Available online at www.sciencedirect.com
SciVerse ScienceDirect
Physics Procedia 24 (2012) 1475 – 1481
Physics Procedia

2012 International Conference on Applied Physics and Industrial Engineering

Theoretical and Empirical Studies of Productivity Growth in the Agricultural Economics —— Cases of China and the United States

Lan Xu

East China University of Science and Technology
Shanghai, China

Abstract

This article investigates agricultural productivity growth over several decades, emphasizing to a great extent the agricultural economic development condition for the nine agricultural divisions of the United States, and China's 27 provinces in terms of Malmquist productivity growth index. The paper sets up a technique to make use of two-stage linear programming method, based on sequential production technology, to estimate the most fitted and reliable distance functions in relevant agricultural sectors, and thus to compute the Malmquist productivity indexes. Especially, it proposes to decompose the productivity growth index into two major components, technical progress and efficiency improvement, and their sub-components, to study the sources of growth in productivity.

Keywords: World economy; Malmquist productivity index; Linear programming optimization; Distance function

JEL Classifications: O47; D24; R11

---

1. Introduction

For several decades, the global agriculture experiences a persistent and rapid decline, to the most obvious contrary to the performances of other economic sectors that exhibits continuously fast development in recent years, the productivity growth of the agricultural sector, however, speeds relatively slow. Among them, the possible main reasons include increasingly resource scarcity, limited technological innovation, environmental degradation, and insufficient agricultural policy support. This article uses the linear programming technique to calculate the Malmquist productivity indexes based on the built-up technical frontiers, in order to investigate the total factor productivity growth of the two main greatest agricultural countries, China and the US, through several decades of years, and especially the function of their

doi:10.1016/j.phpro.2012.02.218

sub-components, technical efficiency and technological innovation, that increase the productivity, which in turn serves a reference basis as to raise the agricultural productivity and efficiency in the future.

Traditional agricultural productivity researches rely heavily on productivity index approaches, such as those of Fisher, Tornqvist, that are incapable of disaggregating the total effect of agricultural productivity into changes in performance and changes in technology. Because these approaches mask some important factors that determine the measurement of productivity change over time. Besides, traditional techniques usually presume that production is always efficient. However, different from the traditional indexing procedures, Malmquist index with distance functions requires neither of the use of input prices nor that of output prices in its construction.

This study examines the agricultural Malmquist productivity index using distance functions in estimating the total factor productivity. This approach allows for the decomposition of productivity growth into changes in technical efficiency over time (or catching-up) and shifts in technology over time (or technical change). Besides, it does not require presumption that production is always efficient. Furthermore, a non-parametric linear programming introduces in the second stage admits inefficient performances in technology.

2. Methodology

2.1. Distance Function and Malmquist Index

The Malmquist index was introduced by Caves et al. (1982) who adopted the output-based Malmquist productivity index after Sten Malmquist, who earlier proposed constructing quantity indexes as ratios of distance functions (Malmquist, 1953; Fare et al, 1994). Distance functions are basic components that define the Malmquist index. Distance functions are function representations of multiple-output and multiple-input technology which require data only on input and output quantities. In measuring total factor productivity growth, output-based Malmquist index of productivity change is assumed in this study.

To define the Malmquist index, two different time periods, t and $t+1$, must be specified. In order to avoid choosing an arbitrary benchmark time period, the geometric mean of two output-based Malmquist indexes with equivalent two consecutive time periods based on different time periods is defined as follows:

$$M_o^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right)\left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}.$$

Equivalently, an alternative form of the above index can be written as follows:

$$M_o^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}.$$

With the second expression, Malmquist productivity index can be decomposed into two components: change in efficiency (EFFCH) and shift in technology (TECHCH). A ratio outside the bracket is efficiency change component, which describes relatively efficiency catch-up between two periods, t and $t+1$, or sometimes called the effect of catching-up. A geometric mean of two ratios inside the bracket captures the shifting effect of frontiers representing the change of technology, on some years' observations for each of two periods, or sometimes called the effect of technological innovation. In sum, Malmquist productivity index can also be expressed in word as following form:

$$M_o^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) = EFFCH * TECHCH.$$

Where, EFFCH represents efficiency change, while TECHCH represents technological change. The level of efficiency can be further decomposed into scale efficiency and pure technical efficiency. Namely,

$$EFF = SCALE * PEFF.$$

Where, EFF represents the level of efficiency, and SCALE and PEFF measure scale effect and pure technical effect in the efficiency level, respectively.

2.2. Productivity Measurement

2.2.1. Optimization Problem

In order to measure the productivity change in each state, we can first construct the benchmark frontier of production technology by estimating observed values of inputs and outputs for all states, then to investigate the production technology of each state over time, and finally to compute the distance function by comparing individual production technology to the reference frontier from aggregating each state's technology. In the sense, Malmquist productivity index is constructed based on the estimated distance values. In addition to the aforementioned advantages of Malmquist-type index over traditional total factor productivity approaches for exempting certain restrictions, the Malmquist-type index can make each state be compared to a common benchmark frontier rather than only to its own previous periods of technology.

Furthermore, we propose to employ a two-stage linear programming technique to construct the benchmark frontier: the first stage called "non-parametric" is to restore each state's original production technology; while the second stage of Translog parametric functional form is to estimate a smoothly best-practiced technological frontier for all states. The non-parametric approach relies on Data Envelopment Analysis (DEA) to estimate the frontier. The advantage of using this technique is obvious. First, this technique best conforms to the actual data when technological frontiers are constructed. Second, it relaxes the restriction for specific functional form. And third, it allows for inefficient performance in constructing the reference frontier. On the other hand, due to the nature of non-parametric, the constructed technological frontier under such technique is piecewise, thus, unsmooth in nature. By using parametric Translog functional form, we can estimate a smoothly best-practiced technological frontier for all observations.

2.2.2. Computation of Distance Function

(1) Non-parametric Approach

In calculating distance functions, we usually need to construct a reference technology frontier to which each state can compare to get its own distance for each period. To this purpose, there is conventional contemporaneous approach to model the non-parametric linear programming problem. By this way, distance function, and thus Malmquist productivity index, in year t are only compared to the reference frontiers of its own period in year t or its adjacent period in year t+1, and production sets continuing for several years may be in essence irrelevant with each other. In this sense, all past histories, under the contemporaneous approach, are neglect when constructing reference frontier. The major problem with this approach is that the set-up of technical production frontier may become unstable, moving back and forth. As a result, it is hard to interpret the constructed frontier that is consistent with past experiences.

In reflecting characteristics that there is certain dependency between production sets consecutive for several years, this paper uses a sequential technological set assuming that data of past history across time accumulate rather than uncorrelated within the examined time. Although sequential approach has certain weakness, for instance it does not take into account technical regress in any possible way, such method eliminates the possibility of deviation to a minimum level in explaining the result.

In calculating the Malmquist productivity index, four distance functions with two adjacent time periods *t* and *t+1* must be estimated. For each time *t*, $t = 1,\ldots,T$, there are $k = 1,\ldots K$ observations on inputs, $x_n^{k,t}$ with $n = 1,\ldots,N$, and outputs, $y_m^{k,t}$ with $m = 1,\ldots M$. Reference technology under the sequential production set assumes that there is some form of dependency between production sets across time. Therefore, for each time period, $t = 1,\ldots,T$, the production technology models an input-output mix, (x^{t-s}, y^{t-s}) with $s = 0,1,2,\ldots,t-1$, using previous years' observations as part of the technology in period *t*. This means successive production sets as to form a sequential reference frontier are nested one another.

(2) Parametric Approach

The non-parametric linear programming technique is widely used in productivity analysis. Due to the aforementioned shortcomings, we can use a parametric Translog functional form to eliminate inefficient technology and estimate a smoothly best-practiced technological frontier for all observations. The advantage of parameterizing Translog functional form is that this specification is most flexible and consistent with the actual technology.

3. Empirical Work

3.1. *Data Sources*

The US agricultural data of this research comes from the Economic Research Services (ERS) in the US Department of Agriculture (USDA), who has constructed aggregate farm accounts of 48 US states on an annual base. The agricultural data of China comes from publication of “Chinese Agricultural Yearbook”, published by Chinese Agricultural Publisher belonging to the Department of Agriculture. And macroeconomic data are all come from statistical yearbooks published officially by each country. Considering that the level of agricultural economic development between two countries is comparable, we adopt the US agricultural data from 1960 till 1996 that is available for the public on ERS’s website, while agricultural data of China covers the time from 1980 to 2006.

The aggregate production accounts are categorized into output, input, and intermediate inputs as well. Two outputs, crop and livestock, are included, and inputs of agricultural sector mainly include labor, land, capital, and intermediates.

3.2. *Estimation Results*

3.2.1. *Productivity Growth*

First, to examine productivity growth in the US agricultural economics, two aggregate outputs, crop and livestock production, and four inputs, capital, labor, land, and intermediate, covering the period of 1960 -1996 are used to estimate the Malmquist index, and their components of efficiency and technological changes with help of computational tools, such as GAMS programming software and SPSS statistical software. For each output productivity index, we make use of two-stage linear programming optimization method to compute a nationwide distance function as reference technology. Then, individual state compares its own technology to this national benchmark to obtain its own distance function, thus in turn to compute its Malmquist index. In the result, a value greater than one for the Malmquist index indicates an improvement in productivity, while a value less than one denotes a deterioration of productivity performance. Subtracting one from these values yields the annual average change of productivity.

As a result, each state of the US agricultural productivity growth index exhibits a positive growth in productivity of crop production. Averaging over the four estimation methods, an overall productivity growth rate of crop production is around 3.5% for the studying period of 1960-1996. However, there is considerable variation of average productivity change rates nationwide by year compared to that by state. For the productivity rate, it varies from average annual productivity regress by 5% in 1981 and 1989, to average annual productivity increase by more than 17% in 1974. A variation range spans more than 20% comparing to that of only 3% difference for productivity change by state.

In a similar way, we also estimate the Malmquist productivity growth index for the Chinese agricultural production through 1980 to 2006. Output indicators encompass total agricultural production value, total value of farm crop production, and factor input data mainly cover farm labor, land area, and capital investments. The estimation procedure of distance functions and thus Malmquist indexes are generated similarly as those of the US case.

3.2.2. Decomposition Analysis

Decomposition of Malmquist productivity index interprets sources that contribute to the productivity growth. As stated in the methodological section, the Malmquist productivity growth index can be decomposed into two major factors, efficiency change and technological change. Efficiency change can be further decomposed into two components, scale change and pure efficiency change. In order to identify an evolutionary trend, we have divided the data into four groups with a 10 years' time for each period.

From the decomposition analysis for crop production, the growth rate of productivity was declining continuously from annual average increasing rate of 4.58% to that of 2.41% through different time periods from 60s to 80s, although the whole economy of the US at the same time was exhibiting tremendously prosperous. But such situation remained steady and showed little increased during the last time period of 90s reaching at an annual growth rate of 3.19%. In the 60s, region that grew fast belongs to NE with an average annual growth rate of 6.21%. On the other hand, PF was the slowest growing region in the 80s, with an annual productivity rate of only 1.85%. In general, the overall productivity growth for crop production shows a slightly increasing trend during the entire past four decades.

From the perspective of decomposition analysis, contribution to productivity growth in crop production is mainly due to technological progress that causes 3.45%, 3.60%, 2.57%, and 2.33% of increases during the 60s, 70s, 80s, and 90s, respectively, accounting for approximately 75%, 94%, 81%, 73% of the total productivity growth in each period. Only a very small portion is due to efficiency enhancement, although there are a few exceptional cases for regions of ENC, ESC, SA, and MA in the 80s and MA, MT, NE, PF, and SA in the 90s when an efficiency effect dominates technological change that contributes to the majority of the productivity growth in crop production.

Efficiency change usually implies a "catching-up" process since states with technological level falling behind trying hard to catch up in order to get away from a difficult situation, incline to follow or mimic an advanced technology, but have shown difficulty in breaking through on an innovative technology. The component of efficiency change can be further divided into scale change and pure efficiency change. In the result, we find that the overall catching-up process, or efficiency change, is commonly attributable to pure efficiency improvement for each period, accounting for almost 100% of the total change in efficiency. But the scale change that takes on a very small portion in contributing to the efficiency improvement is almost negligible or even declining by 0.02% for the average value of crop production in the 90s.

The second component of Malmquist productivity index is technological change, or sometimes called "innovative" process, which captures the effect of frontier shifting inward or outward. The technological change can be further decomposed into three components of output-biased, input-biased, and magnitude changes. Each component of technological change modifies biased components of input-output mix by changing factor ratios. If technology is neutral, it implies both the output-biased and input-biased technological changes are equal to one, thus the total technological change should be equivalent to the magnitude technological change.

According to our study, the growth rate of magnitude technological change for crop production has a minor difference from the overall technological change in each period, accounting for -0.4%, 0.03%, -0.39%, and -0.01% in the 60s, 70s, 80s, and 90s, respectively. However, there still exists huge biased technological change, among which the input-biased technological change accounts for over 90% of the total biased technological change over the entire period.

Contrast to the development progress of the US agricultural economics, China speeds relatively slow at an average rate of 0.11% during a comparable time period of recent 30 years, although the whole economy of China develops rapidly in the meantime. Among them, the growth rate of crop production as main agricultural product increases at only 0.14%, far below 3.5% growth rate of the US agricultural productivity under the same development stage during 60s through 90s. Moreover, of less than 1% productivity growth rate, the scale efficiency predominantly accounts for more than 100% and 89.9% of the total factor productivity growth in the overall agricultural output value and the output value of crop production, respectively. This means, with the progress of agricultural economic development in recent 30 years, the component of technical efficiency in China's agricultural total factor productivity imposes a declining effect, degrading at an average rate of 0.15% annually. It is notice that the effect of technical progress contributes to 75% to 95% of the total factor productivity growth for the US agricultural production during the time of 60's through 90's, which is remarkably high contrasting to that of China. In addition, the total agricultural productivity of China showed a clear descending trend in the 90's, falling behind at an annual average rate of 1.3%, and the productivity of crop production is being decreased at a rate of 0.65% even in the beginning of the 21st century.

3.2.3. Technological Frontiers

Based on the constant-return-to-scale production, the productivity measure can also determine which states take leads in technology for each year. If the value of the distance function of certain state in certain year equals unity, then this state is considered on a national frontier at the time. Value less than one implies the state is under the frontier or technically inefficient. The higher the value, the closer this state is to the frontier. We summarize the US states and Chinese provinces whose distance functions have been estimated to be one or above 0.9, with total numbers of times these states (or provinces) are at the national frontiers over the studied period. Accordingly, these states or provinces are regarded to lead the productivity technology of a relevant agricultural sector at the time.

In crop production, State SD plays a predominant leading role in defining the technological frontier for fourteen years, with the distance function closer to the national frontier for nineteen times, far ahead of the second best performed State SC, which has a record of six times standing on and seven times close to the frontier. Along with the above two, states of KY, MT, DE, IN, and MS have, to some extent, taken a joint leading role in crop production.

Contrarily to that of the US, few provinces in China show clearly leading advantage in the technological productivity growth. In the total of 26 years between 1981 and 2006, provinces of Fujian and Sichuan are both placed on the country's technological frontier for crop production but only for five times, separately, which, to some extent, become leaders in this field. As follows are Beijing and Heilongjiang, which take leads for four times. Further follows are Hunan, Neimenggu, Tianjin, Zhejiang, Anhui, Jiangxi, and Shanghai, who have shown somewhat leading roles in the past 30 years.

In the overall of Chinese agricultural economics, Fujian has a slight advantage in leading the way of productivity growth for 7 years for the total output value of agricultural product, thus is considered to be a major province defining the agricultural production frontier, followed by Beijing and Neimenggu, which also stand on the frontier for a couple of times.

4. Conclusions

This paper examines the agricultural productivity growth of the two greatest agricultural countries in the world, the US and China, through several decades. In the study, it makes use of two-stage linear programming methods to estimate distance functions, and thus in turn to calculate Malmquist productivity indexes. In the programming, a sequential technique is conducted to define production sets, which have a desirable feature of smoothness and differentiability, proved to be the most reasonable and reliable method in estimating distance functions.

According to our analysis, the US in general exhibits a positive growth in agricultural productivity over the examining time of 1960 to 1996. Although a decomposition analysis indicates that agricultural productivity growth in the US has been declining from 1960s to 1980s, their components of technological change contribute over 75% of the total productivity growth in each period of the four decades.

On the other hand, agricultural productivity growth of China speeds relatively slow at an average rate of 0.11% in recent 30 years, far below an average of 3.5% growth rate in the US for a comparable time period, although the whole country's economy develops rapidly in the same time. Moreover, of the less than 1% productivity growth, the scale efficiency predominantly accounts for more than 100% of the total factor productivity growth in the overall agricultural output value, which implicates the effect of technical efficiency contributable to productivity growth is degrading. Such result is a remarkable contrast to that of the US evidence.

Finally, according to the study, State SD leads continuously the productivity technology of crop production during the reported time of four decades. However, few provinces in China exhibit a prevailing advantage in taking a lead of the country's agricultural productivity in the past 30 years.

References

[1] Arnade, C. Gopinath, M., "Capital Adjustment in U.S. Agriculture and Food Processing: The Cross-sectoral Model", Journal of Agricultural and Resource Economics, 1998(July), 23(1), 85-98.

[2] Ball, V. Eldon, Jean-Pierre Butault, and Richard Nehring, "U.S. Agriculture, 1960-96: A Multilateral Comparison of Total Factor Productivity"[M], Report from the Economic Research Service, USDA, No.1895 of Technical Bulletin, May 2001.

[3] Fare, Rolf, Shawna Grosskopf, Mary Norris, Zhongyang Zhang, "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries", American Economic Review, 84(1), 66-83, 1994 (March).

[4] Grosskopf, Shawna, "Some Remarks on Productivity and its Decompositions"[J], Journal of Productivity Analysis, 20, 459-474, 2003.

[5] Lin, Jinzhong, "Improvement of Research Methods on Sustainable Study of Chinese economy growth", College Journal of Xiamen University, Issue 2, 2006.

[6] Nin, Alejandro, Channing Arndt, Thomas W. Hertel, and Paul V. Preckel, " Bridging the Gap Between Partial and Total Factor Productivity Measures Using Directional Distance Functions", American Journal of Agricultural Economics, 85(4), 928-942, 2003 (November).

[7] Pastor, Jesus T., and C.A. Knox Lovell, "Circularity of Malmquist Productivity Index"[J], Economic Theory, 33, 591-599, 2007.

[8] Xu, Chensheng, "Innovative Efficiency and Productivity in the National Science and Technology", Science and Technology Management Research, Issue 1, 2008.

[9] Xu, Lan, "Studies of Productivity Growth Index on Yangtze River Delta Cities", Shanghai Journal of Economics, Issue 7, 2009.