RESHAPING AGRICULTURE'S CONTRIBUTIONS TO SOCIETY

PROCEEDINGS
OF THE
TWENTY-FIFTH
INTERNATIONAL CONFERENCE
OF AGRICULTURAL ECONOMISTS

Held at Durban, South Africa
16-22 August, 2003

Edited by
David Colman, University of Manchester,
England
and
Nick Vink, University of Stellenbosch,
South Africa

2005
Blackwell
Publishing

Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980–2000

Tim J. Coelli*, D. S. Prasada Rao**

Abstract

In this paper we examine the levels and trends in agricultural output and productivity in 93 developed and developing countries that account for a major portion of the world population and agricultural output. We make use of data drawn from the Food and Agriculture Organization of the United Nations and our study covers the period 1980–2000. Due to the nonavailability of reliable input price data, the study uses data envelopment analysis (DEA) to derive Malmquist productivity indices. The study examines trends in agricultural productivity over the period. Issues of catch-up and convergence, or in some cases possible divergence, in productivity in agriculture are examined within a global framework. The paper also derives the shadow prices and value shares that are implicit in the DEA-based Malmquist productivity indices, and examines the plausibility of their levels and trends over the study period.

JEL classification: D24, O13, O47, Q10

Keywords: total factor productivity growth; Malmquist index; data envelopment analysis; agriculture; catch-up; convergence; shadow prices

1. Introduction

Productivity growth in agriculture has been the subject matter for intense research over the last five decades. Development economists and agricultural economists have examined the sources of productivity growth over time and of productivity differences among countries and regions over this period. Productivity growth in the agricultural sector is considered essential if agricultural sector output is to grow at a sufficiently rapid rate to meet the demands for food and raw materials arising out of steady population growth. During the 1970s and 1980s a number of major analyses of cross-country differences in agricultural productivity were conducted, including Hayami and Ruttan (1970, 1971), Kawagoe and Hayami (1983, 1985), Kawagoe et al. (1985), Capalbo and Antle (1988), and Lau and Yotopoulos (1989).

The majority of these studies used cross-sectional data on approximately 40 countries to estimate a Cobb–Douglas production technology using regression methods. The focus was generally on the estimation of the production elasticities and the investigation of the contributions of farm scale, education, and research in explaining cross-country labor productivity differentials.[1]

In the past decade, the number of papers investigating cross-country differences in agricultural productivity levels and growth rates has expanded significantly. This is most likely driven by three factors. First, the availability of some new panel data sets, such as that produced by the Food and Agriculture Organization of the United Nations (FAO). Second, the development of new empirical techniques to analyze this type of data, such as the data envelopment analysis (DEA) and stochastic frontier analysis (SFA) techniques, described in Coelli et al. (1998). Third, a desire to assess

* *Centre for Efficiency and Productivity Analysis, School of Economics, Brisbane, QLD, 4072 Australia.*

** *University of Queensland, Brisbane, QLD, 4072 Australia.*

[1] Lau and Yotopolous (1989) also estimated a translog functional form so as to illustrate the restrictions inherent in the Cobb–Douglas production technology.

Table 1
Analyses of inter-country agricultural total factor productivity (TFP) growth, 1993–2003

Paper	Method	Years	Countries
Fulginiti and Perrin (1993)	CD	1961–85	18 LDC
Bureau et al. (1995)	DEA & Fisher	1973–89	10 DC
Fulginiti and Perrin (1997)	DEA	1961–85	18 LDC
Craig et al. (1997)	CD	1961–90	98
Lusigi and Thirtle (1997)	DEA	1961–91	47 Africa
Fulginiti and Perrin (1998)	CD (VC)	1961–85	18 LDC
Rao and Coelli (1998)	DEA	1980–95	97
Arnade (1998)	DEA	1961–93	70
Fulginiti and Perrin (1999)	DEA & CD	1961–85	18 LDC
Martin and Mitra (1999)	Translog	1967–92	49
Wiebe et al. (2000)	CD	1961–97	110
Chavas (2001)	DEA	1960–94	12
Ball et al. (2001)	Fisher (EKS)	1973–93	10 DC
Suhariyanto et al. (2001)	DEA	1961–96	65 Asia/Africa
Suhariyanto and Thirtle (2001)	DEA	1965–96	18 Asia
Trueblood and Coggins (2003)	DEA	1961–91	115
Nin et al. (2003)	DEA	1961–94	20 LDC

the degree to which the Green Revolution, and other programs, have improved agricultural productivity in developing countries.

In Table 1 we list 17 studies that have been conducted in the last decade. Certain comments can be made about these papers. First, the majority of these papers use FAO panel data, spanning the 1960s through the 1980s. Of these 17 papers, 11 utilize DEA, five estimate Cobb–Douglas production functions, one estimates a translog production function, and one uses the Fisher index.[2] In terms of country coverage, five papers focus on less developed countries (LDCs), two analyze small groups of developed countries (DCs), three papers look at Asia or Africa or the two combined, while the remaining seven study a mix of countries. Four of these latter seven papers cover a large number of countries, ranging from 70 countries in Arnade (1998) to 110 countries in Wiebe et al. (2000).

One of the recurring themes in the reported results in many of these papers is that less developed countries exhibit technological regression while the developed countries show technological progress. For example, Fulginiti and Perrin (1997) studied 18 LDCs and found that 14 of these countries showed a decline in agricultural productivity over the period 1961–1985. Such results indicate a divergence in agricultural productivity. However, these results appear to be in sharp contrast to the trends in the manufacturing sector and gross domestic product level productivity, which show signs of convergence (Barro and Sala-i-Martin, 1991; Maddison, 1995). Furthermore, they do not appear to be in accordance with crop-level evidence coming out of many developing countries in the past few decades, especially in Southeast Asia.

The principal aim of this study is to provide up-to-date information on agricultural total factor productivity (TFP) growth over the past two decades (1980–2000) for 93 of the largest agricultural producers in the world. It should be noted that the study by Wiebe et al. (2000) does analyze total factor productivity (TFP) growth for 110 nations over the 1961–1997 period; however, it does use the Cobb–Douglas production function, which introduces a number of restrictive assumptions, such as, constant production elasticities (and hence input shares) across all countries, Hicks-neutral technical change, plus the requirement that crop and livestock outputs be aggregated into a single output measure. The analysis in the present study uses the DEA technique to calculate the Malmquist TFP index numbers. This method does not make any of the above assumptions. However, it is susceptible to the effects of data noise, and can suffer from the problem of

[2] Two of these papers use two techniques.

"unusual" shadow prices, when degrees of freedom are limited.

This issue of shadow prices is important, and is one that is not well understood among authors who apply these Malmquist DEA methods. A major advantage cited in support of the use of DEA in measuring productivity growth, is that these methods do not require any price data. This is a distinct advantage, because in general, agricultural input price data are seldom available and such prices could be distorted due to government intervention in most developing countries. However, an important point needs to be added here. Even though the DEA-based productivity measures may not *explicitly* use *market price* information, they do *implicitly* use *shadow price* information, derived from the shape of the estimated production surface. This issue is described in some detail in Coelli and Rao (2001), who show that one can use these shadow prices to calculate *shadow shares* information, to help shed light on the factors influencing these productivity growth measures. Hence, an important contribution of this paper is to demonstrate the feasibility of explicitly identifying the implicit shadow shares and to study regional variation and trends in these shares over time.

In our view, this shadow share information can provide valuable insights into why various authors have obtained widely differing TFP growth measures for some countries, when applying these Malmquist DEA methods. This has been particularly evident when the applications have involved panel data sets containing small groups of countries, and the countries included in each data set differ from study to study.

The remainder of this paper is organized into sections. In Section 2 the DEA and Malmquist TFP index methods are described, while in Section 3 the data that are used are presented. The empirical results are presented and discussed in Section 4. Concluding comments are made in the final section.

2. Methodology

In this paper total factor productivity (TFP) is measured using the Malmquist index methods described in Färe et al. (1994) and Coelli et al. (1998, Chapter 10). This approach uses data envelopment analysis (DEA) methods to construct a piece-wise linear production frontier for each year in the sample. Hence, a brief description of DEA methods is provided prior to a description of the Malmquist TFP calculations.

2.1. Data envelopment analysis (DEA)

DEA is a linear programming methodology, which uses data on the input and output quantities of a group of countries to construct a piece-wise linear surface over the data points. This frontier surface is constructed by the solution of a sequence of linear programming problems—one for each country in the sample. The degree of technical inefficiency of each country (the distance between the observed data point and the frontier) is produced as a by-product of the frontier construction method.

DEA can be either input-orientated or output-orientated. In the input-orientated case, the DEA method defines the frontier by seeking the maximum possible proportional reduction in input usage, with output levels held constant, for each country. While, in the output-orientated case, the DEA method seeks the maximum proportional increase in output production, with input levels held fixed. The two measures provide the same technical efficiency scores when a constant returns-to-scale (CRS) technology applies, but are unequal when variable returns to scale (VRS) is assumed. In this paper a CRS technology is assumed (the reasons for this are outlined in the Malmquist discussion below). Hence the choice of orientation is not a big issue in this case. However, an output orientation has been selected because it would be fair to assume that, in agriculture, one usually attempts to maximize output from a given set of inputs, rather than the converse.[3]

Given data for N countries in a particular time period, the linear programming (LP) problem that is solved for the ith country in an output-orientated DEA model is as follows:

$$\begin{aligned} &\max_{\phi,\lambda} \phi, \\ &\text{st} \quad -\phi y_i + Y\lambda \geq 0, \\ &\qquad x_i - X\lambda \geq 0, \\ &\qquad \lambda \geq 0, \end{aligned} \tag{1}$$

[3] There are some obvious exceptions to this. For example, where dairy farmers are required to fill a particular output quota, and attempt to do this with minimum inputs.

where

y_i is a $M \times 1$ vector of output quantities for the ith country;
x_i is a $K \times 1$ vector of input quantities for the ith country;
Y is a $N \times M$ matrix of output quantities for all N countries;
X is a $N \times K$ matrix of input quantities for all N countries;
λ is a $N \times 1$ vector of weights; and
ϕ is a scalar.

Observe that ϕ will take a value greater than or equal to 1, and that $\phi - 1$ is the proportional increase in outputs that could be achieved by the ith country, with input quantities held constant. Note also that $1/\phi$ defines a technical efficiency (TE) score that varies between 0 and 1 (and that this is the output-orientated TE score reported in our results).

The above LP is solved N times—once for each country in the sample. Each LP produces a ϕ and a λ vector. The ϕ-parameter provides information on the technical efficiency score for the ith country and the λ-vector provides information on the *peers* of the (inefficient) ith country. The peers of the ith country are those efficient countries that define the facet of the frontier against which the (inefficient) ith country is projected.

The DEA problem can be illustrated using a simple example. Consider the case where there are a group of five countries producing two outputs (e.g., wheat and beef). Assume for simplicity that each country has identical input vectors. These five countries are depicted in Figure 1. Countries A, B, and C are efficient countries because they define the frontier. Countries D and E are inefficient countries. For country D the technical efficiency score is equal to

$$TE_{\mathrm{D}} = 0D/0D', \tag{2}$$

and its peers are countries A and B. In the DEA output listing this country would have a technical efficiency score of approximately 70% and would have nonzero λ-weights associated with countries A and B. For country E the technical efficiency score is equal to

$$TE_{\mathrm{E}} = 0E/0E', \tag{3}$$

and its peers are countries B and C. In the DEA output listing this country would have a technical efficiency

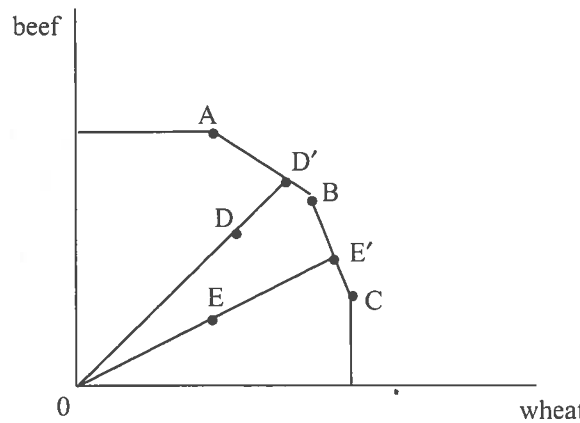

Figure 1. Output-orientated DEA.

score of approximately 50% and would have nonzero λ-weights associated with countries B and C. Note that the DEA output listing for countries A, B, and C would provide technical efficiency scores equal to one and each country would be its own peer. For further discussion of DEA methods see Coelli et al. (1998, Chapter 6).

2.2. *The Malmquist TFP index*

The Malmquist index is defined using distance functions. Distance functions describe a multi-input, multi-output production technology without the need to specify a behavioral objective (such as cost minimization or profit maximization). Both input distance functions and output distance functions may be defined. An input distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector. Only an output distance function is considered in detail in this paper. However, input distance functions can be defined and used in a similar manner.

A production technology may be defined using the output set, $P(x)$, which represents the set of all output vectors, y, which can be produced using the input vector, x. That is,

$$P(x) = \{y\colon x \text{ can produce } y\}. \tag{4}$$

It is assumed that the technology satisfies the axioms listed in Coelli et al. (1998, Chapter 3).

The output distance function is defined on the output set, $P(x)$, as:

$$d_o(x, y) = \min\{\delta: (y/\delta) \in P(x)\}. \tag{5}$$

The distance function, $d_o(x,y)$, will take a value that is less than or equal to 1 if the output vector, y, is an element of the feasible production set, $P(x)$. Furthermore, the distance function will take a value of unity if y is located on the outer boundary of the feasible production set, and will take a value greater than one if y is located outside the feasible production set. DEA-like methods are used to calculate the distance measures in this study. These are discussed shortly.

The Malmquist TFP index measures the TFP change between two data points (e.g., those of a particular country in two adjacent time periods) by calculating the ratio of the distances of each data point relative to a common technology. Following Färe et al. (1994), the Malmquist (output-orientated) TFP change index between period s (the base period) and period t is given by

$$m_o(y_s, x_s, y_t, x_t) = \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} \times \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)}\right]^{1/2}, \tag{6}$$

where the notation $d_o^s(x_t\ , y_t)$ represents the distance from the period t observation to the period s technology. A value of m_o greater than 1 will indicate positive TFP growth from period s to period t while a value less than one indicates a TFP decline. Note that equation (6) is, in fact, the geometric mean of two TFP indices. The first is evaluated with respect to period s technology and the second with respect to period t technology.

An equivalent way of writing this productivity index is

$$m_o(y_s, x_s, y_t, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)}\left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)}\right]^{1/2}, \tag{7}$$

where the ratio outside the square brackets measures the change in the output-oriented measure of Farrell technical efficiency between periods s and t. That is, the efficiency change is equivalent to the ratio of the technical efficiency in period t to the technical efficiency in period s. The remaining part of the index in equation (2) is a measure of technical change. It is the geometric mean of the shift in technology between the two periods, evaluated at x_t and also at x_s.

Following Färe et al. (1994), and given that suitable panel data are available, the required distance measures for the Malmquist TFP index are calculated using DEA-like linear programs. For the ith country, four distance functions are calculated in order to measure the TFP change between two periods, s and t. This requires the solving of four linear programming (LP) problems. Färe et al. (1994) assume a constant returns-to-scale (CRS) technology in their analysis. The required LPs are:

$$\begin{aligned}
&[d_o^t(y_t, x_t)]^{-1} = \max_{\phi,\lambda}, \phi,\\
&\text{st} \quad -\phi y_{it} + Y_t\lambda \geq 0,\\
&\qquad x_{it} - X_t\lambda \geq 0,\\
&\qquad \lambda \geq 0,
\end{aligned} \tag{8}$$

$$\begin{aligned}
&[d_o^s(y_s, x_s)]^{-1} = \max_{\phi,\lambda} \phi,\\
&\text{st} \quad -\phi y_{is} + Y_s\lambda \geq 0,\\
&\qquad x_{is} - X_s\lambda \geq 0,\\
&\qquad \lambda \geq 0,
\end{aligned} \tag{9}$$

$$\begin{aligned}
&[d_o^t(y_s, x_s)]^{-1} = \max_{\phi,\lambda} \phi,\\
&\text{st} \quad -\phi y_{is} + Y_t\lambda \geq 0,\\
&\qquad x_{is} - X_t\lambda \geq 0,\\
&\qquad \lambda \geq 0,
\end{aligned} \tag{10}$$

and

$$\begin{aligned}
&[d_o^s(y_t, x_t)]^{-1} = \max_{\phi,\lambda} \phi,\\
&\text{st} \quad -\phi y_{it} + Y_s\lambda \geq 0,\\
&\qquad x_{it} - X_s\lambda \geq 0,\\
&\qquad \lambda \geq 0.
\end{aligned} \tag{11}$$

Note that in LPs (10) and (11), where production points are compared to technologies from different time periods, the ϕ parameter need not be greater than or equal to 1, as it must be when calculating standard output-orientated technical efficiencies. The data point could lie above the production frontier. This will most likely occur in LP (11) where a production point from period t is compared to technology in an earlier period, s. If technical progress has occurred, then a value of $\phi < 1$ is possible. Note that it could also possibly occur in LP (10) if technical regress has occurred, but this is less likely.

One issue that must be stressed is that the returns-to-scale properties of the technology are very important in TFP measurement. A CRS technology is used in this study for two reasons. First, given that the analysis involves the use of aggregate country-level data, it does not appear to be sensible to consider a VRS technology. That is, how is it possible for a *sector* to achieve scale economies? For example, the index of crop output for India and the U.S. are similar, but their average farm sizes are quite different. Hence, what can be sensibly concluded if a VRS technology is estimated and it is reported that these countries face decreasing returns to scale? The use of a VRS technology when the summary data are expressed on an "average per farm" basis may be sensible, since the scale economies of the "average farm" could be discussed, but when dealing with aggregate data (as is the case in this study) the use of a CRS technology is the only sensible option.

In addition to the above comment regarding the use of aggregate data, a second argument for the use of a CRS technology is applicable to both firm-level and aggregate data. Grifell-Tatjé and Lovell (1995) use a simple one-input, one-output example to illustrate that a Malmquist TFP index may not correctly measure TFP changes when VRS is assumed for the technology. Hence, it is important that a CRS technology be used in calculating Malquist TFP indices using DEA. Otherwise, the resulting measures may not properly reflect the TFP gains or losses resulting from scale effects.

3. Data

The present study is based on data drawn from the AGROSTAT system of the Statistics Division of the Food and Agricultural Organization in Rome. It is possible to access and download all the necessary data from the Web site of the FAO.[4] The following are some of the main features of the data series used.

3.1. Country coverage

The study includes 93 countries. These are the top 93 agricultural producers in the world, which account for roughly 97% of the world's agricultural output as well as 98% of the world's population.[5] The countries included in the study are distributed over all the regions of the world, as follows:

Africa	26 countries
North America	2 countries
South and Central America	19 countries
Asia	23 countries
Europe	20 countries
Australasia	3 countries

Data for the USSR, Czechoslovakia, and Yugoslavia in the 1990s could not be obtained due to changes in the political systems in Eastern Europe. Data for the newly formed countries for the most recent period are available but no corresponding data are available before 1990. Inclusion of USSR in the period before 1990 and replacing it with a large number of smaller countries may introduce some aggregation and scale issues. Hence these countries are omitted from the analysis.

3.2. Time period

Results are presented for the period 1980 to 2000. The initial intention was to study the 1960–2000 period; however, the analysis has been restricted to this shorter period since labor force data were not readily available for the years 1960–1979 from the FAO or the ILO sources. These years will be included in the subsequent stages of the project when appropriate labor data are obtained.[6]

[4] The authors are grateful to the FAO for maintaining an excellent site and for their generosity in making valuable data series available on the Internet.

[5] Ordering of the countries and estimates of country shares of agricultural output are drawn from Table 3.2 in Rao (1993). The original aim was to include 100 countries but three countries had to be dropped since we could not build the output series for those countries. An additional four countries, USSR, Czechoslovakia, Yugoslavia, and Ethiopia, are dropped due to data-related problems.

[6] The study period complements the periods covered in some of the earlier studies, which usually cover the 1960s and 1970s.

3.3. Output series

Due to the problems of degrees of freedom associated with the application of DEA methods, the present study uses two output variables, viz., crops and livestock output variables. The output series for these two variables are derived by aggregating detailed output quantity data on 185 agricultural commodities. The following steps are used in the construction of data.

For the year 1990, output aggregates are drawn from Table 5.4 in Rao (1993). These aggregates are constructed using international average prices (expressed in U.S. dollars) derived using the Geary–Khamis method (see Rao, 1993, Chapter 4 for details) for the benchmark year 1990.[7] Thus the output series for 1990 are at constant prices, expressed in a single currency unit.

The 1990 output series are then extended to cover the study period 1980–2000 using the FAO production index number series for crops and livestock separately.[8] The series that are derived using this approach are essentially equivalent to the series constructed using 1990 international average prices and the actual quantities produced in different countries in various years.

Tables of the output aggregates for the 93 countries for the years 1980 and 2000 are available from the authors on request. These tables demonstrate the differences in output mix across different countries. There are many countries that are mainly producers of crops, some countries are mainly livestock producers, while the remaining countries have a fair balance between crops and livestock.[9] A point to note here is the concept of output used in the study. Consistent with the definition of the FAO production index, the output concept used here is the output from the agriculture sector, net of quantities of various commodities used as feed and seed.[10] This is the reason for not including feed and seed in the input series.

Another point regarding the output series that is important to remember is the fact that the output series are based on 1990 international average prices. So the output series would change when the base is shifted from 1990 to another period, thus potentially influencing the final results. In this study it was decided that it is more appropriate to use 1990 prices as the basis for the study spanning 1980 to 2000 rather than using 1980 or 2000 international average prices.

3.4. Input series

Given the constraints on the number of input variables that can be used in a DEA analysis, this analysis considers only six input variables. Details of these variables are given below.

Land: This variable covers arable land, land under permanent crops as well as the area under permanent pasture. Arable land includes land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than 5 years). Land under permanent crops is the land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest. This category includes land under flowering shrubs, fruit trees, nut trees, and vines but excludes land under trees grown for wood or timber. Land under permanent pasture is the land used permanently (5 years or more) for forage crops, either cultivated or growing wild.

Tractors: This variable covers the total number of wheel and crawler tractors, but excludes garden tractors, used in agriculture. It is important to note that only the number of tractors is used as the input variable with no allowance made to the horsepower of the tractors.[11] This aspect will be examined in future work.

Labor: This variable refers to the economically active population in agriculture. This population is defined as all persons engaged or seeking employment in an economic activity, whether as employers,

---

[7] The Geary–Khamis international average prices are based on prices (in national currency units) and quantities of 185 agricultural commodities in 103 countries.

[8] See the 1997 FAO Production Yearbook for details regarding the construction of production index numbers.

[9] The DEA method employed here is specially suited to this type of situations. The method benchmarks countries against countries with similar output and input mixes.

[10] The output concept used here is consistent with the concept used in some of the earlier inter-country comparison studies (see Kawagoe and Hayami [1985] and Hayami and Ruttan [1970]).

[11] Assuming that farming in developing countries is on fragmented land, average horsepower of tractors in these countries could be significantly lower than those used in countries with large farms using highly mechanized farming techniques. This could understate the productivity levels and changes in developing countries.

own-account workers, salaried employees, or unpaid workers, assisting in the operation of a family farm or business. The economically active population in agriculture includes all economically active persons engaged in agriculture, forestry, hunting, or fishing. This variable obviously overstates the labor input used in agricultural production, where the extent of overstatement depends upon the level of development of the country.[12]

Fertilizer: Following other studies (Hayami and Ruttan 1970; Fulginiti and Perrin 1997) on inter-country comparison of agricultural productivity, fertilizer is measured as the sum of nitrogen, phosphate, and potasn contained in the commercial fertilizers consumed. This variable is expressed in thousands of metric tons.

Livestock: The livestock input variable used in the study is the sheep equivalent of five categories of animals used in constructing this variable. The categories considered are: buffalo, cattle, pig, sheep, and goat. Numbers of these animals are converted into sheep equivalents using conversion factors: 8.0 for buffalo and cattle; 1.00 for sheep, goat, and pig.[13] Chicken numbers are not included in the livestock figures.

Irrigation: In this study, the area under irrigation is used as a proxy for the capital infrastructure associated with the irrigation of farmlands.[14]

4. Results and discussion

The results of the DEA and TFP calculations are summarized in this section. Given that there are 21 annual observations on 93 countries, there is a lot of computer output to describe. The calculations involved the solving of $93 \times (21 \times 3 - 2) = 5{,}673$ LP problems.

Table 2
Means of technical efficiency for the continents, 1980–2000

Continent	Countries	1980	1990	2000
Africa	1–26	0.700	0.746	0.804
North America	27, 37	1.000	1.000	1.000
South America	28–36, 38–47	0.888	0.888	0.911
Asia	48–70	0.681	0.707	0.739
Europe	71–90	0.859	0.871	0.907
Australasia	91–93	1.000	1.000	1.000
Mean	1–93	0.784	0.806	0.842

There are thousands of pieces of information on the efficiency scores and peers of each country in each year. Furthermore, measures of technical efficiency change, technical change, and TFP change for each country in each pair of adjacent years have been calculated.

Hence, by necessity only a selection of the results are presented in this paper. Information on the means of the measures of technical efficiency change, technical change, and TFP change for each country (over the 21-year sample period) and the mean changes between each pair of adjacent years (over the 93 countries) are provided. Furthermore, means for certain groups of countries and plots of the TFP trends of some selected groupings of countries are presented. In addition to this, a table of peers for all countries in the first year (1980) and in the final year (2000) is provided.[15] Each of these sets of results is now discussed in turn.

Average technical efficiency scores in 1980 and 2000 are reported in Table 2 for the six regions and the full sample. Note that the average technical efficiency score of 0.784 in 1980 implies that these countries are, on average, producing 78.4% of the output that could be potentially produced using the observed input quantities.[16] It is interesting to note that those regions with the lowest mean technical efficiency scores in 1980—Asia and Africa—also achieved the largest increases in mean technical efficiency over the sample period. This provides evidence of catch-up in these countries, which was not found in many of the studies listed in Table 1. This is most likely due to the fact that the data in this study span the past two decades, while the

[12] There could be a significant percentage of the labor force (as defined here) in disguised unemployment.

[13] The conversion figures used in this study correspond very closely with those used in the 1970 study of Hayami and Ruttan.

[14] This irrigation variable was not included in an earlier analysis of the 1980–1995 data (see Rao and Coelli, 1998). In the present study, the DEA analysis was run with this variable included and also excluded. It was interesting to note that the (unweighted) mean TFP growth increased from 1.1% to 1.3% when this variable was excluded. This is not surprising, given that there has been significant investment in irrigation infrastructure in many countries over the past two decades, especially in Asian countries.

[15] These can obviously change from year to year, but it is not feasible to present this information for every year.

[16] This figure should be interpreted with care. No attempt has been made to adjust the data for differences in climate, soil quality, labor quality, etc.

Table 3
Peers from DEA, 1980 and 2000

	Country	Peers												Count*	
		1980						2000							
1	Algeria	10	62	31	39	57		8	97	40	34	93		0	0
1	Algeria	79	38	72	56	9	82	93	33	82	89	39		0	0
2	Angola	92	33	62	93	38		18	62					0	0
3	Burundi	65	18					3						0	0
4	Cameroon	4						4						4	2
5	Chad	5						5						3	1
6	Egypt	6						6						0	4
7	Ghana	93	92	33	62	24		7						0	2
8	Guinea	18	93	39	33			33	24	18	7			0	0
9	Cote d'Ivoire	9						9						17	16
10	Kenya	10						10						1	1
11	Madagascar	93	30	39	33			39	33	62	18			0	0
12	Malawi	65	93	9	18	4	33	18	65	9	93			0	0
13	Mali	10	5	4	33	32		9	62	33	17	32		0	0
14	Morocco	43	61	38	56	30	9	30	28	9	56	93		0	0
15	Mozambique	79	93	33	82			33	93	18				0	0
16	Niger	16						18	33					0	0
17	Nigeria	18	33	4	5	93		17						0	3
18	Rwanda	18						18						11	10
19	Senegal	33	4	18	65			9	33	18	4			0	0
20	South Africa	72	79	61	56	38	9	28	43	38				0	0
21	Sudan	33	39	30	93			33	39	18	62			0	0
22	Tanzania	93	62	34	33	44		39	33	24	62	18		0	0
23	Tunisia	9	56	93	38			82	38	56	9	78		0	0
24	Uganda	24						24						1	4
25	Burkina Faso	18	33	5				24	5	4	10	33		0	0
26	Zimbabwe	9	92	72	61	79	38	9	92	72	93	17	82	0	0
27	Canada	27						27						0	1
28	Costa Rica	38	92	79	61	9	30	28						0	6
29	Cuba	30	92	82	79	61		17	39	89	33	82	46	0	0
30	Dominican Republic	30						30						17	7
31	El Salvador	31						31						3	0
32	Guatemala	32						32						1	1
33	Haiti	33						33						21	16
34	Honduras	34						34						1	0
35	Mexico	30	56	61	79	38		28	43	56	30	9		0	0
36	Nicaragua	44	30	79	9	61		62	39	33	46	92	30	0	0
37	United States	37						37						1	1
38	Argentina	38						38						18	11
39	Bolivia	39						39						3	6
40	Brazil	44	79	61	9	72		38	9	72	61	92		0	0
41	Chile	56	9	61	30	38		38	28	56	43	73	61	0	0
42	Colombia	9	44	92	30	79		42						0	0
43	Ecuador	43						43						3	5
44	Paraguay	44						44						6	0
45	Peru	9	38	44	30	43		38	9	62	30	43		0	0
46	Uruguay	46						46						0	3
47	Venezuela	44	92	72	9	79	38	46	38	30	82	92		0	0
48	Bangladesh	93	59	18				48						0	1
49	Myanmar	93	18	33	65			65	48	93	33			0	0
50	Sri Lanka	61	93	56				93	65	6				0	0

(Continued)

Table 3
(Continued)

	Country	Peers												Count*	
		1980						2000							
51	China	59	79	93	33			28	93	30				0	0
52	India	65	82	31	93	30		56	6	82	65	93		0	0
53	Indonesia	53						61	9	93	65			0	0
54	Iran	56	9	61	30	38		43	38	61	9	56		0	0
55	Iraq	9	56	93	43	38		78	61	38	9			0	0
56	Israel	56						56						17	12
57	Japan	57						59	82	56				0	0
58	Cambodia	93	33	18	65			24	93	7	33	18		0	0
59	Korea Rep	59						59						4	2
60	Laos	93	65	33	18			60						0	0
61	Malaysia	61						61						17	11
62	Mongolia	62						62						3	7
63	Nepal	65	93	18	59	33		93	33	6	65			0	0
64	Pakistan	31	30	65	93	82		65	82	33	30			0	0
65	Philippines	65						65						10	7
66	Saudi Arabia	61	30	31	33	93		28	93	61				0	0
67	Syria	67						78	56	9	61	38		0	0
68	Thailand	93	65	30	33	9		56	61	93				0	0
69	Turkey	9	61	81	56	93		9	61	72	78	81	93	0	0
70	Vietnam	82	59	93	33			93	59	6				0	0
71	Austria	71						71						0	2
72	Bel-Lux	72						72						10	7
73	Bulgaria	61	56	92	38	79		73						0	1
74	Denmark	56	37	82	72			74						0	0
75	Finland	82	89	79				72	89	82	79			0	0
76	France	76						76						1	2
77	Germany	82	89	79	72			61	79	76	72	27		0	0
78	Greece	38	79	61	81	56		78						0	5
79	Hungary	79						79						22	3
80	Ireland	80						80						0	0
81	Italy	81						81						4	2
82	Netherlands	82						82						12	13
83	Norway	89	79	82				89	82					0	0
84	Poland	79	93	89	72			61	89	93	71			0	0
85	Portugal	89	56	33	30	93	38	78	82	93	56	9		0	0
86	Romania	56	61	82	30	92	79	38	9	82	56			0	0
87	Spain	61	38	81	79	56		38	81	37	56	76		0	0
88	Sweden	79	89	72	82			79	82	89	72			0	0
89	Switzerland	89						89						6	6
90	United Kingdom	79	56	81	72	76	38	71	72	93				0	0
91	Australia	91						91						0	0
92	New Zealand	92						92						9	4
93	Papua N. Guin.	93						93						26	19

* The *count* is the peer count. That is, the number of times that firm acts as a peer for another firm.

majority of these other studies consider the 1960–1985 period.

This information on changes in average technical efficiency only tells the "catch-up" part of the productivity story. TFP change can also appear in the form of technical change (or frontier shift). The means of the measures of technical efficiency change, technical change and TFP change for each country (over the

Table 4
Mean technical efficiency change, technical change, and TFP change, 1980–2000

	Country	Efficiency Change	Technical Change	TFP Change
51	China	1.044	1.015	1.060
58	Cambodia	1.024	1.033	1.057
1	Algeria	1.033	1.013	1.046
3	Burundi	1.015	1.030	1.046
66	Saudi Arabia	1.031	1.010	1.042
2	Angola	1.061	0.978	1.037
17	Nigeria	1.016	1.020	1.037
20	South Africa	1.014	1.023	1.037
60	Laos	1.022	1.011	1.034
27	Canada	1.000	1.033	1.033
74	Denmark	1.009	1.022	1.032
28	Costa Rica	1.003	1.026	1.028
62	Mongolia	1.000	1.028	1.028
37	U.S.	1.000	1.026	1.026
85	Portugal	1.019	1.007	1.026
91	Australia	1.000	1.026	1.026
29	Cuba	1.005	1.020	1.025
21	Sudan	1.016	1.008	1.024
48	Bangladesh	1.007	1.017	1.024
70	Vietnam	1.027	0.997	1.024
64	Pakistan	1.012	1.011	1.023
86	Romania	1.008	1.015	1.023
7	Ghana	1.010	1.012	1.022
12	Malawi	1.013	1.009	1.022
82	Netherlands	1.000	1.022	1.022
19	Senegal	1.008	1.013	1.021
84	Poland	1.015	1.007	1.021
89	Switzerland	1.000	1.021	1.021
40	Brazil	1.001	1.019	1.020
54	Iran	1.013	1.008	1.020
73	Bulgaria	1.014	1.006	1.020
76	France	1.000	1.020	1.020
15	Mozambique	1.031	0.988	1.019
23	Tunisia	1.011	1.008	1.018
36	Nicaragua	1.014	1.004	1.018
49	Myanmar	1.008	1.011	1.018
78	Greece	1.007	1.010	1.017
14	Morocco	1.004	1.012	1.016
35	Mexico	1.000	1.015	1.015
45	Peru	1.011	1.004	1.015
9	Cote d'Ivoire	1.000	1.014	1.014
42	Colombia	1.001	1.013	1.014
52	India	1.008	1.006	1.014
71	Austria	1.000	1.014	1.014
90	U.K.	1.001	1.013	1.014
77	Germany	1.003	1.011	1.013
6	Egypt	1.000	1.012	1.012
39	Bolivia	1.000	1.011	1.011
41	Chile	0.998	1.013	1.011
75	Finland	1.002	1.009	1.011
80	Ireland	1.000	1.011	1.011
30	Dominican Republic	1.000	1.010	1.010
63	Nepal	1.010	1.000	1.010
87	Spain	1.009	1.001	1.010
4	Cameroon	1.000	1.009	1.009
69	Turkey	1.005	1.004	1.009
81	Italy	1.000	1.009	1.009
26	Zimbabwe	0.997	1.011	1.008
31	El Salvador	1.000	1.008	1.008
65	Philippines	1.000	1.008	1.008
47	Venezuela	0.997	1.009	1.006
10	Kenya	1.000	1.005	1.005
32	Guatemala	1.000	1.005	1.005
56	Israel	1.000	1.004	1.004
61	Malaysia	1.000	1.004	1.004
92	New Zealand	1.000	1.004	1.004
22	Tanzania	1.013	0.990	1.003
34	Honduras	1.000	1.003	1.003
43	Ecuador	1.000	1.003	1.003
79	Hungary	1.000	1.003	1.003
88	Sweden	0.992	1.012	1.003
50	Sri Lanka	1.004	0.998	1.002
57	Japan	0.993	1.009	1.002
46	Uruguay	1.000	1.000	1.000
11	Madagascar	1.008	0.990	0.998
16	Niger	0.995	1.004	0.998
25	Burkina Faso	0.990	1.007	0.997
72	Bel-Lux	1.000	0.996	0.996
59	Korea Republic	1.000	0.995	0.995
68	Thailand	0.994	1.000	0.995
83	Norway	0.986	1.010	0.995
93	Papua N. Guin.	1.000	0.992	0.992
67	Syria	0.982	1.007	0.989
44	Paraguay	1.000	0.984	0.984
13	Mali	0.982	1.001	0.983
53	Indonesia	0.978	1.003	0.981
24	Uganda	1.000	0.977	0.977
55	Iraq	0.968	1.008	0.976
38	Argentina	1.000	0.973	0.973
18	Rwanda	1.000	0.967	0.967
8	Guinea	1.006	0.958	0.964
33	Haiti	1.000	0.957	0.957
5	Chad	1.000	0.947	0.947
	Mean	1.005	1.006	1.011

(Continued)

Table 4
(Continued)

21-year sample period) are presented in Table 4. Tables 5 and 6, respectively, show the unweighted and weighted annual averages (averaged over the 93 countries) of efficiency change, technical change, and TFP change. Table 7 shows the regional averages of changes

Table 5
Annual mean technical efficiency change, technical change, and TFP change, 1980–2000

Year*	Efficiency Change	Technical Change	TFP Change
1981	1.021	0.966	0.987
1982	0.993	1.027	1.020
1983	0.999	0.997	0.996
1984	1.023	0.990	1.012
1985	0.993	1.023	1.016
1986	1.011	0.988	0.999
1987	0.991	0.985	0.976
1988	1.012	1.048	1.060
1989	1.007	0.987	0.993
1990	0.995	1.025	1.020
1991	0.996	1.018	1.014
1992	1.009	0.979	0.987
1993	1.023	0.979	1.001
1994	1.010	0.986	0.995
1995	0.994	1.030	1.023
1996	1.020	1.039	1.059
1997	1.009	0.980	0.989
1998	0.997	1.033	1.030
1999	0.989	1.044	1.033
2000	1.006	1.003	1.009
Mean	1.005	1.006	1.011

* Note that 1981 refers to the change between 1980 and 1981, etc.

Table 6
Weighted annual mean technical efficiency change, technical change, and TFP change, 1980–2000

Year*	Efficiency Change	Technical Change	TFP Change
1981	1.017	1.011	1.028
1982	0.990	1.028	1.018
1983	1.012	0.985	0.996
1984	1.022	1.022	1.044
1985	1.008	1.021	1.030
1986	1.003	0.996	1.000
1987	0.991	1.008	0.999
1988	1.018	1.007	1.025
1989	1.008	1.005	1.013
1990	0.990	1.029	1.019
1991	1.008	1.011	1.019
1992	1.035	0.995	1.030
1993	1.030	0.981	1.010
1994	1.029	1.011	1.041
1995	0.984	1.048	1.031
1996	1.028	1.010	1.038
1997	1.030	1.011	1.041
1998	1.002	1.011	1.012
1999	0.983	1.039	1.022
2000	0.996	1.019	1.015
Mean	1.009	1.012	1.021

* Note that 1981 refers to the change between 1980 and 1981, etc.

Table 7
Weighted means of annual technical efficiency change, technical change, and TFP change for the continents, 1980–2000

Continent	Countries	Efficiency Change	Technical Change	TFP Change
Africa	1–26	1.006	1.007	1.013
North America	27, 37	1.000	1.027	1.027
South America	28–36, 38–47	1.000	1.006	1.006
Asia	48–70	1.019	1.010	1.029
Europe	71–90	1.002	1.011	1.014
Australasia	91–93	1.000	1.018	1.018
Mean	1–93	1.009	1.012	1.021

in efficiency and TFP. Table 8 shows the changes in TFP for groups of countries classified by their technical efficiency score in the initial period 1980.

In Table 3 we can identify all those countries that define the frontier technology for the years 1980 and 2000 (in the vicinity of their observed output and input mixes). The table shows that there are 39 and 45 countries that are on the frontier in 1980 and 2000, respectively. Only four countries, Niger, Indonesia, Japan, and Syria, which were on the frontier in 1980, were no longer in the frontier in 2000. Table 3 also provides a list of countries that define the best practice (peers) for each of the countries that are not on the frontier. It is interesting to observe the changes in the sets of peer countries over the two periods. For example, in 1980 Cuba had the Dominican Republic, the Netherlands, Malaysia, New Zealand, and Hungary as its peers. However, in 2000 only the Netherlands remained in the peer country set, the other countries in the new set being Nigeria, Bolivia, Switzerland, Haiti, and Uruguay. Sets of peer countries defining best practice for countries in Asia seem to be relatively stable over the study period.

Table 8
Weighted means of annual technical efficiency change, technical change, and TFP change for efficient and inefficient countries, 1980–2000

Efficiency Level in 1980	Efficiency Change	Technical Change	TFP Change
$TE = 1$	0.998	1.013	1.012
$0.6 < TE < 1$	1.003	1.012	1.015
$TE < 0.6$	1.025	1.011	1.036
Mean	1.009	1.012	1.021

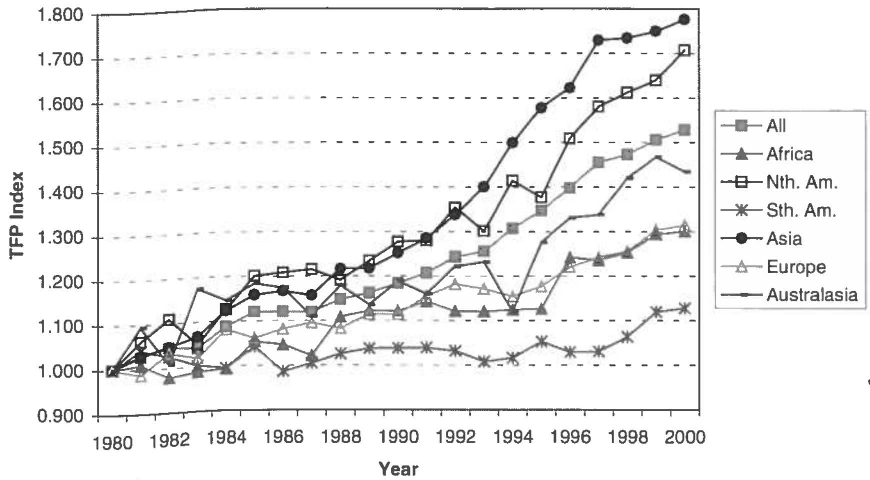

Figure 2. Cumulative TFP indices.

The last two columns of Table 3 show the number of times each of the efficient countries on the frontier appear as a peer for the technically inefficient countries. Countries that do not appear as a peer for any other country may be considered to be on the frontier due to the unique nature of their input and output mixes. For example, Australia does not appear as a peer for any country in 1980. In contrast, Papua New Guinea appears as a peer for 26 countries in 1980.

Table 4 shows the mean technical efficiency change, technical change, and TFP change for the 93 countries over the period 1980 to 2000. Countries in the table are presented in descending order of the magnitude of the TFP changes. The table shows China and Cambodia as the two countries with maximum TFP growth. China shows a 6.0% average growth in TFP, which is due to 4.4% percent growth in technical efficiency, and 1.5% growth in technical change.[17] Australia, United States, and India, respectively, exhibit TFP growth rates of 2.6, 2.6, and 1.4%. The unweighted average (across all countries) growth in TFP is 1.1%.

Tables 5 and 6 show the annual average technical efficiency change, technical change, and TFP change using, respectively, unweighted (where each country has the same weight) and weighted (where each country change is weighted by the country's share in total agricultural output). These tables show the effect of using weights on the annual averages derived. Unweighted averages show only 1.1% growth in TFP whereas the weighted TFP growth over the period is 2.1%. The results show that the use of unweighted averages understates the changes in TFP and in its components. Another implication of this difference is that TFP growth has been higher in countries with a higher share of global agricultural output. It seems reasonable to argue that for purposes of assessing regional and global performance a weighted average (across countries) of annual growth rates is more appropriate.

Tables 5 and 6 show that over the whole period there has been no technological regression though for some individual years there has been some evidence of technological regression. The extent of technological regression seems to be less serious when weighted average changes are considered.

Table 7 provides measures of annual changes in technical efficiency, technical change, and TFP change by different regions. Asia posted the highest TFP growth of 2.9% (mainly due to efficiency change growth of 1.9%) followed by North America (consisting of the United States and Canada), Australasia, Europe, Africa, and South America. South America has posted the lowest growth rate of 0.6%, followed by Africa with 1.3% growth in TFP. A surprising result is that over the period 1980–2000, these results show no evidence of global or regional technological regression. This is in

[17] This result appears to be consistent with some of the recent studies on Chinese economic growth (Maddison, 1997).

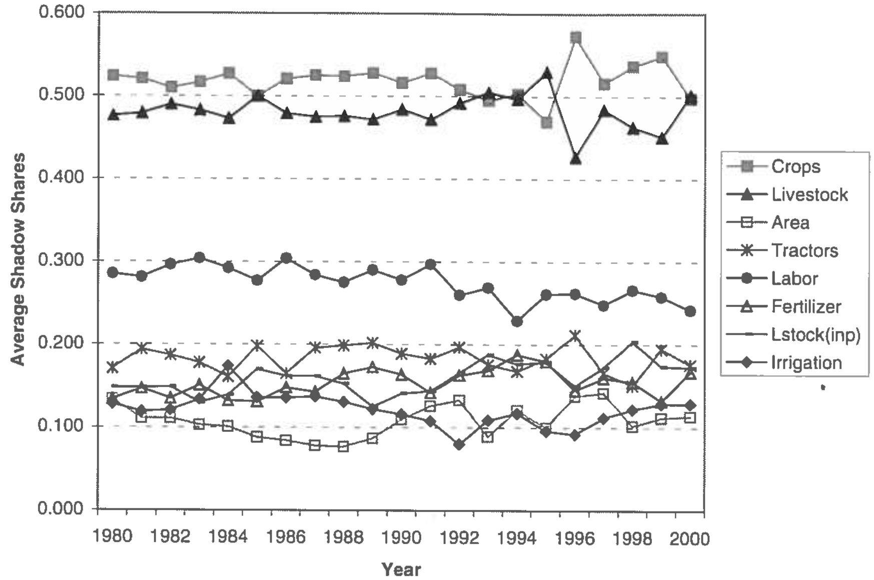

Figure 3. Mean shadow shares.

Table 9
Annual mean shadow shares, 1980–2000

Year	Outputs		Inputs					
	Crops	Livestock	Area	Tractors	Labor	Fertilizer	Livestock	Irrigation
1980	0.524	0.476	0.134	0.171	0.285	0.134	0.148	0.128
1981	0.521	0.479	0.111	0.194	0.281	0.147	0.148	0.119
1982	0.510	0.490	0.111	0.187	0.296	0.135	0.149	0.121
1983	0.517	0.483	0.103	0.178	0.304	0.151	0.130	0.134
1984	0.527	0.473	0.101	0.161	0.292	0.132	0.139	0.174
1985	0.500	0.500	0.088	0.198	0.277	0.131	0.170	0.136
1986	0.521	0.479	0.084	0.165	0.304	0.148	0.162	0.136
1987	0.525	0.475	0.078	0.196	0.284	0.143	0.162	0.137
1988	0.524	0.476	0.077	0.199	0.275	0.165	0.153	0.131
1989	0.528	0.472	0.087	0.202	0.290	0.173	0.125	0.122
1990	0.516	0.484	0.110	0.189	0.278	0.164	0.141	0.116
1991	0.528	0.472	0.126	0.183	0.297	0.142	0.144	0.108
1992	0.508	0.492	0.133	0.197	0.260	0.163	0.166	0.080
1993	0.495	0.505	0.089	0.176	0.269	0.169	0.188	0.109
1994	0.503	0.497	0.121	0.168	0.229	0.188	0.177	0.117
1995	0.470	0.530	0.100	0.183	0.261	0.180	0.179	0.096
1996	0.573	0.427	0.138	0.212	0.262	0.145	0.150	0.092
1997	0.516	0.484	0.142	0.166	0.248	0.160	0.173	0.112
1998	0.537	0.463	0.102	0.151	0.266	0.155	0.204	0.122
1999	0.549	0.451	0.112	0.195	0.258	0.132	0.174	0.129
2000	0.498	0.502	0.114	0.176	0.242	0.167	0.173	0.129
Mean	0.519	0.481	0.108	0.183	0.274	0.154	0.160	0.121

Table 10
Mean shadow shares, 1980–2000

Country	Outputs		Inputs					
	Crops	Livestock	Area	Tractors	Labor	Fertilizer	Livestock	Irrigation
Algeria	0.393	0.607	0.000	0.025	0.222	0.449	0.244	0.060
Angola	0.227	0.773	0.000	0.003	0.276	0.222	0.250	0.249
Burundi	1.000	0.000	0.000	0.159	0.044	0.065	0.731	0.000
Cameroon	0.308	0.692	0.030	0.254	0.349	0.015	0.000	0.352
Chad	0.149	0.851	0.000	0.483	0.160	0.092	0.001	0.263
Egypt	0.785	0.215	0.657	0.081	0.120	0.130	0.012	0.000
Ghana	0.455	0.545	0.000	0.091	0.191	0.246	0.281	0.192
Guinea	0.553	0.447	0.001	0.188	0.359	0.452	0.000	0.000
Cote d'Ivoire	0.992	0.008	0.000	0.264	0.407	0.084	0.109	0.136
Kenya	0.002	0.998	0.045	0.287	0.166	0.121	0.014	0.368
Madagascar	0.531	0.469	0.007	0.180	0.608	0.205	0.000	0.000
Malawi	0.817	0.183	0.006	0.438	0.381	0.000	0.158	0.016
Mali	0.112	0.888	0.049	0.092	0.342	0.074	0.006	0.438
Morocco	0.620	0.380	0.012	0.198	0.408	0.186	0.197	0.000
Mozambique	0.536	0.464	0.000	0.011	0.000	0.256	0.731	0.002
Niger	0.295	0.705	0.001	0.600	0.150	0.125	0.023	0.101
Nigeria	0.568	0.432	0.019	0.241	0.473	0.032	0.019	0.215
Rwanda	0.721	0.279	0.160	0.216	0.118	0.258	0.058	0.190
Senegal	0.656	0.344	0.000	0.235	0.621	0.069	0.050	0.026
South Africa	0.566	0.434	0.000	0.401	0.214	0.129	0.179	0.077
Sudan	0.191	0.809	0.005	0.267	0.536	0.191	0.000	0.000
Tanzania	0.479	0.521	0.005	0.121	0.518	0.180	0.005	0.172
Tunisia	0.814	0.186	0.037	0.080	0.361	0.370	0.153	0.000
Uganda	0.550	0.450	0.165	0.043	0.057	0.498	0.017	0.219
Burkina Faso	0.000	1.000	0.066	0.254	0.111	0.050	0.060	0.459
Zimbabwe	0.704	0.296	0.098	0.185	0.455	0.071	0.017	0.175
Canada	0.751	0.249	0.001	0.000	0.539	0.112	0.214	0.134
Costa Rica	0.260	0.740	0.047	0.413	0.293	0.025	0.158	0.064
Cuba	0.142	0.858	0.102	0.325	0.087	0.382	0.104	0.000
Dominican Republic	0.114	0.886	0.136	0.413	0.186	0.043	0.139	0.083
El Salvador	0.056	0.944	0.440	0.213	0.118	0.021	0.136	0.071
Guatemala	0.015	0.985	0.039	0.219	0.141	0.007	0.263	0.331
Haiti	0.023	0.977	0.118	0.343	0.045	0.359	0.004	0.131
Honduras	0.078	0.922	0.034	0.281	0.249	0.199	0.017	0.221
Mexico	0.471	0.529	0.000	0.272	0.320	0.169	0.237	0.002
Nicaragua	0.136	0.864	0.009	0.252	0.221	0.178	0.025	0.315
United States	0.844	0.156	0.000	0.105	0.641	0.043	0.069	0.141
Argentina	0.630	0.370	0.021	0.113	0.469	0.297	0.089	0.010
Bolivia	0.286	0.714	0.021	0.140	0.350	0.339	0.029	0.121
Brazil	0.917	0.083	0.143	0.126	0.331	0.138	0.000	0.262
Chile	0.559	0.441	0.013	0.397	0.261	0.155	0.174	0.000
Colombia	0.441	0.559	0.000	0.356	0.353	0.016	0.000	0.275
Ecuador	0.688	0.312	0.160	0.210	0.423	0.154	0.034	0.018
Paraguay	0.821	0.179	0.035	0.141	0.346	0.321	0.000	0.157
Peru	0.447	0.553	0.000	0.197	0.369	0.281	0.153	0.000
Uruguay	0.030	0.970	0.036	0.039	0.172	0.523	0.000	0.231
Venezuela	0.381	0.619	0.107	0.314	0.145	0.200	0.003	0.231
Bangladesh	0.874	0.126	0.550	0.426	0.021	0.003	0.000	0.000
Myanmar	0.867	0.133	0.137	0.311	0.358	0.194	0.000	0.000
Sri Lanka	1.000	0.000	0.257	0.127	0.549	0.067	0.000	0.000

(Continued)

Table 10
(Continued)

Country	Outputs		Inputs					
	Crops	Livestock	Area	Tractors	Labor	Fertilizer	Livestock	Irrigation
China	0.133	0.867	0.022	0.222	0.000	0.017	0.740	0.000
India	0.710	0.290	0.328	0.156	0.445	0.070	0.000	0.001
Indonesia	1.000	0.000	0.021	0.293	0.422	0.006	0.258	0.000
Iran	0.855	0.145	0.084	0.237	0.360	0.221	0.098	0.000
Iraq	0.949	0.051	0.073	0.265	0.347	0.230	0.085	0.000
Israel	0.658	0.342	0.472	0.099	0.173	0.032	0.223	0.000
Japan	0.298	0.702	0.564	0.000	0.019	0.004	0.389	0.023
Cambodia	0.771	0.229	0.036	0.246	0.537	0.181	0.000	0.000
Korea Republic	0.710	0.290	0.629	0.089	0.140	0.023	0.086	0.034
Laos	0.492	0.508	0.102	0.053	0.640	0.204	0.000	0.000
Malaysia	0.818	0.182	0.253	0.118	0.218	0.066	0.302	0.043
Mongolia	0.003	0.997	0.000	0.248	0.127	0.354	0.040	0.231
Nepal	0.580	0.420	0.594	0.221	0.142	0.044	0.000	0.000
Pakistan	0.320	0.680	0.325	0.401	0.227	0.048	0.000	0.000
Philippines	0.767	0.233	0.237	0.328	0.280	0.030	0.124	0.000
Saudi Arabia	0.137	0.863	0.000	0.260	0.092	0.006	0.643	0.000
Syria	0.956	0.044	0.003	0.235	0.351	0.248	0.162	0.001
Thailand	0.940	0.060	0.121	0.073	0.608	0.156	0.041	0.000
Turkey	1.000	0.000	0.104	0.021	0.377	0.306	0.030	0.161
Vietnam	0.543	0.457	0.718	0.182	0.000	0.026	0.002	0.073
Austria	0.866	0.134	0.051	0.036	0.159	0.181	0.414	0.158
Bel-Lux	0.452	0.548	0.078	0.031	0.261	0.030	0.110	0.489
Bulgaria	0.770	0.230	0.036	0.402	0.331	0.166	0.064	0.000
Denmark	0.234	0.766	0.025	0.000	0.508	0.000	0.460	0.008
Finland	0.034	0.966	0.000	0.000	0.017	0.000	0.865	0.118
France	0.928	0.072	0.104	0.030	0.529	0.041	0.173	0.123
Germany	0.204	0.796	0.016	0.000	0.070	0.000	0.832	0.082
Greece	1.000	0.000	0.033	0.025	0.238	0.279	0.237	0.187
Hungary	0.633	0.367	0.181	0.105	0.174	0.104	0.250	0.186
Ireland	0.080	0.920	0.000	0.215	0.057	0.000	0.000	0.728
Italy	0.975	0.025	0.146	0.001	0.209	0.285	0.073	0.285
Netherlands	0.029	0.971	0.277	0.052	0.438	0.103	0.093	0.036
Norway	0.006	0.994	0.005	0.000	0.002	0.000	0.808	0.185
Poland	0.836	0.164	0.028	0.036	0.352	0.008	0.468	0.109
Portugal	0.531	0.469	0.085	0.005	0.128	0.690	0.074	0.018
Romania	0.597	0.403	0.155	0.246	0.195	0.353	0.051	0.000
Spain	0.966	0.034	0.000	0.040	0.261	0.291	0.107	0.301
Sweden	0.162	0.838	0.000	0.000	0.075	0.035	0.750	0.140
Switzerland	0.042	0.958	0.021	0.002	0.120	0.507	0.228	0.123
United Kingdom	0.951	0.049	0.000	0.415	0.258	0.018	0.110	0.200
Australia	0.510	0.490	0.000	0.240	0.586	0.013	0.110	0.051
New Zealand	0.015	0.985	0.013	0.169	0.382	0.097	0.078	0.260
Papua N. Guin.	0.906	0.094	0.297	0.116	0.022	0.015	0.122	0.429
Mean	0.519	0.481	0.108	0.183	0.274	0.154	0.160	0.121

contrast to the work of Fulginiti and Perrin (1997) who report technical regression in a group of 18 developing countries over the period 1961–1985. Another interesting feature is the predominance of efficiency change (or "catch-up") as a source of TFP growth. Both in Asia and Africa efficiency change is the principal source of TFP growth.

Figure 2 shows cumulative TFP indices from 1980 to 2000 for the different regions. From the figure it is evident that Asia has the highest cumulative growth by

2000, followed by North America and Europe. Asia has a higher cumulative growth than the global growth in TFP. Africa and South America remain as the bottom groups.

Table 8 shows the average annual changes for groups of countries classified by their technical efficiency scores in 1980. The first group, consisting of 39 countries on the frontier in 1980, posted only 1.2% growth in TFP driven by a 1.3% growth in technical change. In contrast, those countries that had an efficiency score between 0.6 and 1, posted a 1.5% growth in TFP mainly driven by 0.3% growth in technical change and 1.2% growth in technical efficiency. However, the bottom group of countries, with a technical efficiency score of less than 0.6, posted an impressive 3.6% growth in TFP mainly driven by 2.5% growth in technical efficiency and 1.5% growth in technical change. These results indicate a degree of catch-up due to improved technical efficiency along with growth in technical change.

While the results in Tables 7 and 8 are very encouraging in terms of the catch-up and convergence shown by many countries, a feature of concern is the low TFP growth experienced by a number of countries in Africa and South America. These are the two continents with the highest population growth during 1980–2000, which suggests that food security will remain an issue on these continents for some time yet.

Figure 3 summarizes our estimated shadow shares obtained from the DEA frontiers used in computing the Malmquist TFP indices. Summary information on these shares is also given in Tables 9 and 10. The top two series in Figure 3 represent the value shares for crops and livestock (both sum to unity) over the study period. These shares appear to be fairly steady over the period, with crops accounting for more than 50% of the total output in most years.

The six series graphed at the bottom of Figure 3 represent the shadow input shares resulting from the application of the DEA methodology. The figure serves to demonstrate the plausibility of the input shares derived here. The average labor share shows a steady decline from 28.5% in 1980 to 24.2% in 2000. The share of land, aggregated over all the countries, seems to be quite stable at around 11%. While the share of tractors remained essentially the same, the shares of fertilizer and livestock have shown small increases.

Table 10 shows the country-specific output and input shares underlying the TFP indices reported here. These shares are averaged over the study period from 1980 to 2000. These shadow shares seem to be quite meaningful. For example, India shows 71% share for crops and 29% for livestock confirming the importance of crops in India. Similarly, in the Netherlands the share of livestock is shown to be 97.1%. Similar livestock shares are shown for Norway (99.4%), Switzerland (95.1%), and Finland (96.6%).

The last six columns of Table 10 show the shares of the six inputs. These shares also appear to be meaningful and consistent with the general factor endowments enjoyed by these countries. For example, the shadow shares of labor are quite high in countries like the United States (64.1%), Canada (53.9%), and Australia (58.6%). Labor shares are also quite high in those countries where labor is abundant and agriculture is very labor intensive. India and Indonesia, respectively, have shadow labor shares of 44.5 and 42.2%, respectively. In countries where land is a limiting factor its shadow share is quite high. For example, in the

Table 11
Mean shadow shares for the continents, 1980–2000

Continent	Outputs		Inputs					
	Crops	Livestock	Area	Tractors	Labor	Fertilizer	Livestock	Irrigation
Africa	0.501	0.499	0.052	0.208	0.294	0.176	0.128	0.143
North America	0.798	0.203	0.001	0.053	0.590	0.078	0.142	0.138
South America	0.342	0.658	0.077	0.251	0.257	0.200	0.082	0.133
Asia	0.669	0.331	0.245	0.200	0.280	0.110	0.140	0.025
Europe	0.515	0.485	0.062	0.082	0.219	0.155	0.308	0.174
Australasia	0.477	0.523	0.103	0.175	0.330	0.042	0.103	0.247
Mean	0.519	0.481	0.108	0.183	0.274	0.154	0.160	0.121

Table 12
Comparison of mean TFP change when average DEA shadow prices used as shares in a Tornqvist index, 1980–2000

	Country	Malmquist	Tornqvist	Difference
5	Chad	0.947	0.984	−0.037
38	Argentina	0.973	1.004	−0.031
18	Rwanda	0.967	0.995	−0.028
53	Indonesia	0.981	1.005	−0.024
24	Uganda	0.977	0.997	−0.020
8	Guinea	0.964	0.983	−0.019
33	Haiti	0.957	0.973	−0.016
93	Papua N. Guin.	0.992	1.007	−0.015
77	Germany	1.013	1.028	−0.015
61	Malaysia	1.004	1.019	−0.015
50	Sri Lanka	1.002	1.017	−0.015
92	New Zealand	1.004	1.019	−0.015
46	Uruguay	1.000	1.015	−0.015
72	Bel-Lux	0.996	1.010	−0.014
44	Paraguay	0.984	0.998	−0.014
13	Mali	0.983	0.997	−0.014
22	Tanzania	1.003	1.017	−0.014
43	Ecuador	1.003	1.016	−0.013
59	Korea Republic	0.995	1.007	−0.012
45	Peru	1.015	1.027	−0.012
23	Tunisia	1.018	1.028	−0.010
6	Egypt	1.012	1.022	−0.010
39	Bolivia	1.011	1.020	−0.009
67	Syria	0.989	0.997	−0.008
56	Israel	1.004	1.011	−0.007
87	Spain	1.010	1.016	−0.006
4	Cameroon	1.009	1.015	−0.006
75	Finland	1.011	1.016	−0.005
65	Philippines	1.008	1.013	−0.005
57	Japan	1.002	1.007	−0.005
40	Brazil	1.020	1.025	−0.005
54	Iran	1.020	1.025	−0.005
83	Norway	0.995	0.999	−0.004
80	Ireland	1.011	1.015	−0.004
41	Chile	1.011	1.014	−0.003
88	Sweden	1.003	1.006	−0.003
26	Zimbabwe	1.008	1.011	−0.003
19	Senegal	1.021	1.024	−0.003
14	Morocco	1.016	1.019	−0.003
81	Italy	1.009	1.011	−0.002
71	Austria	1.014	1.016	−0.002
47	Venezuela	1.006	1.007	−0.001
11	Madagascar	0.998	0.999	−0.001
74	Denmark	1.032	1.033	−0.001
73	Bulgaria	1.020	1.020	0.000
9	Cote d'Ivoire	1.014	1.014	0.000
82	Netherlands	1.022	1.022	0.000
16	Niger	0.998	0.998	0.000
7	Ghana	1.022	1.021	0.001
2	Angola	1.037	1.036	0.001

(Continued)

Table 12
(Continued)

	Country	Malmquist	Tornqvist	Difference
69	Turkey	1.009	1.008	0.001
30	Dominican Republic	1.010	1.009	0.001
90	U.K.	1.014	1.012	0.002
42	Colombia	1.014	1.012	0.002
27	Canada	1.033	1.031	0.002
76	France	1.020	1.018	0.002
28	Costa Rica	1.028	1.025	0.003
35	Mexico	1.015	1.012	0.003
34	Honduras	1.003	1.000	0.003
32	Guatemala	1.005	1.002	0.003
91	Australia	1.026	1.023	0.003
31	El Salvador	1.008	1.004	0.004
79	Hungary	1.003	0.999	0.004
49	Myanmar	1.018	1.013	0.005
63	Nepal	1.010	1.005	0.005
37	U.S.	1.026	1.021	0.005
64	Pakistan	1.023	1.018	0.005
10	Kenya	1.005	1.000	0.005
12	Malawi	1.022	1.017	0.005
68	Thailand	0.995	0.990	0.005
52	India	1.014	1.009	0.005
85	Portugal	1.026	1.021	0.005
36	Nicaragua	1.018	1.012	0.006
25	Burkina Faso	0.997	0.990	0.007
21	Sudan	1.024	1.016	0.008
66	Saudi Arabia	1.042	1.032	0.010
17	Nigeria	1.037	1.027	0.010
78	Greece	1.017	1.007	0.010
15	Mozambique	1.019	1.009	0.010
55	Iraq	0.976	0.965	0.011
89	Switzerland	1.021	1.009	0.012
60	Laos	1.034	1.021	0.013
86	Romania	1.023	1.010	0.013
51	China	1.060	1.047	0.013
84	Poland	1.021	1.007	0.014
48	Bangladesh	1.024	1.009	0.015
20	South Africa	1.037	1.019	0.018
70	Vietnam	1.024	1.003	0.021
1	Algeria	1.046	1.025	0.021
29	Cuba	1.025	1.000	0.025
58	Cambodia	1.057	1.031	0.026
62	Mongolia	1.028	0.997	0.031
3	Burundi	1.046	0.972	0.074
	Mean	1.011	1.011	

Netherlands the land share is 27.7%. In Japan and Israel the land shares are, respectively, 56.4% and 47.2%. These large shares for land also reflect the scarcity of land resulting from increasing urbanization of agricultural land.

Table 13
Comparison of weighted mean TFP change when average DEA shadow prices used as shares in a Tornqvist index for the continents, 1980–2000

Continent*	Countries	Malmquist	Tornqvist	Difference
Africa	1–26	1.013	1.016	0.003
North America	27, 37	1.027	1.022	−0.005
South America	28–36, 38–47	1.006	1.015	0.009
Asia	48–70	1.029	1.025	−0.004
Europe	71–90	1.014	1.015	0.001
Australasia	91–93	1.018	1.021	0.003
Mean	1–93	1.021	1.021	0.000

Shares of other factors, including fertilizers, tractors, livestock, and irrigation are also plausible and appear to support the general scarcities of these resources in different countries. We find that the general trends in these shares over time and differences across countries appear to support the discussion in Ruttan (2002) where various constraints to productivity growth in world agriculture are identified. Table 11 summarizes the shadow share information by continents. The Asian continent has the highest input share associated with land whereas North America and Europe have large shares for labor, livestock, and irrigation inputs.

As one final exercise, we have taken the average shadow share estimates from the bottom of Table 11 and used them as fixed shares in the calculation of the Tornqvist TFP index numbers for each country.[18] These Tornqvist TFP indices are reported in Table 12, along with the original Malmquist TFP indices from the final column of Table 4. The differences between these two columns of indices are reported in the final column of Table 12. This table has been sorted by the size of this difference. The reported differences are quite large in some cases, with 40 countries reporting differences of 1% per annum or more. These differences may be rationalized in two ways. Either the shadow shares for some countries are not well estimated (due to the dimensionality problem in DEA) or the shadow shares are well estimated, but they differ significantly from the sample average, because of country-specific factors, such as land scarcity, labor abundance, etc. For many countries, the observed difference may well be a combination of these two factors, to varying degrees.

Finally, the country-level information in Table 12 is summarized in Table 13 for our six regions. The largest difference occurs for South and Central America, where the average TFP growth measure increases from 0.6% to 1.5% per annum. This is not a minor difference, and emphasizes the key point that TFP indices depend crucially upon the prices that are used—be they market prices or shadow prices.

5. Conclusions

This paper presents some important findings on levels and trends in global agricultural productivity over the past two decades. The results presented here examine the growth in agricultural productivity in 93 countries over the period 1980 to 2000. The results show an annual growth in TFP of 2.1%, with efficiency change (or catch-up) contributing 0.9% per year and technical change (or frontier shift) providing the other 1.2%. There is little evidence of the technological regression discussed in a number of the papers listed in Table 1. This is most likely a consequence of the use of a different sample period and an expanded group of countries. In terms of individual country performance, the most spectacular performance is posted by China with an average annual growth of 6.0% in TFP over the study period. Other countries with strong performance are, among others, Cambodia, Nigeria, and Algeria. The United States has a TFP growth rate of 2.6% whereas India has posted a TFP growth rate of only 1.4%.

Turning to the performance of various regions, Asia is the major performer with an annual TFP growth of 2.9%. Africa seems to be the weakest performer with only 0.6% growth in TFP. Examining the question of catch-up and convergence, we find that those countries that were well below the frontier in 1980 (with technical efficiency coefficients of 0.6 or below) have a TFP growth rate of 3.6%. This is in contrast to a low 1.2% growth for those countries that were at the frontier in 1980. These results indicate a degree of catch-up in productivity levels between high-performing and low-performing countries. These results are of interest since they indicate an encouraging reversal (during 1980–2000 period) in the phenomenon of negative productivity trends and technological regression reported in some of the earlier studies for the period 1961–1985.

Though the results are quite plausible and meaningful, the authors are quite conscious of the data limitations and the need for further work in this area. Future work could include: (i) an examination of the robustness of the results to shifts in the base period for the

[18] The Tornqvist index is described in chapter 4 in Coelli et al. (1998).

computation of output aggregates; (ii) the inclusion of pesticides, herbicides, and purchased feed and seed in the input set; (iii) an investigation of the effects of land quality, irrigation, and rainfall; and (iv) utilization of parametric distance functions to study the robustness of the findings to the choice of methodology.

References

Arnade, C., "Using a Programming Approach to Measure International Agricultural Efficiency and Productivity," *Journal of Agricultural Economics* 49 (1998), 67–84.

Ball, V. E., J. C. Bureau, J. P. Butault, and R. Nehring, "Levels of Farm Sector Productivity: An International Comparison," *Journal of Productivity Analysis* 15 (2001), 5–29.

Barro, R., and X. Sala-i-Martin, "Convergence across States and Regions," *Brookings Paper on Economic Activity* (1991), p. 107.

Bureau, C., R. Färe, and S. Grosskopf, "A Comparison of Three Nonparametric Measures of Productivity Growth in European and United States Agriculture," *Journal of Agricultural Economics* 46 (1995), 309–326.

Capalbo, S. M., and J. M. Antle, eds., *Agricultural Productivity: Measurement and Explanation* (Resources for the Future: Washington, DC: 1988).

Chavas, J. P., "An International Analysis of Agricultural Productivity," in L. Zepeda, ed., *Agricultural Investment and Productivity in Developing Countries* (FAO: Rome, 2001).

Coelli, T. J., and D. S. P. Rao, "Implicit Value Shares in Malmquist TFP Index Numbers," *CEPA Working Papers No. 4/2001* (School of Economics, University of New England: Armidale, 2001), pp. 27.

Coelli, T. J., D. S. P. Rao, and G. E. Battese, *An Introduction to Efficiency and Productivity Analysis* (Kluwer Academic Publishers: Boston, 1998).

Craig, B. J., P. G. Pardey, and J. Roseboom, "International Productivity Patterns: Accounting for Input Quality, Infrastructure, and Research," *American Journal of Agricultural Economics* 79 (1997), 1064–1077.

Färe, R., S. Grosskopf, M. Norris, and Z. Zhang, "Productivity Growth, Technical Progress and Efficiency Changes in Industrialised Countries," *American Economic Review* 84 (1994), 66–83.

Fulginiti, L., and R. Perrin, "Prices and Productivity in Agriculture," *Review of Economics and Statistics* 75 (1993), 471–482.

Fulginiti, L. E., and R. K. Perrin, "LDC Agriculture: Nonparametric Malmquist Productivity Indexes," *Journal of Development Economics* 53 (1997), 373–390.

Fulginiti, L. E., and R. K. Perrin, "Agricultural Productivity in Developing Countries," *Journal of Agricultural Economics* 19 (1998), 45–51.

Fulginiti, L. E., and R. K. Perrin, "Have Price Policies Damaged LDC Agricultural Productivity?" *Contemporary Economic Policy* 17 (1999), 469–475.

Grifell-Tatjé, E., and C. A. K. Lovell, "A Note on the Malmquist Productivity Index," *Economics Letters* 47 1995), 169–175.

Hayami, Y., and V. Ruttan, "Agricultural Productivity Differences among Countries," *American Economic Review* 40 (1970), 895–911.

Hayami, Y., and V. Ruttan, *Agricultural Development: An International Perspective* (Johns Hopkins University Press: Baltimore, 1971).

Kawagoe, T., and Y. Hayami, "The Production Structure of World Agriculture: An Intercountry Cross-Section Analysis," *Developing Economies* 21 (1983), 189–206.

Kawagoe, T., and Y. Hayami, "An Intercountry Comparison of Agricultural Production Efficiency," *American Journal of Agricultural Economics* 67 (1985), 87–92.

Kawagoe, T., Y. Hayami, and V. Ruttan, "The Intercountry Agricultural Production Function and Productivity Differences among Countries," *Journal of Development Economics* 19 (1985), 113–132.

Lau, L., and P. Yotopoulos, "The Meta-Production Function Approach to Technological Change in World Agriculture," *Journal of Development Economics* 31 (1989), 241–269.

A., Lusigi, and C. Thirtle, "Total Factor Productivity and the Effects of R&D in African Agriculture," *Journal of International Development* 9 (1997), 529–538.

Maddison, A., *Monitoring the World Economy: 1820–1992* (OECD: Paris, 1995).

Maddison, A., *Chinese Economic Performance in the Long Run* (OECD: Paris, 1997).

Martin, W., and Mitra, D., "Productivity Growth and Convergence in Agriculture and Manufacturing," *Agriculture Policy Research Working Papers No. 2171* (World Bank: Washington, DC, 1999).

Nin, A., C. Arndt, and P. V. Preckel, "Is Agricultural Productivity in Developing Countries Really Shrinking? New Evidence Using a Modified Nonparametric Approach," *Journal of Development Economics* 71 (2003), 395–415.

Rao, D. S. P., *Intercountry Comparisons of Agricultural Output and Productivity* (FAO: Rome, 1993).

Rao, D. S. P., and T. J. Coelli, "Catch-up and Convergence in Global Agricultural Productivity, 1980–1995," *CEPA Working Papers No. 4/98* (Department of Econometrics, University of New England: Armidale, 1998), pp. 25.

Ruttan, V. W., "Productivity Growth in World Agriculture: Sources and Constraints," *Journal of Economic Perspectives* 16 (2002), 161–184.

Suhariyanto, K., and C. Thirtle, "Asian Agricultural Productivity and Convergence," *Journal of Agricultural Economics* 52 (2001), 96–110.

Suhariyanto, K., A. Lusigi, and C. Thirtle, "Productivity Growth and Convergence in Asian and African Agriculture," in P. Lawrence and C. Thirtle, eds., *Asia and Africa in Comparative Economic Perspective* (Palgrave: London, 2001), pp. 258–274.

Trueblood, M. A., and J. Coggins, *Intercountry Agricultural Efficiency and Productivity: A Malmquist Index Approach* (World Bank: Washington, DC, 2003) mimeo.

Wiebe, K., M. Soule, C. Narrod, and V. Breneman, *Resource Quality and Agricultural Productivity: A Multi-Country Comparison* (USDA: Washington, DC, 2000) mimeo.