played an important role in the production process. A number of economists , headed by Robert Solow , attributed that economic growth was caused by other factors over and above labor and capital input , which was designated as total factor productivity(TFP)^[3]. TFP was defined as the ratio of produced output and total inputs employed at time t ^[2]. By employing TFP approach , it is much easier to convert the utilization ratio of resources using complicated technology processes into a simple number , which also enables international comparison. However , this method postulates full use of input factors and overemphasizes the role of technology , and only measures the degree of economic development in quantitative terms.

Finally , with the widespread adoption of modern science and technology in the pursuit of economic growth , scarce nature resources started to decline. As a result , the level of massive economic growth had already surpassed the safe operating space of the planet as far as climate change , biodiversity loss and

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global environmental issues are concerned^[4]. Given this scenario , the traditional productivity theory is challenged due to its failure to address widespread environmental and social problems. Therefore , in order to correctly guide sustainable development , the productivity theory needs to be explored further and extended.

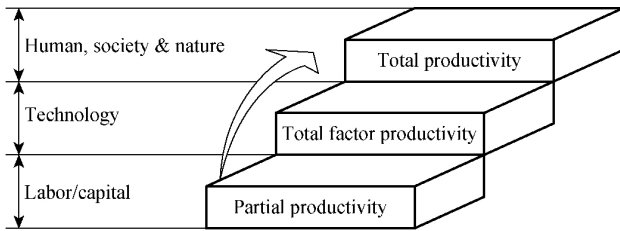


Fig. 1 Development history of productivity

Generally speaking , the production process is a synthetic process of all elements of the productive force; hence productivity should be determined by efficient utilization of these elements. Although productivity is very important , it is becoming more difficult to measure which may lead to overlook productivity^[5]. Therefore , having a new and clear definition of the concept is an important first step^[6] for economic sustainability. Based on this , this paper postulates an extended theory of productivity termed as TP which pays more attention to the harmonious development of nature , human and society , especially social welfare and environmental protection. This concept of productivity takes into account not only the market value of input and output elements , but also economic efficiency , ecological environment , and social welfare.

1.2 Decomposition of the production process

The production process is a dynamic interaction amongst human , nature and society. Now , environment plays a larger role in accelerating or limiting economic growth and development^[7]. Unilateral emphasis on rapid economic growth will result in a situation where the lion’s share of contribution to growth comes from damaging activities^[8]. Given this backdrop , this paper decomposes the production process into three aspects: socioeconomic process , management process and production technology process , which include environmental and social welfare factors in the measurement of productivity(Fig. 2) .

In general , the production process comprises of production technology process and social economic process. From the viewpoint of production technology process , the production process is the technical relations between human and nature. Using natural resources and technology , products are produced by human labor. The use of technology and machineries can increase the productivity of labor. Hence , the production technology process can be represented by efficiency , *i. e.* , the output-input ratio. From the view of social economic process , the production process must exist in some economic system. In this system , value expressed in prices is produced through commodity markets and currency circulation. Hence , production cost and the operation of social-economic process is represented by effectiveness , *i. e.* , the outcome-expenditure ratio. Efficiency is the source and material basis of effectiveness. However , productivity and efficiency will be meaningless without effectiveness. According to the economic law of minimum-maximum and the subject matter of productivity , there must be a management process between the production process and the social economy process. Through efficient management , three goals will be achieved: more output with less input from the technical relations , more outcomes with less expenditure from market operations , and harmonious coexistence of human , society and nature.

Based on the above analysis , the production process was decomposed into three processes with four metrics of measurements(Fig. 2) . Respectively , there were four aspects to the expanded concept of productivity: (1) physical metric of output-input ratio , which reflects the technical relations between human and nature and the efficiency of economic system; (2) value metric of outcome-expenditure ratio , which reflects market relations between human and economic effectiveness; (3) welfare metric of enjoyment-sacrifice ratio , *i. e.* the degree of public facilities and social welfare , which reflects relationships between human and the society; and (4) environmental metric of output-environmental cost ratio , which reflects relationships between human and nature. By taking this decomposition as the theoretical foundation , three productivity concepts were forwarded , *i. e.* , environment oriented productivity , welfare oriented productivity , and TP which is a product of the first two.

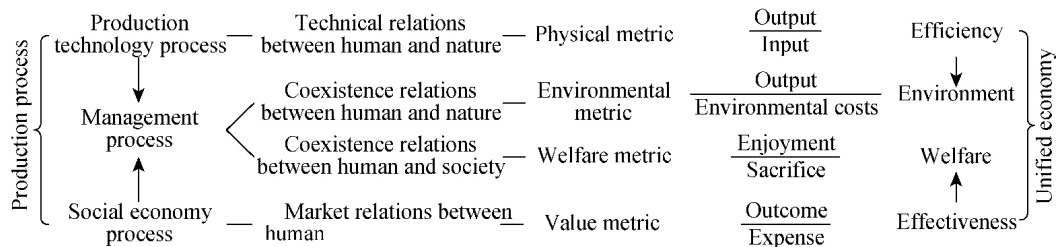


Fig. 2 Conceptual framework of TP

2 Methodology

2.1 Underlying assumptions of directional distance functions

This paper employs output directional distance function to aggregate multiple environmental/welfare objectives into a single measure of environmental/welfare performance. Supposing that a vector of inputs $x = (x_1, x_2, \dots, x_M) \in R_+^M$

can produce desirable outputs $y = (y_1, y_2, \dots, y_N) \in R_+^N$ and undesirable outputs $u = (u_1, u_2, \dots, u_J) \in R_+^J$. The technology can be characterized in terms of production possibility set(PPS) as

$$P(x) = \{ (y, u) : x \text{ can produce } (y, u) \} \tag{1}$$

Assuming that there are $k = 1, 2, \dots, K$ observations of $n = 1, 2, \dots, N$ inputs $x_n^{k,t}$ in each period $t = 1, 2, \dots, T$ to produce $k = 1, 2, \dots, K$ of $m = 1, 2, \dots, M$ observed outputs $y_m^{k,t}$. In this paper , k represents 8 regions. Following Färe *et al.* , the PPS can be established as

$$P(x) = \left\{ (y, u) \mid \sum_{k=1}^K z^{k,t} y_n^{k,t} \geq y_n^t, n = 1, 2, \dots, N, \right. \\ \sum_{k=1}^K z^{k,t} u_j^{k,t} = u_j^t, j = 1, 2, \dots, J, \\ \sum_{k=1}^K z^{k,t} x_m^{k,t} < x_m^t, m = 1, 2, \dots, M, \\ \left. z^{k,t} \geq 0 \quad k = 1, 2, \dots, K \right\}. \quad (2)$$

In Formula (2), inputs, desirable outputs and undesirable outputs are presented by $(M \times K)$, $(N \times K)$ and $(J \times K)$ matrices, respectively. The vector $z_k = (z_1, z_2, \dots, z_k) \in R_+^K$ is the intensity variable, which are weights assigned to each observation in constructing the production frontier. The non-negativity constraint on z_k allows the model to exhibit constant returns to scale.

2.2 Malmquist-Luenberger index to measure productivity

Distance function measures inefficiency of Decision Making Units (DMU) relative to the frontier determined, and offers a method to measure productivity and efficiency. Let $g = (g_y, -g_u) \in R_+^N \times R_+^J$ be a directional vector that expand desirable outputs y and contract undesirable outputs u under given direction. Based on Luenberger^[9], the directional output distance function can be written as Eq. (3).

$$\bar{D}_o(x, y, u; g) = \sup \{ \delta : (y + \delta g_y, u - \delta g_u) \in P(x) \}. \quad (3)$$

Following the pioneering work of Chambers *et al.*^[10], Chung *et al.*^[11] and Bampatsou and Halkos^[12] let the direction vector $g = (y, u)$. Through Eq. (3), $\forall (x, y) \in T$ the relationship between these two distance functions can be expressed as follows

$$\bar{D}_o(x, y, u; y, u) = \sup \{ \delta : D_o(x, (y, u) + \delta(y, u)) < 1 \} = \\ \sup \{ \delta : (1 + \delta) D_o(x, y, u) < 1 \} = \\ \sup \left\{ \delta : \delta < \frac{1}{D_o(x, y, u)} - 1 \right\} = \\ \frac{1}{D_o(x, y, u)} - 1. \quad (4)$$

Malmquist indices are suitable for situations with non-marketable outputs^[13]. This paper employs Malmquist-Luenberger productivity index to measure TP (environment/welfare oriented productivity). Based on traditional Malmquist index and Eq. (4), the output-oriented Malmquist-Luenberger productivity is given by

$$ML_t^{t+1} = \left[\frac{1 + \bar{D}_o^t(x^t, y^t, u^t; y^t, -u^t)}{1 + \bar{D}_o^t(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})} \times \frac{1 + \bar{D}_o^{t+1}(x^t, y^t, u^t; y^t, -u^t)}{1 + \bar{D}_o^{t+1}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})} \right]^{1/2}. \quad (5)$$

Eq. (5) can be decomposed into two parts

$$E_t^{t+1} = \frac{(1 + \bar{D}_o^t(x^t, y^t, u^t; y^t, -u^t))}{(1 + \bar{D}_o^t(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1}))}, \quad (6)$$

$$T_t^{t+1} = \left[\frac{(1 + \bar{D}_o^{t+1}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1}))}{(1 + \bar{D}_o^t(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1}))} \times \frac{(1 + \bar{D}_o^{t+1}(x^t, y^t, u^t; y^t, -u^t))}{(1 + \bar{D}_o^t(x^t, y^t, u^t; y^t, -u^t))} \right]^{1/2}. \quad (7)$$

Equation (6) measures the change in output efficiency between two periods t and $t + 1$, namely the ratio of "how close" the observations are to the respective frontiers. It is a catching-

up to the optimal frontier. $E_t^{t+1} > 1$ means that the observation is closer to the frontier in period $t + 1$ than it was in period t , and vice versa; $E_t^{t+1} = 1$ means the distance to the frontier is same in two periods. Equation (7) measures technical change in the production process, *i. e.*, the shift in the frontier between t and $t + 1$. $T_t^{t+1} > 1$ is a shift along the PPS in the direction of more desirable outputs and fewer undesirable outputs, and vice versa. $T_t^{t+1} = 1$ means that there is no shift in the PPS.

$$ML_t^{t+1} = E_t^{t+1} \times T_t^{t+1}. \quad (8)$$

To sum up, ML_t^{t+1} can simply be expressed as a product of efficiency change and technical change Eq. (8). The ML index indicates productivity improvements if $ML_t^{t+1}(\ast) > 1$ and decreases when $ML_t^{t+1}(\ast) < 1$.

2.3 Computation of the directional distance functions

A nonparametric linear programming approach using data envelopment analysis (DEA) is employed to calculate directional distance function. For every DMU, the distance is the optimum solution of linear programming. Therefore, there are four linear programming problems to be solved for each DMU, two of them use current technology of time period t or $t + 1$, *i. e.*, $\bar{D}_o^t(x^t, y^t, u^t; y^t, -u^t)$, $\bar{D}_o^{t+1}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})$; the other two use mixed time periods for observations, such as technology computed from period t with the observation in $t + 1$, *i. e.*, $\bar{D}_o^t(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})$, or $\bar{D}_o^{t+1}(x^t, y^t, u^t; y^t, -u^t)$.

By employing the PPS defined in Eq. (2), the directional distance function for DMU k' , $k' = 1, 2, \dots, K$ at period t using current technology is the solution of linear programming of Eq. (9).

$$\bar{D}_o^t(x^{k',t}, y^{k',t}, \mu^{k',t}; y^{k',t}, -\mu^{k',t}) = \max \delta, \\ \text{s. t. } \sum_{k=1}^K z^{k,t} y_n^{k,t} \geq (1 + \delta) y_n^{k',t} \quad n = 1, 2, \dots, N, \\ \sum_{k=1}^K z^{k,t} \mu_j^{k,t} = (1 - \delta) \mu_j^{k',t} \quad j = 1, 2, \dots, J, \\ \sum_{k=1}^K z^{k,t} x_m^{k,t} < x_m^{k',t} \quad m = 1, 2, \dots, M, \\ z^{k,t} \geq 0 \quad k = 1, 2, \dots, K. \quad (9)$$

The calculation of $\bar{D}_o^{t+1}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})$ is similar to Eq. (9) except that the superscript of the variable t should be replaced by $t + 1$. The remaining two distance functions need mixed period information, it can be written as Eq. (10).

$$\bar{D}_o^t(x^{k',t+1}, y^{k',t+1}, \mu^{k',t+1}; y^{k',t+1}, -\mu^{k',t+1}) = \max \delta, \\ \text{s. t. } \sum_{k=1}^K z^{k,t} y_n^{k,t} \geq (1 + \delta) y_n^{k',t+1} \quad n = 1, 2, \dots, N, \\ \sum_{k=1}^K z^{k,t} \mu_j^{k,t} = (1 - \delta) \mu_j^{k',t+1} \quad j = 1, 2, \dots, J, \\ \sum_{k=1}^K z^{k,t} x_m^{k,t} < x_m^{k',t+1} \quad m = 1, 2, \dots, M, \\ z^{k,t} \geq 0 \quad k = 1, 2, \dots, K. \quad (10)$$

Similarly, the calculation of $\bar{D}_o^{t+1}(x^t, y^t, u^t; y^t, -u^t)$ is the same as Eq. (10), only need to change the superscript t to $t + 1$.

2.4 Construction and processing of data

By employing Malmquist-Luenberger productivity index, this paper estimates environment/welfare oriented productivity changes of 30 Chinese provinces over an 18 years period (1997–2014). This paper assumes that the vector of outputs includes desirable

outputs y represented by GDP, and undesirable outputs u represented by environmental pollution discharge, while the vector of inputs mainly includes capital stock, labor force, energy consumption, investments in environmental protection, and social welfare inputs. Data are from China Environmental Yearbooks (CEY) and China Statistical Yearbooks(CSY). Particularly, data on capital stock and labor force are calculated by the authors.

Nowadays, there are different indices to measure environmental status which mainly include ecological footprint and Environmental Kuznets Curve (EKC). But the results of ecological footprint cannot inform the influence of human life style, improvement in management level and technological advance; and there is no single and consistent measure of environment performance in the EKC. This paper tries to include environmental inputs and outputs into the analysis of production process to calculate TP, because only when resource productivity grows faster than economic growth, the development will be environmentally sustainable. Based on ecological footprint, EKC and CEY, the index of environmental input and output system is presented in Table 1.

Table 1 Index of environmental input-output index system

Factors	Sub-factors
Input factors	Investment completed in pollution treatment projects
	Electricity power consumption
	Energy consumption
Output factors	Wastewater discharge
	Chemical oxygen demand
	Waste gas emission
	SO ₂
	Soot/dust emission

Generally, gross domestic product (GDP) measures the performance of economic activities, and per capita GDP is usually used as approximate value for the quality of life in different countries. However, welfare is more than just the sum of economic activities that GDP measures, GDP is adjusted every now and then. In recent years, the public discussion on welfare measurement beyond GDP has considerably gained momentum^[14]. Fleurbaey and Gaulier^[15] constructed a full-income measure, incorporating life expectancy, leisure, inequality, and unemployment; Decancq and Ooghe^[16] evaluated whether the world moved forward between 1980—2008 on the basis of GDP per capita, longevity and education; Based on the wide ranges of options to measure social welfare, this paper considers annual wages, education expenditure and medical information to compute the index of welfare (Table 2). This is because increase in wages, education expenditures and medical expenditures can improve quality of life, which will in turn improve sustainability.

Table 2 Index of welfare input-output index system

Factors	Sub-factors
Input factors	Average annual wages of staff and workers
	Education expenditure
	Medical beds
	Medical professionals

The formula for calculating capital stock is presented in

Eq. (11). Data on new fixed capital and price index for investment in fixed assets come from CSY. In Eq. (11), K , δ , I , and P represent capital stock, depreciation rate, new fixed capital and price index respectively.

$$K_t = I_t/P_t + (1 - \delta_t) K_{t-1}. \tag{11}$$

In addition, this paper assumes that higher education makes labor to enhance their ability to accumulate experience, accept new technology and new knowledge, and earn higher income^[17]. The average years of schooling of regions is calculated by using Eq. (12). This paper re-measures the labor force of 30 regions as in Eq. (13), where H_t is the total labor force in period t , P_j is the total employed workers of j^{th} region; \bar{y} is average years of education; E is the sum of total education year of certain population group, and P is the total number of this population group; P_i is total population with i education level, and E_i is the total years of population with i education level; Generally speaking, i is determined by the length of schooling in China. Following Bils and Klenow's study^[18] study on 52 countries, the value of μ is 10%.

$$\bar{y} = \frac{E}{P} = \frac{\sum P_i E_i}{P} = \frac{\sum P_i e^{\mu E_i}}{P}. \tag{12}$$

$$H_t = \sum_j \bar{y}_j P_j. \tag{13}$$

3 Results

3.1 Summary characteristics of the regions

In 2014, Eastern coast region witnessed the highest annual GDP (84.08 thousand yuan), led by Shanghai (97.37 thousand yuan). However, the area with highest average annual growth rate of GDP is Inner Mongolia (16.30%) followed by Middle Yellow River (13.81%). Besides, the growth rate of capital stock in Middle Yellow River is also highest (16.43%) followed by Southwest (15.75%) and Middle Yangtze River (15.39%), which means that the government encouraged capital investments in these regions. The Middle Yangtze River has a good advantage in human capital stock (12.59 million) and its growth rate is 3.20%, implying that this area could be an engine of growth of Chinese economy with proper policy support and investment. However, there is negative growth rate in human capital stock (-2.05%) in Northeast, which means that human resources and investment in this area is relatively scarce.

This paper measures three undesirable outputs: wastewater, waste gas, and soot/dust; and three environmental inputs: consumption of electricity and energy, and completed investment in pollution control based on EKC principle and data availability. Negative growth at variable levels was observed on industrial wastewater discharge, chemical oxygen demand and industrial soot/dust emission in most parts of China which is a good sign. However, the quantity of industrial waste gas emission and industrial sulphur dioxide emission (SO₂) has increased. The high level of investment completed in pollution treatment project (1.48 billion Yuan) and high growth of treatment cost (22.43%) in Middle Yellow River indicates that this region attach more importance on environmental protection in the pursuit of economic growth. It is worthwhile to note that Northwest witnessed a relatively low pollution discharge quantities but growing at a higher rate. The implication is that this area may be undertaking high-polluting projects from the developed regions. Therefore, more attention should be paid on

the cleaner production instead of end-of-pipe treatment in the process of industry transferring between developed and undeveloped area.

This study investigates social welfare from average wages of employed persons , education and health care. The results showed that the average wages is relative high in coastal areas , 24. 1 and 17. 6 thousand yuan in Eastern Coast and South Coast , respectively. Educational expenditure from the Central Government expenditure kept leaning towards the coastal area. Northwest has the least investment in health care , and its numbers of beds and employed persons are also the lowest. The correlation results show that only waste gas emission has high correlation with electricity power consumption , energy consumption and investments in pollution treatment. Since the focus of the paper is to calculate the directional distance to the frontier , the existence of correlation will not influence the results.

3.2 Regional differences in productivity indices

Based on the directional distance function given by Eqs. (9) and (10) , this paper calculated four productivity indices and their components. Wilcoxon rank-sum test was employed to test the difference of four productivity indices. The implication is that when the undesirable outputs are included , the rank of DMUs changes and the disparity mainly comes from the negative externality of undesirable outputs.

Table 3 presents geometric mean values of the four productivity indices and their components for each of the 8 economic zones. The growth of traditional TFP index (M) is only 0. 7% , whereas the figure for TP index (ML) is 6. 5% . The main drivers of TP growth is technical change (6. 6 %) with stagnant increase in efficiency change (0. 1%) . The main contributor to ML is environment oriented productivity (MLE) with growth rate of 7. 1% . The welfare oriented productivity (MLW) experiences a decline 8. 7% overall , due to decline in both technical change as well as efficiency change.

Zhang *et al.*^[19] provided an estimate of traditional TFP growth rate of 4. 8% , which is much higher than the TFP growth reported here but substantially lower than TP growth (6. 6%) . The possible reasons of discrepancy between this study and Zhang *et al.* , may be as follows: (a) Zhang *et al.*

used different periods (1989—2008) and excluded financial crisis; (b) difference in the computation of capital stock data as it is not centrally reported; (c) adjustment of the labor force according to average years of education; and (d) difference in selection of indicators of environmental factors between the two studies.

The result also showed that when environmental undesirable outputs are included , Guangxi experienced the highest TP growth of 22. 2% followed by Inner Mongolia (21. 4%) , Shanxi (17. 1%) , and Qinghai (16. 8%) respectively; while Guangdong , Liaoning and Gansu reported marginal declines in TP. Although coastal economic zones have experienced relatively rapid economic growth , the average TP growth is much lower in the 8 economic zones once ecological environment and social welfare are included in the measurements (Table 3) . The implication is that pollution co-exists with economic growth and social welfare did not improve. Only a few regions (*e. g.* , Gansu , Chongqing and Jilin) showed very small improvements in efficiency change , which means that these provinces is paying more attention to efficiency; and therefore , their development mode is worth investigating. The results are consistent with Kumar^[20] who noted that the economic zones with higher economic growth rate usually experience lower productivity growth.

Judging from welfare oriented productivity (MLW) , the overall performance is not encouraging at all. Only Liaoning witnessed improvement in welfare oriented productivity of 12. 0% while all other regions experienced decline in MLW. The most severe decline is in Northwest at 10. 7% followed by Middle Yellow River (10. 2%) and Middle Yangtze River (10. 0%) . The implication is that the benefits of economic growth are not actually enjoyed by the mass. Although Middle Yangtze River has obvious human capital advantage it needs to strengthen its social welfare investment if it wants to become a high growth area. Chongqing shows that its productivity indices are lower than its predecessor (*i. e.* , the Sichuan province) . The implication is that the growth mode of the new municipality is not good and should take actions to change , particularly on social welfare improvement.

Table 3 Productivity growth , efficiency change and technical change of 8 economic regions in China , 1997—2014 (Geometric means)

Regions	E	T	M	E-MLE	T-MLE	MLE	E-MLW	T-MLW	MLW	E-ML	T-ML	ML
Northern coast	0. 903	1. 164	1. 052	1. 020	1. 003	1. 023	1. 001	0. 923	0. 924	1. 003	1. 031	1. 034
Northeast	0. 966	1. 060	1. 024	0. 999	1. 022	1. 021	1. 006	0. 958	0. 964	1. 003	1. 040	1. 043
Eastern coast	0. 901	1. 196	1. 078	0. 986	1. 040	1. 025	0. 975	0. 949	0. 926	0. 996	1. 021	1. 017
South coast	0. 914	1. 102	1. 007	1. 017	1. 035	1. 053	0. 991	0. 922	0. 914	1. 004	1. 039	1. 044
Middle Yangtze River	0. 888	1. 075	0. 955	1. 003	1. 074	1. 077	0. 995	0. 904	0. 900	0. 992	1. 047	1. 038
Southwest	0. 888	1. 068	0. 948	0. 997	1. 125	1. 121	0. 996	0. 911	0. 907	1. 007	1. 099	1. 107
Northwest	0. 897	1. 075	0. 964	0. 995	1. 111	1. 105	1. 001	0. 893	0. 893	1. 003	1. 103	1. 106
Middle Yellow River	0. 896	1. 045	0. 937	0. 987	1. 123	1. 108	0. 992	0. 905	0. 898	0. 996	1. 115	1. 111
Overall China	0. 904	1. 094	0. 989	1. 000	1. 071	1. 071	0. 995	0. 918	0. 913	1. 001	1. 065	1. 066

Note: M is traditional Malmquist productivity index (*i. e.* , TFP) ; ML is TP which includes environmental resource use , environmental protection expenditure , and social welfare input and environmental undesirable output; MLE is environment oriented productivity; MLW is welfare oriented productivity; E = efficiency change; T = technical change

As far as the 22 regions out of 30 are concerned , their productivity growth improves when environmental undesirable outputs are included , which is consistent with the conclusions of Chung *et al.*^[11] , Du *et al.*^[21] and Färe *et al.*^[13]. This is because the behavior of government and/or enterprises on environmental protection will force transfer of resources from production to pollution reduction. However , the traditional TFP measures not only ignore the positive effects of inputs on improvements in undesirable outputs , but also assume that this kind of inputs are not good for the production of desirable outputs. Actually , the new measurement of TP which included social welfare input and environmental undesirable outputs will support in improving the degree of environmental regulation , and will oblige government and/or enterprises to introduce modern pollution abatement technology and cleaner energy in the production process. This will finally reduce pollution emissions and improve ecological environment , economic performance and social development.

3.3 Convergence analysis of productivity indices

In China , energy-saving emission reduction policies began in 11th Five Year Plan period(2006—2010) , and therefore , the sample data was divided into two time periods , *i. e.* , Period 1 (1999—2005) and Period 2 (2006—2014) . Absolute β -convergence analysis was used to analyze the changes between two periods and also among regions. For example , the convergence in TP for a region is expressed as

$$(\ln ML_{i,t} - \ln ML_{i,0}) / n = \alpha + \beta \ln(ML_{i,0}) + \varepsilon. \quad (14)$$

Equation (14) presents the average annual growth rate changes in regional productivity from base period to t period , where α is the intercept , β is the productivity coefficient of i region in base period , ε is the error term. A negative value of β indicates inverse relationship between the growth rate of productivity and its initial level , *i. e.* , convergence , and vice versa. According to Mankiw *et al.*^[22] , the calculation of convergence rate λ can be written as

$$\beta = \frac{1 - e^{-\lambda\tau}}{\tau}. \quad (15)$$

Results from the convergence analyses of productivity indices in two phases showed that values of β are all negative and significant at 1% , implying that there is a converging tendency in productivity level , except TP(ML) in Period 1. It is clear from Table 4 that there is little change in β values of M in the two periods. This paper found that the implementation of energy-saving emission reduction policies speeds up the convergence rate of MLE , implying that management of environmental issues has resulted in productivity improvements. Furthermore , this result refutes the traditional view that environmental protection is incompatible with economic growth. It is clear from this conclusion that reasonable measures against environmental pollution will stimulate economic development eventually. Finally , the welfare oriented productivity index showed no direct bearing upon the implementation of energy-saving emission reduction policies. The conclusion is that the convergence rate of China's welfare level is very slow (-0.06%) .

The convergence results of productivity indices by regions showed that the gap between these productivity indices is gradually reduced all over China. But social welfare level in regions of China is quiet unbalanced with only North coast and South west have significant converging tendency. This means that the overall level of welfare in Chinese regions is low with rising inequality. Significant convergence of environment oriented productivity(MLE) of the South coast implies that the

growth rates of this area will rise after including undesirable outputs , *i. e.* , environmental protection is much higher in these two areas. Also , significant convergence of welfare oriented productivity of North coast and South west implies that the growth rates of these two areas will rise after including social welfare input , *i. e.* , the quality of life in these two areas is much higher.

Table 4 Results of convergence analysis in different stages , OLS regression

Variable	1999—2005	2006—2014	Total period	
M	β value	-0.115***	-0.129***	-0.074***
	t value	55.745	-7.241	-92.325
	R^2	0.993	0.674	0.995
	Convergence rate	0.298	0.189	0.195
MLE	β value	-0.109***	-0.185***	-0.178***
	t value	-5.402	-4.562	-4.853
	R^2	0.576	0.469	0.562
	Convergence rate	0.194	0.301	-0.003
MLW	β value	-0.129***	-0.120***	-0.065***
	t value	-22.043	-5.820	-14.512
	R^2	0.956	0.478	0.902
	Convergence rate	-	-	0.121
ML	β value	-0.057	-0.185***	-0.066***
	t value	-1.624	-6.723	-4.317
	R^2	0.087	0.590	0.417
	Convergence rate	0.060	0.321	0.121

Note: *** , ** , * means significant at 1% , 5% , 10% level respectively. “-” means the convergence rate is incalculable

4 Conclusions

This paper highlights the weaknesses of the traditional productivity theory and introduces the concept of ‘TP’ which includes economic growth , ecological environment and social welfare. The study used Malmquist-Luenberger directional distance function approach to empirically apply the concept of TP on China using a panel data of 30 regions covering a 18 years period (1997—2014) which eventually provided rich information on the quality of its regional economic growth over time.

Results revealed that the average rate TP growth is estimated at 6.6% lead mainly by technical change(6.5%) and a slow efficiency change(0.1%) . The main contributor to TP index improvement is from environment oriented productivity growth which implies that great achievements have been made in environmental pollution control in China. There are various degrees of negative growth in industrial wastewater discharge , chemical oxygen demand and industrial smoke and dusts. However , the discharge of industrial waste gas and SO₂ is still very high. In the future , much more attention should be paid to the governing of industrial waste gas and urban pollution. However , welfare oriented productivity index showed a declining trend , implying that although China has experienced considerable economic growth , its welfare level has actually decreased. Results of the convergence analysis revealed that there is convergence in TP and the energy-saving and emission reduction policies speed up convergence rate of environment

oriented productivity. Besides, the welfare oriented productivity amongst regions is quite unbalanced, and their convergence rate is very slow, except in North coast and South west regions. The welfare level of China needs further improvement.

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