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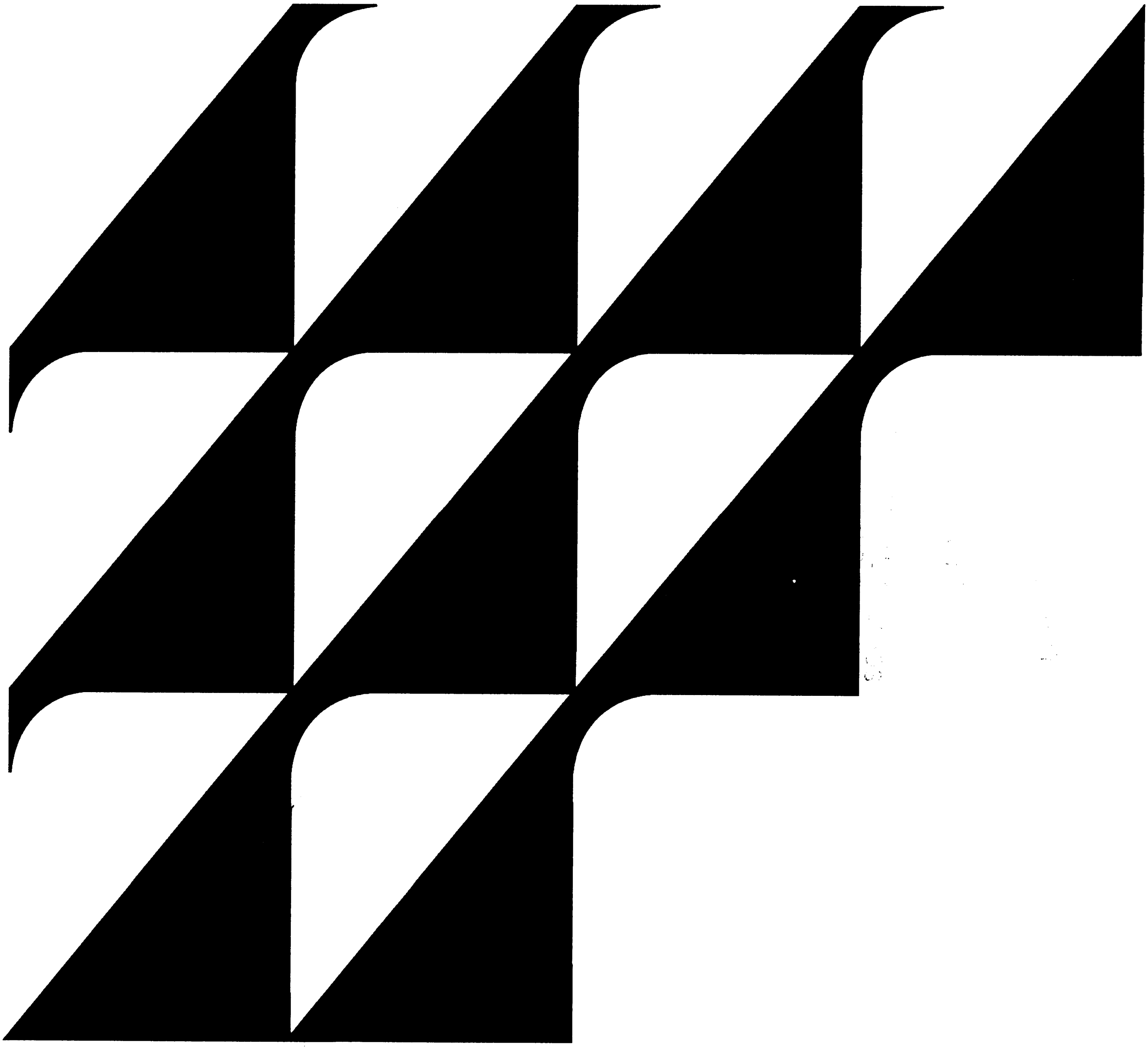
Using Data Envelopment Analysis To Measure International Agricultural Efficiency and Productivity

Carlos A. Arnade



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Abstract

Numerous methods for measuring multifactor productivity have been used by economists. This report uses a recently developed approach, data envelopment analysis, to measure productivity. This method can be used not only to calculate productivity changes but also to divide productivity measures into indices that measure technical efficiency and technical change. Technical efficiency measures the efficiency with which resources are used. Technical change measures changes in output arising from improved technology. In this report, relative efficiency measures and multifactor productivity measures are calculated for the agricultural sectors of 77 countries. Analysis shows that multifactor productivity of the agricultural sector has risen in most developed countries and fallen in many developing countries over the past two decades. Adoption of input-intensive technology by developing countries may have offset productivity gains from improved yields and improved labor productivity.

Keywords: Productivity, efficiency, technical change, data envelopment analysis

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Contents

Summary

Agricultural productivity gains from 1961 to 1987 were greatest in Northern European countries. Productivity growth in the United States was significantly below the European average and that of Australia and New Zealand.

Technical efficiency and productivity measures were calculated over 1961-87 for the agricultural sectors of 77 countries. Countries were classified into one of four technological categories--advanced, middle, low, and Asian rice--which served as the basis for measuring technical efficiency. Technical efficiency measures the efficiency with which resources are used. A country is inefficient if inputs can be reduced without reducing output. Agriculture in most developed countries was shown to be efficient.

Previous studies have centered on calculating productivity for developed nations. Single-factor productivity has been used to analyze the changing production technology in developing countries. There have been few studies that measure multifactor productivity in developing nations. Agricultural productivity declined in many developing countries, where newly adopted technology led to immense increases in fertilizer and machine use without much decline in agricultural labor use.

Although agriculture in many Latin American countries was technically efficient, most countries, on average, experienced declines in multifactor productivity. Agriculture in most Asian countries was technically efficient but, with the exception of Japan, Malaysia, North Korea, and Taiwan, these countries, on average, also experienced declines in agricultural productivity. Of the African countries where data were available, only Nigeria and Zaire were efficient. Multifactor productivity rose consistently only in Zimbabwe, though productivity rose for a significant number of years in Sudan. Of the Mideast countries, Israel, Jordan, and Turkey were efficient. Productivity rose significantly in Iraq and Egypt and to a lesser degree in Israel.

Declines in multifactor productivity may result from inefficiencies that occur, in the short run, when new and unfamiliar technology is adopted. The technical efficiency and technical change indices of many countries, including developed countries such as England, show declines in efficiency during periods of increased technical change. Unfamiliarity with new technology could make producers less efficient. For example, when a technology is new, producers may be less willing to substitute one input for another as input prices change.

Long-term declines in multifactor productivity could also indicate that a country has adopted a technology that does not suit its technical needs. Many countries whose factor endowments favor a labor-intensive technology adopted a technology developed in countries with a scarcity of agricultural labor. Input subsidies to encourage adoption of new technology may also have encouraged waste of inputs.

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Carlos A. Arnade

Introduction

Since Solow's paper on U.S. aggregate growth (1956), productivity measurement has played an important role in applied economics (*35*).[1] Theorists have improved their understanding of the relationship between productivity and other economic variables while applied economists have improved their understanding of the components of productivity growth. This improved understanding has coincided with better data processing capabilities. Therefore, numerous methodologies for measuring productivity have developed over the last three decades.

This report enlists data envelopment analysis (DEA) to measure technical efficiency, technical change, and multifactor productivity. A technical efficiency index measures the efficiency with which inputs are utilized in the production of outputs. DEA has been widely used to calculate and compare technical efficiency across individual firms. This report applies DEA to international agricultural data to compare technical efficiency and productivity of each country's agricultural sector. Application of DEA to aggregate data is analogous to estimation of aggregate production functions or aggregate supply functions.[2]

International agricultural productivity has been a prominent issue in the past few decades. Agricultural productivity growth has been related to countries' agricultural competitiveness, has been used to measure the success of the "Green Revolution," and has been cited as the source of low prices of specific agricultural commodities. Therefore, the measures in this report should serve a variety of interests.

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[1] Italicized numbers in parentheses refer to sources listed in the References section.

[2] Economic texts often review firm-level production functions and firm-level supply functions. However, in practice, economists often estimate functions that represent an aggregate of firms within a country. Similarly, DEA can be applied to data representing an aggregate of firms.

Traditional Approaches to Measuring Productivity

In traditional approaches to multifactor productivity measurement, economists calculated multifactor productivity by estimating aggregate production functions (*2*, *37*). This approach was fraught with aggregation assumptions, was limited by the chosen functional forms, and often gave divergent estimates of productivity. Later, productivity was calculated indirectly by estimating cost functions, which imposed more restrictions on econometric parameters and reduced the number of parameters to be estimated (*2*, *11*).[3]

Production was also calculated using indices. When using an index approach, economists moved from measuring single-factor productivity to measuring multifactor productivity with Laspeyres, Paasche, or Fisher indices. These indices allowed prices to serve as weights on inputs and outputs but implied a highly restrictive fixed-proportions production technology. Later, the Tornqvist-Theil index was adapted for productivity measurement (*2, 6, 11, 29*).[4] This index used the first-order conditions of profit maximization to determine the weights on inputs and outputs and imposed few restrictions on production technology.

Economists have expressed a keen interest in uncovering the sources of productivity growth. Using a cost function, Denny and others divided productivity growth in the Canadian telecommunications industry into growth originating from improvements in efficiency, growth originating from technical change, and growth originating from changing the scale of production (*21*). Capalbo and Shoemaker each used a cost function and a Tornqvist index to divide productivity growth of U.S. agriculture into similar components (*9, 34*). Arnade used a cost function to divide productivity growth of Brazilian agriculture and relate the efficiency and technical change components of productivity growth to Brazilian subsidies (*3*).

Economists are familiar with the concepts of economies of scale and technical change. In contrast, the meaning of production efficiency has been less precise and its influence on productivity less well understood. One type of production inefficiency has been identified as a technical inefficiency. Technical inefficiencies arise when a firm does not operate on the boundary of its production function. Recently, economists have measured technical inefficiencies using DEA and have demonstrated that these inefficiencies are widespread (*33*).

Computation of technical inefficiency has led to several extensions. Caves and others developed a productivity index, the Malmquist index, composed of different measures of technical efficiency (*10*). Fare and others defined a generalized Malmquist productivity index that combines a technical efficiency index with a technical change index (*24*). Chambers and others provided a framework that relates indices composed of other technical efficiency indices to many well-known indices (*12*). They also demonstrated the relationship between technical inefficiencies and Debreu's concept of a distance function (*20*).

This report provides estimates of technical efficiency and productivity of the agricultural sector for 77 countries. An empirical section provides worldwide estimates of indices that measure the efficiency of agricultural resource use, the impact of technical change on agricultural productivity, and changes in multifactor productivity for the agricultural sector.

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[3] Parameter restrictions permitted estimation of more general functions which, in turn, imposed fewer restrictions on technology.

[4] The Tornqvist index is a discrete approximation to a Divisia index and is exact to a second-order translog production function. A second-order translog production function approximates a wide variety of functional forms.

Indices

Caves and others developed the Malmquist productivity index using distance functions (*10*). Distance functions, proposed by Debreu and further developed by Malmquist, become meaningful when production technology is described by the input requirement set:

$$L(y) \;=\; [x \;\varepsilon\; R_+^n\text{: } x \text{ can produce } y],\; y \;\varepsilon\; R_+^m \tag{1}$$

where x is a non-negative input vector x = $(x_1,x_2....x_n)$ and y is a non-negative output vector y = $(y_1,y_2....y_m)$. Assumptions regarding the input requirement set are listed in Fare (*23*). For any x and y belonging to the set of real numbers, the distance function is defined as:

$$\lambda^{*}{=}D(y{,}x) \;=\; Max\;\left[\lambda \;{:}\frac{x}{\lambda} \;\varepsilon\; L(y)\right] \tag{2}$$

where λ^* stands for the optimal value of a shrinkage parameter. Suppose the input vector x is used to produce the output vector y. The value of the parameter at λ^* represents the largest number that can be divided into the input vector x and produce the same output. If inputs are not overused (or wasted), this number will be one. When inputs are overused, this parameter will be greater than one.

In formal terms, the distance function computes the largest possible contraction of the vector x under the condition that the vector x/λ (equivalent to x/D(y,x)) remain in the input requirement set L(y). When there are two inputs and one output, the distance function radially shrinks an input vector (whose length represents a particular level of inputs) to a point that lies on an isoquant.

For example, in figure 1, the boundary of the input requirement set is represented by the isoquant I. Point A, interior to the isoquant, represents an observed input vector. The length of this vector represents the amount of x_1 and x_2 used to produce the level of output represented by isoquant I. Point B represents the observed input vector divided by the distance function. The length of the input vector at B represents a reduced amount of x_1 and x_2. Point B lies on the isoquant or the boundary of the input requirement set. Reducing inputs from point A to point B does not reduce the amount of output produced. The value of the function D(y,x) represents the largest number that can be divided into the elements of the vector x and yet still produce the output vector y (*12, 16, 17, 31*).

Farrell describes two categories of inefficiency, one of which is related to the distance function D(y,x) (*28*). A technically inefficient point uses more inputs to produce the same level of output than points represented by an isoquant. For example, in figure 2, point A is technically inefficient relative to point B or any other point on the isoquant I. In contrast, an allocatively inefficient point lies on an isoquant, but given a set of relative input prices, does not represent the optimal input mix. For example, assume producers minimize costs. In figure 2, when line Co represents the cost line, point AA is allocatively inefficient.[5] The distance function measures the degree of technical inefficiency.[6]

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[5] See Chavas and Aliber (*14*) for a discussion on how to measure allocative inefficiency. Data are not currently available to measure allocative inefficiency on an international basis.

[6] The inefficiency often discussed in the trade or policy literature refers to market inefficiencies. Even when there are market inefficiencies, producers remain on the boundaries of their input requirement sets and consumers on the boundaries of their preference sets, though distorted prices may lead producers and consumers to be at the wrong point on their boundaries.

Figure 1

An input distance function

Point A is technically inefficient. Point B is efficient. The distance function measures the distance between these two points.

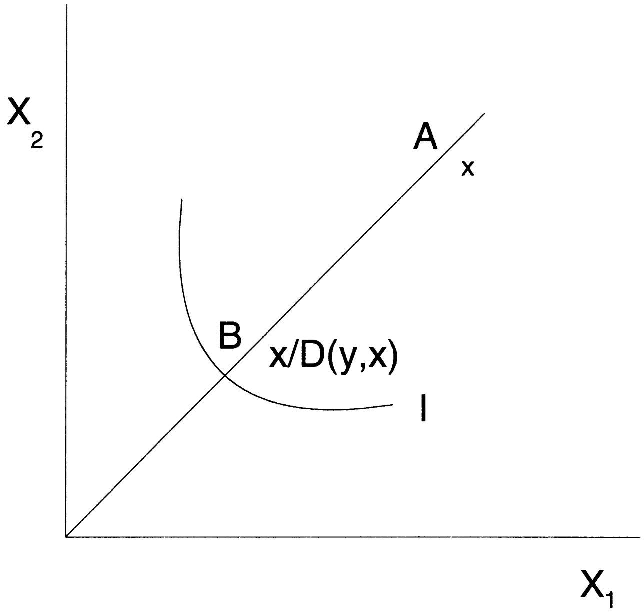
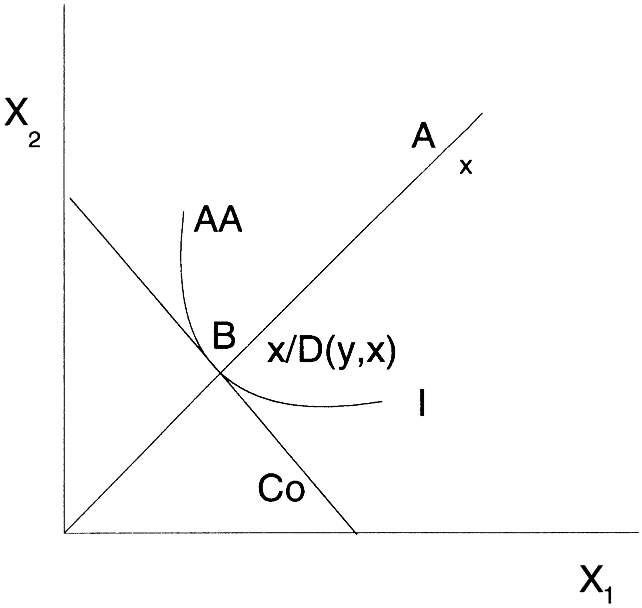


Figure 2

Allocative and technical inefficiency

The budget line Co is tangent to the isoquant at B. Producers located at AA are allocatively inefficient.



Productivity changes arising from changes in technical efficiency can be measured as the ratio of two distance functions at different points in time, or as:

$$E(y^0,y^1,x^0,x^1)=\frac{D^1(y^1,x^1)}{D^o(y^o,x^o)} \tag{3}$$

where superscripts refer to time period 0 and time period 1 and the function E(.) represents a technical efficiency index. When placed above the data, superscripts refer to the time period of the data. When placed above the function, superscripts refer to the time period of the technology.

Changes in productivity due to technical change also can be measured using distance functions. In figure 3, technical progress is reflected by inward movement of the isoquant from $I(T_0)$ to $I(T_1)$. This progress can be measured with a distance function that mixes technology from one time period with observations from other time periods. For example, the observation at point A (the vector x_0) is efficient relative to technology T_0 but is technically inefficient relative to technology T_1.

If the observation x^0 represented data from time period 0, then a distance function using these data combined with estimates of reference technology from time period 1 would measure technical change. This distance function would be defined as:

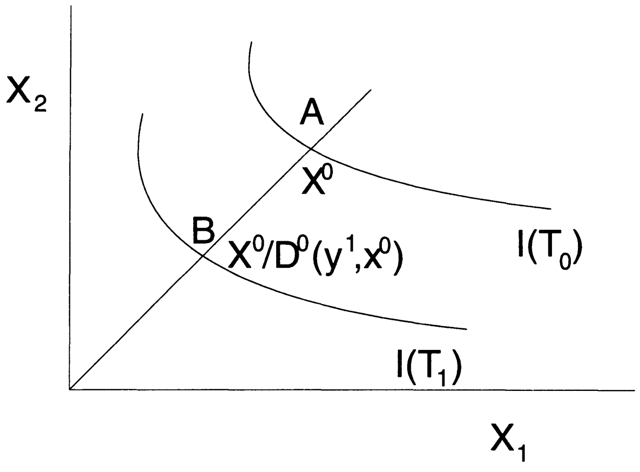
$$D^1(y^0,x^0) = Max\ [\ \lambda : \frac{x^0}{\lambda}\ \varepsilon\ L^1(y^0)]. \tag{4}$$

$L^1(y^o)$ represents the input requirement set using technology from time period 1 to produce outputs observed in time period 0.

Figure 3

A mixed-distance function

A mixed-distance function measures the distance between isoquant $I(T_0)$ representing one technology and isoquant $I(T_1)$ representing another technology.



The above mixed-distance function computes the largest possible contraction of inputs observed in time period 0 such that $x^o/D^1(y^o,x^o)$ belongs to the input requirement set representing the technology in time period 1. In figure 3, this would represent the distance from point A to point B.

Unfortunately, an observation is not always efficient relative to any time period's technology. Equation 5 represents a ratio of two distance functions. The numerator measures technical efficiency in time period 1 relative to technology in time period 0. This is the mixed-distance function. The denominator measures technical efficiency in time period 1 relative to the technology in time period 1. This is the distance function for time period 1.

$$\frac{D^0(y^1,x^1)}{D^1(y^1,x^1)} \tag{5}$$

If the observation is efficient in time period 1, the denominator of equation 5 is 1 and this equation is equivalent to the mixed-distance function. If the observation in time period 1 is not efficient, then the mixed-distance function is divided by a measure of efficiency. The ratio in equation 5 will measure the distance the isoquants have shifted from time period 0 to time period 1, even when there are technical inefficiencies.

Fare and others combine the ratio in equation 5 with a counterpart ratio to measure technical change (*24*). They take one mixed index that measures time period 0 data against time period 1 technology ($D^1(x^o,y^o)$) and another mixed index that measures time period 1 data against time period 0 technology ($D^0(x^1,y^1)$). Fare and others calculate the technical change component of productivity as the geometric mean of these two mixed-distance functions relative to technical efficiency indices, or as:

$$T(y^0,y^1,x^0,x^1) = \left[\frac{D^0(y^1,x^1)D^0(y^0,x^0)}{D^1(y^1,x^1)D^1(y^0,x^0)}\right]^{1/2} \tag{6}$$

where the function T(.) represents a technical change index.[7]

Fare and others represent changes in total factor productivity by a generalized Malmquist index, which is defined as:

$$M_i(y^0,y^1,x^0,x^1) \;=\; E_i(y^1,y^0,x^1,x^0) * T_i(y^1,y^o,x^1,x^0) \tag{7}$$

where the first component of equation 7 is equivalent to equation 3 and the second component is equivalent to equation 6 (*24*). Subscript i has been introduced to label specific functions.

The generalized Malmquist productivity index in equation 7 has two components: a relative efficiency index and a technical change index. The relative efficiency index measures the ratio of technical efficiency at time period 0 and time period 1. This is a measure of a firm or country i catching up to a frontier representing best-practice technology. The technology index measures the shift in the frontier. The generalized Malmquist index, which measures changes in total factor productivity for the ith observation, combines both the ith observation catching up to the best-practice frontier and shifts in the frontier itself.

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[7] The distance function in the denominator measures technical change in opposite direction than the one in the numerator. This is why the geometric mean uses the reciprocal of this function.

An Economic Reason for Technical Inefficiency

Economic explanations of technical change are widespread (*1, 30, 32*). In contrast, there are few economic explanations for the existence of technical inefficiency. Fare and others found that expenditure constraints can make agricultural firms financially inefficient (*26*). Whittaker and Morehart demonstrated that farm expenditure constraints have caused many agricultural producers to be cost-inefficient (*43*).[8] This section provides an additional explanation for the existence of technical inefficiency.

Ahmad introduced the innovation possibilities curve (IPC) to explain technical change (*1*). The IPC is a hypothetical isoquant giving the efficient combinations of inputs using all possible technologies that could produce a given output. Tangent to the IPC are isoquants representing actual technologies. Ahmad's induced innovation argument states that countries adopt a technology that is tangent to the prevailing cost line (*1*). In figure 4, isoquants T1 and T2 represent distinct technologies enveloped by an innovation possibilities frontier (IPC), which serves as the boundary of an input requirement set for all possible technologies.

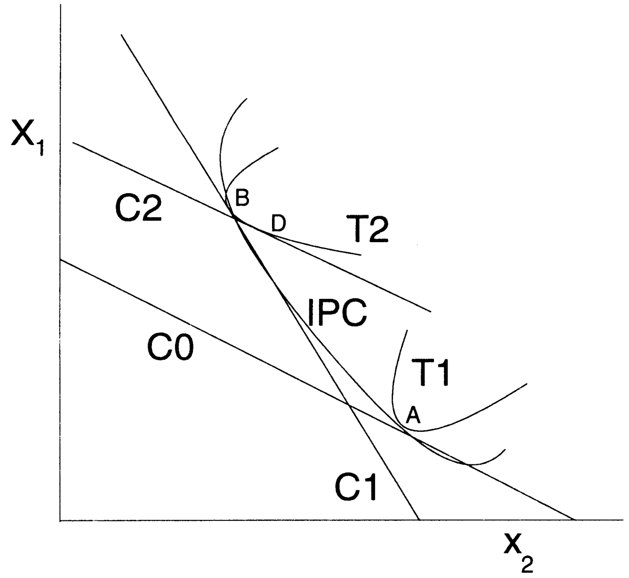
Suppose there are two budget lines--line CO, which reflects the true scarcity of inputs, and line C1, which represents a budget line when there are input subsidies. Without subsidies, producers adopt technology T1 and move to point A. With subsidies, producers adopt technology T2, which intensively uses scarce inputs, and move to point B on isoquant T2. Points such as B are often designated as allocatively inefficient relative to the optimum point A.

Suppose that after producers have adopted technology T2, subsidies are removed so that CO becomes the relevant cost line. If producers can switch technologies, they will adopt technology T1 and move from point B to the efficient point A. However, adjustment costs and lack of funds may prevent

Figure 4

IPC frontier and technical inefficiency

The IPC frontier, representing possible technologies, envelops isoquants T1 and T2.



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[8] Whittaker and Morehart define cost efficiency as the maximum profit achieved with the minimum expenditure. This is analogous to technical efficiency, which obtains the maximum output with the minimum input use.

producers from changing technologies. In this case, producers must move to point D on the T2 isoquant. This point is tangent to the higher cost line C2.

Note that point D lies inside the IPC and is technically inefficient relative to the IPC frontier. If producers are at a point similar to D and the boundary of an input requirement set is represented by a general technology on the IPC frontier, these producers will appear to be technically inefficient. More generally, any decision unit (a firm or an aggregate of firms) operating on an isoquant with a lower elasticity of resource substitution than the reference technology could operate at points that are technically inefficient relative to the reference technology. Evidence that an observational unit is technically inefficient may signify that its substitution possibilities are less flexible than observational units operating on the best-practice frontier.[9]

Data Envelopment Analysis

Data envelopment analysis (DEA) was introduced by Charnes and others as a way to establish a best-practice frontier without imposing restrictions on production technology (*13*). Seiford and Thrall argue that "DEA is a methodology directed to frontiers rather than central tendencies. Instead of trying to fit a regression plane through the center of data, one floats a piecewise linear surface to rest on top of the observations" (*33*). The distance from a frontier calculated by DEA and one particular observation provides a measure of Farrell's technical efficiency (*28*). Fare shows that this estimate of technical efficiency represents the inverse of the distance function (*23*). Chambers and others show that DEA can estimate each distance function used in the Malmquist index (*12*).

One key feature to DEA is its generality. Reference technology levels for each input and output are defined by a linear combination of sample observations on each input and a linear combination of sample observations on each output. Restrictions inherent in assuming specific production functions are avoided. Seiford and Thrall state, "DEA does not require any assumptions about functional form, the efficiency of a decision making unit is measured relative to all other decision making units with the simple restriction that all decision making units lie on or below the efficient frontier" (*33*).

Suppose there are K production units that produce M goods using N inputs. DEA can be understood by expressing the input requirement for production of outputs y^t as:

$$\begin{aligned} L^t(y^t) = [x^t : y^t_m \le \sum_{k=1}^{K} z_k y^t_{km} & \qquad m=1..,M, \\ \sum_{k=1}^{K} z_k x^t_{kn} \le x^t_n & \qquad n=1..,N, \\ z_k \ge 0 & \qquad k=1..,K\ ] \end{aligned} \tag{8}$$

where t refers to time, m refers to outputs of each decision unit, and n refers to inputs of each unit. There are observations on k production units at one point in time. Individual z terms represent weights on each specific cross-sectional observation. $L^t(y^t)$ represents the input requirement set using technology from time period t to produce output in time period t.

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[9] If the elasticity of substitution of best-practice technology is zero, this argument does not hold.

The above expression defines the set of inputs that can produce outputs y^t and belong to the technology set t. The production technology consists of reference outputs and reference inputs. The reference outputs are defined by a linear combination of outputs across k cross-section observations (the right-hand side of the first M constraints). The reference inputs are defined by a linear combination of inputs across k cross-section observations (the left-hand side of the ensuing N constraints). The technology is defined such that (1) the level of the mth output is less than or equal to a reference output, and (2) the level of the nth input is greater than or equal to a reference input.

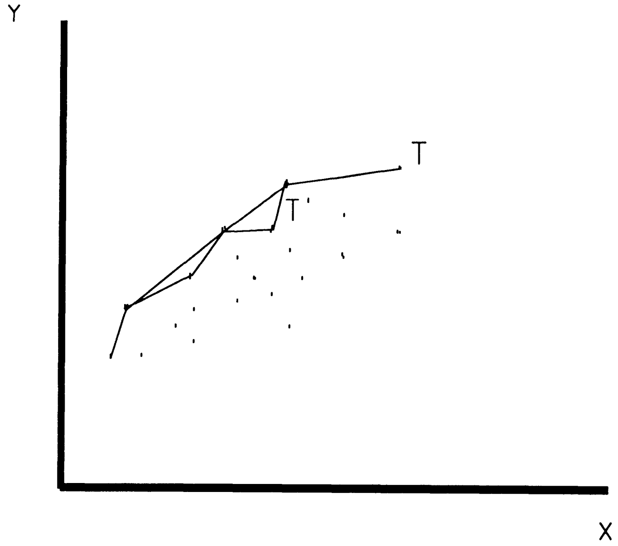
The combination of each output and each input across all K observations forms a series of line segments that specifies the boundary of the technology set. When there is one output and two inputs, the boundary of the input requirement set defines an isoquant. The weights on the outputs and inputs (the z_k) must be non-negative. If an additional requirement, $\Sigma\, z_k = 1$, is imposed, the boundary of the technology set will be represented as a convex combination of outputs and inputs across all K observations.[10]

Figure 5 presents hypothetical data representing several firms that use one variable input to produce one output. The boundary line T connecting the efficient observations represents a convex combination of relevant outputs and inputs. This boundary line is the "reference technology." The boundary line T' represents a nonconvex combination of relevant outputs and inputs. The boundary T' would only represent the reference technology if outputs were assumed to be produced with constant returns-to-scale technology. The efficiency of each data point is measured relative to the boundary representing the reference technology. Observations interior to either frontier are considered technically inefficient.

Figure 5

Two-dimension frontiers

By connecting several observations, frontiers T and T' are created, which envelop the remaining observations.



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[10] Imposing the restriction $\Sigma\, z_k = 1$ permits the technology to exhibit any degree of returns to scale.

To calculate technical efficiency of the kth observation, the reference technology must be defined and the distance of the kth observation from the reference technology must be measured. The programming problem used to calculate the Farrell measure of technical efficiency for a specific observation, k', in time period 0 is set up as:

$$\begin{array}{rll} F^0(y^0_{k'},x^0_{k'}) = (D^0(y^0_{k'},x^0_{k'}))^{-1} & = \min\lambda & \\ & s.t.\ y^0_{k'm} \le \sum_{k=1}^{K} z_k y^0_{km} & m=1..,M \\ & \sum_{k=1}^{K} z_k x^0_{kn} \le \lambda x^0_{k'n} & n=1..,N \\ & z_k \ge 0, & k=1..,K \\ & \sum_{k=1}^{K} z_k = 1 & \end{array} \tag{9}$$

Superscripts on the data represent the time period 0. Superscripts on functions represent the technology that is defined by the data. Subscript k' refers to a specific cross-sectional observation. Subscripts m and n refer to outputs and inputs.

The above programming problem finds the minimum value of λ such that both outputs and inputs for the specific observation k' lie within the input requirement set. The value of λ in this problem is an estimated index of technical efficiency, relative to the best-practice frontier for observation k'. This value of λ represents the inverse of the value of the distance function for observation k'. Subtracting λ from 1 gives the largest proportional reduction in inputs that can be achieved without reducing output (*14*).

The programming problem also calculates the z terms (the weights on the inputs and outputs) by calculating the piecewise linear convex combination of outputs and inputs across all K observations. An example problem is solved in the appendix. This convex combination of outputs and inputs, the best-practice frontier, defines the technology. A major advantage of this approach is that the z terms, which define the best-practice technology, and the optimal value of λ are jointly calculated from the same data.

Mixed-distance functions are estimated by comparing observations in one time period with the best-practice frontier of another time period. For example, set up a programming problem that calculates the shrinkage required of inputs for observation k' in time period 1 relative to the technology of time period 0. The result is an estimate of the inverse of the mixed-distance function for observation k'. This can be defined as:

$$\begin{aligned}(D^0(y^1_{k'},x^1_{k'}))^{-1} &= \min\lambda \\ s.t.\ y^1_{k'm} &\le \sum_{k=1}^{K} z_k y^0_{km} & m&=1..,M \\ \sum_{k=1}^{K} z_k x^0_{kn} &\le \lambda x^1_{k'n} & n&=1..,N \\ z_k &\ge 0 & k&=1..,K \\ \sum_{k=1}^{K} z_k &= 1\end{aligned} \tag{10}$$

The technology is defined from data in time period 0, whereas the efficiency of the specific observation k' is defined using data from time period 1.

Empirical Details

This report presents country-specific indices of technical efficiency, technical change, and productivity. Allocative efficiency indices were not calculated because reliable input prices, which are required to calculate allocative efficiency, are not available for many countries. Furthermore, allocative efficiency is not a component of the Malmquist productivity index.

Economists have concentrated on calculation of firm-level indices from cross-sectional survey data. Empirical calculations of mixed-distance functions, which form the basis of the technical change and Malmquist productivity indexes, are less prevalent. Few studies have calculated either index using international data.[11]

Suppose each observation in time period 0 represents output and input data for a country's agricultural sector. Solving the programming problem K times, once for each country, provides a measure of technical efficiency for each country's agricultural sector in time period 0. It is possible to repeat the process for another time period. The ratio of these two measures defines the reciprocal of the technical efficiency index in equation 5. Solving a programming problem that combines specific country observations from one time period with cross-sectional data from another time period provides country estimates of the mixed-distance functions. Therefore, all of the mixed-distance functions contained in the Malmquist indices can be calculated from country-level data.

Table 1 reports indices that measure the technical efficiency for countries belonging to four technology categories. Table 2 reports indices that measure productivity changes originating from technical change. Table 3 reports indices that measure changes in multifactor productivity. These results should be viewed in light of the experimental nature of this study. DEA is more sensitive to data errors than standard econometric modeling, and international agricultural data tend to be less reliable than U.S. agricultural data.

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[11] Calculation of the Malmquist index requires calculation of each of the four distance functions represented in the Malmquist index. A separate index must be calculated for each observation in a cross-sectional data set. To calculate a Malmquist index, which compares 2 time periods for 20 countries, 80 programming problems must be solved.

Data

Countries were classified into four categories of agricultural technology--advanced technology, middle technology, low technology, and Asian rice technology. Countries were ranked by the number of tractors per agricultural employee. This ranking was used to divide countries into advanced-, middle-, and low-technology categories. A second ranking of countries by land/labor ratios was used to place several countries which, by tractor/labor ratios, could be reasonably placed in more than one technology category. Countries that primarily produced rice were placed into the Asian rice technology category. India and Pakistan were grouped in both low-technology and Asian rice technology categories.

ERS's *World Agriculture: Trends and Indicators* served as the source of data (*41*). To reduce the effects of weather on production, 1961-87 data were divided into nine time periods where each point represents a 3-year average. For example, time period 1 represents 1961-63 averages for all inputs and outputs. Agricultural output was represented by the total value of agricultural production in real international dollars. This measure of output is used by the United Nations' Food and Agriculture Organization to convert worldwide agricultural production into a common unit. The complete data set is available from the author or from ERS publications (*41*).

DEA allows inputs to be categorized as either fixed or variable. Since each observation in this study's data represents an average of 3 years of data, all inputs were treated as variable. The measured inputs are agricultural land, agricultural labor, tractors, and fertilizer. Ideally, input production should represent inputs consumed in the production process. For example, on a 1-hectare farm, the flow of services from a hectare of land represents a better calculation of the land input in a particular year than does a measure of 1 hectare. However, many international data are recorded as stocks rather than the service flows that represent each year's input into production.

Typically, stock data are converted to service flows using various accounting techniques (*3, 6, 29*). However, international data are not precise enough nor are there sufficient proxies for interest rates, taxes, and depreciation rates to undertake this conversion without distorting the data. If it is assumed that service flows from a resource are proportional to its stock and that this proportion is similar across the observations that belong to a technology category, then stock data can be used to represent input use (*24*). However limiting this assumption may be, it is frequently used by economists and is less distorting to productivity measurement than converting stock data to flows using techniques that require the use of questionable data.

Economists sometimes convert input data into common quality units. For example, economists have argued that land in a country with poor soil and lack of rain should count for less than land in a country with good soil and abundant rain. A similar argument was used by Jorgenson and others to justify their precise and detailed correction for differences in input quality when measuring productivity (*29*). Ball adapted Jorgenson's techniques to express agricultural land, labor, and capital in common quality units (*6*). To a lesser degree, Arnade and Bottomley and others converted agricultural input data into common quality units (*3, 8*).

As input quality changes over time or across regions, productivity changes. If economists want to measure productivity growth net of differences in input quality, they should adjust inputs. If economists want to measure multifactor productivity growth that includes distinctions arising from variation in input quality, inputs should not be quality-adjusted.[12] In this study, input data were not adjusted for differences in quality.

Results

Tables 1-3 contain estimated indices of technical efficiency, the technical change component of agricultural productivity, and agricultural productivity. Table 4 summarizes these results by recording whether each country, on average, was efficient, whether the technology index, on average, rose or fell, and whether the productivity index, on average, rose or fell. Indices were calculated for each country in all technology categories.

Countries on the production frontier are called "best practice" and demonstrate no inefficiency in resource utilization **relative** to the best-practice frontier. An index measure of 1 indicates that a country lies on the best-practice frontier. An index measure less than 1 indicates that a country uses its agricultural resources inefficiently; the lower the index, the less efficient relative to countries on the best-practice frontier. An efficiency index subtracted from one represents the largest proportional amount inputs can be reduced without reducing output (*14*).

Indices representing multifactor productivity growth due to technical change are calculated by estimating technical efficiency in one time period against the best-practice technology of another time period. This study's estimates represent the inverse of the technology index defined by equation 6, so a number greater than 1 represents an improvement in productivity due to technical change. Index numbers are defined so that the 1961-63 observation equals 1.

A Malmquist multifactor productivity index is calculated from a combination of technical efficiency indices and technical change indices. The estimated indices represent the inverse of the Malmquist index described in equation 7, so productivity improvements are greater than 1.

Advanced-Technology Countries

Most countries with advanced agricultural technology lie on the best-practice frontier for most years. The exceptions are Austria, Finland, Ireland, and Sweden. The United Kingdom, Denmark, and Canada were each relatively efficient in the 1960's and early 1970's, but became relatively inefficient in the late 1970's.

Except for Argentina, Ireland, and Uruguay, productivity and technical change indices grew significantly for all countries with advanced agricultural technology. Technical change rose in Ireland, but productivity fell. The United Kingdom experienced the greatest growth in absolute productivity and growth in productivity arising from technical change. Interestingly, the United Kingdom was measured as inefficient during its period of technical change. This inefficiency could stem from producer unfamiliarity with newly adopted technology.

Argentina's productivity both rose and fell throughout the nine time periods. The productivity of Uruguay's agriculture fell throughout most of the period while Italy's fell in the 1960's and 1970's but

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[12] If input quality adjustment is done, economists must be extremely careful to avoid a circular exercise if they seek to measure productivity. For example, the price of an input often serves as the most reliable measure of its quality. However, input prices reflect their productivity.

rose significantly in the 1980's. This fluctuating productivity growth coincides with periods of economic instability in each country. Interestingly, productivity growth in the United States was significantly below the European average and that of Australia and New Zealand.

Middle-Technology Countries

Seven middle-technology countries were interior to the best-practice frontier in 1985-87. Four countries--Czechoslovakia, South Africa, Portugal, and Venezuela--were significantly less efficient than the others. South Africa's agriculture combines large, capital-intensive farming with smaller traditional agriculture, so it is not surprising that, on average, South African agriculture was inefficient. Agriculture in Venezuela, an oil producing and exporting (OPEC) country, grew relatively inefficient after its oil boom, supporting arguments that rapid growth in one sector of the economy can create inefficiencies in another sector of the economy (*15*).

There is wide variation in the technology and productivity indices of middle-technology countries. Both total agricultural productivity and agricultural productivity arising from technical change grew significantly in the Eastern European countries, the Soviet Union, and Spain.

Productivity fell significantly for many South American countries and Turkey. These countries employ a large amount of agricultural labor and yet adopted technologies developed in countries with scarce agricultural labor. Many of these countries also subsidized the use of commercial inputs to encourage technology adoption. The combination of intensive use of labor with intensive use of inputs such as machinery and fertilizer may explain the observed declines in multifactor productivity.

Low-Technology Countries

Eight low-technology countries were inside the best practice frontier in 1985-87. Unlike other technology categories, some low-technology countries (Peru, Zambia, Zimbabwe, and Sudan) began (in 1961-63) far off the best-practice frontier. Iraq lay on the frontier in the early 1960's but rapidly fell off the frontier in the early 1970's and only slowly improved its relative position in the 1970's and 1980's.

With the exception of five countries (Egypt, Honduras, Iraq, Sudan, and Zimbabwe), productivity declined for all low-technology countries. Nicaragua's productivity decline was the most severe, followed by Bolivia's. As in some middle-technology countries, the adoption of input-intensive technology by labor-abundant countries may have caused productivity to decline.

Technical change led to significant increases in productivity in Iraq and Peru (and to a lesser extent Zimbabwe), although these countries displayed sizable relative inefficiencies in their agriculture. It is possible that these production inefficiencies arose when an unfamiliar technology was adopted. Production inefficiencies also could have originated from input subsidies used to promote technical change.

India shows a significant decline in agricultural productivity even though it moved from being a cereal importer in 1961 to becoming an exporter of wheat in the later periods. India's agriculture combines low technology and Asian rice technology. Its mixed performance as a member of the low-technology category may signify that a large part of India's agriculture belongs to the Asian rice technology.[13]

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[13] In Asian rice production, tractor size is sufficiently smaller than in the other categories.

Table 1--Technical efficiency indices for selected countries, 1961-87[1]

Country	1961-63	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87
Advanced technology:									
Argentina	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Australia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Austria	0.73	0.75	0.65	0.61	0.69	0.67	0.67	0.71	0.76
Belgium	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Canada	1.00	1.00	1.00	1.00	0.98	0.96	0.85	0.82	0.82
Denmark	1.00	1.00	1.00	0.88	0.86	0.91	0.93	0.98	0.98
Finland	0.63	0.59	0.56	0.55	0.54	0.58	0.59	0.56	0.56
France	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
West Germany	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Holland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ireland	0.98	0.94	0.93	0.82	0.75	0.72	0.67	0.66	0.66
Italy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
New Zealand	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Norway	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sweden	0.71	0.70	0.70	0.69	0.70	0.70	0.69	0.71	0.71
Switzerland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
United Kingdom	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.86	0.86
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Uruguay	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Middle technology:									
Brazil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bulgaria	0.95	0.78	0.87	0.98	1.00	1.00	0.92	0.89	0.88
Chile	0.85	0.75	0.78	0.76	0.74	0.95	1.00	0.94	0.83
Colombia	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Costa Rica	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Czechoslovakia	0.93	0.84	0.87	0.83	0.81	0.78	0.74	0.79	0.76
East Germany	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greece	0.81	0.84	0.96	1.00	1.00	0.96	0.95	0.85	0.81
Hungary	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Israel	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mexico	0.63	0.70	0.78	0.82	0.92	1.00	1.00	1.00	1.00
Poland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Portugal	1.00	1.00	1.00	1.00	0.98	0.72	0.72	0.75	0.77
Romania	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
South Africa	0.84	0.70	0.68	0.71	0.68	0.73	0.75	0.67	0.77
Spain	0.77	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turkey	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	1.00
USSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Venezuela	1.00	1.00	1.00	1.00	0.89	0.78	0.87	0.93	0.67
Low technology:									
Bolivia	1.00	1.00	0.95	0.99	0.94	1.00	1.00	1.00	1.00
Dominican Republic	0.85	0.78	0.81	0.89	1.00	1.00	1.00	1.00	1.00
Ecuador	0.91	1.00	0.78	0.89	0.90	0.71	0.71	0.58	0.54
Egypt	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
El Salvador	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Guatemala	0.79	0.80	0.80	0.89	0.98	0.97	1.00	1.00	0.92
Honduras	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
India	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Iran	0.93	0.81	0.88	0.90	1.00	1.00	1.00	1.00	1.00
Iraq	0.87	1.00	0.54	0.49	0.51	0.56	0.64	0.64	0.76
Jordan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Kenya	0.70	0.64	0.63	0.65	0.82	0.88	0.90	0.81	0.69
Nicaragua	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nigeria	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pakistan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Paraguay	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peru	0.71	0.73	0.56	0.57	0.64	0.51	0.43	0.50	0.33
Sudan	0.42	0.37	0.40	0.46	0.54	0.51	0.61	0.65	0.64
Zaire	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Zambia	0.38	0.61	0.66	0.42	0.45	0.52	0.53	0.55	0.54
Zimbabwe	0.33	0.33	0.33	0.36	0.40	0.39	0.38	0.33	0.35
Asian rice technology:									
Bangladesh	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bhutan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Brunei	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cambodia	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.82	1.00
China	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
India	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Indonesia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Japan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
North Korea	0.90	0.86	0.73	0.73	0.84	0.83	0.83	0.88	0.89
South Korea	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Laos	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Malaysia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Myanmar	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nepal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.88	0.75
Pakistan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Philippines	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sri Lanka	1.00	0.98	0.92	0.92	0.89	0.78	0.79	0.76	0.74
Thailand	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Taiwan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vietnam	1.00	1.00	1.00	0.91	0.99	0.80	1.00	1.00	1.00

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[1] In best-practice countries, the efficiency index equals one. This index is the inverse of the distance function so that less efficient countries are less than one.

Table 2--Technical change indices for selected countries, 1961-87[1]

Country	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87
Advanced technology:								
Argentina	0.85	1.13	0.72	1.22	1.50	1.12	1.16	0.93
Australia	1.13	1.18	1.27	1.33	1.48	1.44	1.57	1.74
Austria	0.98	1.06	1.07	1.12	1.13	1.22	1.31	1.31
Belgium	0.93	0.94	1.00	1.06	1.09	1.17	1.24	1.33
Canada	0.97	1.00	1.00	0.98	1.16	1.33	1.54	1.72
Denmark	1.05	1.16	1.35	1.49	1.36	1.69	1.79	1.93
Finland	0.96	0.99	1.03	1.05	1.05	1.07	1.12	1.15
France	1.04	1.17	1.23	1.33	1.31	1.56	1.68	1.76
West Germany	1.04	1.25	1.35	1.42	1.48	1.68	1.88	1.98
Holland	0.92	1.02	1.15	1.24	1.32	1.47	1.60	1.72
Ireland	0.89	0.81	0.85	0.90	0.94	0.99	1.02	1.05
Italy	0.97	0.95	0.88	0.91	0.87	1.01	1.06	1.10
New Zealand	0.96	1.10	1.09	1.03	1.16	1.23	1.35	1.53
Norway	0.97	0.98	1.00	1.01	1.02	1.02	1.05	1.10
Sweden	1.01	1.14	1.22	1.31	1.36	1.42	1.47	1.52
Switzerland	0.97	0.99	1.01	1.00	1.01	1.01	1.01	1.05
United Kingdom	1.09	1.16	1.31	1.41	1.50	1.78	2.14	2.26
United States	0.95	0.98	0.97	0.97	1.01	1.07	1.16	1.32
Uruguay	0.81	0.69	0.59	0.66	0.67	0.61	0.82	0.74
Middle technology:								
Brazil	1.31	0.87	0.66	0.57	0.64	0.50	0.60	0.59
Bulgaria	0.96	0.89	0.89	0.82	1.10	1.00	1.14	1.14
Chile	1.05	1.06	0.98	0.92	1.15	0.94	0.94	0.90
Colombia	0.99	0.94	0.81	0.76	1.18	0.80	0.75	0.70
Costa Rica	0.94	0.78	0.75	0.67	0.97	0.67	0.62	0.63
Czechoslovakia	1.05	1.09	1.17	1.38	1.66	1.67	1.90	2.21
East Germany	1.24	1.44	1.50	1.72	2.03	1.98	2.18	2.58
Greece	0.90	0.81	0.79	0.80	1.05	0.92	0.99	1.02
Hungary	0.99	0.91	0.95	1.05	1.38	1.23	1.46	1.56
Israel	1.04	1.05	1.05	1.06	1.27	1.20	1.21	1.13
Mexico	0.96	0.80	0.61	0.51	0.70	0.48	0.51	0.47
Poland	1.13	1.25	1.17	1.35	1.50	1.15	1.14	1.40
Portugal	0.83	0.71	0.68	0.69	0.94	0.84	0.85	0.86
Romania	0.89	0.72	0.63	0.59	0.77	0.77	0.85	0.92
South Africa	0.99	0.97	0.91	0.95	1.15	1.08	1.09	0.99
Spain	0.93	0.86	0.95	1.05	1.31	1.33	1.50	1.74
Turkey	1.03	0.70	0.52	0.43	0.52	0.41	0.50	0.54
USSR	1.29	1.34	1.27	1.23	1.42	1.21	1.51	1.63
Venezuela	0.68	0.63	0.53	0.48	0.62	0.49	0.50	0.51
Low technology:								
Bolivia	0.72	0.62	0.47	0.49	0.57	0.45	0.35	0.35
Dominican Republic	1.05	0.92	0.80	0.71	0.84	0.64	0.63	0.68
Ecuador	1.14	1.08	0.97	1.00	1.26	1.16	1.16	1.04
Egypt	1.23	1.38	1.55	1.58	1.95	1.71	1.83	2.10
El Salvaldor	1.00	0.90	0.88	0.87	1.01	0.83	0.81	0.77
Guatemala	1.03	0.92	0.84	0.74	0.89	0.67	0.63	0.68
Honduras	1.14	1.33	1.33	1.08	1.32	0.97	1.04	1.10
India	0.31	0.54	0.49	0.49	0.57	0.41	0.41	0.40
Iran	0.38	0.67	0.62	0.63	0.73	0.52	0.61	0.57
Iraq	1.06	0.82	0.80	1.29	2.51	2.10	2.14	2.20
Jordan	0.75	0.67	0.63	0.60	0.69	0.58	0.53	0.55
Kenya	1.02	0.93	0.89	0.82	0.91	0.74	0.74	0.80
Nicaragua	0.64	0.55	0.52	0.46	0.47	0.30	0.29	0.26
Nigeria	1.01	0.87	0.57	0.48	0.58	0.56	0.52	0.56
Pakistan	0.77	0.80	0.59	0.54	0.63	0.56	0.56	0.62
Paraguay	0.72	0.58	0.38	0.77	0.69	0.51	0.48	0.50
Peru	1.14	1.58	1.97	1.57	2.28	1.97	1.90	1.66
Sudan	1.00	1.01	0.99	0.94	1.01	0.74	0.67	0.83
Zaire	0.94	0.91	0.89	0.83	0.89	0.67	0.64	0.67
Zambia	0.55	0.43	0.45	0.39	0.39	0.29	0.26	0.30
Zimbabwe	1.07	1.08	1.03	1.09	1.21	1.06	1.03	1.36
Asian rice technology:								
Bangladesh	0.85	0.70	0.49	0.46	0.40	0.37	0.36	0.37
Bhutan	0.98	0.82	0.91	0.89	0.87	0.85	0.79	0.78
Brunei	0.68	0.48	0.41	0.35	0.33	0.33	0.35	0.33
Cambodia	0.83	0.56	0.63	0.32	0.81	0.26	0.29	0.93
China	0.90	0.85	0.76	0.76	0.68	0.65	0.68	0.74
India	0.71	0.67	0.72	0.68	0.62	0.58	0.57	0.58
Indonesia	1.04	0.97	0.93	0.86	0.83	0.81	0.82	0.80
Japan	1.05	1.09	1.17	1.22	1.39	1.55	1.73	2.00
North Korea	1.03	1.09	1.10	1.02	1.16	1.22	1.27	1.36
South Korea	1.87	1.37	0.96	0.57	0.41	0.22	0.17	0.17
Laos	0.99	0.45	0.51	0.51	0.44	0.37	0.56	0.39
Malaysia	1.01	1.04	1.10	1.20	1.28	1.36	1.44	1.60
Myanmar	0.97	0.49	0.45	0.42	0.38	0.36	0.33	0.36
Nepal	0.80	0.53	0.26	0.27	0.20	0.22	0.26	0.26
Pakistan	0.96	0.80	0.76	0.69	0.60	0.56	0.56	0.64
Philippines	1.00	0.93	0.93	0.96	1.01	0.94	0.92	0.92
Sri Lanka	1.03	1.05	1.12	1.21	1.25	1.29	1.29	1.26
Thailand	0.90	0.64	0.59	0.60	0.56	0.57	0.54	0.55
Taiwan	1.25	1.59	1.98	1.61	1.76	1.83	1.70	1.24
Vietnam	1.03	0.83	0.90	0.81	0.88	0.90	0.89	0.91

[1] The numbers represent the inverse of the technical change index described in the text so that technical change should be > 1 for productivity to increase.

Table 3--Productivity indices for selected countries, 1961-87[1]

Country	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87
Advanced technology:								
Argentina	0.85	1.13	0.72	1.22	1.50	1.13	1.16	0.93
Australia	1.13	1.18	1.27	1.33	1.48	1.44	1.57	1.74
Austria	0.99	0.95	0.89	1.06	1.04	1.11	1.26	1.36
Belgium	0.93	0.95	1.01	1.06	1.09	1.17	1.24	1.33
Canada	0.97	1.00	1.00	0.96	1.11	1.13	1.27	1.41
Denmark	1.05	1.16	1.19	1.29	1.23	1.57	1.75	1.89
Finland	0.90	0.87	0.89	0.90	0.96	1.00	0.98	1.01
France	1.04	1.16	1.23	1.33	1.31	1.56	1.68	1.76
West Germany	1.04	1.25	1.35	1.42	1.48	1.68	1.88	1.98
Holland	0.92	1.02	1.15	1.24	1.32	1.47	1.60	1.72
Ireland	0.86	0.77	0.71	0.66	0.70	0.68	0.69	0.71
Italy	0.97	0.96	0.88	0.91	0.87	1.01	1.06	1.10
New Zealand	0.96	1.10	1.09	1.03	1.16	1.23	1.35	1.53
Norway	0.97	0.98	1.00	1.01	1.02	1.02	1.05	1.10
Sweden	0.99	1.16	1.80	1.28	1.32	1.38	1.46	1.52
Switzerland	0.97	0.99	1.01	0.99	1.01	1.01	1.01	1.06
United Kingdom	1.09	1.16	1.31	1.41	1.51	1.92	2.50	2.64
United States	0.95	0.98	0.97	0.97	1.01	1.07	1.16	1.32
Uruguay	0.81	0.69	0.59	0.66	0.67	0.61	0.82	0.74
Middle technology:								
Brazil	1.31	0.87	0.66	0.57	0.64	0.50	0.60	0.59
Bulgaria	0.78	0.81	0.91	0.86	1.15	0.96	1.06	1.05
Chile	0.93	0.98	0.88	0.80	1.28	1.11	1.03	0.88
Colombia	1.05	0.99	0.85	0.80	1.25	0.85	0.79	0.74
Costa Rica	0.94	0.78	0.75	0.67	0.97	0.67	0.62	0.63
Czechoslovakia	0.94	1.03	1.04	1.20	1.40	1.32	1.62	1.81
East Germany	1.24	1.44	1.50	1.72	2.03	1.98	2.18	2.58
Greece	0.93	0.95	0.97	0.99	1.24	1.06	1.04	1.01
Hungary	0.99	0.91	0.95	1.05	1.38	1.23	1.46	1.56
Israel	1.04	1.05	1.05	1.06	1.27	1.20	1.21	1.13
Mexico	1.08	1.00	0.80	0.75	1.12	0.76	0.81	0.75
Poland	1.13	1.25	1.17	1.35	1.50	1.15	1.14	1.40
Portugal	0.84	0.72	0.68	0.70	0.67	0.61	0.63	0.66
Romania	0.89	0.72	0.63	0.59	0.77	0.77	0.85	0.92
South Africa	0.82	0.79	0.77	0.77	0.84	0.96	0.86	0.91
Spain	1.08	1.11	1.23	1.36	1.69	1.72	1.94	2.25
Turkey	1.03	0.70	0.52	0.43	0.52	0.41	0.46	0.54
USSR	1.29	1.34	1.27	1.23	1.42	1.21	1.51	1.63
Venezuela	0.68	0.63	0.53	0.43	0.48	0.43	0.47	0.34
Low technology:								
Bolivia	0.72	0.59	0.47	0.46	0.57	0.45	0.35	0.35
Dominican Republic	0.96	0.86	0.86	0.84	0.98	0.75	0.74	0.80
Ecuador	1.26	0.92	0.91	0.99	0.99	0.90	0.74	0.61
Egypt	1.23	1.38	1.55	1.58	1.95	1.71	1.83	2.10
El Salvador	1.01	0.91	0.89	0.88	1.03	0.85	0.82	0.78
Guatemala	1.05	0.93	0.94	0.92	1.09	0.85	0.80	0.79
Honduras	1.14	1.33	1.33	1.08	1.32	0.97	1.05	1.10
India	0.31	0.54	0.49	0.49	0.58	0.42	0.41	0.40
Iran	0.33	0.64	0.60	0.68	0.79	0.57	0.66	0.62
Iraq	1.22	0.51	0.46	0.76	1.61	1.54	1.57	1.92
Jordan	0.75	0.67	0.63	0.60	0.67	0.58	0.53	0.55
Kenya	0.92	0.84	0.83	0.95	1.14	0.96	0.85	0.78
Nicaragua	0.64	0.55	0.52	0.46	0.47	0.30	0.29	0.26
Nigeria	1.01	0.87	0.57	0.48	0.59	0.56	0.52	0.56
Pakistan	0.77	0.80	0.59	0.54	0.63	0.56	0.56	0.62
Paraguay	0.72	0.58	0.38	0.77	0.69	0.51	0.48	0.50
Peru	1.16	1.25	1.58	1.40	1.61	1.97	1.34	0.76
Sudan	0.87	0.95	1.09	1.21	1.22	1.09	1.04	1.26
Zaire	0.94	0.92	0.89	0.83	0.89	0.67	0.64	0.67
Zambia	0.89	0.76	0.51	0.48	0.55	0.40	0.38	0.43
Zimbabwe	1.06	1.07	1.13	1.31	1.44	1.22	1.04	1.44
Asian rice technology:								
Bangladesh	0.85	0.70	0.49	0.46	0.40	0.37	0.36	0.37
Bhutan	0.98	0.82	0.91	0.89	0.87	0.85	0.79	0.78
Brunei	0.68	0.48	0.41	0.35	0.33	0.33	0.35	0.33
Cambodia	0.83	0.56	0.63	0.32	0.81	0.21	0.24	0.93
China	0.90	0.85	0.76	0.76	0.68	0.65	0.68	0.74
India	0.71	0.67	0.72	0.68	0.62	0.58	0.57	0.58
Indonesia	1.04	0.97	0.93	0.86	0.83	0.81	0.82	0.80
Japan	1.05	1.09	1.17	1.22	1.39	1.55	1.73	2.00
North Korea	0.98	0.89	0.90	0.95	1.08	1.13	1.24	1.35
South Korea	1.87	1.37	0.96	0.57	0.41	0.22	0.17	0.17
Laos	0.99	0.45	0.51	0.51	0.44	0.37	0.56	0.39
Malaysia	1.01	1.04	1.10	1.20	1.28	1.36	1.44	1.60
Myanmar	0.97	0.49	0.45	0.42	0.38	0.36	0.33	0.36
Nepal	0.80	0.53	0.26	0.27	0.20	0.22	0.23	0.20
Pakistan	0.96	0.80	0.76	0.69	0.60	0.56	0.56	0.64
Philippines	1.00	0.93	0.93	0.96	1.01	0.94	0.92	0.92
Sri Lanka	1.01	0.97	1.03	1.06	0.97	1.02	0.98	0.93
Thailand	0.90	0.64	0.59	0.60	0.56	0.57	0.54	0.55
Taiwan	1.25	1.59	1.98	1.61	1.76	1.83	1.70	1.24
Vietnam	1.03	0.83	0.82	0.81	0.70	0.90	0.89	0.91

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[1] The numbers represent the inverse of the Malmquist index described in the text so that productivity change should be > 1 for productivity to increase.

Table 4--Summary of technical efficiency and productivity measures for selected countries, 1961-87

Yes means the country was relatively efficient over the 1961-87 period; no, inefficient; mixed, sometimes efficient. Up or down refers to the direction of the technology and productivity indices.

Country	Efficiency	Technology	Productivity	Country	Efficiency	Technology	Productivity
High technology:				Middle technology:			
Argentina	Yes	Mixed	Mixed	Brazil	Yes	Down	Down
Australia	Yes	Up	Up	Bulgaria	No	Mixed	Mixed
Austria	No	Up	Up	Chile	No	Mixed	Mixed
Belgium	Yes	Up	Up	Colombia	Yes	Mixed	Mixed
Canada	Mixed	Up	Up	Costa Rica	Yes	Mixed	Mixed
Denmark	Mixed	Up	Up	Czechoslovakia	No	Up	Up
Finland	No	Up	Mixed	East Germany	Yes	Up	Up
France	Yes	Up	Up	Greece	No	Mixed	Mixed
West Germany	Yes	Up	Up	Hungary	Yes	Up	Up
Holland	Yes	Up	Up	Israel	Yes	Up	Up
Ireland	No	Mixed	Mixed	Mexico	Mixed	Mixed	Mixed
Italy	Yes	Mixed	Mixed	Poland	Yes	Mixed	Mixed
New Zealand	Yes	Up	Up	Portugal	Mixed	Mixed	Down
Norway	Yes	Up	Up	Romania	Yes	Mixed	Mixed
Sweden	No	Up	Up	South Africa	No	Mixed	Mixed
Switzerland	Yes	Up	Up	Spain	Mixed	Up	Up
United Kingdom	Mixed	Up	Up	Turkey	Yes	Mixed	Mixed
United States	Yes	Up	Up	USSR	Yes	Mixed	Mixed
Uruguay	Yes	Mixed	Mixed	Venezuela	Mixed	Mixed	Down
Low technology:				Asian rice technology:			
Bolivia	Mixed	Down	Mixed	Bangladesh	Yes	Down	Down
Domin. Repub.	Mixed	Mixed	Down	Bhutan	Yes	Down	Down
Ecuador	No	Mixed	Down	Myanmar	Yes	Down	Down
Egypt	Yes	Up	Up	Cambodia	Mixed	Mixed	Mixed
El Salvador	Yes	Mixed	Down	China	Yes	Mixed	Mixed
Guatemala	No	Down	Down	Taiwan	Yes	Mixed	Mixed
Honduras	Yes	Mixed	Mixed	India	Yes	Mixed	Mixed
India	Yes	Mixed	Mixed	Indonesia	Yes	Down	Down
Iran	Mixed	Mixed	Mixed	Japan	Yes	Up	Up
Iraq	No	Up	Up	North Korea	No	Up	Up
Jordan	Yes	Down	Down	South Korea	Yes	Down	Down
Kenya	No	Mixed	Mixed	Laos	Yes	Down	Down
Nicaragua	Yes	Down	Down	Malaysia	Yes	Up	Up
Nigeria	Yes	Down	Down	Nepal	Mixed	Down	Down
Pakistan	Yes	Mixed	Down	Pakistan	Yes	Down	Down
Paraguay	Yes	Mixed	Mixed	Philippines	Yes	Mixed	Mixed
Peru	No	Up	Mixed	Sri Lanka	No	Up	Mixed
Sudan	No	Mixed	Mixed	Thailand	Yes	Down	Down
Zaire	Yes	Down	Down	Vietnam	Mixed	Mixed	Mixed
Zambia	No	Down	Down	Brunei	Yes	Down	Down
Zimbabwe	No	Up	Up				

Asian Rice Technology Countries

Draft animals, which play a large role in rice production, were included as an additional input for countries belonging to this technology category. Several countries have substituted small tractors for draft animals over the past few decades. Therefore, an adequate measure of productivity change requires an inclusion of both draft animals and small tractors as inputs.

Among the Asian rice technologies, only North Korea's agriculture remained relatively inefficient throughout all nine periods. Cambodia dropped abruptly off the best-practice frontier in the late 1970's but returned to a relatively efficient position by the mid-1980's. This could be a result of Cambodia's extensive economic restructuring. Similarly, Vietnam fell off the frontier during the height of its civil war. Sri Lanka shows a continuous decline in relative efficiency after moving off the frontier in the early 1960's.

Agricultural productivity improved in only three Asian rice technology countries. Japan's productivity improved the most, followed by Malaysia and Taiwan. Sri Lankan agriculture follows a pattern similar to many countries in other technology categories. Increases in productivity due to technical change are accompanied by decreases in efficiency.

Many Asian countries experienced declining agricultural productivity. The reason for this may be similar to the reason for declining multifactor productivity in other developing countries. Countries with large labor forces adopted technology intensive in the use of commercial inputs.

Interpretation

Tables 5A-5D provide measures of land and labor productivity that were calculated by dividing output by the appropriate input. Declines in multifactor productivity have occurred in countries where the productivity of agricultural land and agricultural labor has risen significantly. These results emphasize what is often overlooked in evaluations of developing country agriculture. Increases in land or labor productivity need not be associated with rises in multifactor productivity.

A measure of multifactor productivity can (1) represent an index of the profitability of the agricultural sector, (2) represent a critical component of competitiveness, (3) be used to distinguish two theories of trade, (4) be related to economic growth, (5) measure the response of production to research and investment expenditures, and (6) reflect improvement in human and nonhuman capital (*2, 5, 38*). Indices of multifactor productivity can serve as either endogenous or exogenous variables in models that analyze any of the above issues.

Measurement of multifactor productivity by others has centered on calculating productivity for developed nations (*6, 8, 9*). Single-factor productivity has been used to analyze the changing production technology in developing countries. When economists have considered more than one input in analyzing technical change in developing countries, they usually have tested for input biases arising from technical change or have tested the induced innovation hypothesis (*7*). There have been few studies that measure multifactor productivity in developing nations. There is little precedent for discussing the developing country indices, many of which show a decline in multifactor productivity.

Declines in multifactor productivity may result from inefficiencies that occur, in the short run, when new and unfamiliar technology is adopted. The technical efficiency and technical change indices of many countries, including developed countries such as England, show declines in efficiency during

Table 5A--Advanced-technology countries: Single-factor productivity[1]

Country	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87	Multifactor productivity 1961-87
Labor productivity:									
Argentina	1.03	1.20	1.19	1.29	1.52	1.59	1.70	1.78	None
Australia	1.31	1.44	1.61	1.67	1.84	1.86	1.98	2.24	Up
Austria	1.12	1.43	1.62	1.88	2.27	2.81	3.49	3.91	Up
Belgium	1.11	1.47	1.88	2.23	2.52	3.11	3.75	4.44	Up
Canada	1.28	1.48	1.75	1.89	2.33	2.65	3.22	3.93	Up
Denmark	1.15	1.30	1.42	1.62	1.91	2.37	2.92	3.48	Up
Finland	1.15	1.29	1.52	1.69	2.07	2.43	2.92	3.05	None
France	1.15	1.39	1.65	1.94	2.18	2.82	3.39	4.00	Up
West Germany	1.16	1.57	1.87	2.00	2.19	2.52	3.04	3.61	Up
Holland	1.11	1.43	1.79	2.02	2.28	2.74	3.29	3.88	Up
Ireland	1.09	1.38	1.55	1.79	2.13	2.38	2.70	3.07	Down
Italy	1.22	1.52	1.74	2.02	2.28	2.93	3.45	4.00	Up
New Zealand	1.09	1.24	1.30	1.22	1.30	1.37	1.52	1.66	Up
Norway	1.15	1.38	1.59	1.79	2.01	2.35	2.79	3.13	Up
Sweden	1.14	1.33	1.52	1.76	2.04	2.34	2.80	3.02	Up
Switzerland	1.06	1.26	1.35	1.50	1.68	1.93	2.23	2.53	Up
United Kingdom	1.16	1.34	1.53	1.60	1.65	1.85	2.15	2.32	Up
United States	1.14	1.36	1.55	1.68	1.90	2.11	2.26	2.66	Up
Uruguay	1.03	1.06	1.13	1.15	1.28	1.30	1.49	1.47	Down
Land productivity:									
Argentina	1.00	1.10	1.07	1.14	1.33	1.37	1.43	1.45	None
Australia	1.23	1.27	1.38	1.42	1.59	1.58	1.64	1.74	Up
Austria	1.02	1.14	1.13	1.20	1.27	1.34	1.49	1.50	Up
Belgium	1.00	1.17	1.31	1.39	1.39	1.55	1.59	1.68	Up
Canada	1.14	1.14	1.18	1.16	1.30	1.26	1.31	1.40	Up
Denmark	1.06	1.06	1.04	1.08	1.14	1.25	1.37	1.46	Up
Finland	1.05	1.06	1.12	1.12	1.21	1.23	1.33	1.27	None
France	1.06	1.14	1.21	1.30	1.31	1.48	1.58	1.63	Up
West Germany	1.00	1.11	1.16	1.18	1.22	1.30	1.39	1.42	Up
Holland	1.05	1.22	1.44	1.63	1.81	2.10	2.30	2.43	Up
Ireland	1.01	1.15	1.20	1.31	1.45	1.51	1.61	1.67	Down
Italy	1.10	1.19	1.31	1.45	1.46	1.62	1.66	1.67	Up
New Zealand	1.08	1.20	1.24	1.19	1.24	1.24	1.34	1.42	Up
Norway	1.02	1.09	1.18	1.28	1.32	1.33	1.40	1.35	Up
Sweden	1.07	1.11	1.11	1.18	1.23	1.27	1.36	1.37	Up
Switzerland	0.99	1.10	1.12	1.25	1.29	1.38	1.44	1.45	Up
United Kingdom	1.07	1.11	1.23	1.28	1.32	1.41	1.52	1.54	Up
United States	1.08	1.16	1.23	1.29	1.43	1.54	1.50	1.59	Up
Uruguay	1.03	1.05	1.10	1.07	1.10	1.11	1.24	1.20	Down

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[1] Single-factor productivity was calculated by dividing output by the input in question.

Table 5B--Middle-technology countries: Single-factor productivity[1]

Country	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87	Multifactor productivity 1961-87
Labor productivity:									
Brazil	1.04	1.09	1.19	1.35	1.55	1.84	2.01	2.23	Down
Bulgaria	1.37	1.69	2.03	2.41	3.11	4.13	5.02	5.07	None
Chile	1.07	1.20	1.24	1.28	1.48	1.75	1.80	2.06	Down
Colombia	1.05	1.10	1.21	1.30	1.48	1.61	1.62	1.69	Down
Costa Rica	1.07	1.24	1.48	1.67	1.91	2.10	2.15	2.32	Down
Czechoslovakia	1.16	1.51	1.74	2.01	2.16	2.39	2.88	3.22	Up
East Germany	1.25	1.51	1.69	1.98	2.08	2.32	2.63	3.14	Up
Greece	1.17	1.32	1.59	1.97	2.20	2.56	2.87	3.03	None
Hungary	1.19	1.52	1.80	2.24	2.60	3.16	3.90	4.39	Up
Israel	1.23	1.55	1.89	2.24	2.69	3.50	3.88	3.60	Up
Mexico	1.19	1.28	1.33	1.42	1.58	1.76	1.86	1.91	Down
Poland	1.11	1.25	1.34	1.59	1.71	1.71	1.81	2.11	Up
Portugal	1.10	1.28	1.42	1.56	1.44	1.64	1.89	2.18	Down
Romania	1.20	1.42	1.61	2.01	2.79	3.34	4.07	5.24	Down
South Africa	0.95	0.99	1.02	1.17	1.48	1.90	1.67	1.72	Down
Spain	1.18	1.45	1.85	2.34	2.64	3.29	3.95	4.69	Up
Turkey	1.38	1.45	1.57	1.60	1.87	1.96	2.06	2.23	Down
USSR	1.91	2.46	2.91	3.27	3.59	3.61	4.19	4.94	Up
Venezuela	0.93	1.05	1.17	1.33	1.55	1.92	2.14	2.35	Down
Land productivity:									
Brazil	1.02	1.06	1.11	1.16	1.22	1.33	1.40	1.52	Down
Bulgaria	1.20	1.25	1.29	1.33	1.36	1.44	1.54	1.43	None
Chile	1.02	1.07	1.03	0.98	1.00	1.08	1.10	1.19	Down
Colombia	1.05	1.08	1.18	1.28	1.47	1.59	1.56	1.61	Down
Costa Rica	1.01	1.12	1.24	1.25	1.30	1.25	1.19	1.25	Down
Czechoslovakia	1.10	1.24	1.28	1.42	1.47	1.53	1.67	1.75	Up
East Germany	1.15	1.27	1.31	1.45	1.44	1.54	1.56	1.76	Up
Greece	1.12	1.17	1.32	1.53	1.61	1.75	1.84	1.85	None
Hungary	1.08	1.22	1.30	1.51	1.64	1.78	1.98	1.96	Up
Israel	1.20	1.43	1.66	1.86	2.11	2.17	2.32	2.11	Up
Mexico	1.22	1.34	1.44	1.59	1.81	2.03	2.18	2.26	Down
Poland	1.09	1.20	1.23	1.40	1.41	1.32	1.31	1.43	Up
Portugal	1.02	1.10	1.13	1.20	1.14	1.25	1.27	1.29	Down
Romania	1.11	1.24	1.32	1.50	1.84	1.94	2.11	2.43	Down
South Africa	1.07	1.26	1.37	1.45	1.58	1.75	1.60	1.74	Down
Spain	1.07	1.17	1.32	1.55	1.63	1.83	1.98	2.09	Up
Turkey	1.27	1.37	1.50	1.57	1.88	1.96	2.19	2.39	Down
Ussr	1.37	1.54	1.62	1.75	1.86	1.76	1.86	1.97	Up
Venezuela	0.69	0.79	0.88	0.96	1.05	1.20	1.27	1.37	Down

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[1] Single-factor productivity was calculated by dividing output by the input in question.

Table 5C--Low-technology countries: Single-factor productivity[1]

Country	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87	Multifactor productivity 1961-87
Labor productivity:									
Bolivia	1.03	1.12	1.27	1.53	1.55	1.62	1.61	1.78	Down
Dominican Republic	0.93	0.92	1.06	1.12	1.19	1.16	1.27	1.29	Down
Ecuador	1.15	1.08	1.06	1.12	1.18	1.25	1.16	1.32	Down
Egypt	1.06	1.11	1.19	1.21	1.23	1.27	1.30	1.37	Up
El Salvador	1.01	0.97	1.02	1.19	1.28	1.37	1.28	1.19	Down
Guatemala	1.11	1.11	1.20	1.35	1.44	1.43	1.36	1.23	Down
Honduras	1.00	1.21	1.26	1.11	1.19	1.01	1.11	1.15	Up
India	0.94	0.97	1.00	1.00	1.06	1.04	1.13	1.12	Down
Iran	1.12	1.27	1.38	1.58	1.76	1.78	1.97	2.06	Down
Iraq	1.10	0.49	0.53	1.01	1.45	1.40	1.54	1.90	Up
Jordan	1.31	0.90	0.71	0.82	1.17	2.03	2.50	2.99	Down
Kenya	0.97	1.01	1.02	1.02	1.04	0.94	0.88	0.89	Down
Nicaragua	1.34	1.45	1.48	1.60	1.76	1.35	1.27	1.08	Down
Nigeria	1.03	1.08	1.17	1.01	1.18	1.42	1.47	1.55	Down
Pakistan	1.03	1.13	1.16	1.16	1.20	1.28	1.32	1.45	Down
Paraguay	1.10	1.10	1.15	1.15	1.35	1.43	1.56	1.66	Down
Peru	1.04	1.02	1.08	1.06	1.06	1.01	1.03	1.07	Up
Sudan	0.95	1.05	1.14	1.20	1.20	1.23	1.19	1.23	Up
Zaire	1.00	1.07	1.14	1.19	1.21	1.19	1.27	1.29	Down
Zambia	1.07	1.08	1.15	1.24	1.43	1.06	1.00	1.06	Down
Zimbabwe	1.05	1.10	1.24	1.26	1.28	1.14	1.04	1.17	Up
Land productivity:									
Bolivia	1.11	1.23	1.45	1.74	1.84	1.94	2.01	2.34	Down
Dominican Republic	0.97	0.99	1.18	1.27	1.35	1.33	1.44	1.43	Down
Ecuador	1.19	1.19	1.16	1.17	1.12	1.05	0.92	0.99	Down
Egypt	1.05	1.07	1.15	1.20	1.35	1.57	1.66	1.80	Up
El Salvador	1.09	1.14	1.26	1.45	1.52	1.56	1.39	1.29	Down
Guatemala	1.15	1.22	1.38	1.58	1.72	1.76	1.72	1.61	Down
Honduras	1.07	1.26	1.34	1.21	1.34	1.30	1.41	1.62	Up
India	0.98	1.07	1.17	1.23	1.38	1.43	1.62	1.69	Down
Iran	1.14	1.32	1.46	1.70	2.02	2.15	2.45	2.60	Down
Iraq	1.09	0.53	0.58	1.05	1.48	1.45	1.59	1.86	Up
Jordan	1.34	1.00	0.73	0.73	0.84	1.01	1.23	1.41	Down
Kenya	1.04	1.18	1.30	1.41	1.60	1.60	1.66	1.83	Down
Nicaragua	1.32	1.43	1.49	1.67	1.89	1.54	1.39	1.25	Down
Nigeria	1.06	1.09	1.10	1.13	1.08	1.19	1.26	1.43	Down
Pakistan	1.01	1.19	1.31	1.37	1.46	1.64	1.80	2.06	Down
Paraguay	1.14	1.17	1.28	1.32	1.59	1.79	1.90	1.96	Down
Peru	1.11	1.16	1.28	1.29	1.32	1.28	1.36	1.44	Up
Sudan	0.99	1.14	1.29	1.45	1.55	1.71	1.75	1.90	Up
Zaire	1.00	1.10	1.18	1.26	1.30	1.32	1.46	1.56	Down
Zambia	1.12	1.21	1.38	1.57	1.91	1.54	1.55	1.84	Down
Zimbabwe	1.12	1.21	1.44	1.53	1.67	1.59	1.49	1.82	Up

---

[1] Single-factor productivity was calculated by dividing output by the input in question.

Table 5D--Asian rice technology countries: Single-factor productivity[1]

Country	1964-66	1967-69	1970-72	1973-75	1976-78	1979-81	1982-84	1985-87	Multifactor productivity 1961-87
Labor productivity:									
Bangladesh	1.05	1.12	1.01	1.02	1.06	1.08	1.08	1.07	Down
Bhutan	1.03	1.07	1.09	1.11	1.15	1.20	1.29	1.44	Down
Brunei	1.10	1.19	1.50	1.89	1.69	1.65	1.92	1.98	Down
Cambodia	1.05	1.06	1.00	0.55	0.67	0.47	0.63	0.74	Down
China	1.22	1.31	1.39	1.47	1.46	1.59	1.82	1.95	Down
India	0.98	1.01	1.06	1.08	1.16	1.16	1.25	1.25	Down
Indonesia	1.03	1.10	1.22	1.34	1.43	1.67	1.86	2.03	Down
Japan	1.17	1.53	1.82	2.14	2.66	3.29	3.94	4.71	Up
North Korea	1.06	1.12	1.28	1.46	1.73	1.93	2.12	2.40	Up
South Korea	1.22	1.27	1.41	1.61	2.17	2.37	2.63	2.96	Down
Laos	1.22	1.35	1.34	1.28	1.19	1.69	1.94	2.19	Down
Malaysia	1.07	1.27	1.50	1.78	1.98	2.26	2.53	3.00	Up
Myanmar	1.08	1.05	1.08	1.12	1.18	1.40	1.63	1.68	Down
Nepal	1.02	1.01	1.03	1.08	1.03	0.99	1.01	1.03	Down
Pakistan	1.04	1.16	1.21	1.21	1.23	1.31	1.34	1.44	Down
Philippines	1.06	1.11	1.18	1.29	1.46	1.50	1.46	1.46	Down
Sri Lanka	1.03	1.04	1.05	1.01	0.98	1.04	1.03	1.03	None
Thailand	1.02	1.09	1.14	1.32	1.47	1.52	1.61	1.62	Down
Taiwan	1.08	1.20	1.24	1.26	1.33	1.32	1.26	1.29	Up
Vietnam	1.03	0.98	1.07	1.08	1.16	1.29	1.50	1.60	Down
Land productivity:									
Bangladesh	1.06	1.17	1.08	1.13	1.22	1.28	1.37	1.43	Down
Bhutan	1.06	1.14	1.19	1.23	1.30	1.39	1.52	1.77	Down
Brunei	0.99	0.96	1.38	2.15	2.37	2.80	4.03	4.52	Down
Cambodia	1.01	1.02	1.00	0.55	0.66	0.48	0.67	0.80	Down
China	1.27	1.45	1.63	1.83	1.93	2.23	2.69	2.99	Down
India	1.00	1.07	1.17	1.23	1.38	1.43	1.62	1.69	Down
Indonesia	1.04	1.13	1.27	1.38	1.50	1.79	1.99	2.18	Down
Japan	1.09	1.28	1.36	1.46	1.58	1.65	1.72	1.83	Up
North Korea	1.06	1.12	1.28	1.45	1.69	1.87	2.05	2.27	Up
South Korea	1.17	1.21	1.40	1.61	2.14	2.29	2.48	2.72	Down
Laos	1.33	1.53	1.59	1.60	1.49	2.10	2.43	2.86	Down
Malaysia	1.07	1.26	1.51	1.79	2.01	2.31	2.59	3.06	Up
Myanmar	1.08	1.05	1.10	1.23	1.35	1.64	1.92	2.01	Down
Nepal	1.05	1.07	1.08	1.10	1.08	1.12	1.20	1.27	Down
Pakistan	1.01	1.19	1.31	1.37	1.46	1.64	1.80	2.06	Down
Philippines	1.07	1.15	1.26	1.45	1.66	1.72	1.71	1.77	Down
Sri Lanka	0.92	0.92	0.96	0.95	1.00	1.15	1.18	1.22	None
Taiwan	1.13	1.33	1.48	1.56	1.74	1.89	1.96	2.10	Up
Thailand	1.01	1.08	1.13	1.20	1.33	1.39	1.48	1.49	Down
Vietnam	1.03	0.99	1.09	1.11	1.15	1.29	1.57	1.75	Down

---

[1] Single-factor productivity was calculated by dividing output by the input in question.

periods of increased technical change. Unfamiliarity with new technology could make producers less efficient. For example, when a technology is new, producers may be less willing to substitute one input for another as input prices change. As discussed earlier, if producers are relatively inflexible in substituting inputs, they will appear to be relatively inefficient.

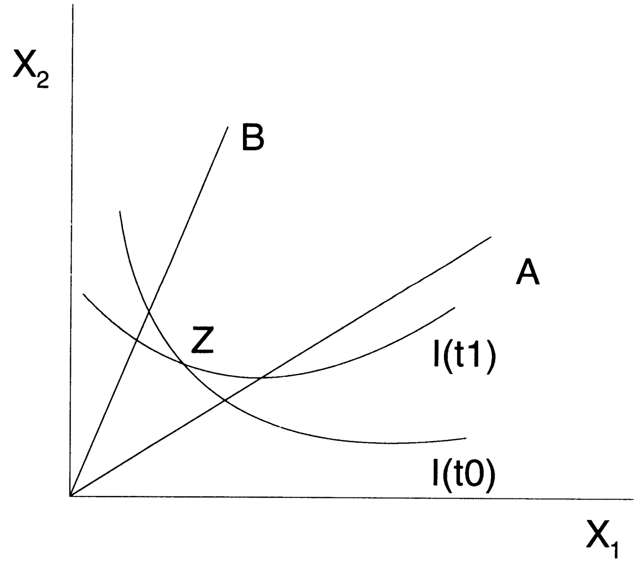
Long-term declines in multifactor productivity could also indicate that a country has adopted a technology that does not suit its technical needs. Many countries whose factor endowments favor a labor-intensive technology adopted a technology developed in countries with a scarcity of agricultural labor. Input subsidies to encourage adoption of new technology may also have encouraged waste of inputs.[14] [15]

Figure 6 shows isoquants representing two distinct technologies. The traditional technology is represented by isoquant I(t0) while the new technology is represented by isoquant I(tl). Point Z represents a point where the two isoquants representing the two technologies cross. With the input ratio (X2/X1) represented by a line A technology, I(t0) remains optimal. Yet at a higher X2/X1 input ratio represented by line B, technology I(tl) is optimal.

Figure 6

Two technologies

To the right of point Z, technology represented by I(t0) is more efficient. To the left of Z, technology represented by I(t1) is more efficient.



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[14] Governments, often in the interest of food self-sufficiency, provided incentives to increase agricultural output by increasing the use of commercial inputs. Subsidies for fertilizer and tractor use led to dramatic increases in the use of those inputs.

[15] The decline in multifactor productivity among many developing countries may also be due to increased fragmentation of farms arising from population growth.

In the 1970's, many developing countries planted their grain crops with new high-yielding varieties (HYV) of seeds, which required a significant amount of commercial inputs, particularly fertilizer. HYV seeds are more productive than traditional technology only if the use of commercial inputs such as fertilizer is significantly increased. If, in figure 6, input X1 represents traditional inputs such as labor and draft animals, and X2 represents commercial inputs, then figure 6 depicts the situation faced by many developing countries. Commercial technology is more productive only when the ratio of commercial to traditional inputs reaches a level beyond point Z representing a specific input ratio X2/X1.

Many countries where technical change has been measured to be regressive (Brazil, India, Iran, Mexico, Nicaragua, Nigeria, Pakistan, Thailand, Paraguay, Zaire, and Zambia) did adopt HYV technology.[16] In these countries, use of agricultural labor has not diminished significantly so the ratio of commercial to traditional inputs may not be high enough to insure that the new technology is optimal. In other words, the input ratio in many of these countries is located to the right of Z in figure 6.

Conclusions

Economists have used many approaches to measure multifactor productivity. Data envelopment analysis (DEA), which has been widely used to measure efficiency, can be extended to measure changes in multifactor productivity. This measure of productivity consists of two components: productivity changes due to changes in efficiency, and productivity changes arising from technical change.

An observed decision unit (or aggregate of decision units) may appear technically inefficient if its substitution possibilities are less flexible than other decision units (other aggregates). Various measures of technical efficiency can be used not only to devise efficiency indices, but also to devise technical change indices and productivity indices. Each of these indices can be calculated using DEA.

Data envelopment analysis (DEA) was used in this report to measure the efficiency of resource use (technical efficiency) of the agricultural sector of many countries, to measure changes in productivity of these countries' agricultural sectors, and to measure productivity arising from technical change. Technical efficiency and productivity indices were calculated from 1961 to 1987. Productivity indices include productivity differences arising from differences in input quality across countries and across time.

Agriculture in most developed countries was shown to be efficient. Agricultural productivity gains were greatest in Northern European countries. Agriculture in most Latin American countries was technically efficient, though most countries also experienced declines in multifactor productivity. Agriculture in most Asian countries was efficient but, with the exception of Japan, Malaysia, North Korea, and Taiwan, these countries experienced declines in multifactor productivity. Of the African countries where data were available, only Nigeria and Zaire were efficient. All African countries, with the exception of Sudan and Zimbabwe, experienced declines in productivity. Of the Mideast countries where data were available, Israel, Jordan, and Turkey were efficient. Productivity rose significantly in Iraq and Egypt and to a lesser degree in Israel.

---

[16] Many of these countries used subsidies to encourage adoption of commercial technology even though their factor endowments favored adoption of technology that intensively used traditional inputs.

Multifactor productivity declined in many developing countries, where newly adopted agricultural technology led to immense increases in fertilizer and machine use without much decline in agricultural labor use. The commercial input/labor ratio in some developing countries may not have been high enough to optimize the use of newly adopted technology.

Countries that experience increases in land and/or labor productivity can have significant declines in multifactor productivity of agriculture. Whether such a situation signifies an improvement in the agricultural economy is uncertain. A better understanding of the link between multifactor productivity and other economic variables is needed. Methods for measuring multifactor productivity will continue to improve. More empirical studies are required to determine whether DEA will be considered useful in measuring efficiency, productivity, and productivity due to technical change.

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Appendix

To solve for an efficiency index requires data across many observations at one point in time. In this study, country data on four or more inputs and one output were used to solve for each country's efficiency index. Since the number of cross sections equaled the number of countries, it would be difficult to write out a complete program for calculating an efficiency index. However, a simple numerical example, involving data from five countries, is provided to give readers a better understanding of the larger DEA optimization problems undertaken in this report.

Suppose there are five countries (A,B,C,D,E) that produce one output (out) using three inputs: labor (lb), land (ld), and fertilizer (frt). The observations can be arranged as:

	out	lb	ld	frt
A	266.7	1.403	3967	3089
B	1103.3	2.030	62100	7064
C	468.0	1.069	2256	5612
D	165.0	0.558	2178	1308
E	1700.3	12.867	20435	10460

The optimization problem for calculating efficiency for the kth observation is represented by the optimization conditions labeled 9 in the text. To calculate efficiency for country A in the above example, the programming problem would be set up as:

$$
\begin{gathered}
MIN \quad \lambda \quad S.T. \\
z_a*266.7+z_b*1103+z_c*468+z_d*165+z_e*17003.3 \geq 266.7 \\
z_a*1.403+z_b*2.03+z_c*1.069+z_d*.558+z_e*12.867 \leq \lambda*1.403 \\
z_a*3967+z_b*62100+z_c*2256+z_d*2178+z_e*204357.7 \leq \lambda*3967 \\
z_a*3089+z_b*7064+z_c*5612+z_d*1308+z_e*10460 \leq \lambda*3089 \\
z_a \geq 0 \\
z_b \geq 0 \\
z_c \geq 0 \\
z_d \geq 0 \\
z_e \geq 0 \\
z_a+z_b+z_c+z_d+z_e = 1
\end{gathered} \tag{11}
$$

The solution to this problem is: λ^* =.844, za = 0, z_b =.019, z_c =.276, z_d =.705, z_e = 0.

The number 0.844 represents the index of technical efficiency. If country A were completely efficient, it could reduce the use of its inputs by 15.6 percent and not reduce agricultural output. To create a frontier, the output and input observations for country D received the largest weight in the above example, followed by those for countries C and B.

To execute this problem using the Gams package:

```
$ Title Country wrapping
SET k / 1*5/
 ko input output
   / out, lb, ld, frt, one/;
set dat(k);
TABLE T2(K,ko)
             out      lb       ld      frt   one
        1   266.7   1.403    3967     3089  1
        2  1103.3   2.030    62100     7064  1
        3   468.0   1.069     2256    5612  1
        4   165.0   0.558     2178    1308  1
        5  1700.3  12.867   204357    10460  1
;
VARIABLES
lm
lambda
theta(k)
;
Positive variable theta, lm;
theta.up(k) = 100;
*theta.lo(k) = .0001;
lm.up = 200;
*lm.lo = .00001;
equations
out1 tot
eqv1 lb
eqv2 ld
eqv3 frt
iff unit equ
obj min lambda;
out1..Sum(dat,T2(dat,’out’)) =l= SUM(k,T2(k,’out’)*theta(k));
eqv1.. SUM(k,theta(k)*T2(k,’lb’)) =l=
   Sum(dat,T2(dat,’lb’))*lambda;
eqv2.. SUM(k,theta(k)*T2(k,’ld’)) =l=
   Sum(dat,T2(dat,’ld’))*lambda;
eqv3.. SUM(k,theta(k)*T2(k,’frt’)) =l=
   Sum(dat,T2(dat,’frt’))*lambda;
iff.. sum(k,theta(k)*t2(k,’one’)) =E= 1;
obj.. lambda =E= lm;
parameter par(*);
dat(k) = no; dat(’1’) = yes;
model year1 prod model /
out1,
eqv1,
eqv2,
eqv3,
iff,
obj/;
solve year1 using nlp minimizing lambda;
PAR(’1’)=Lm.L;
```

U.S. Department of Agriculture
Economic Research Service

SUMMARY OF REPORT AER-675

More Cleaning of All U.S. Export Wheat Does Not Pay; But Targeting Cleaning to Specific Markets Can Pay

December 1993

Contact: William Lin (202) 219-0840

Cleaning all U.S. export wheat beyond current practice is not economically feasible, according to a new report by USDA's Economic Research Service. Costs of additional cleaning would outweigh benefits by at least $8 million per year in the short run. The best strategy of promoting cleanliness of U.S. export wheat is to target clean wheat for niche markets, those that use wheat to meet very specific end-use demands for high-quality food products.

Concern over the quality of grain exported from the United States versus the quality of competitors' grain has increased in recent years. Some observers believe that selling grain that contains higher levels of dockage and foreign material than that of our competitors has reduced U.S. competitiveness in the world grain market. (Dockage is all matter other than wheat, such as chaff, stems, and stones. Foreign material is all matter other than wheat after dockage is removed; it is the most difficult material to remove from wheat.) Advocates argue that improving the cleanliness of U.S. grain will increase market share or is necessary to maintain U.S. market share at current levels. Critics argue that improving cleanliness will increase marketing costs, reduce profits, and diminish U.S. competitiveness.

In response to a request from Congress, the Economic Research Service (ERS), in cooperation with researchers at land-grant universities and the U.S. grain industry, conducted a study on the costs and benefits of cleaning U.S. grain. *Costs and Benefits of Cleaning U.S. Wheat* presents an overview and implications of this study and summarizes two other ERS reports produced in response to this study. The first, *Economic Implications of Cleaning Wheat in the United States,* focuses on the costs and domestic benefits of cleaning wheat. The second, *The Role of Quality in Wheat Import Decisionmaking,* focuses on importers' preferences with respect to cleanliness and other quality factors, and assesses the benefits of cleaning export wheat for international markets.

The wheat industry could gain $8 to $10 million in net benefits if it targets wheat cleaning to the cleanliness-conscious markets, which account for about 20 percent of all U.S. wheat exports. These markets include Italy, Venezuela, Togo, Ghana, and possibly Japan and the Philippines. The United States competes with Canada and Australia for these markets. Targeted wheat classes for cleaning are primarily dark northern spring (DNS) and durum wheat exported from the Pacific and Gulf ports.

While selling cleaner U.S. wheat in cleanliness-conscious markets may increase export prices or enhance the U.S. competitive position, cleanliness is not the most important factor affecting importers' demand for wheat. Price considerations, cleanliness, quality considerations, and institutional factors all influence the selection of a supply source in the world wheat market. In the many low-income countries that account for a majority of world wheat imports, wheat price, not quality, is the most important factor in the purchase decision.

To Order These Reports...

The information presented here is excerpted from ***Costs and Benefits of Cleaning U.S. Wheat: Overview and Implications,*** AER-675, by William Lin and Mack Leath. The cost is $9.00.

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U.S. Department of Agriculture
Economic Research Service

SUMMARY OF REPORT #FAER-250

African Nations Reduce Government Intervention in Agriculture

September 1993

Contact: Stacey Rosen, (202) 219-0630

Taxes on farmers and food subsidies for consumers fell as the governments of nine African nations reformed their agricultural policies in the 1980's. *Agricultural Policy Reform: Issues and Implications for Africa,* from USDA's Economic Research Service, traces effects of former government policies and subsequent reforms during 1982-89. Countries studied were Egypt, Morocco, Kenya, Tanzania, Zambia, Senegal, Nigeria, Zimbabwe, and South Africa.

Governments of these nations intervened significantly in agriculture during the 1970's and early 1980's, with heavily taxed farmers and widespread urban food subsidies. Governments also set prices and manipulated exchange rates which had the net effect of transferring income from producers to consumers. Such policies depressed farm production, leading to more food imports and higher foreign debt. Reforms began in the 1980's.

The new report measures government policy effects by estimating producer and consumer subsidy equivalents (PSE's and CSE's). PSE's are the ratios between the total value of policy transfers to producers and total producer revenue. A negative PSE signifies that government policies reduced producer revenue. CSE's are similar indicators on the consumer side. This study measures PSE's and CSE's for selected commodities for the nine African nations.

Government Intervention Distorted Both Foreign and Domestic Trade

These nine governments intervened in all stages of agricultural production and consumption. Marketing boards, often poorly managed, set production quotas and prices, and at times, imposed obligatory sales to government agencies. Artificially set food and producer prices distorted domestic trade, and unrealistic exchange rates deteriorated the balance of payments. At the same time, imports of raw materials and capital goods, essential for economic growth, were crowded out by the need to import food for the growing populations. Since agriculture contributes more than 30 percent of gross domestic product in Africa, the poor performance of this sector damaged these nations' overall economies.

International Response Brought Policy Reform

The World Bank and the International Monetary Fund insisted in the early 1980's on reforms in the agricultural policies of the affected countries. The goals of the reforms include limiting government borrowing and expenditures, reducing government deficits relative to the gross domestic product, reforming exchange rate policies, liberalizing markets, and decontrolling prices.

To Order This Report...

The information presented here is excerpted from ***Agricultural Policy Reform: Issues and Implications for Africa,*** FAER-250, edited by Stacey Rosen. The cost is $15.00.

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SUMMARY OF REPORT #TB-1830

New Model Can Assist NAFTA Analysis for Trade in Animal Products

December 1993

Contact: William F. Hahn, (202) 219-0712

A new mathematical programming model can help analyze the effects on the animal products trade under NAFTA, the North American Free Trade Agreement among the United States, Canada, and Mexico. The model can predict how changes in policies will affect the longrun production, trade, and prices of animals, meats, and dairy products of the three North American nations. This technical report, *North American Trade Model for Animal Products* from the USDA's Economic Research Service, describes the basic structure of the North American animal products industries and discusses the important policies that affect trade in animals and their products in North America. The model, called NATMAP, makes possible predictions as to how changes in government policies, income growth, and varying costs of productions can affect trade, production, and prices of animal products under the NAFTA agreement.

The report features a technical discussion of the economic theories underlying the model. The NATMAP model is based on the economic theory that competitive economies produce socially "ideal" patterns of production, consumption, and trade. NATMAP combines mathematical techniques with data on supply and demand to find optimal patterns of production and trade. The program calculates the socially ideal pattern of production and trade and allows the user to compare the patterns that result from changing policies and varying consumer incomes and production costs.

The Program Can Be Customized for Specific Uses

The documentation describes how a user can construct a specialized version of NATMAP for more customized longrun predictions. The ERS model runs on the General Algebraic Modeling System (GAMS) software, a system for mathematical programming. The baseline can be readily reconstructed with relevant and current data.

The Entire Program, User-Ready, Is Included In the Report

A user need only add an appropriate set of baseline assumptions to construct the customized working model. The documentation describes the construction of such a baseline. NATMAP has unusual latitude in specifying the economic parameters of the animal products industry. Two other appendixes provide further highly technical information on the NATMAP model, which is a static, spatial equilibrium, nonlinear, mathematical programming model. NATMAP uses cost minimization instead of surplus maximization to solve for prices, production, trade, and consumption. A discussion is given of the use of this cost minimization approach and its theoretical validity, and a final section provides GAMS programs for calculating the demand parameters for two different demand systems.

To Order This Report...

The information presented here is excerpted from ***North American Trade Model for Animal Products,*** TB-1830, by William F. Hahn. The cost is $12.00.

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