PRODUCTIVITY IN LDC AGRICULTURE: NONPARAMETRIC MALMQUIST MEASURES

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ABSTRACT

This paper examines changes in agricultural productivity in 18 developing countries over the period 1961 to 1985. Because input price series are not available, we use the concept of distance function and the nonparametric, quantity-based Malmquist index approach, and contrast the results with our previous Cobb-Douglas production function approach. The objective is to present an analysis of technological change that is less dependent on the parametric specification of the model. In average terms, the Malmquist constant-returns-to-scale approach indicates that half of these countries have experienced productivity declines. The partitioning of productivity into technical change and technical efficiency components indicates that negative technical change has been responsible for these declines, while most countries have experienced improvements in Farrell efficiency. In addition, countries that tax agriculture most heavily had the most negative rates of productivity change.

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Introduction

In the economics literature, aggregate productivity refers to the amount of output obtained from given levels of inputs in an economy or a sector of the economy. It is an important topic of study because it is one of two fundamental sources of larger income streams; the other being savings, which permit more inputs to be employed. Moreover, productivity rather than additional inputs has been the real engine driving growth in agricultural output, inasmuch as changes in output from decade to decade in this century have borne little or no relationship to changes in inputs. Schultz (1956) first noted this phenomenon at midcentury, and it has been even more pronounced since then.

Because productivity improvements have been of such paramount importance in increasing agricultural output (and/or reducing its cost), it is important to learn as much as possible about why it occurs or fails to occur. The first step in explaining agricultural productivity gains, however, is to measure them. There is a need to distinguish between the contributions of technical progress and those of returns to scale and input prices. However, in the absence of a priori hypotheses concerning the structure of technical change, Diamond et. al (1978) and Sato (1980) have shown that technical progress is undistinguishable from scale effects. This identification problem suggests that traditional parametric analysis of technology and technical change may give results that are sensitive to the particular parametric specification utilized. In this context, analyses of technical change that are less dependent on the parametric specification might be desirable. Recent advances in nonparametric techniques of productivity measurement now make it possible to do this for a wider set of countries than was heretofore possible. This paper employs some of those techniques to estimate rates of agricultural productivity change in a set of less developed countries (LCDs) economies. In addition, it contrasts them with the corresponding parametric results using the same data. We are also able to make some inferences about the role of income levels and agricultural taxation in explaining these rates.

Though productivity is defined as the amount of output from given levels of input, both the concept and its measurement become problematic in application because both the quantity and the mix of outputs change through time and inputs are not held at given levels. Conceptually, productivity changes might be due either to technological change (a shift in the production possibilities set) or to changes in technical efficiency (distance from the frontier of the production possibilities set, as in Farrell, 1957, and Timmer, 1971). The suitability of an empirical measure depends upon which of these is the source of productivity change. The traditional empirical measure of productivity is the ratio of an index representing output level to an index representing input level, with the Tornqvist-Theil share-weighted indexing procedure being the most common. This approach yields a valid conceptual measure of *technological* change if price ratios are measures of marginal productivities and if production is technically efficient. But if price ratios are distorted measures of marginal products, the share-weighted index approach yields distorted measures of productivity change, and if prices are unavailable (as is the case in many LDC situations), the approach is not even feasible. Quantity-based measures of productivity are then in order.

Quantity-based approaches to productivity measurement have been delineated by Caves, Christensen, and Diewert (1982); by Fare, Grosskopf, and Lovell (1985); and by Chavas and Cox (1990). These approaches conceptualize productivity changes as being due either to technological change, or to changes in technical efficiency, or to both. If technical efficiency is assumed, then all that remains is to estimate changes in the production frontier, upon which all empirical observations are assumed to be located (except perhaps for random departures). Elsewhere, we have used an approach of this type to measure agricultural productivity changes in the same set of countries that we examine in the present study (Fulginiti and Perrin, 1993). If the assumption of technical efficiency is relaxed, however, some new assumption must be invoked to allow one to distinguish empirically between changes in technology and changes in efficiency. The parametric approach to this problem is to estimate the parameters of specific production functions or distance functions utilizing estimators appropriate to the error structure assumed (see, Timmer). Changes in the estimated functions through time provide estimates of technological change, while changes in the (nonstochastic component of) distance of individual observations from the estimated technology frontier measure efficiency change.

Nonparametric quantity-based approaches assume that the true production possibilities set is defined by the convex hull of observed input-output combinations, implying no stochastic errors in these observations. In the study reported here, we follow Fare and Grosskopf (1990,1992) in measuring productivity growth as the geometric mean of two Malmquist productivity ratios of the type introduced by Caves, Christensen, and Diewert. This approach permits us to partition productivity changes into a component due to changes in technology and a component due to changes in efficiency.

Malmquist Productivity Indexes

One quantity-based conceptual approach to measuring productivity change is to compare observed change in output with the imputed change in output that would have been possible from the observed input changes, the imputation being based on the production possibilities set for either the current or the subsequent period. Since in the multiple-output, multiple-input situation, the concept of a production function is not operable for such a comparison, Caves, Christensen, and Diewert proposed using the ratio of two distance functions to implement this measure of productivity change.[1] They also show that under certain circumstances[2], the Malmquist ratio is equivalent to the Tornqvist

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[1] They named it the Malmquist index after Malmquist (1953), who had proposed constructing quantity indexes as ratios of distance functions.

[2] The underlying technology must be translog and all second order terms must be identical over time. It also assumes technical and allocative efficiency.

productivity index. They show further that the Tornqvist index is 'exact' for a technology that is translog, and since the translog is flexible, the Tornqvist index is 'superlative' in the sense of Diewert.

Since two Malmquist ratios are available for any time interval (depending on whether the reference technology is that of the initial period or the subsequent period), Fare and Grosskopf proposed the use of the geometric mean of the two. This Malmquist index has the additional capability of being decomposed into the product of an efficiency change component and a technological change component. Fare and Grosskopf show that under constant returns to scale and profit maximization, the input-based Malmquist productivity index equals the ratio of two Fisher indexes. In terms of data requirements, the Malmquist index requires only quantity data, whereas both the Fisher approach and the Tornqvist approach require data on prices as well as quantities of both the inputs and the outputs.

In this paper, we closely follow Grosskopf (1992) in defining the output-based Malmquist index of productivity change. We assume that for each time period t = 1,...,T, the production technology S^t models the transformation of inputs, $x_t \in \Re^N_+$, into outputs $y^t \in \Re^M_+$,

$$S^t = \{(x^t, y^t) : x^t \text{ can produce } y^t\}, \tag{1}$$

i.e., the technology consists of the set of all feasible input/output pairs. We assume that the set S^t is nonempty, closed, and convex, and that both inputs and outputs are freely disposable.[3]
Following Shephard (1970), the output distance function at time t is defined[4] as

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[3] For a list of properties on S^t see Shephard (1970).

[4] The input distance function is defined similarly:

$$D_i^t(x^t, y^t) = \{\lambda : (\frac{x^t}{\lambda}, y^t) \in S^t\}.$$

Under constant returns to scale,

$$D(x, y) = [D_i(x, y)]^{-1}.$$

$$D^t(x^t,y^t) \equiv inf\{\theta:\ (x^t,\frac{y^t}{\theta}) \in S^t\}. \tag{2}$$

Note that $D^t(x^t,y^t) \leq 1$, if and only if $(x^t,y^t) \in S^t$. In addition, $D^t(x^t,y^t) = 1$, if and only if (x^t,y^t) is on the boundary or frontier of technology. In the terminology of Farrell, that occurs when production is technically efficient.[5] These concepts can be illustrated for the case of a single output and single input, as in Figure 1. Here the boundary of the technology is equivalent to a production function, $y=f(x)$. Observed production at t is interior to the boundary at t. The distance function $D(x^t,y^t)$ is the ratio of observed output to maximum output, or OA/OB, which is less than one, and it is said that the observed point is not Farrell-efficient. That is, the observed output could be inflated by a factor of OB/OA and still be contained within the production possibilities set S_t. In the multiple-output, multiple-input case, the notion of a production function no longer describes the frontier, but the output distance function can be used to generate the production correspondence

$$PC^t(x^t) = \{y^t:\ D^t(x^t,y^t) \leq 1\} \tag{3}$$

and the analog of the production function, the frontier correspondence

$$FC^t(x^t) = \{y^t:\ D^t(x^t,y^t) = 1\}. \tag{4}$$

It follows that $D^t(x^t,y^t)$ in (2) defines the substitution alternatives among the outputs y_t, given inputs x^t. The distance function of equation (2) thus provides a complete characterization of the underlying technology.

To define the Malmquist index, we need to define distance functions comparing output at one period with the technology of another period, such as

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[5] For an interpretation of Farrell's measures of technical efficiency as reciprocals of distance functions, see Fare, Grosskopf, and Lovell (1985).

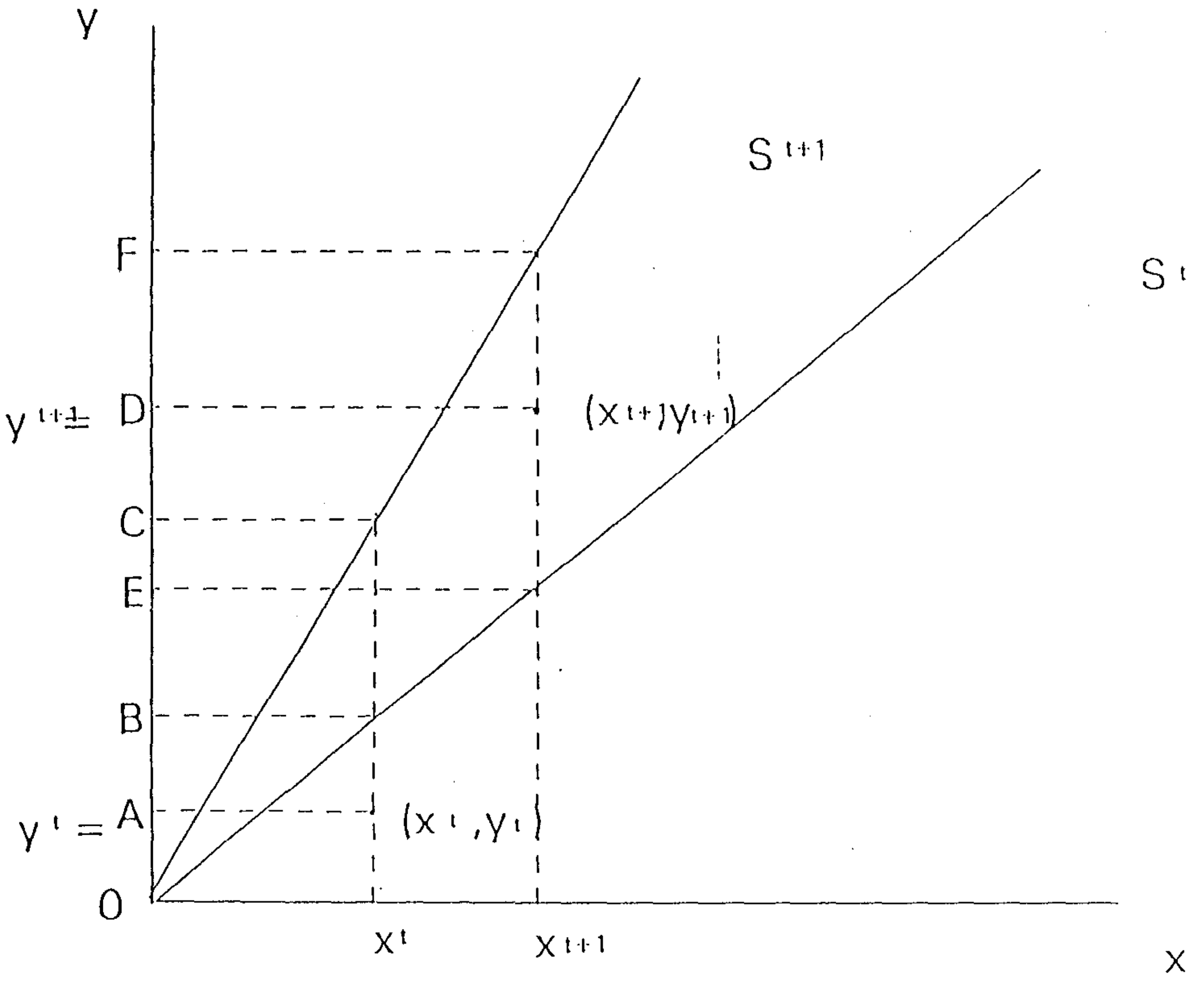

Figure 1. Output Distance Functions

$$D^{t}(x^{t+1},y^{t+1}) = inf\{\theta:\ (x^{t+1},\frac{y^{t+1}}{\theta}) \in S^{t}\}. \qquad (5)$$

The superscript of D indicates the reference period for the technology set being considered, whereas the superscripts of x and y indicate the time period of the observation. This distance function measures the maximum proportional change in outputs required to make (x^{t+1},y^{t+1}) feasible in relation to the technology at t. The one-input, one-output case is again illustrated in Figure 1. Note that the observed point (x^{t+1},y^{t+1}) is outside the set of feasible production in period t, i.e., technical change has occurred. The value of $D^{t}(x^{t+1},y^{t+1})$ is OD/OE, which is greater than one. Similarly, the distance function $D^{t+1}(x^{t+1},y^{t+1})$ is equal to $(OD/OF)<1$, indicating that relative to time t+1 technology, the observed point (x^{t+1},y^{t+1}) is feasible but inefficient. The Caves, Christensen, and Diewert version of the Malmquist productivity ratio is[6]

$$m^{t} = \frac{D^{t}(x^{t+1},y^{t+1})}{D^{t}(x^{t},y^{t})}. \qquad (6)$$

The reference technology for this ratio is S^{t} and, relative to that technology, m^{t} is the ratio of the efficiency of (x^{t+1},y^{t+1}) to the efficiency of (x^{t},y^{t}). If $m^{t} > 1$, productivity has increased between t and t+1. Alternatively, it is possible to define another Malmquist ratio using S^{t+1} as the reference technology:

$$m^{t+1} = \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t+1}(x^{t},y^{t})}. \qquad (7)$$

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[6] This is an output-based index, since it uses output-based distance functions. They also propose an input-based productivity index.

The Fare and Grosskopf (1990) Malmquist productivity change index is the geometric mean of the two indexes above,[7]

$$M(x^{t+1},y^{t+1},x^t,y^t) = \left[\frac{D^t(x^{t+1},y^{t+1})}{D^t(x^t,y^t)}\ \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t+1}(x^t,y^t)}\right]^{1/2}. \tag{8}$$

They note that this expression can be factored as

$$M(x^{t+1},y^{t+1},x^t,y^t) = \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)}\left[\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})}\ \frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)}\right]^{1/2}, \tag{9}$$

where the ratio outside the brackets measures the change in relative efficiency (i.e., the change in the distance of observed production from maximum feasible production) between years t and t+1,

$$Efficiency\ Change = \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)}, \tag{10}$$

while the bracketed term measures the shift in technology between the two periods evaluated at x^t and x^{t+1},

$$Technical\ Change = \left[\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})}\ \frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)}\right]^{1/2}. \tag{11}$$

Note that if $x^t = x^{t+1}$ and $y^t = y^{t+1}$, there has been no change in inputs and outputs between the periods, and the productivity change index (9) signals no change, M(.) = 1. In this case, the component measures of efficiency change and technical change are reciprocals, but not necessarily equal to one, because a change in efficiency might exactly offset a technological change.

The Malmquist index and its components for scalar output and input are illustrated in Figure 1, where technical advance has occurred in the sense that $S^t \subset S^{t+1}$. Note that $(x^t,y^t) \in S^t$ and

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[7] This is the form that Caves, Christensen, and Diewert use to prove that the Tornqvist is exact. This form is also typical of Fisher ideal indexes.

$(x^{t+1},y^{t+1}) \in S^{t+1}$; however, $(x^{t+1},y^{t+1}) \notin$ to S^t, so technical progress has occurred. In terms of the distances along the y-axis, the index becomes

$$M(x^{x+1},y^{x+1},x^t,y^t) = \frac{OD}{OF}\,\frac{OB}{OA}\left[\frac{\frac{OD}{OE}}{\frac{OD}{OF}}\;\frac{\frac{OA}{OB}}{\frac{OA}{OC}}\right]^{\frac{1}{2}} \tag{12}$$

$$= \frac{OD}{OF}\,\frac{OB}{OA}\left[\frac{OF}{OE}\;\frac{OC}{OB}\right]^{\frac{1}{2}}$$

and in terms of the production function, it is

$$M(x^{x+1},y^{x+1},x^t,y^t) = \frac{y^{t+1}/f^{t+1}(x^{t+1})}{y^t/f^t(x^t)}\left[\frac{f^{t+1}(x^t)}{f^t(x^t)}\;\frac{f^{t+1}(x^{t+1})}{f^t(x^{t+1})}\right]^{\frac{1}{2}}. \tag{13}$$

These expressions show that the two ratios inside the brackets measure shifts in technology at input levels x^t and x^{t+1}, respectively, and thus, that technological change is measured as the geometric mean of those two shifts.[8] The terms outside the brackets measure relative technical efficiency at t and t+1, indicating whether production is getting relatively closer to or farther from the frontier. A Malmquist index with value greater than unity reveals improved productivity. Likewise, efficiency and technical change indexes exceeding unity reflect gains in those components. Note, however, that net productivity growth may involve technological regression if gains in efficiency dominate that regression.

It is possible to calculate the Malmquist index in several ways. Caves, Christensen, and Diewert showed that if the distance functions are of translog form with identical second order terms, if $D^t(x^t,y^t)$ and $D^{t+1}(x^{t+1},y^{t+1})$ are each equal to unity (i.e., assuming technical efficiency), and if firms maximize profits, then (9) can be computed as the ratio of Tornqvist indexes of outputs and inputs.

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[8] This has the same form as the Fisher ideal index, but each component is the multiple output generalization of the technical change index defined by Diewert (1980).

Fare and Grosskopf show that given allocative efficiency, the Malmquist index may also be calculated as a ratio of Fisher ideal indexes. Alternatively, it is possible to parametrically or nonparametrically estimate the frontiers and then use these frontiers to obtain the Malmquist index for each observation.[9] The nonparametric techniques employ programming techniques to identify the technology frontier and measure the distance to that frontier for each observation in the sample.[10]

In this paper, we follow the linear programming approach of Fare, Grosskpof, and Lovell to calculate the Malmquist productivity change index. We assume that there are k = 1,..., K countries using n = 1,..., N inputs x_n^{kt} at each time period t = 1,..., T. These inputs are used to produce m = 1,..., M outputs y_m^{kt}.

The technology set in period t is constructed from the data as

$$\begin{aligned} S^t = \{(x^t, y^t) :\ & y_m^t \leq \sum_{k=1}^{K} z^{kt} y_m^{kt}, && m = 1, \ldots, M, \\ & \sum_{k=1}^{K} z^{kt} x_n^{kt} \leq x_n^t, && n = 1, \ldots, N, \\ & z^{kt} \geq 0, && k = 1, \ldots, K\}, \end{aligned} \tag{14}$$

which is a cone exhibiting constant returns to scale and strong disposability of inputs and outputs. Less restrictive technologies are allowed by including restrictions that relax the constant returns to scale requirement. To construct a technology set characterized by nonincreasing returns to scale, we add the restriction

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[9] These would include econometric estimation of deterministic or stochastic frontiers, as well as the parametric linear programming approach.

[10] This is also referred to as data envelopment analysis or activity analysis.

$$\sum_{k=1}^{K} z^{kt} \le 1, \tag{15}$$

for all k = 1,...,K; for a variable returns technology, we replace it with

$$\sum_{k=1}^{K} z^{kt} = 1, \tag{16}$$

and for a Koopmans type technology, we use

$$z^{kt} = 1. \tag{17}$$

z^{kt} is an intensity variable indicating the intensity at which a particular activity (in this case, each country is an activity) is employed in constructing the frontier of the technology set.[11]

To calculate the productivity of country k' between t and t+1, we need to solve four different linear programming problems: $D^t(x^t,y^t)$, $D^{t+1}(x^t,y^t)$, $D^t(x^{t+1},y^{t+1})$, and $D^{t+1}(x^{t+1},y^{t+1})$. For each k'= 1,...,K, we first compute

$$\begin{aligned} &\left[D^t(x^{k't},y^{k't})\right]^{-1} = \max \theta^{k'} \\ &s.t. \quad \theta^{k'} y_m^{k't} \le \sum_{k=1}^{K} z^{kt} y_m^{kt}, \qquad m = 1,\ldots,M, \\ &\sum_{k=1}^{K} z^{kt} x_n^{kt} \le x_n^{k't}, \qquad n = 1,\ldots,N, \\ &z^{kt} \ge 0, \qquad k = 1,\ldots,K. \end{aligned} \tag{18}$$

Since by construction of this problem all observations are feasible (or equivalently, an element of S^t), $D^t(x^{k't},y^{k't}) \ge 1$. The computation of $D^{t+1}(x^{k't+1},y^{k't+1})$ is exactly like (18), with t+1 substituted for t.

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[11] Imposing constant returns to scale is sufficient to guarantee that the solutions exist to the linear programming problems used to calculate the mixed period distance functions. Under variable returns to scale, if technical progress occurs, observations in period t may not be feasible in period t+1.

The other two distance functions used to construct the Malmquist index require information from two periods. The first of these is computed from observation k' as

$$\begin{aligned} &\left[D^{t}(x^{k't+1}, y^{k't+1})\right]^{-1} = \max \theta^{k'} \\ s.t. \quad &\theta^{k'} y_m^{k't+1} \leq \sum_{k=1}^{K} z^{kt} y_m^{kt}, \quad m = 1, \ldots, M, \\ &\sum_{k=1}^{K} z^{kt} x_n^{kt} \leq x_n^{k't+1}, \quad n = 1, \ldots, N, \\ &z^{kt} \geq 0, \quad k = 1, \ldots, K. \end{aligned} \tag{19}$$

The reference technologies in (18) and (19) are the same and are formed from observations at t. Equation (18) evaluates observations from time t, while (19) evaluates observations from time t+1, both relative to technology in t.

The last distance function component of the index, namely $D^{t+1}(x^{k't}, y^{k't})$, is also a mixed period problem and may be calculated using (19) by substituting the t observations for the t+1.

Data and Results

This empirical study examines productivity changes in the agricultural sectors of eighteen LDCs previously examined by using a modified aggregate agricultural production function. This set of countries is of interest because it includes a wide range of geographic locations, income levels, and agricultural policies. A data set of consistently measured, quantity-based variables is available for these countries over the period 1961 to 1985 (Elisiana et al., 1993), but the lack of price data for inputs has precluded using Tornqvist-type indexes to examine productivity changes. Not only is the Malmquist index feasible, but it provides nonparametric estimates of productivity change that can be compared with those implied by our previous parametric study.

The data consist of one output (aggregate agricultural output) and five inputs (land, labor, fertilizer, machinery, and livestock). These are the same input variables as those in the Hayami and Ruttan series of studies.[12] The more specific definitions of these variables are:

Output (y): Value of agricultural production in millions of 1980 "international" dollars.[13]

Land (x_1): Thousands of hectares of arable and permanent cropland and permanent pastures.

Livestock (x_2): Number of cow-equivalent livestock units as defined by Hayami and Ruttan.

Machinery (x_3): Agricultural tractors and garden tractors (FAO) in thousands of horsepower units, aggregated according to Hayami and Ruttan's procedures.

Fertilizer (x_4): The sum of nitrogen, potash, and phosphate content of various fertilizers consumed, measured in thousands of metric tons in nutrient units.

Labor (x_5): Thousands of participants in the economically active population in agriculture.[14]

The countries included are presented in Table 1, along with the growth rate of agricultural output for the period and the degree of taxation of the agricultural sector measured by nominal protection coefficients.

For each successive pair of years, we calculate the four required distance functions by solving the linear programming programs of equations (18) and (19). A total of 2,592 such linear programming problems were solved, under the restrictions of constant returns to scale and, alternately, increasing returns to scale. These distances are used to calculate the Malmquist

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[12] See Hayami and Ruttan (1970, 1985).

[13] "International" dollars are obtained by the United Nations Food and Agricultural Organization (FAO) using the Geary-Khamis (see Elisiana et. al., 1993) price index with the purpose of aggregating agricultural products for international comparison. The international average prices of agricultural commodities are determined simultaneously with the exchange rates of the national currencies in such a manner that the calculated exchange rates equalize the purchasing power of national currencies with respect to the defined groups of commodities.

[14] This measure of the agricultural labor input, also used in the other cross-country studies cited, is a crude one, uncorrected for hours worked and labor quality (education, experience, age, etc.).

Table 1. Agricultural Protection and Growth, 18 countries

Countries	Years	NPR[a] (Percent)	Production growth[b] Percent)
Argentina	1961-84	-40	2.1
Brazil	1969-83	-13	3.8
Chile	1961-83	-25	1.8
Colombia	1961-83	-33	2.8
Dominican Republic	1966-85	-40	2.8
Egypt	1964-84	-53	2.7
Ghana	1958-76	-24	1.1
Ivory Coast	1961-82	-53	5.2
Korea	1961-84	16	4.2
Malaysia	1961-83	-18	3.3
Morocco	1963-84	-34	4.0
Pakistan	1961-84	-47	3.8
Philippines	1961-82	-32	3.8
Portugal	1961-83	-18	-0.1
Sri Lanka	1961-85	-49	2.1
Thailand	1961-84	-41	4.7
Turkey	1961-83	-36	2.8
Zambia	1966-84	-53	2.2

[a] NPR= nominal protection rate= (domestic price/border price)-1, adjusted for exchange rate misalignment and protection to industry (Valdes, 1991).

[b] calculated from FAO production indexes.

productivity change index, the efficiency change index, and the technical change index using equations 9, 10, and 11 for each successive pair of years for each country. Although all countries are presumed to share a common technology set, their rates of technical change can differ because each country is located near a different point on the frontier and the technology frontier may not shift uniformly. Rates of efficiency change might differ because some countries are changing policies, market incentives, etc. Country-to-country differences in the absolute level of Farrell efficiency, $1/D^t(x^t,y^t)$, might arise because of fundamental differences in economic structure (policies, market incentives, human capital, etc), or because of systematic errors in measuring the variables. If, for example, countries A and B are identical in all respects except that a hectare of land in A is twice as productive as in B, then country B will appear to be Farrell inefficient. Year-to-year changes in efficiency, however, must be due to some other cause, as suggested.

Table 2 reports Farrell efficiency ($1/D^t(x^t,y^t)$, or OB/OA in Figure 1) for the countries in the sample for selected years. Values of unity imply that the country is on the frontier in the associated year. Values exceeding unity imply that the country is below the frontier or technically inefficient. For the years reported in the table, Argentina, Egypt, and Korea consistently determine the frontier.

Instead of presenting the disaggregated results for each country and year, we show the average index values for each country over the entire 1961 to 1985 period, as well as the average for each country in the 1961 to 1973 and the 1973 to 1985 subperiods (see Table 3). Looking first at the bottom of the table, we see that on average for all countries over the entire period, productivity decreased about 1 percent annually. The reduction was due to a regression of the technology frontier, that is, of the standard of productivity reflected by the most productive countries.

Turning to the country-by-country results, we note that Turkey has the highest average productivity growth rate in the sample for 1961 to 1985, because of improvements in both efficiency and technical change. In contrast, Korea's overall performance was surprisingly below average.

Table 2. Farrell efficiency in selected years, by country

Country	1961	1970	1980	1984
Argentina	1.00	1.00	1.00	1.00
Brazil	7.55	7.52	6.87	6.35
Chile	8.89	7.53	7.01	6.65
Colombia	8.25	5.77	5.09	4.83
Dominican Rep.	3.53	2.34	2.08	1.57
Egypt	1.00	1.00	1.00	1.00
Ghana	1.44	2.11	3.45	2.62
Ivory Coast	1.00	1.30	1.63	1.55
Korea	1.00	1.00	1.00	1.00
Malaysia	1.52	1.19	1.05	1.19
Morocco	9.20	6.05	8.98	6.37
Pakistan	2.01	3.01	3.09	2.64
Philippines	2.18	1.92	1.49	1.53
Portugal	1.64	1.41	1.72	1.60
Sri Lanka	1.78	2.05	1.86	1.83
Thailand	1.00	1.41	2.07	1.97
Turkey	4.55	3.89	3.03	2.79
Zambia	14.59	11.36	11.83	9.09

Table 3. Measured rates of productivity change and its components (under constant returns to scale)

	1961-85			1961-73			1974-85		
Country	Malmquist	Technical Change	Technical Efficiency	Malmquist	Technical Change	Technical Efficiency	Malmquist	Technical Change	Technical Efficiency
Argentina	0.955	0.955	1.000	0.940	0.940	1.000	0.970	0.970	1.000
Brazil	0.997	0.984	1.014	0.964	0.968	0.997	1.031	1.001	1.030
Chile	1.013	0.997	1.016	0.997	0.990	1.007	1.029	1.004	1.025
Colombia	1.001	0.979	1.025	1.002	0.967	1.037	0.999	0.992	1.013
Dominican Rep.	1.009	0.977	1.036	1.014	0.961	1.055	1.004	0.992	1.017
Egypt	1.010	1.010	1.000	1.019	1.019	1.000	1.001	1.001	1.000
Ghana	0.957	0.977	0.982	0.931	0.961	0.968	0.984	0.992	0.996
Ivory Coast	0.950	0.954	0.997	0.892	0.914	0.977	1.007	0.995	1.017
Korea	0.932	0.932	1.000	0.865	0.865	1.000	1.000	1.000	1.000
Malaysia	1.006	0.993	1.013	1.025	0.989	1.037	0.987	0.997	0.989
Morocco	1.016	0.984	1.032	0.989	0.964	1.030	1.042	1.005	1.034
Pakistan	0.968	0.978	0.991	0.924	0.957	0.967	1.013	0.998	1.014
Philippines	0.998	0.981	1.017	0.987	0.966	1.021	1.010	0.996	1.014
Portugal	1.014	1.006	1.008	1.020	1.008	1.012	1.008	1.004	1.004
Sri Lanka	1.005	1.003	1.002	0.993	1.010	0.985	1.016	0.996	1.020
Thailand	0.942	0.965	0.976	0.887	0.932	0.953	0.997	0.999	0.998
Turkey	1.024	1.001	1.023	1.010	1.000	1.010	1.038	1.002	1.036
Zambia	1.008	0.977	1.036	1.003	0.962	1.045	1.014	0.992	1.027
All	0.989	0.981	1.009	0.970	0.965	1.006	1.008	0.997	1.013

Zambia and the Dominican Republic were especially good at moving towards the frontier (catching up), showing a positive overall performance even though their rates of technical change have been negative.

Next, we turn to the results broken down into the pre- and post- oil shock periods. We note that agricultural productivity declined at an average annual rate of 3 percent during 1961 to 1973, with this trend being reversed in the 1974 to 1985 period. Deterioration in average agricultural productivity during the 1960s was due to a regression of the technology frontier that was to some extent offset by an improvement in efficiency. The results by country indicate the highest productivity gains for Egypt, due mainly to technological gains, with Thailand at the opposite end. During this period, most countries show deteriorating technical change in their agricultural sectors. During the 1970s and 1980s, average productivity in agriculture improved at a rate close to 1 percent annually, driven mainly by improved efficiency. Technical change growth rates also improved relative to the earlier period. The increase in efficiency may reflect the catching-up effect of late adopters of green revolution innovations. Such a lag might occur because of the need to adapt techniques introduced by the green revolution to the geoclimatic and economic conditions of each country. During the later period, Morocco showed the greatest overall productivity gains and the greatest technical change. The poorest performer was Ghana, with a productivity decline of 1.6 percent annually.

Grouping these countries according to per capita GNP, they fall into three categories: upper middle income countries, lower middle income countries, and low income countries.[15] Table 4 shows that simple average agricultural productivity was declining in all groups. Upper middle income countries showed the greatest drop (1.9 percent a year), followed by the low income countries (1.5

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[15] According to the World Bank classification, GNP per capita in 1986 dollars is higher than $1800 for upper middle income countries, between $450 and $1800 for lower middle income countries, and lower than $450 for low income countries.

Table 4. Average rate of agricultural productivity change by GNP per capita classification, 1961-85

Countries	Malmquist Index
Upper middle income[1]	0.981
Lower middle income[2]	0.996
Low income[3]	0.985

[1] Argentina, Brazil, Korea, Malaysia, Portugal
[2] Chile, Colombia, Dominican Republic, Egypt, Ivory Coast, Morocco, Phillipines, Thailand, Turkey
[3] Ghana, Pakistan, Sri Lanka, Zambia

Table 5. Average rate of agricultural productivity change by level of taxation of the sector, 1961-85

Countries	Malmquist Index
Extremely taxed[1] (more than 40 percent)	0.982
Highly taxed[2] (30 percent to 39 percent)	0.991
Taxed[3] (0 to 29 percent)	1.007

[1] Argentina, Dominican Republic, Egypt, Ivory Coast, Pakistan, Sri Lanka, Thailand, Zambia
[2] Colombia, Morocco, Phillipines, Turkey
[3] Brazil, Chile, Ghana, Malaysia, Portugal

percent a year). Lower middle income countries were the best performers with average agricultural productivity remaining almost constant during the period.

Table 5 groups the countries according to the level of discrimination against the agricultural sector as measured by nominal protection coefficients. These protection coefficients are obtained from Valdes (1991), and they measure the gap between domestic and border prices after accounting for implicit protection to the nonagricultural sector and exchange rate policies. In countries with more than 40 percent taxation of the agricultural sector, agricultural productivity decreases at a pace of 1.8 percent a year. Productivity decreases at a slower rate, 0.9 percent a year, in countries with taxes ranging from 30 to 39 percent, and the rate of productivity change is positive for those countries in which agricultural prices are not so severely depressed. The latter group of countries shows an average productivity increase of 0.7 percent. This figure coincides with the one calculated by Fare, Grosskpof, Norris, and Zhang (1992) for the entire economies of a group of OECD countries during the same period of time.

Countries that are Farrell efficient are not necessarily the ones that are shifting the frontier. For the innovating countries, it must also be true that $D^t(x^{t+1},y^{t+1}) > 1$, i.e., the frontier at that point must be shifting. An examination of year-by-year results showed that for those years in which Argentina's rate of technical change was positive, this country contributed to shifts in the frontier. Korea and Egypt had an important role in shifting the frontier during the 1970s and 1980s.

Further evidence concerning technological change is presented in Table 6. This table contains a disaggregation of the technical change component of the Malmquist index. The first column contains the shift in the frontier evaluated at period t

$$TC1 = \frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)} . \qquad \textbf{(20)}$$

The second is the shift in the frontier evaluated using period t+1 data

Table 6. Comparison of Malmquist, Caves-Christensen-Diewert, and Cobb Douglas Indexes of Productivity Change; 1961-85

Country	Malmquist	TC1	TC2	m^t	m^{t+1}	Cobb Douglas
Argentina	0.955	0.860	1.064	1.064	0.860	0.994
Brazil	0.997	0.984	0.985	0.998	0.997	0.973
Chile	1.013	0.997	0.997	1.013	1.013	1.008
Colombia	1.001	0.979	0.980	1.001	1.001	1.015
Dominican Republic	1.009	0.977	0.977	1.009	1.009	0.989
Egypt	1.010	0.984	1.038	1.038	0.984	0.997
Ghana	0.957	0.975	0.979	0.960	0.955	0.992
Ivory Coast	0.950	0.941	0.972	0.967	0.937	0.986
Korea	0.932	0.831	1.054	1.054	0.831	0.957
Malaysia	1.006	0.991	0.995	1.008	1.004	0.984
Morocco	1.016	0.983	0.986	1.017	1.014	1.010
Pakistan	0.968	0.976	0.979	0.969	0.967	0.971
Philippines	0.998	0.982	0.981	0.998	0.998	1.001
Portugal	1.014	1.006	1.006	1.014	1.014	0.974
Sri Lanka	1.005	1.003	1.003	1.005	1.005	0.988
Thailand	0.942	0.957	0.974	0.951	0.934	0.963
Turkey	1.024	1.001	1.001	1.024	1.024	0.976
Zambia	1.008	0.976	0.978	1.009	1.008	0.977
All	0.989	0.967	0.997	1.005	0.975	0.986

$$TC2 = \frac{D^{t}(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} . \qquad (21)$$

If technical change were scale and input neutral, these two values would have to be the same every year. Inspection of the year-to-year results showed that TC1 and TC2 are very close for most countries and years except for Argentina, Egypt, Ivory Coast, and Thailand. This suggests either constant input mix and scale by country or neutral shifts of the frontier.

The Malmquist productivity index of equation (9) does not satisfy the circular test for index numbers. This means that the index is not path independent, i.e., calculating the index between years 1961 and 1985 and solving for the appropriate root would not necessarily give the same results as those reported in Table 3. Also in Table 6, we include Caves, Christensen, and Diewert's version of the Malmquist ratios m^{t} and m^{t+1} (defined in equations (6) and (7)) because these do satisfy the circular test. Note that the Malmquist index is bounded by these two indexes.

As a final point of comparison, we present results from an econometric estimation of total factor productivity growth. Although this approach has the advantage of allowing for measurement error, it may introduce specification error. The metaproduction function was parametrized and estimated with a variable coefficient Cobb-Douglas specification. The portion of the variation in output not explained by the traditional inputs, the Solow residual, is usually interpreted as productivity change. In this particular study, the parameters of the production function were specified as dependent on a set of technology-changing variables that included expected output and input prices, research stock, schooling, and quality of land. This specification allowed explanation of a portion of the residual.[16] The last column in Table 6 presents the average productivity change indexes derived from this study, including both the explained and the residual portions. Average productivity change was found to decline at the rate of 1.4 percent, compared with the 1.1 percent decline measured with

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[16] For more details on this approach, see Fulginiti and Perrin (1993).

the Malmquist approach of the present study. On a country-by-country basis, the econometric approach revealed only four of the 18 countries with positive rates of productivity growth (Chile, Colombia, Morocco, and Philippines) whereas the Malmquist approach measured ten positive rates. Where the two approaches indicated contrary directions of growth, however, the measured rates of change were very near zero. In addition, differences could arise because the Malmquist index is based on data for the 1961 to 1985 period, whereas the production function approach was based on shorter time periods for most countries.

The Malmquist index results just discussed were based on the assumption that technology satisfies constant returns to scale. We also calculated the Malmquist productivity index and its components under the assumption of variable returns to scale. A summary of the results is displayed in Table 7. (For some countries, in some years, the index could not be computed because the mixed period distance functions did not have a solution. This can occur when there is technical change and the observation from period t, for example, is not feasible in period t+1.) Even though the data are more closely enveloped under the assumption of variable returns to scale, the overall averages are very similar to those in Table 3. Portugal shows the greatest average agricultural productivity increases, resulting mainly from technical change, while Zambia has the lowest rate.

Conclusions

This paper has examined changes in agricultural productivity in 18 LDC's over the period 1961 to 1985. Because input price series are not available, we used the nonparametric, quantity-based Malmquist index approach and contrasted the results with our previous Cobb-Douglas (C-D) production function approach. In average terms, the Malmquist constant-returns-to-scale (crs) approach indicated that agricultural productivity in these countries has been declining at the rate of about 1.1 percent per year. This is slightly less than the 1.4 percent annual decline indicated both by our previous production function approach and by a variable-returns-to-scale (vrs) Malmquist index.

Table 7. Measured rates of productivity change and its components (under variable returns to scale)

	1961-85			1961-73			1973-85		
Country	Malmquist	Technical Change	Technical Efficiency	Malmquist	Technical Change	Technical Efficiency	Malmquist	Technical Change	Technical Efficiency
Argentina	0.957	0.957	1.000	0.934	0.934	1.000	0.979	0.979	1.000
Brazil	1.014	0.987	1.027	0.982	0.974	1.009	1.045	1.000	1.045
Chile	1.089	1.009	1.098	1.098	0.937	1.197	1.081	1.081	1.000
Colombia	1.000	0.978	1.026	1.003	0.966	1.039	0.998	0.991	1.012
Dominican Rep.	1.009	1.009	1.000	1.010	1.010	1.000	1.007	1.007	1.000
Egypt	0.991	0.991	1.000	1.000	1.000	1.000	0.982	0.982	1.000
Ghana	0.965	0.965	1.000	0.922	0.922	1.000	1.004	1.004	1.000
Ivory Coast	0.923	0.923	1.000	0.952	0.952	1.000	0.895	0.895	1.000
Korea	0.960	0.960	1.000	0.957	0.957	1.000	0.962	0.962	1.000
Malaysia	0.962	0.962	1.000	0.974	0.974	1.000	0.951	0.951	1.000
Morocco	1.012	0.978	1.035	0.989	0.960	1.032	1.036	0.997	1.038
Pakistan	0.974	0.980	0.994	0.922	0.957	0.965	1.025	1.003	1.022
Philippines	0.996	0.980	1.017	0.987	0.969	1.019	1.005	0.990	1.015
Portugal	1.031	1.031	1.000	1.016	1.016	1.001	1.045	1.045	1.000
Sri Lanka	1.006	1.006	1.000	0.972	0.972	1.000	1.039	1.039	1.000
Thailand	0.938	0.960	0.977	0.883	0.924	0.957	0.993	0.996	0.997
Turkey	1.026	1.002	1.025	1.013	1.000	1.013	1.040	1.003	1.036
Zambia	0.907	0.991	1.101	0.926	0.977	1.275	0.888	1.006	0.927
All	0.986	0.988	0.998	0.970	0.976	1.028	1.002	0.999	1.005

All three of these measures indicated that average productivity declined, but this was true for only eight of the 18 individual countries using the crs Malmquist, and for ten using the C-D and the vrs Malmquist. Although the average result from the crs Malmquist indicated better productivity performance than did the other two measures, that result was only modestly consistent from country to country. The crs Malmquist showed better performance than the C-D measure in ten of 18 cases and better than the vrs Malmquist measure in eight of 18 cases. All three measures concurred in showing negative productivity rates for Argentina, Ghana, Ivory Coast, Korea, Pakistan, and Thailand. All three showed positive rates only for Chile, Colombia, and Morocco.

The relative consistency of these measures from country to country, over the whole time period, is thus not particularly impressive. When the measures are estimated separately for the pre- and post-oil shock periods, however, the two Malmquist measures are much more consistent with one another, and they agree in sign for 15 countries in the early period, and for 13 in the late period. They both indicate an average loss of productivity in the early period at the rate of 3 percent, and an average increase of less than 1 percent in the late period. Thus, we conclude that the results of this study, considered on the whole, are reasonably convincing evidence that productivity was in fact declining in much of LDC agriculture, a process that may have been reversed during the late period. This is a somewhat surprising result in view of fact that the green revolution seed varieties had been adopted during the early period. These results suggest that if the green revolution was the main engine of productivity change during this time, the productivity effects were not fully realized for some years after adoption.

Our results should be interpreted with caution. The data are highly aggregated and the sample of countries is arbitrary. (They are those chosen by a World Bank project to study agricultural taxation and for which we were able to obtain additional data.) The proxies used for land, capital, and labor are not adjusted for quality or vintage. We expect that inclusion of resources devoted to agricultural research and development as an additional input and consideration of input quality adjustments could provide additional information.

A full exploration of why these productivity patterns have emerged is beyond the scope of the present study, but the study offers some insights, nonetheless. Although the analysis here showed no strong relationship between the rate of productivity and per capita GNP, there is a clear relationship between the rate of agricultural taxation and productivity measures. Those countries that tax agriculture most heavily had the most negative rates of productivity change, whereas those with low taxation rates had slightly positive productivity gains. These results corroborate our previous parametric study of the same countries, where we estimated that a 10 percent increase in the level of taxation resulted in a 1.3 percent reduction in productivity.

The partitioning of productivity into technical change and technical efficiency components indicated that the rate of change in average technical efficiency has been quite small but positive, suggesting that, on the average, the countries inside the production frontier are gaining slightly on those at the frontier. Average changes in productivity were thus associated with technical change, that being negative at the rate of 3 percent per year in the early period and near zero (though very slightly negative) in the later period. This result would seem to conflict with the notion that green revolution technology has been shifting the production frontier outward for LDC agriculture. An interpretation that seems more plausible to us is that the role of the green revolution was to make the high-input technology that had already been available to some of these countries accessible to a wider variety of locations. Using this explanation, much of the productivity progress would appear to be improvements in technological efficiency ("catching-up"), rather than technical change.

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