International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Interregional Comparison of Agricultural Productivity Growth, Technical Progress, and Efficiency Change in China's Agriculture: A Nonparametric Index Approach

Spitzer, M.

IIASA Interim Report
December 1997

International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Tel: +43 2236 807 • Fax: +43 2236 71313 • E-mail: info@iiasa.ac.at • Web: www.iiasa.ac.at

INTERIM REPORT IR-97-89 / December 1997

Interregional Comparison of Agricultural Productivity Growth, Technical Progress, and Efficiency Change in China's Agriculture: A Nonparametric Index Approach

Martin Spitzer(spitzer@iiasa.ac.at)

Approved by
Günther Fischer(fisher@iiasa.ac.at)
Leader, *Land Use Change Project*

Abstract

A linear programming technique is used to decompose agricultural total factor productivity change in China's provinces during the period 1985 to 1994. The method allows the decomposition of productivity growth into two mutually exclusive and exhaustive parts: technological change and changes in pure technical efficiency. The decomposition provides a natural way to differentiate innovations from catching up phenomena in China's agriculture.

Keywords: agriculture; China; productivity; efficiency; technical progress

Contents

List of Tables

List of Figures

Interregional Comparison of Agricultural Productivity Growth, Technical Progress, and Efficiency Change in China's Agriculture: A Nonparametric Index Approach

Martin Spitzer(spitzer@iiasa.ac.at)

1 Introduction

Considering the importance of productivity growth for raising the standard of living it is not surprising that productivity analyses receive substantial attention from the economic and political communities. Total factor productivity is traditionally calculated as the ratio of total output to the weighted sum of inputs, i.e., the total sum of factors. As a consequence the total factor productivity growth is measured as a ratio of the growth index of outputs to the growth index of inputs. Quite often, growth in total factor productivity is interpreted as a shift of the production function. This interpretation is valid only if the firm is perfectly technically efficient in production, realising the full potential of the given technology. Technically efficient production can be achieved if farmers follow the best practice to apply the technology. To the extent that farmers do not produce with technical efficiency due to differences in their capacity to use new technological knowledge and due to differences in the motivation of farmers, technical progress is not the only source of total factor productivity growth. Changes in productivity arise from two connected parts: technical progress and changes in efficiency. Hence, the decomposition of total factor productivity growth into technical progress and changes in efficiency provides more information about the application of production technology. From a policy point of view this decomposition is important because without using the existing technology to its full potential it may not be meaningful to embark on the introduction of new technologies. Recently developed techniques allow decomposition of changes in productivity into these two parts. Common to such methods is the construction of a production frontier to which each observation is compared. Observations lying on the production frontier are considered to be technically efficient, whereas shifts in the production frontier are interpreted as changes in the technology.

In the case of China's food production, increases in productivity are an essential requirement of meeting the growing demands for food in the future. It is a widespread opinion that this growing demand can be met by increased use of inputs or increases in agricultural productivity (Fan 1991). However, input use and agricultural productivity are two mutually influencing factors determining agricultural output. Recent studies have shown that increased input use has lead to higher environmental pressure on agricultural land which could in turn wipe out expected increases in outputs (Huang & Rozelle 1995). Although mere increases in input may lead to impressive short term increases in agricultural production, in the long term productivity growth has to be considered as the only source of sustainable increases in agricultural output. Increases in total factor productivity of the agricultural production show to what extent agriculture is contributing to the overall economic growth of a specific country.

In this study a nonparametric index number approach developed by Färe, Grosskopf, Lindgren & Roos (1992) is used to construct a best-practice production frontier for China. One important advantage of this method is that it uses only data on input and output quantities to construct the frontier. Observed input-output combinations of each of China's provinces are then compared to this frontier. If an observation lies inside the constructed production frontier it will be considered as technically inefficient. This can happen when production in a province do not apply the existing knowledge of production technology to its full extent and can be interpreted as a lack of diffusion of technology. Technically efficient production lies always on the production frontier. Technological progress is measured as shifts in the constructed production frontier over time. Together, technological progress and changes in efficiency determine total productivity growth.

In the past eight years two major studies on productivity growth and its components in China's agriculture were conducted using two different methodological approaches. Fan (1991) used the stochastic frontier production function approach. However, the specification of the stochastic production frontier implies some restrictive assumptions related to the measurement of technical progress. One major restriction in Fan's study is that technical changes are treated over time as neutral shifts in the production frontier implying that technical change is also of a neutral type. Kalirajan, Obwona & Zhao (1996) did not have to adopt such restrictive assumptions by applying the varying coefficients production frontier approach which allows for a nonneutral type of technological change. However, both approaches require the specification of a functional form and data on prices of both inputs and outputs. Prices of inputs are, at least in the case of China's agriculture, not available for most of the production factors.

The method employed in this paper (Färe et al. 1992), addresses all the limitations mentioned above. The approach uses linear programming techniques to construct a piecewise linear production frontier. The observations are then compared to this production frontier through distance functions (Shephard 1953) which are, subsequently, used for the calculation of a Malmquist-type index of productivity changes. Compared to the other methods, the approach has four major advantages (Färe et al. 1992): First, since it is calculated from distance functions, it only requires data on quantities. Second, it allows for inefficient performance and does not presume an underlying functional form of the production technology. Third, no assumptions regarding the optimizing behavior of the producer is necessary. And fourth, since it is a nonparametric index, it does not require econometric estimation. The chosen type of index number then allows decomposition of changes in productivity into technical progress and efficiency changes. Conventional methods of productivity change measurement are usually fraught with various problems related to the availability of price data and to the treatment of capital (Bureau, Färe & Grosskopf 1995). This study avoids such common problems owing to the advantageous characteristics of the chosen method. It provides an interesting application of a modern approach to the measurement of productivity change.

The results show that China's agricultural productivity has somewhat stagnated in the postreform period. Productivity growth rates have varied between -0.6% and +1.3% following the overall economic cycle of China. Specifically, almost all of the provinces are producing on the production frontier and hence the only source of total factor productivity growth arises from technical change. These findings have major implications for policy makers, showing that the reforms and the introduction of the household responsibility system successfully increased efficiency in production through a one-shot acceleration brought about by the removal of barriers to efficient production. Once a high level of efficiency had been achieved, further growth in productivity could be achieved mainly by continuing investments in research and development of agricultural production techniques. The findings are quite consistent with those in Sun (1997, p.126).

The outline of this paper is as follows: Section 2 gives a brief overview of China's agriculture. Section 3 emphasizes the theoretical background of the method and describes two intuitive graphical illustrations of the theory. In Section 4, provincial level data of China's agriculture for the years 1985, 1990, and 1994 are used to construct the productivity change indexes. The last section presents some conclusions from the empirical results discussed in Section 4.

2 Background

Generally, the importance of China's agriculture is seen in the challenge of meeting the demand for food of about 20% of the world's population using only 9% of the world's cultivated area. In 1994, 54.3% of the workforce was engaged in agriculture. Apart from supplying food, agriculture serves also as a main supplier of raw materials for industry. The export of both unprocessed and processed agricultural products makes a substantial proportion of China's total exports, amountingn to 41.9% of total exports in 1992 (Sun 1997, p.103).

Table 1 illustrates the existence of agricultural cycles reported by Sun (1997). Agricultural production in the period from 1985 to 1994 overlaps with two business cycles in China. The first started in 1980 and ended in 1989. The period from 1980 to 1984 constitutes the expanding period of the first economic cycle. It was characterized by impressive growth rates of agricultural outputs. Most scientists explain this growth rate to a large extent by the introduction of the rural households responsibility system (HRS) (Wen 1993, Kalirajan et al. 1996, Sun 1997). Though still collectively owned, land was now contracted out to individual households, Village authorities controlled only the contract allocation. Farm households became independent production and accounting units (Wen 1993). This reform brought greater responsibility and control over outputs and production factors to the farmers. But full control over outputs by the farmers was still not achieved since a state procurement system controlled the flow of the bulk of produced goods: One part of the output went to the state. Another part went to the village authorities as payment for rents or taxes and as contributions to the public welfare and the accumulation fund. The rest of the output remained in the farm households for consumption and savings. As the main barriers to efficient production were removed, agricultural production in the contracting period of the business cycle between 1984 and 1989 turned to be at a more sustainable level. The policy shift from 1985 to 1988 characterized by reducing material reward to farmers and lowering agriculture's terms of trade with industry resulted in an outflow of educated labour forces from agriculture by 8.6% per year. As a consequence, per capita grain production declined by 2.3% annually and the growth rate of real value added per labourer was only 1.7% between 1984 and 1989 (Sun 1997, p.129).

Agricultural production in the expanding period of the second economic cycle between 1989 and 1993 was dominated by the economic readjustment program and increasing material incentives to farmers. However, the continued growth in the income gap between urban areas and the countryside caused further outflows of labour forces from agricultural production. It also stimulated farmers to switch to more profitable cash crops and to use other technologies. As a consequence, output of grain increased annually by 1.6% and the growth rate of real value added per labourer was 4.1% between 1989 and 1993. The

Table 1: Changes in real value added per labourer and per capita output of grain in three periods between 1984 and 1993.

Agricultural cycle	Expanding period average annual growth rate, %	Contracting period average annual growth rate, %	Expanding period average annual growth rate, %
	1980–1984	1984–1989	1989–1993
Real value added per labourer	8.5	1.7	4.1
Per capita output of grain	4.8	–2.3	1.6

Source: Sun (1997), pp. 124, 126

peak of the agricultural cycle is considered to have been reached in 1993 (Sun 1997, pp. 126–130).

3 Methodology

3.1 The structure of technology

Consider a production technology transforming an input vector $x = (x_1, \ldots, x_n)$, $x \in \mathbb{R}^n_+$ into net outputs $u = (u_1, \ldots, u_m)$, $u \in \mathbb{R}^m_+$. This technology may be modeled by the input correspondence $u \to L(u) \subseteq \mathbb{R}^n_+$ or, conversely, by the output correspondence $x \to P(x) \subseteq \mathbb{R}^m_+$.[1] $L(u)$ denotes the subset of all input vectors $x \in \mathbb{R}^n_+$ which yield at least u. Conversely, for any $x \in \mathbb{R}^n_+$, $P(x)$ denotes the subset of all output vectors obtainable from x or less than x, i.e. the inverse relationship between $L(u)$ and $P(x)$ is given by

$$x \in L(u) \Longleftrightarrow u \in P(x) \tag{1}$$

and may be computed by

$$P(x) = \{u : x \in L(u)\} \qquad \text{and} \qquad L(u) = \{x : u \in P(x)\}. \tag{2}$$

Both of these correspondences are assumed to satisfy certain properties (axioms). Since this paper deals only with output correspondences, only the corresponding axioms for the output correspondence (Färe et al. 1985) are introduced:

P.1. $P(0) = \{0\}$,

P.2. $P(x)$ is bounded for $x \in \mathbb{R}^n_+$,

P.3. $P(\lambda x) \subseteq P(x)$ for $\lambda \in [0, 1]$,

P.4. P is a closed correspondence ,

P.5. $u \in P(x) \Longrightarrow \theta u \in P(x)$ for $\theta \in [0, 1]$.

[1] For a detailed discussion of input and output correspondences see Shephard (1970). For a discussion of input and output correspondences in relation with the measurement of efficiency see Färe, Grosskopf & Lovell (1985).

Property **P.1.** states that the null vector of inputs yields zero output. **P.2.** says that finite input can not produce infinite output. **P.3.** states that a proportional increase in inputs does not reduce output (according to Färe et al. (1985), this property is called "weak disposability" of inputs). **P.4.** is a mathematical requirement to enable the definition of output isoquants as subsets of the boundaries of the output sets $P(x)$. **P.5.** states that a proportional decrease in outputs remains producible with no change in inputs (following Färe, Grosskopf, Norris & Zhang (1994) this is called "weak disposability" of outputs). In places in this study stronger axioms than in P.3. and P.5. are needed. These axioms are

P.3.S. $y \geq x \Rightarrow P(y) \supseteq P(x)$,

P.5.S. $v \leq u \in P(x) \Rightarrow v \in P(x)$.

Axioms **P.3.S.** and **P.5.S.** impose "strong disposability" of inputs and outputs. Thus, by **P.3.S.** any increase in inputs, not limited to a proportional increase, cannot lead to a reduction in output. Similarly, by **P.5.S.** any reduction in outputs, not necessarily proportional, remains producible with no change in inputs. Hence, the difference between strong and weak input and output disposability lies in the proportional or disproportional increase or decrease of inputs and outputs. If inputs or outputs are strongly disposable they are also weakly disposable but the converse is not true. Strong disposability of outputs excludes congestion of technology which means that outputs are freely disposable. However, such an approach is, especially in the output case, not always justified, since outputs could also be undesired such as negative externalities. Only if these negative externalities can be disposed at zero net cost, the assumption of strong disposability of outputs can be maintained. Since strong disposability of outputs is assumed throughout this paper, only the definition of the strongly disposable output correspondence is presented here (Färe et al. 1985):

$$P^{SO}(x) := \{u : x \in L(v),\, v \geq u \geq 0\} \tag{3}$$

3.2 The decomposition of productivity growth

The purpose of this paper is to measure China's agricultural productivity growth and to decompose the growth rate into a technical change component and an efficiency change component. The index used here is the output-based Malmquist productivity change index (Färe, Grosskopf, Norris & Zhang 1994). The Malmquist index was named by Caves, Christensen & Diewert (1982) after Sten Malmquist who proposed quantity indexes as ratios of distance functions (Malmquist 1953). Distance functions are functional representations of multiple–output, multiple–input technologies which require (theoretically) data only on input and output quantities. It was shown by Caves et al. (1982) that the traditional Törnquist index[2] used for productivity analysis is under certain circumstances equivalent to the geometric mean of two Malmquist productivity indexes. But these conditions impose rather strong assumptions since they assume technical efficiency, allocative efficiency, and a translog form of technology with all second order terms identical over time. In contrast, the direct computation of distance functions used in this study allows us to relax all the assumptions regarding efficiency or functional form.

[2] An example of a Törnquist index is an index with the form $\left[\ln p_{t,t+1} = \frac{1}{2}(\ln p_t + \ln p_{t+1})\right]$. This would be the geometric mean of two Malmquist productivity indexes, one based on year t and one based on year $t+1$. Caves et al. (1982) calculated the components of the Törnquist index in a nonparametric way (in the sense that one need not estimate the parameters of technology) requiring data on input and output prices.

To define the output based Malmquist index it is assumed that the production technology S^t transforms $n\,(n = 1, \dots N)$ inputs $x^t \in I\!R^n_+$ into $m\,(m = 1, \dots M)$ outputs $u^t \in I\!R^m_+$ for each time period $t = 1, \dots T$:

$$S^t = \{(x^t, u^t) : \ u^t \leq f(x^t)\}, \tag{4}$$

i.e. the production technology consists of all feasible input-output vectors and in the most general form $S^t \subseteq I\!R^{n+m}_+$. It is further assumed that S^t satisfies axioms **P.1.** to **P.5.**, **P.3.S.** and **P.5.S.** mentioned above. These axioms are necessary to define meaningful output distance functions. Following Shephard (1970) and Färe et al. (1994) the output distance function at time t is defined as[3]

$$\begin{aligned} D^t_o(x^t, u^t) \ &= \inf\{\theta : \ (x^t, u^t/\theta) \in S^t\}, \quad \ \theta > 0 \\ &= \sup\{\theta : \ (x^t, \theta u^t) \in S^t\}^{-1}, \quad \theta > 0. \end{aligned} \tag{5}$$

According to 5, the output distance function is defined as the maximum proportional expansion of the output vector u^t at given inputs x^t, keeping $(x^t, \theta u^t)$ feasible. It completely characterizes the technology. In particular, note that $D^t_o(x^t, u^t) \leq 1$ if and only if $(x^t, u^t) \in S^t$. Furthermore, $D^t_o(x^t, u^t) = 1$ if and only if (x^t, u^t) lies on the production frontier S^t_F, which occurs only if production is technically efficient. An intuitive interpretation of the construction of the output distance is given in Figure 1.[4] In this figure scalar input is used to produce scalar output with a constant returns to scale technology. Suppose that (x^t, u^t) is an observed input-output combination located inside the production frontier at t; i.e. the production is not technically efficient. The distance function measures the reciprocal of the greatest proportional increase in output for a given input such that the output is still feasible. This is shown in Figure 1 by $(\overline{0a}/\overline{0b})$ which is less than one. Farell's (1957) measure of technical efficiency is given by the ratio $(\overline{0b}/\overline{0a})$ which is greater than one and which indicates "how far" an observation is from the frontier of production technology. More generally, one can write the value of the distance function $D^t(x^t, u^t)$ for observation (x^t, u^t) as $\parallel u^t \parallel / \parallel u^t/\theta \parallel$.

The output distance for the observation at time $t + 1$, (x^{t+1}, u^{t+1}), relative to the production frontier S^{t+1} is given in Figure 1 by the ratio $(\overline{0f}/\overline{0d})^{-1}$. For the Malmquist index it is further necessary to define distance functions with respect to two different points in time such as $D^{t+1}(x^t, u^t)$ and $D^t(x^{t+1}, u^{t+1})$. The definition for $D^t(x^{t+1}, u^{t+1})$ is given by

$$D^t(x^{t+1}, u^{t+1}) \ = \inf\{\theta : \ (x^{t+1}, u^{t+1}/\theta) \in S^t\}, \quad \theta > 0. \tag{6}$$

It measures the proportional change in outputs required to make (x^{t+1}, u^{t+1}) feasible with technology available at time t. The distance $D^t(x^{t+1}, u^{t+1})$ is given in Figure 1 by the ratio $(\overline{0e}/\overline{0d})^{-1}$ which is greater than one. Note that the production for observation (x^{t+1}, u^{t+1}) occurs outside the production technology for time t, which means that technical change has occured. Similarly, one may define the output distance for observation (x^t, u^t) relative to technology S^{t+1}. The distance for this case is given in Figure 1 by the ratio $(\overline{0c}/\overline{0a})^{-1}$.

The Malmquist productivity change index as defined by Färe et al. (1994) is then calculated as

[3]The values of the distance function are the reciprocal of Farrels (1957) measure of technical efficiency, which calculates "how far" an observation is from the frontier technology.

[4]Figure 1 is taken from Färe et al. (1994).

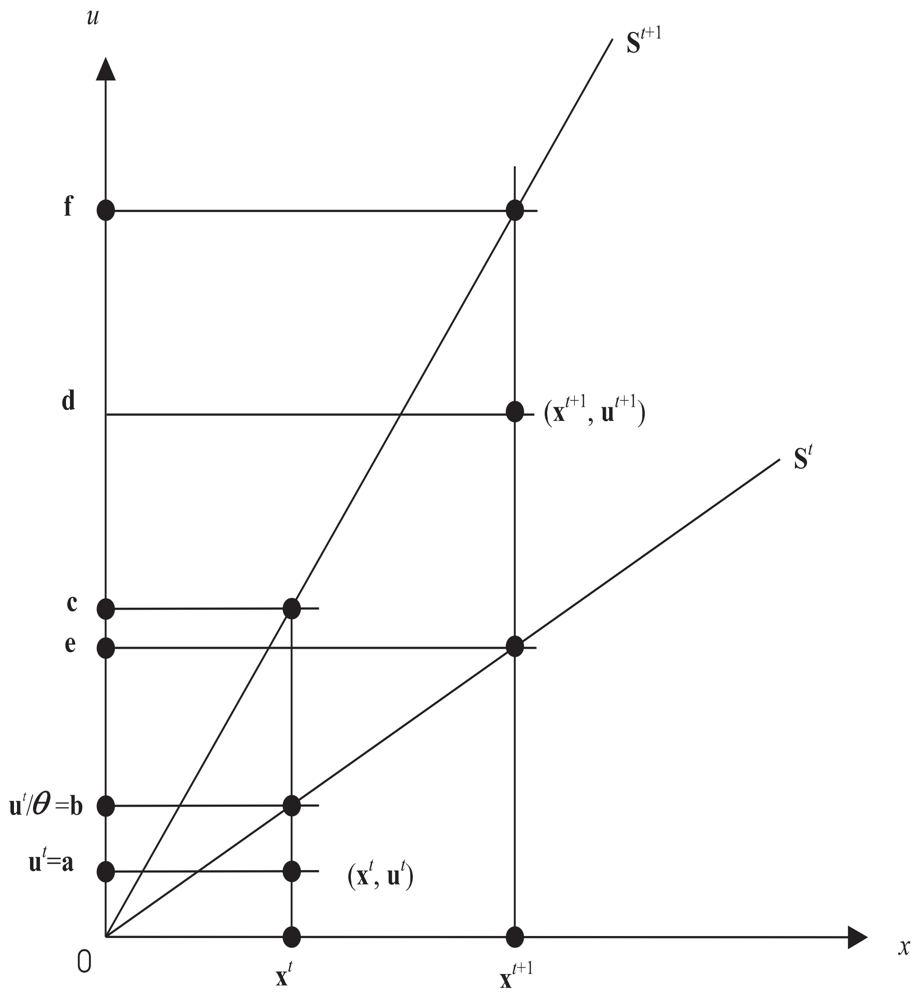

Figure 1: Constant returns to scale production frontiers.

$$M_o(x^{t+1},u^{t+1},x^t,u^t)=\sqrt{\frac{D_o^t(x^{t+1},u^{t+1})}{D_o^t(x^t,u^t)}\,\frac{D_o^{t+1}(x^{t+1},u^{t+1})}{D_o^{t+1}(x^t,u^t)}}\ . \tag{7}$$

In the first term inside the square root, technology in period t is used as reference technology and in the second term inside the square root technology of period $t+1$ is used as reference technology. Following Färe et al. (1985), this index can be decomposed into two components, one measuring technical change and one measuring changes in efficiency. Using the decomposition of total factor productivity change one may find, after some rearrangement, an equivalent way of writing equation (7):

$$M_o(x^{t+1},u^{t+1},x^t,u^t)=$$
$$\frac{D_o^{t+1}(x^{t+1},u^{t+1})}{D_o^t(x^t,u^t)}\times\sqrt{\frac{D_o^t(x^{t+1},u^{t+1})}{D_o^{t+1}(x^{t+1},u^{t+1})}\,\frac{D_o^t(x^t,u^t)}{D_o^{t+1}(x^t,u^t)}} \tag{8}$$

The first ratio on the right hand side of equation (8) measures the changes in efficiency between t and $t+1$. The second term is the measure of technical change. The way the four different distance functions are arranged to allow for a decomposition of productivity changes can also be seen in Figure 1. The efficiency changes component simply compares the distances of the two observations, (x^t,u^t) and (x^{t+1},u^{t+1}), to the corresponding production frontiers, S^t and S^{t+1}. It measures wether production is catching up with or falling behind the production frontier. It is assumen that this component captures diffusion of technology related to differences in knowledge, and institutional settings. The remainder of equation (8) measures technical changes. Particularly, it takes the geometric mean of the changes in technology in time t and $t+1$ at input levels x^t and x^{t+1}. This term is considered to capture changes in technology at a national level. This could happen if new inputs are used (e.g. new seeds) or changes in the climate at the national level have occured. According to the notation in Figure 1 the decomposed index becomes

$$M_o(x^{t+1},u^{t+1},x^t,u^t)=\ \frac{(\overline{0a}/\overline{0b})}{(\overline{0d}/\overline{0f})}\times\sqrt{\left[\left(\frac{(\overline{0d}/\overline{0e})}{(\overline{0d}/\overline{0f})}\right)\left(\frac{(\overline{0a}/\overline{0b})}{(\overline{0a}/\overline{0c})}\right)\right]}. \tag{9}$$

The Malmquist index can be calculated in several ways.[5] This study follows Färe et al. (1992) by applying a nonparametric linear programming approach.

The first step in the calculation procedure is, though not explicitly calculated, the construction of the frontier technology. The reference or frontier technology S_F for period t is constructed from the data as

$$\begin{aligned}S_F^t=\{(x^t,u^t):\ \ & u^t\le z^t\cdot\mathcal{H}^t\\ & x^t\ge z^t\cdot\mathcal{P}^t\\ & z^t\ge 0\},\end{aligned} \tag{10}$$

which exhibits constant returns to scale. z^t is the k-dimensional vector of intensity variables, indicating at what intensity a particular region is involved in production. $\mathcal{H}^t$ is the $k\times m$ dimensional matrix of output quantities at time t and $\mathcal{P}^t$ is the $k\times n$ dimensional matrix of input quantities at time t. u^t and x^t are the observed output and input quantities

[5]Nishimizu & Page(1982) proposed a decomposition using a stochastic production frontier approach. Kalirajan & Obwona (1994) were using the varying coefficients production frontier approach to decompose total factor productivity. Both approaches need information about data on prices and require specifications of the underlying functional form of technology. The approach chosen in this paper needs neither of these requirements.

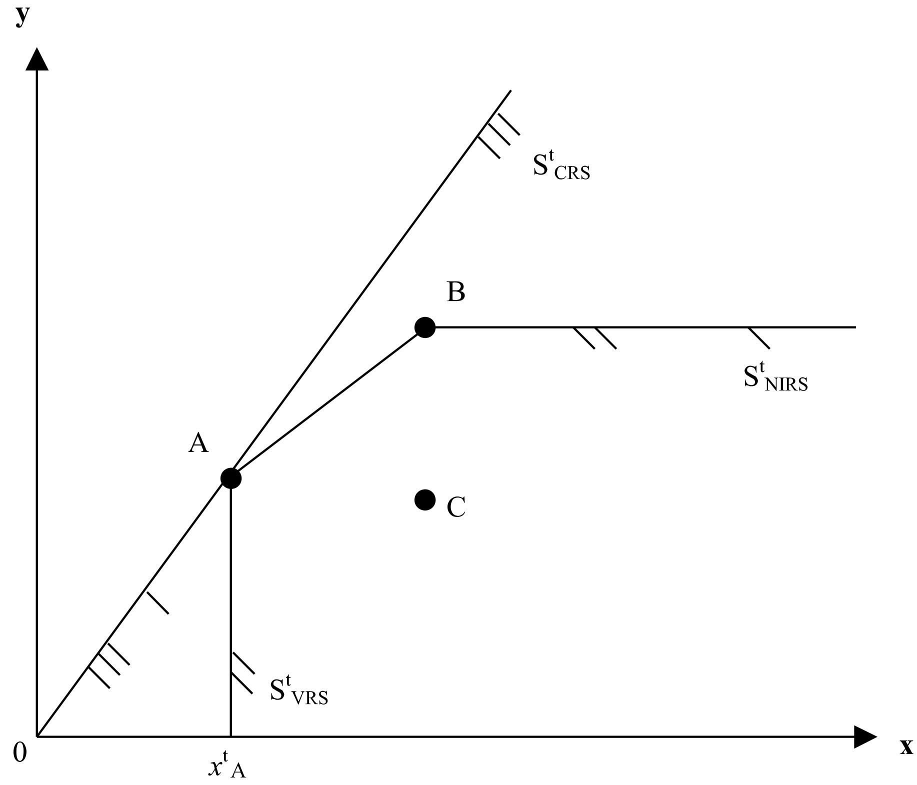

Figure 2: Production frontiers with different returns to scale technologies.

at time t summed up over all regions. The assumption of constant returns to scale may be relaxed by an additional restriction to the set of equations (10) to allow for nonincreasing returns to scale (Afriat 1972, Färe et al. 1994):

$$\sum_{t=1}^{k} z^t \leq 1. \tag{11}$$

Thus requiring that the sum of z^t over all regions k is less or equal to one. To allow for variable returns to scale one can follow Afriat (1972) and change the inequality (11) into an equality

$$\sum_{t=1}^{k} z^t = 1, \tag{12}$$

that is, the sum of elements z^t over all regions k is equal to one. In principle, the Malmquist index can be related to any kind of technology (constant, nonincreasing, or variable returns to scale). In this study the Malmquist indexes are calculated relative to variable returns to scale. Färe et al. (1994) termed the efficiency changes component obtained with variable returns to scale technology "pure efficiency change".

The differences between the three possible technological restrictions stated in equations (10) to (12) are illustrated in Figure 2 (Färe et al. 1994). Suppose we have three observations (provinces). If the sum of the intensity variables is restricted to be less or equal one according to equation (11) (i.e. we are allowing for nonincreasing returns to scale) the frontier technology will be the line defined be points 0, A, B and the horizontal extension from B. If we restrict the sum of the intensity variables to one according to equation (12) (variable returns to scale), the frontier technology will be the line passing through points x_A^t, A, B and the horizontal extension from B. Finally, assuming a technology with constant returns to scale, as in the last line of equation (10) (i.e. the intensity variables are allowed to take any nonnegative value) the technology becomes a cone with the frontier represented by the line through 0 and A.

The Malmquist productivity index is expressed in terms of four output distance functions. Accordingly, to calculate the productivity of province k' it is necessary to solve four different linear programming problems: $D_o^t(x^t, u^t)$, $D_o^{t+1}(x^{t+1}, u^{t+1})$, $D_o^t(x^{t+1}, u^{t+1})$, and $D_o^{t+1}(x^t, u^t)$. The value of the distance function $D_o^t(x^t, u^t)^{-1}$ at time t is calculated as the solution of the following linear programming problem for each region $k = (1, \ldots K)$ (Färe et al. 1994)

$$
\begin{aligned}
D_o^t(x^t, u^t)^{-1} &= \max \theta \\
\text{s.t.} \quad & \theta u^t \leq z^t \cdot \mathcal{H}^t \\
& x^t \geq z^t \cdot \mathcal{P}^t \\
& z^t \geq 0 \\
& \textstyle\sum_{t=1}^{k} z^t = 1,
\end{aligned}
\tag{13}
$$

were $\mathcal{H}^t$ is the $k \times m$ dimensional matrix of output quantities at time t and $\mathcal{P}^t$ is the $k \times n$ dimensional matrix of input quantities at time t. The definition and calculation of the distance function for the next time period $D_o^{t+1}(x^{t+1}, u^{t+1})$ is exactly like (5) and (13) where t is substituted for $t+1$. Two of the required distance functions refer to information from two different points in time. The first, $D_o^t(x^{t+1}, u^{t+1})$, is computed for each $t = (1, \ldots T)$ and $k = (1, \ldots K)$ as

$$
\begin{aligned}
D_o^t(x^{t+1}, u^{t+1})^{-1} &= \max \theta \\
\text{s.t.} \quad & \theta u^{t+1} \leq z^t \cdot \mathcal{H}^t \\
& x^{t+1} \geq z^t \cdot \mathcal{P}^t \\
& z^t \geq 0 \\
& \textstyle\sum_{t=1}^{k} z^t = 1.
\end{aligned}
\tag{14}
$$

Finally, the linear programming problem needed to solve for $D_o^{t+1}(x^t, u^t)$ is also a mixed-period problem. It is calculated like (14) but with interchanging superscripts t and $t+1$.

4 Data and empirical results

Productivity growth and its components were calculated for 29 provinces in China. (Guangdong and Hainan treated as a single province.[6]) Input and output data were compiled from various statistical yearbooks for the years 1985, 1990, and 1994. Input quantities were aggregated into eight groups: labour, paddy fields, rainfed fields, grassland, machinery, draft animals, chemical fertilizer, and organic fertilizer. Output quantities were aggregated into real gross output value of farming and animal husbandry based on prices of the year 1985.[7]

The method used in this study constructs a best practice frontier from the data set, i.e. a China–production–frontier is constructed and each province is compared to that

[6] Guangdong and Hainan were one province before 1988 (called Guangdong). In 1988 Guangdong was separated into Guangdong-Province and Hainan-Province.

[7] The procedure used for data set assembly is available from the author upon request.

frontier. Technology in each of the three chosen time points is characterized by a distance function.[8]

Since the basic component of the Malmquist index is related to the measurement of technical efficiency, Table 2 reports technical efficiency for the provinces in the selected years assuming variable returns to scale technology. Following Färe et al. (1994), technical efficiency dealing with this king of technology is called pure technical efficiency. Values of unity denote technically efficient production, i.e. the respective province produced on the China production frontier in the associated year. Values exceeding unity indicate technically inefficient production and show by which factor the gross output value of the particular province could have been increased if the province had been able to produce on the production frontier. The estimates indicate that provinces such as Anhui, Henan, Hunan, Guangxi, Guizhou, Yunnan, and Shaanxi failed to keep pace with technically feasible production possibilities and increased their distance to the production frontier. The inverse of the values in Table 2 shows the percentage of the realized output level compared to the maximum potential output level at the given input mix. Thus, for example, Guangxi province produced 77% of its potential output and Yunnan province produced only 71% of its potential output in 1994. The provinces Hebei, Fujian, Jiangxi, and Hubei managed to catch up to the frontier and produced in 1994 at the maximum potential output level. All the other provinces appeared to have been producing technically efficiently in all chosen years. As indicated by the weighted geometric mean, the average technical efficiency decreased continuously from 1985 to 1994. In 1994, China produced 96% of its maximum potential output achievable with the observed input level.

Table 3 reports the performance of China's provinces between 1985 and 1990. Note that a value of the Malmquist index or of its components less than one implies decrease or deterioration. Conversely, values greater than one indicate improvements in the relevant aspect. The columns in Table 3 list the values of the Malmquist productivity change index (PRODCH), the technical change component (TECHCH) and the efficiency change component (EFFCH). Turning first to the weighted geometric mean at the bottom of Table 3, we see that, on average, productivity decreased by 3.42% per year, and the average efficiency of China decreased slightly. On a provincial level, we see that Hebei and Yunnan managed to increase efficiency in production. The highest decreases in total factor productivity happened in the provinces Guizhou with -16.7% and Ningxia with -23.3% per year. Recall that the productivity index shows the output level at the given input mix compared to the maximum potential output. That is, due to the substantial increase of input-use, real gross output did not decrease in the provinces Guizhou and Ningxia but the inputs were used in a less efficient way. Figure 3 gives an additional graphical illustration of the productivity patterns in China's provinces between 1985 and 1990.

Table 4 lists the results of total factor productivity and its components for the period 1990 to 1994. The weighted geometric mean at the bottom of the table shows the average annual change rates of productivity, technical progress, and efficiency. Efficiency was, on average, slightly decreasing which lowered the effect of the average rate of technical progress of 5.17% per year such that productivity growth in this period was 4.68%. The highest increases in productivity were reached in the provinces Liaoning, Shanghai, Zejiang, Fujian, and Jiangxi. All of them increased their productivity by at least 8% per year. Figure 4 gives the graphical illustration corresponding to Table 4.

For the entire period between the years 1985 and 1994 the values of productivity

[8]The general description of the distance to the frontier is $D^t(x^t, u^t) = \parallel u^t \parallel / \parallel u^t/\theta \parallel$, whereby the denominator characterizes the point on the production frontier at given input vector x. In the single output case the distance function becomes $D^t(x^t, u^t) = u^t/f(x^t)$, which is the ratio of the observed output to the maximum potential output.

Table 2: Pure technical efficiency in China's provinces in the years 1985, 1990, and 1994.

Provinces		Pure Technical Efficiency		
		1985	1990	1994
[1]	Beijing	1.0000	1.0000	1.0000
[2]	Tianjin	1.0000	1.0000	1.0000
[3]	Hebei	1.1778	1.0637	1.0000
[4]	Shanxi	1.0000	1.0000	1.0000
[5]	Inner Mongolia	1.0000	1.0000	1.0000
[6]	Liaoning	1.0000	1.0000	1.0000
[7]	Jilin	1.0000	1.0000	1.0000
[8]	Heilongjiang	1.0000	1.0000	1.0000
[9]	Shanghai	1.0000	1.0000	1.0000
[10]	Jiangsu	1.0000	1.0000	1.0000
[11]	Zhejiang	1.0000	1.0000	1.0000
[12]	Anhui	1.0000	1.1442	1.2301
[13]	Fujian	1.0000	1.0426	1.0000
[14]	Jiangxi	1.0282	1.0257	1.0000
[15]	Shandong	1.0000	1.0000	1.0000
[16]	Henan	1.0000	1.0000	1.1089
[17]	Hubei	1.0000	1.0075	1.0000
[18]	Hunan	1.0000	1.0503	1.0916
[19]	Guangdong–Hainan	1.0000	1.0000	1.0000
[20]	Guangxi	1.1433	1.1991	1.2961
[21]	Sichuan	1.0000	1.0000	1.0000
[22]	Guizhou	1.0000	1.0000	1.0062
[23]	Yunnan	1.1679	1.0364	1.4047
[24]	Xizang	1.0000	1.0000	1.0000
[25]	Shaanxi	1.0214	1.0000	1.0536
[26]	Gansu	1.0000	1.0000	1.0000
[27]	Qinghai	1.0000	1.0000	1.0000
[28]	Ningxia	1.0000	1.0000	1.0000
[29]	Xinjiang	1.0000	1.0000	1.0000
Weighted geometric mean		1.0181	1.0221	1.0411

Table 3: Malmquist productivity change indexes and components for China's provinces with variable–returns–to–scale technology for the period 1985–1990.

Provinces		average annual changes		
		PRODCH	TECHCH	EFFCH
[1]	Beijing	1.0279	1.0279	1.0000
[2]	Tianjin	1.0496	1.0496	1.0000
[3]	Hebei	0.9679	0.9484	1.0206
[4]	Shanxi	1.0087	1.0087	1.0000
[5]	Inner Mongolia	0.9374	0.9374	1.0000
[6]	Liaoning	1.0092	1.0092	1.0000
[7]	Jilin	0.9845	0.9845	1.0000
[8]	Heilongjiang	0.9750	0.9750	1.0000
[9]	Shanghai	0.9896	0.9896	1.0000
[10]	Jiangsu	0.9696	0.9696	1.0000
[11]	Zhejiang	0.9679	0.9679	1.0000
[12]	Anhui	0.9338	0.9593	0.9734
[13]	Fujian	0.9587	0.9667	0.9917
[14]	Jiangxi	0.9702	0.9698	1.0005
[15]	Shandong	0.9523	0.9523	1.0000
[16]	Henan	0.9423	0.9423	1.0000
[17]	Hubei	0.9770	0.9785	0.9985
[18]	Hunan	0.9675	0.9771	0.9902
[19]	Guangdong–Hainan	0.9868	0.9868	1.0000
[20]	Guangxi	0.9510	0.9601	0.9905
[21]	Sichuan	0.9734	0.9734	1.0000
[22]	Guizhou	0.8328	0.8328	1.0000
[23]	Yunnan	0.9825	0.9593	1.0242
[24]	Xizang	0.9367	0.9367	1.0000
[25]	Shaanxi	0.9683	0.9642	1.0042
[26]	Gansu	0.9770	0.9770	1.0000
[27]	Qinghai	0.9971	0.9971	1.0000
[28]	Ningxia	0.7671	0.7671	1.0000
[29]	Xinjiang	1.0020	1.0020	1.0000
Geometric mean		0.9627	0.9630	0.9998
Weighted geometric mean		0.9658	0.9666	0.9992

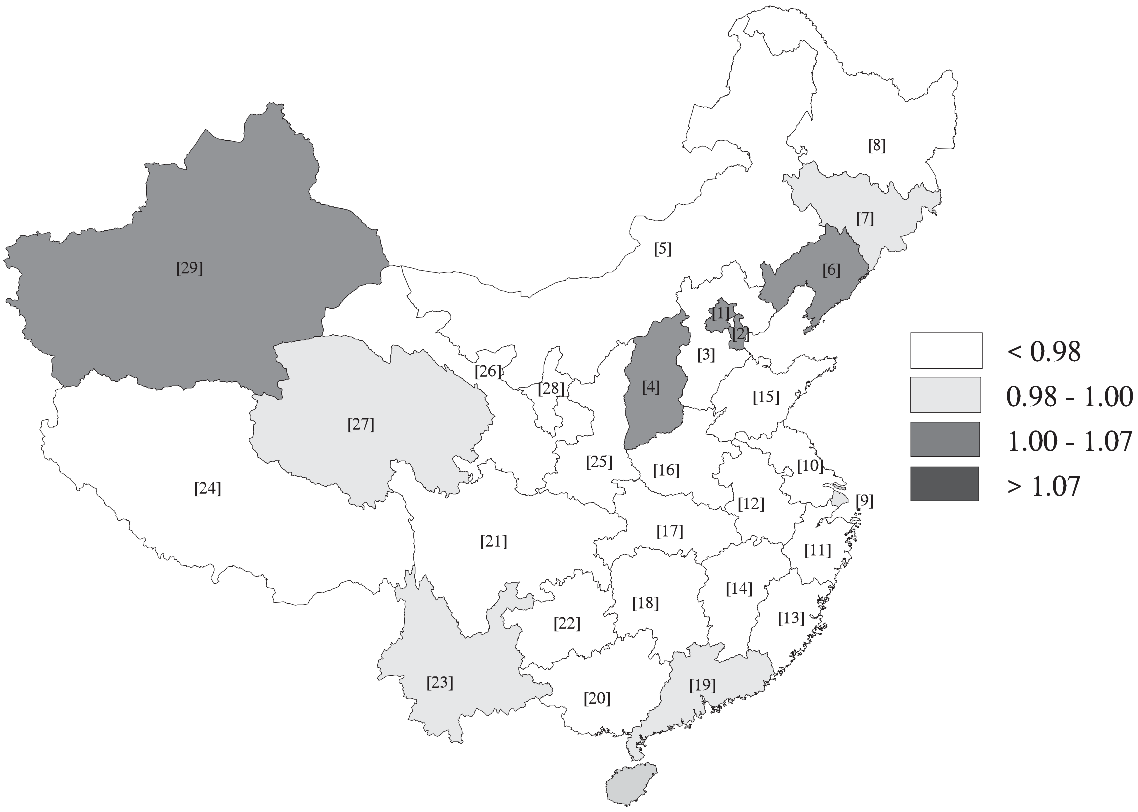

Figure 3: Changes in productivity over the period 1985–1990.

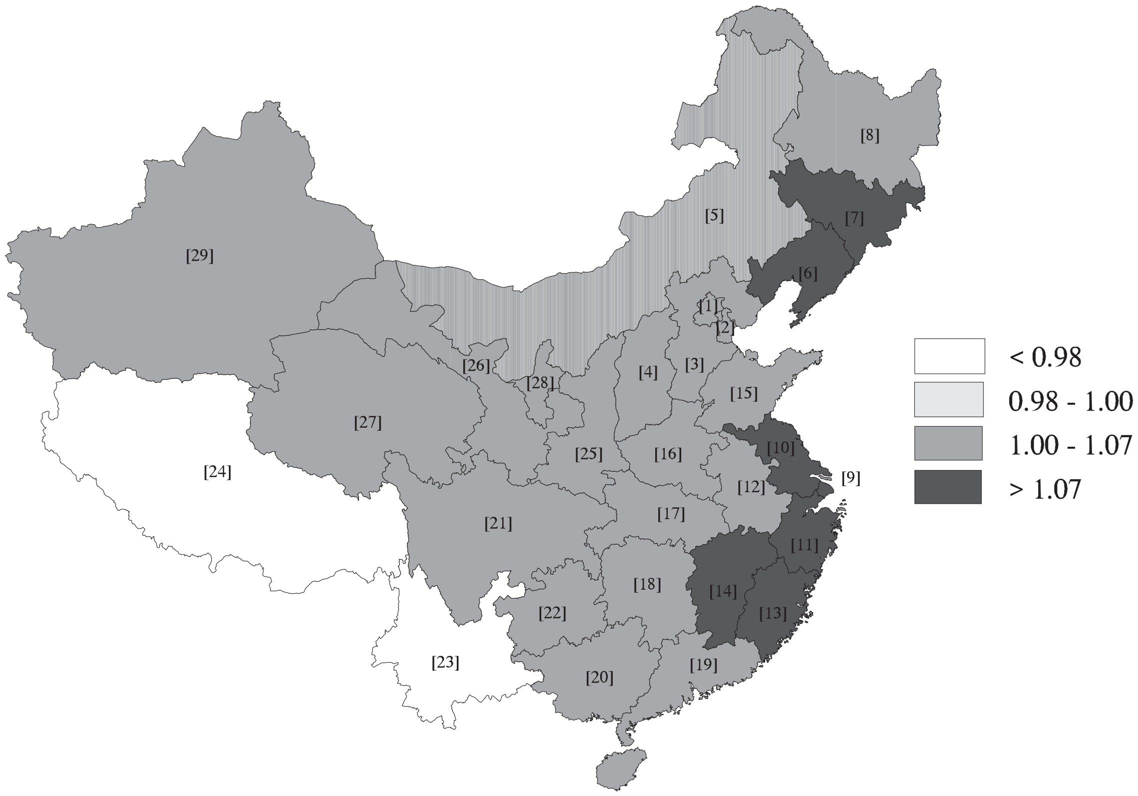

Figure 4: Changes in productivity over the period 1990–1994.

Table 4: Malmquist productivity change indexes and components for China's provinces with variable–returns–to–scale technology for the period 1990–1994.

Provinces		average annual changes		
		PRODCH	TECHCH	EFFCH
[1]	Beijing	1.0478	1.0478	1.0000
[2]	Tianjin	1.0162	1.0162	1.0000
[3]	Hebei	1.0375	1.0216	1.0156
[4]	Shanxi	1.0267	1.0267	1.0000
[5]	Inner Mongolia	1.0458	1.0458	1.0000
[6]	Liaoning	1.0874	1.0874	1.0000
[7]	Jilin	1.0787	1.0787	1.0000
[8]	Heilongjiang	1.0584	1.0584	1.0000
[9]	Shanghai	1.1009	1.1009	1.0000
[10]	Jiangsu	1.0928	1.0928	1.0000
[11]	Zhejiang	1.0885	1.0885	1.0000
[12]	Anhui	1.0389	1.0578	0.9821
[13]	Fujian	1.0883	1.0770	1.0105
[14]	Jiangxi	1.0825	1.0757	1.0064
[15]	Shandong	1.0193	1.0193	1.0000
[16]	Henan	1.0056	1.0319	0.9745
[17]	Hubei	1.0499	1.0479	1.0019
[18]	Hunan	1.0447	1.0548	0.9904
[19]	Guangdong–Hainan	1.0525	1.0525	1.0000
[20]	Guangxi	1.0214	1.0415	0.9807
[21]	Sichuan	1.0414	1.0414	1.0000
[22]	Guizhou	1.0354	1.0370	0.9985
[23]	Yunnan	0.9594	1.0352	0.9268
[24]	Xizang	0.9349	0.9349	1.0000
[25]	Shaanxi	1.0431	1.0569	0.9870
[26]	Gansu	1.0111	1.0111	1.0000
[27]	Qinghai	1.0666	1.0666	1.0000
[28]	Ningxia	1.0604	1.0604	1.0000
[29]	Xinjiang	1.0593	1.0593	1.0000
Geometric mean		1.0440	1.0487	0.9955
Weighted geometric mean		1.0468	1.0517	0.9954

changes, technical progress, and efficiency changes are reported in Table 5. Note that the Malmquist index is a multiplicative index but does not satisfy the circular test (Fisher 1927).[9] But, since we would have lost the information of the data for the year 1990 by using the programming method, we calculated the values for the full period using the geometric mean of the results shown in Tables 3 and 4. The weighted geometric mean at the bottom of Table 5 shows the average annual values of productivity change, technical progress and efficiency change. China's efficiency in production declined in this period. Due to the decrease in the first period and the increase in the second period, the overall increase of average productivity in China remained at the low level of 0.55% per year. The highest average increase in productivity was reached in Liaoning province and the strongest average decrease of productivity occured in the Ningxia province. Recalling the results listed in Tables 3 and 4, and illustrated in Figures 3 and 4, it can be seen that there is a cycle of total factor productivity in China'agriculture with a contracting period between 1985 and 1990 and an expanding period between 1990 and 1994. Since distribution of technology, captured by changes in efficiency, decreased continuously, the cycle is induced mainly by changes in the rate of technical progress. The results of Tables 2 to 5 also partly prove one of the hypothesis stipulated by Sun (1997, p.126). Sun argued that the success of China's agriculture between 1980 and 1984 was a one-shot acceleration brought about by the removal of barriers to efficient production (pure efficiency). Once a higher level of pure efficiency had been achieved, the agricultural productivity growth would depend on increases in the rate of technical progress.

The fact that almost all provinces had a positive technical change component in the second period as well as for the overall period tells us what happened to the frontier at the input mix of each province. However, it can not tell us whether a particular province has caused the frontier to shift. Färe et al. (1994) list the conditions to identify which provinces have contributed to a shift in the national production frontier between year t and $t+1$. That is, when

$$TECHCH^k > 1,$$
$$D^{k,t}(x^{k,t+1}, u^{k,t+1}) > 1$$

and

$$D^{k,t+1}(x^{k,t+1}, u^{k,t+1}) = 1$$

then province k has contributed to a shift in the production frontier. Provinces meeting these criteria can be considered as the "innovators" in China's agricultural production. Table 6 lists the provinces which contributed to a shift in the frontier between 1985 and 1994.

While the product of the efficiency-change and the technical-change component must be equal to the Malmquist productivity change, its components may be moving in opposite directions. To show patterns of productivity growth and its components an exemplary illustration is given in Figure 5 for Yunnan province. This province has been catching up in the period between 1985 and 1990 and had a technological deterioration during the same period. The productivity decreasing by 1.75% per year. In the following period from 1990 to 1994, the province showed an opposite pattern: Efficiency decreased by annually 7.32% and technological progress was at 3.52%. Thus, productivity change remained on a negative level at 4.06% per year.

[9] The circular test is one of Fisher's tests and means $\frac{y^{t+1}}{y^t} \times \frac{y^{t+2}}{y^{t+1}} = \frac{y^{t+2}}{y^t}$. Thus, the results obtained by applying the geometric mean of the two indices for the periods 1985–1990 and 1990–1994 does not necessarily coincide with the result we would have obtained by using the endpoint data for 1985 and 1994 and solving for the appropriate root.

Table 5: Malmquist productivity change indexes (geometric means) and components for China's provinces with variable–returns–to–scale technology for the period 1985–1994.

Provinces		average annual changes		
		PRODCH	TECHCH	EFFCH
[1]	Beijing	1.0378	1.0378	1.0000
[2]	Tianjin	1.0328	1.0328	1.0000
[3]	Hebei	1.0021	0.9843	1.0181
[4]	Shanxi	1.0176	1.0176	1.0000
[5]	Inner Mongolia	0.9902	0.9902	1.0000
[6]	Liaoning	1.0476	1.0476	1.0000
[7]	Jilin	1.0305	1.0305	1.0000
[8]	Heilongjiang	1.0158	1.0158	1.0000
[9]	Shanghai	1.0438	1.0438	1.0000
[10]	Jiangsu	1.0293	1.0293	1.0000
[11]	Zhejiang	1.0264	1.0264	1.0000
[12]	Anhui	0.9849	1.0074	0.9777
[13]	Fujian	1.0215	1.0204	1.0010
[14]	Jiangxi	1.0248	1.0214	1.0034
[15]	Shandong	0.9853	0.9853	1.0000
[16]	Henan	0.9734	0.9861	0.9872
[17]	Hubei	1.0128	1.0126	1.0002
[18]	Hunan	1.0053	1.0152	0.9903
[19]	Guangdong–Hainan	1.0192	1.0192	1.0000
[20]	Guangxi	0.9856	0.9999	0.9856
[21]	Sichuan	1.0068	1.0068	1.0000
[22]	Guizhou	0.9286	0.9293	0.9992
[23]	Yunnan	0.9709	0.9965	0.9743
[24]	Xizang	0.9358	0.9358	1.0000
[25]	Shaanxi	1.0050	1.0095	0.9956
[26]	Gansu	0.9939	0.9939	1.0000
[27]	Qinghai	1.0313	1.0313	1.0000
[28]	Ningxia	0.9019	0.9019	1.0000
[29]	Xinjiang	1.0302	1.0302	1.0000
Geometric mean		1.0025	1.0049	0.9976
Weighted geometric mean		1.0055	1.0082	0.9973

Table 6: Provinces shifting their frontiers in the periods 1985–1990, 1990–1994, and 1985–1994.

Province		Period		
		1985–1990	1990–1994	1985–1994
[1]	Beijing	Beijing	Beijing	Beijing
[2]	Tianjin	Tianjin		Tianjin
[3]	Hebei		Hebei	
[4]	Shanxi	Shanxi	Shanxi	Shanxi
[5]	Inner Mongolia		Inner Mongolia	
[6]	Liaoning	Liaoning	Liaoning	Liaoning
[7]	Jilin		Jilin	Jilin
[8]	Heilongjiang		Heilongjiang	Heilongjiang
[9]	Shanghai		Shanghai	Shanghai
[10]	Jiangsu		Jiangsu	Jiangsu
[11]	Zhejiang		Zhejiang	Zhejiang
[12]	Anhui			
[13]	Fujian		Fujian	Fujian
[14]	Jiangxi		Jiangxi	Jiangxi
[15]	Shandong		Shandong	
[16]	Henan			
[17]	Hubei		Hubei	
[18]	Hunan			
[19]	Guangdong–Hainan		Guangdong–Hainan	Guangdong–Hainan
[20]	Guangxi			
[21]	Sichuan		Sichuan	Sichuan
[22]	Guizhou			
[23]	Yunnan			
[24]	Xizang			
[25]	Shaanxi			
[26]	Gansu		Gansu	
[27]	Qinghai		Qinghai	Qinghai
[28]	Ningxia			
[29]	Xinjiang	Xinjiang	Xinjiang	Xinjiang

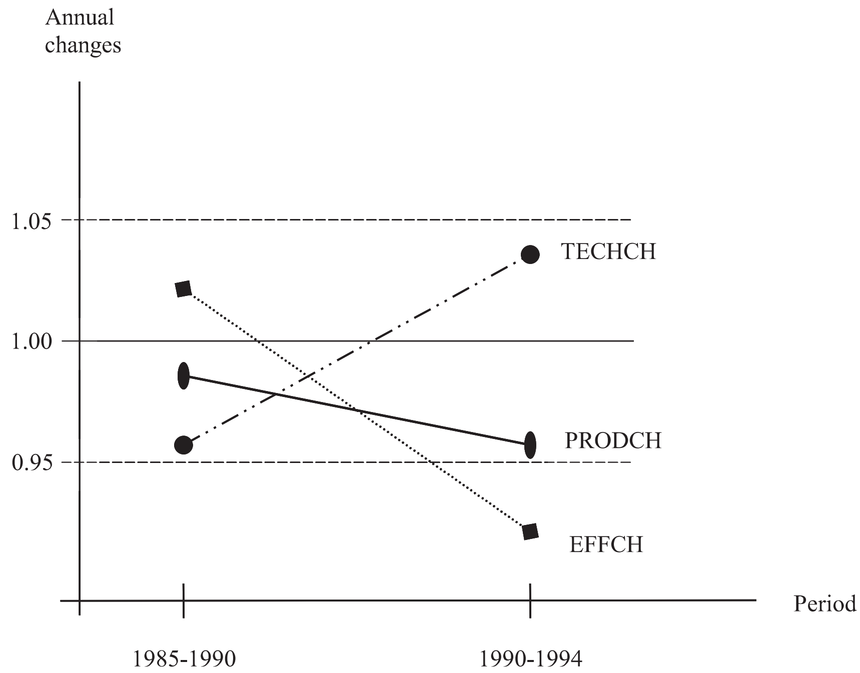

Figure 5: Changes in productivity, technical progress, and efficiency changes in Yunnan province.

5 Summary and conclusion

This paper applies a nonparametric index number approach to decompose total factor productivity in China's agriculture. The technical change component captures shifts in the production frontier, providing a measure of innovation. The phenomenon of catching up is measured as an efficiency change component and captures the diffusion of technology. The approach uses only data on input and output quantities and does not require detailed price information. Also, no specific assumptions on the functional specification of the production frontier are needed.

From 1985 to 1994, the rates of technical progress remained on a low level of less than one percent. The continuous decrease in efficiency over both sub-periods indicates differences in the diffusion of technology. Thus, the rate of technical progress, low as it was, did not apply in all provinces resulting in an even lower level of productivity growth of one-half percent from 1985 to 1994. However, splitting the decade into two sub-periods, 1985–1990 and 1990–1994, reveals a drop in technology mainly in the first period, yet a substantial rate of technical progress in the second period. The results partly speak in support of the hypothesis raised by Sun (1997) that the success of China's agriculture between 1980 and 1984 had been a one-shot acceleration brought about by the removal of barriers to efficient production. Moreover, the decrease of total factor productivity in the first period followed by the increase of total factor productivity in the second period could point to a cycle of total factor productivity in China's agricultural production. Finally, the approach enables identification of the "innovators" of China's agricultural production, i.e., provinces that have contributed to a shift in China's overall production frontier

References

Afriat, S. (1972), 'Efficiency estimations of production functions.', *International Economic Review* **13**(3), 568–598.

Balk, B. M. (1993), 'Malmquist productivity indexes and fisher ideal indexes: Comment.', *The Economic Journal* **103**, 680–682.

Bauer, P. W. (1990), 'Decomposing tfp growth in the presence of cost ineffieciency, non-constant returns to scale, and technological progress.', *Journal of Productivity Analysis* **1**, 287–300.

Bureau, J.-C., Färe, R. & Grosskopf, S. (1995), 'A comparison of three nonparametric measures of productivity growth in european and united states agriculture', *Journal of Agricultural Economics* **46**(3), 309–326.

Caves, D. W., Christensen, L. R. & Diewert, W. E. (1982), 'Multilateral comparisons of output, input, and productivity using superlative index numbers.', *The Economic Journal* **92**, 73–86.

Caves, Douglas W.and Christensen, L. R. & Diewert, W. E. (1982), 'The economic theory of index numbers and the measurement of input, output, and productivity', *Econometrica* **50**(6), 1393–1413.

Diewert, W. E. (1976), 'Exact and superlative index numbers', *Journal of Econometrics* **4**, 115–145.

Fan, S. (1991), 'Effects of technological change and institutional reform on production growth in chinese agriculture', *American Journal of Agricultural Economics* **73**, 266–275.

Färe, R. & Grosskopf, S. (1992), 'Malmquist productivity indexes and fisher ideal indexes', *The Economic Journal* **102**, 158–160.

Färe, R., Grosskopf, S. & Lovell, C. K. (1985), *The Measurement of Efficiency of Production*, Boston: Kluwer-Nijhoff.

Färe, R., Grosskopf, S., Lindgren, B. & Roos, P. (1992), 'Productivity changes in swedish pharmacies 1980-1989: A non-parametric malmquist approach', *The Journal of Productivity Analysis* **3**, 81–101.

Färe, R., Grosskopf, S., Norris, M. & Zhang, Z. (1994), 'Productivity growth, technical progress, and efficiency change in industrialized countries', *The American Economic Review* **84**, 66–83.

Farell, M. J. (1957), 'The measurement of productive efficiency.', *Journal of the Royal Statistical Society* **120**(3), 253–282.

Fisher, I. (1927), *The making of index numbers*, third edn, Boston: Houghton Mifflin.

Huang, J. & Rozelle, S. (1995), 'Environmental stress and grain yields in china', *American Journal of Agricultural Economics* **77**, 853–864.

Kalirajan, K. & Obwona, M. (1994), 'Frontier production function: The stochastic coeffcients approach', *Oxford Bulletin of Economics and Statistics* **56**, 85–94.

Kalirajan, K., Obwona, M. & Zhao, S. (1996), 'A decomposition of total factor productivity growth: The case of chinese agricultural growth before and after reforms', *American Journal of Agricultural Economics* **78**, 331–338.

Lin, J. Y. (1990), 'Collectivization and china's agricultural crisis in 1959-1961', *Journal of Political Economy* **98**, 1228–1252.

Lin, J. Y. (1992), 'Rural reforms and agrucultural growth in china', *American Economic Review* **82**, 34–51.

Malmquist, S. (1953), 'Index numbers and indifference curves.', *Trabajos de Estatistica* **4**(1), 209–242.

Nishimizu, M. & Page, J. (1982), 'Total factor productivity growth, technological progress, and technical changes: Dimensions of productivity change in yugoslavia, 1965-1978', *Economic Journal* **92**, 921–936.

People's Republik of China, State Statistical Bureau (1986), *China Statistical Yearbook 1986*, China Statistical Publishing House.

People's Republik of China, State Statistical Bureau (1991), *China Statistical Yearbook 1991*, China Statistical Publishing House.

People's Republik of China, State Statistical Bureau (1995), *China Statistical Yearbook 1995*, China Statistical Publishing House.

Shephard, R. W. (1953), *Cost and Production Functions*, Princeton University Press, Princeton, New Jersey.

Shephard, R. W. (1970), *Theory of Cost and Production Functions*, Princeton University Press, Princeton, New Jersey.

Sun, L. (1997), Aggregate Behaviour of Investment in China (1953-1993), Ph.D. dissertation, Institute of Social Studies, The Hague, Netherlands.

Wen, G. J. (1993), 'Total factor productivity change in china's farming sector: 1952–1989', *Economic Development and Cultural Change* **42**(1), 1–43.