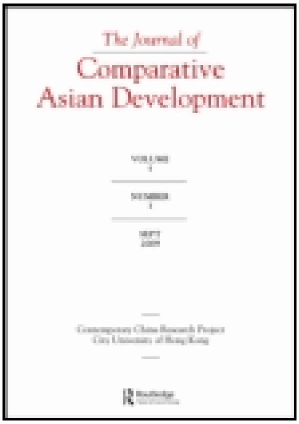

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Agricultural Productivity in the WANA Region*

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Abstract

The interest of governments, international organizations, NGOs and the general public has recently been aroused by studies considering the use of existing agricultural technology, the use of innovations in such technology and the production of agricultural goods. The attention received by such studies has grown as a result of an unprecedented wave of trade liberalization in the world (involving bilateral, regional and multilateral trade-integration processes), coupled with concerns over food security, high rates of population growth and the use of limited and frequently degraded natural resources. In this context, the Malmquist Index, used to measure agricultural productivity, is a powerful tool, providing insights into whether or not a country is approaching what may be termed "best practice" by using and disseminating existing technology (efficiency change), and/or by innovating technology (technical change). Using the Malmquist Index on a sample of 12 countries within West Asia and North Africa (WANA) indicated that, between 1961 and 1997, Turkey, Tunisia, Syria and Algeria (in that order) were the "most productive" countries. Following them, in terms of agricultural productivity, were Iran, Egypt, Jordan and Morocco, while Pakistan, Sudan, Yemen and Ethiopia were the "least productive" countries of the 12 considered. Recurring negative results, with

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respect to both technical change and efficiency change, in Ethiopia, Sudan, Pakistan and Yemen, suggest that governments and national and international organizations and research institutions should make greater efforts to strengthen agricultural research and extension services if food security and competitiveness are to be improved.

Keywords: Productivity; agriculture; Malmquist

1. Introduction

In West Asia and North African (WANA) countries, the basic resources on which agriculture depends (land and water) are limited and are being reduced and degraded by many factors, such as high urbanization, overuse of land and excessive water use for competing sectors (industry and services). In addition, a fast-growing population in WANA countries and the current wave of trade liberalization in the world (i.e., removal or elimination of subsidies, tariffs and non-tariff barriers to trade), have compelled countries to be competitive in agriculture not only for food security reasons, but also because agriculture is a sensitive sector for livelihoods, employment generation and associated multiplicatory effects.

In this context of risk for both agriculture and natural resources, the measurement of agricultural performance may serve as a key indicator to take policy actions if governments want to ensure food security, in terms of both quantity and quality. The assessment of agriculture can provide insights about how efficiently the agricultural sector is using its endowments. Agricultural history shows that the only proven way to improve agricultural productivity in the long term has been through research and extension investments. Hence, the results of this study may inspire the allocation of support to agricultural research and extension services.

Thus, the aim of this study is to measure agricultural productivity[1] in 12 countries of the WANA region. To this end, the Malmquist Index method was used, which allows the decomposition of total factor productivity (TFP) growth into "efficiency change" (ECh) and "technical change" (TCh). It facilitates the examination of whether technological progress is stagnant over time, and whether the given technology has been used in such a way as to realize its potential.

1 Understood as the product of changes in technical progress and efficient use of existing technology.

This study is organized as follows: Section 2 provides a literature survey on alternative approaches to measure agricultural productivity. Section 3 presents the theory underlying the Malmquist Index, where concepts of ECh, TCh and TFP are introduced. In Section 4, scores for all ECh, TCh and TFP calculated using the Malmquist Index are presented for each country included in the sample. Section 5 discusses the findings obtained with the Malmquist Index. Finally, Section 6 presents the conclusions and policy implications.

2. Literature Survey

In comparative economics, a country's achievable inputs and outputs are depicted using a production function. This function shows the maximum output which can be achieved with any possible combination of inputs, which is the so-called production technology frontier (Seiford & Thrall, 1990; Cook & Seiford, 2009). For the last 40 years, frontier techniques have set out the question of how to make comparisons of productivity between countries while overcoming the problem of using different inputs, prices and quantities, knowing the possible inputs–outputs combinations cannot be observed.

Different studies have sought to quantify productivity differentials between countries by indicators such as the yield per hectare or cost per hectare of output. These relationships have the advantage of being easy to calculate and understand, however they are of limited value when comparing agricultural productivity between countries. For instance, the yield per hectare does not give any indication about the input costs that have been employed in the production process (e.g., countries may use different inputs to obtain the same output level). This problem may be solved by using the cost per hectare approach, but because of the existence of different input prices between regions or countries, it is not possible to make valid comparisons. Both the yield and cost per hectare ignore economies of scale. As pointed out by Thirtle and Piesse (2007), simple cost analysis does not tell anything about what portion of the cost difference is due to inefficient use of the given input package (technical inefficiency) and what part is due to incorrect choice of input ratios (allocative inefficiency), given input prices.

To circumvent these issues, economists have developed different approaches that generate better indicators of agricultural productivity.

There are two fundamental approaches used to measure agricultural productivity, which are frequently labelled as parametric and non-parametric approaches. The parametric, which comprises the index number approach and the econometric approach, is probably the more common and has been described in Fried, Lovell and Schmidt (1993) and in Fried, Lovell, Knox and Schmidt (2008); and discussed in Fare et al. (1994) and Fare and Grosskopf (2009).

In the past, the parametric approach has widely used the Laspeyres Index (which uses base year prices but current quantities, i.e., base-period weights) to measure agricultural productivity through value added per unit of input. Applied to Iran and Pakistan (two of the countries included in this paper), Nomura, Lau and Mizobuchi (2008) based their GDP estimates on Laspeyres Aggregation Index to compare the total factor productivity performance between the countries. This index would state that an economy in the current period can afford to produce the same quantity as it consumed in the previous period. The Theil-Tornqvist Index, which uses prices from both the base period and the comparison period, is preferred to the Laspeyres Index because it does not require the unrealistic assumption that all inputs are perfect substitutes in production (Wiebe & Gollehon, 2006). Yet the main problem with the Theil-Tornqvist Index is that it does not satisfy transitivity conditions, making it inapplicable for comparisons involving a set of three or more countries (Prasada Rao & Selvanathan, 1990). Additionally Wiebe and Gollehon (2006) observes that index numbers use local currencies (such as dollars) to aggregate heterogeneous outputs and inputs, but such currencies are not adjusted to account for changes in the value of the currency over time, thus limiting the understanding of trends in agricultural productivity.

The index number also uses partial productivity and total factor productivity indices. Partial productivity indices relate output to a single input and is useful for indicating factor-saving biases, but it assigns overriding significance to the average physical productivity of a single factor as a measure of the overall productivity of the entire process, being therefore an inadequate indicator. Ellis (1993, p. 210) observes that partial productivity "inevitably results in ambiguity about the relative efficiency of farms of different sizes. Land productivity may be low when labour productivity is high and vice versa." The total factor productivity index relates the ratio of aggregate output to an aggregate of all inputs, describing the overall rate of productivity growth as a single series. An advantage of this approach is that it allows an arbitrary set of inputs and outputs, avoiding problems of good aggregations. A critical issue of this method, pointed out by Page, Bateman and Nishimizu (1988), is that it assumes that the individual countries are efficient, thus any improvement in agricultural productivity is due to technical progress. Therefore, this approach may confuse and not distinguish between technical change and efficiency change.

The econometric approach to agricultural productivity measurement is based on econometric estimation of the production technology. Broadly speaking, it assumes a functional form of the production function, then derives a system of input demand equation and adds errors to them, and finally uses the resulting equation system to estimate the unknown parameters. Once the model is stated, estimations of total factor productivity can be done. An advantage of this method is that it allows for statistical inference based on results. Perhaps its major weakness is the assumption of an explicit functional form for the technology and frequently for the distribution of the inefficiency terms. Cooper, Seiford and Zhu (2004) and Seiford and Thrall (1990) highlight that the regression approach has a number of weaknesses: it only gives residuals; it does not readily yield a judgement on efficiency; its ability to identify sources of inefficiency is weak; and it is influenced by outliers fitting a function on the basis of average behaviour. According to Fried et al. (2008), it may confound the effects of mis-specification of econometric functional form with inefficiency.

The non-parametric method, initiated as the Data Envelopment Analysis (DEA) by Charnes, Cooper and Rhodes (1978), builds on the individual firm evaluations of Farrell (1957) applying linear programming to estimate an empirical production technology frontier for the first time. In contrast to the preceding parametric approach, the DEA does not require any assumptions about the functional form. The efficiency of a country is measured relative to all other countries with the simple restriction that all countries lie on or below the efficient frontier. In their original study, Charnes, Cooper and Rhodes (1981, p. 668) described the DEA as a "mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations — such as the production functions and/or efficient production possibility surfaces that are a cornerstone of modern economics". More generally, the DEA is a methodology directed to frontiers rather than central tendencies. Instead of trying to fit a regression plane through the centre of the data, one floats a piecewise linear surface to rest on top of the observations (Emrouznejad & Thanassoulis, 2010).

While the parametrical procedures are based on central tendencies, the non-parametric approach or DEA is an external process. The DEA measures the relative efficiency with respect to the entire set being evaluated. An interesting characteristic noted by Egemen, de la Garza and Triantis (2009, p. 828) is that "a variable that is neither an economic resource nor a product, but is an attribute or of the environment or of the production process can be easily included in a DEA-based production model". Therefore, the non-parametric criterion appears to be a more robust procedure for agricultural productivity estimation.

The Malmquist Index uses the DEA, and though the Index is not a new approach, there have been a large number of books and journal articles applying DEA to estimate this index to compare technology and efficiency, and various sets of productivity problems, but none are specifically addressed to carry out a comparative study for the WANA region. This approach was adopted because one of the most important uses of the estimates is to gain an understanding of the sources of growth in agricultural productivity.

3. The Malmquist Index

The non-parametric approach, in the form of the Malmquist Index or total factor productivity was chosen for measuring agricultural productivity in the WANA countries. Fare et al. (1994) and Tauer (1998) identify this index as a more robust procedure for measuring agricultural productivity than parametric approaches (such as index numbers and econometric methods):

(1) It requires only data on quantities (of inputs and outputs) and so contributes to solving the difficult problem of service flow measurement for fixed factors.
(2) It does not require information on prices of inputs and outputs. This is important, because a characteristic problem in the WANA countries is the lack of reliable price information. Without this information, parametric approaches cannot be used; both index numbers and econometric methods require price information for the calculation of costs, profits and other functions.

(3) It does not require any assumptions to be made about the optimizing behaviour of economic units (in contrast to traditional index numbers).
(4) It does not require econometric estimations to be made, but can be implemented using a data envelopment technique.

To understand the construction of the Malmquist Index, it is necessary first to describe, briefly, the concepts of efficiency change and technical change. ECh refers to the degree to which a country uses the minimum feasible amount of inputs to produce a given level of outputs (also known as the Farrell Input-oriented Efficiency Measure (Farrell, 1957)). Knowledge of a production frontier permits the measurement of technical efficiency by measuring the input-distance function between each country in the sample and the production frontier (determined by the "leading" countries within the sample). To calculate ECh, the method involves the use of linear programming to envelope observed input–output data as tightly as possible, and thus to construct a non-parametric piecewise linear frontier based on the observed data. When a country "lies" on the frontier it is deemed to be technically efficient, otherwise it is technically inefficient.

Suppose that for each time period $t = 1,2,\ldots T$, there are $j = 1,2,\ldots J$ countries which use $n = 1,2\ldots N$ inputs to produce $m = 1,2,\ldots M$ outputs. An input-distance function may be evaluated for each country j as the solution to the following linear programming problems:

$$\frac{1}{D_j^t(y^{t,j}, x^{t,j})} = F_j^t(y^{t,j}, x^{t,j}) = min\lambda \quad \text{or} \quad \left[D_j^t(y^{t,j}, x^{t,j})\right]^{-1} = F_j^t(y^{t,j}, x^{t,j}) = min\lambda \qquad (1)$$

where x is a vector of inputs, y is a vector of outputs, $D_j^t\ (y^{t,j}, x^{t,j})$ is the input-distance function, $F_j^t\ (y^{t,j}, x^{t,j})$ is the Farrell input-orientated measure of technical efficiency, and λ (between 1 and ∞) is the maximum reduction of the input vector that can be achieved without reducing the output (the reciprocal of the input-distance function is the Farrell input-oriented measure of technical efficiency).

Subjecting (1) to:

$$y^t_{jm} \leq \sum_{j=1}^{J} z_j y^t_{jm} \quad m = 1, 2, \ldots.. M$$

and

$$\sum_{j=1}^{J} z_j y^t_{jm} \leq \lambda x^t_{jn} \quad n = 1, 2, \ldots.. N$$

$$z_j \geq 0 \quad j = 1, 2, \ldots.. J$$

where z_j is a $j_x 1$ vector that captures the convexity of the underlying technology, when non-zero it identifies the neighbourhood points that are used to evaluate the frontier technology. The linear programming problems have to be solved J times, one for each country. Minimizing inputs per unit of output determines the efficiency of the "best practice" production units and then determines the efficiency of all the other production units relative to the frontier.

TCh refers to shifts in technology over time, indicating whether the production frontier is improving, stagnant or deteriorating. As discussed by Bureau, Fare and Grosskopf (2008), the Malmquist Index is constructed from ratios of input-distance functions, which provide a very general description of the technology, especially when that technology involves many inputs and many outputs. To formalize the Malmquist Index, it is necessary to define four input-distance functions. Notations are the same as those presented above, and it is assumed that there are two time periods: t and $t + 1$. The first input-distance for period t is:

$$D^t_i(y^t, x^t) = max\left[\lambda : \left(\frac{x^t}{\lambda}\right) \in L^t(y^t)\right] \tag{2}$$

where L^t (y^t) denotes all input vectors x^t capable of producing a given output vector y^t, such that:

$$L^t(y^t) = \left[x^t : (x^t, y^t) \in S^t\right] = \left[x^t \ can\ produce\ y^t\right]$$

Similarly, the second input-distance function for the period $t + 1$ can be defined as:

$$D_i^{t+1}(y^{t+1}, x^{t+1}) = max\left[\lambda : \left(\frac{x^{t+1}}{\lambda}\right) \in L^{t+1}(y^{t+1})\right] \tag{3}$$

The input-distance functions (2) and (3) are known as within-period distance functions, given that technological changes take place in the same period. The third input-distance function, known as an adjacent-period function (as technological changes are “measured” from one period (t) to another ($t + 1$)), may also be defined as:

$$D_i^{t}(y^{t+1}, x^{t+1}) = max\left[\lambda : \left(\frac{x^{t+1}}{\lambda}\right) \in L^{t}(y^{t+1})\right] \tag{4}$$

and the fourth function, also classified as an adjacent function, can be expressed as:

$$D_i^{t+1}(y^{t}, x^{t}) = max\left[\lambda : \left(\frac{x^{t}}{\lambda}\right) \in L^{t+1}(y^{t})\right] \tag{5}$$

These four input-distance functions are not independent of each other, and are used to construct the Malmquist Productivity Index. Equation (6) is the mathematical expression of the Malmquist Index. The expression within the first set of brackets measures the ECh between periods t and $t + 1$. The calculated value can be greater than, equal to or less than one according to whether the ECh improves, remains unchanged or declines between periods t and $t + 1$. The calculated value is a measure of how close to (or far away from) the production frontier a country is. It is expected that the expression within the first set of brackets captures the diffusion of technology.

$$M_i^{t,t+1} = \left[\frac{D_i^{t}(y^{t}, x^{t})}{D_i^{t+1}(y^{t+1}, x^{t+1})}\right] x \left[\frac{D_i^{t+1}(y^{t}, x^{t})}{D_i^{t}(y^{t+1}, x^{t+1})} x \frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^{t}(y^{t}, x^{t})}\right]^{1/2} \tag{6}$$

The geometric mean provided by the second bracket is a measure of TCh, and it captures the shifts in technology between the two periods evaluated (i.e., t and $t + 1$). Its value can also be greater than, equal to or less than one, indicating whether the frontier is improving, stagnant or deteriorating. An improvement in the TCh component is considered to be evidence of innovation. The Malmquist Index value, or TFP, is the product of ECh and TCh. Its value can also be greater than, equal to or less than one indicating whether agricultural productivity improves, remains unchanged or declines.

4. Measuring Agricultural Productivity: An Application of the Malmquist Index

This section presents the results obtained from the use of the Malmquist productivity index. The Data Envelopment Analysis Program (DEAP), developed by Coelli (1992), was used for computing TFP, ECh and TCh scores.

4.1. Sample

The sample used comprised the agricultural sectors of six West Asian (Iran, Jordan, Pakistan, Syria, Turkey and Yemen) and six North African (Algeria, Egypt, Ethiopia, Morocco, Sudan and Tunisia) countries. For the calculation of agricultural productivity, the study included one output (agricultural GDP) and five inputs (land, labour, livestock, fertilizer and machinery), which were chosen because they were representative of both the traditional and modern inputs used in these countries. Data for the output and five inputs covered the period 1961–2007. The definition of each one is as follows:

Output

- *Aggregate agricultural output*: this is the total value (measured in US dollars) of agricultural production for each of the countries included in the sample. This value is expressed in current international dollars, which were derived using purchasing power parity conversion rates. This aggregate includes food and non-food outputs. Data was obtained online from the *World Development Indicators* (World Bank 2009), with variable agriculture value added.

Traditional inputs

- *Land*: measured in hectares, this variable includes arable land and permanent crops. The former includes land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The latter comprises land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber. This category also includes land under flowering shrubs, fruit trees, nut trees and vines. Excluded from this category is land under trees grown for wood or timber and the abandoned land resulting from shifting cultivation. The source of information was the FAO ResourceStat online database.
- *Labour*: measured in number of workers, it is defined as all persons depending for their livelihood on agriculture, fishing or forestry. This estimate comprises all people actively engaged in agriculture and their non-working dependants. Labour data was obtained from the FAO PopStat online database.
- *Livestock*: it is an aggregate of the number of cattle, sheep, chicken, goats, asses, mules, horses, buffalo, camels, ducks and turkeys. Following Hayami and Ruttan (1985), the weights of aggregation were: 1.1 camels, 1.0 buffalo, horses and mules, 0.8 cattle and asses, 0.2 pigs, 0.1 sheep and goats and 0.01 poultry. The source of information was the FAOSTAT online database — Production, live animals.

Modern inputs

- *Fertilizer*: measured in quantities of fertilizers, it is the aggregate of nitrogen, phosphate and potassium soil nutrients consumed in agriculture by a country. Fertilizer data was obtained from the FAOSTAT online database — ResourceStat, Fertilizer archive.
- *Machinery*: refers to quantities of tractors and pedestrian tractors used in agriculture (it excludes garden tractors). Machinery data was obtained from the FAOSTAT online database — ResourceStat, Machinery archive.

Our calibration consisted of comparing one known magnitude or standard country data set with another measurement made in a similar possible way with a second device, e.g., data from the *Annual Agricultural Statistic*

Abstract of the Syrian Arabic Republic was the known magnitude that was compared with data from the FAO or from the *World Development Indicators*, which estimates the global, national and regional figures. We used the known magnitude to remove the short-run disturbing fluctuations or unusual information from the macroeconomic panel or time series data.

4.2. Technological Change and Total Factor Productivity

Conceptually, there are two different ways by which a country can increase its agricultural productivity. One way is to improve efficiency change through the "best practice" by increasing the diffusion of technology, and the other way is to promote technical change, through importation and adaptation of new technology. Of course, a combination of both also increases agricultural productivity. Computed values of the Malmquist Indices are presented in Table 1.

In North Africa, for Algeria and Tunisia (in that order), scores of TFP greater than one were recorded for all periods, indicating the highest agricultural productivity relative to the other countries considered in the study. The driving forces were improvements in ECh as well as in TCh. TFP scores in the Moroccan case were higher than one in all periods, except in 1991–2000 when it experienced a decline in ECh (a score of less than one), also indicating high agricultural productivity relative to the other countries of the sample.

Ethiopia, Egypt and Sudan (in that order) were the "least productive" or "least efficient" in Northern African countries included in the sample. In the Ethiopian case, its values for TCh were lower than one in the 1960s, 1970s and 1980s, which indicated both a decline in agricultural productivity and a lack of applied technological innovations. These scores may reflect the socio-political problems that Ethiopia faced during those decades. For example, between 1973 and 1993, there was a civil war, as well as warfare with neighbouring countries and conflict between separatist groups. This, coupled with drought and famine in the 1980s,[2] caused severe damage to the Ethiopian economy.

In these three countries, ECh scores were exactly one for all of the periods considered (except for Sudan in 1971–80), meaning that there was no change in efficiency over those periods. Arnade (1998) gives a poss-

2 During the 1980s, an estimated 1 million Ethiopians died from starvation as a result of famine.

Table 1 Efficiency Change (ECh), Technical Change (TCh) and Total Factor Productivity (TFP) per Country

		North Africa						West Asia					
Period		Algeria	Egypt	Ethiopia	Morocco	Sudan	Tunisia	Iran	Jordan	Pakistan	Syria	Turkey	Yemen
1961–70	ECh	1.01	1.00	1.00	1.01	1.00	1.03	1.00	1.05	1.05	1.00	1.00	1.00
	TCh	1.02	1.02	0.89	1.01	0.98	1.01	0.97	1.00	0.96	0.96	0.99	0.97
	TFP	1.03	1.02	0.89	1.02	0.99	1.04	0.97	1.05	1.00	0.96	0.99	0.97
1971–80	ECh	1.12	1.00	1.00	1.11	1.09	1.16	0.98	1.08	0.99	1.00	1.00	1.00
	TCh	1.08	1.05	0.92	1.01	1.00	1.05	0.97	1.05	1.01	1.04	1.07	0.87
	TFP	1.21	1.05	0.92	1.12	1.09	1.22	0.95	1.14	1.00	1.04	1.07	0.87
1981–90	ECh	1.02	1.00	1.00	1.04	1.00	1.03	0.98	0.98	0.97	0.99	1.01	0.99
	TCh	1.05	1.05	0.99	1.00	1.12	1.03	1.02	1.05	1.03	1.01	1.06	1.03
	TFP	1.07	1.05	0.99	1.03	1.12	1.06	1.00	1.03	1.00	1.00	1.07	1.01
1991–2000	ECh	1.00	1.00	1.00	0.99	1.00	1.00	1.05	0.97	1.03	1.04	1.00	1.02
	TCh	1.02	1.04	1.02	1.05	1.07	1.01	1.01	1.00	1.03	1.02	1.02	1.04
	TFP	1.02	1.04	1.02	1.04	1.07	1.01	1.06	0.98	1.06	1.07	1.02	1.06
2001–07	ECh	1.00	1.00	1.00	1.02	1.00	1.00	1.02	1.08	1.03	1.00	1.01	0.98
	TCh	1.16	1.01	1.12	1.09	1.02	1.08	1.07	1.06	1.03	1.06	1.10	1.19
	TFP	1.16	1.01	1.12	1.11	1.02	1.08	1.10	1.15	1.06	1.06	1.12	1.16

Source: Own elaboration, with computed values of the Malmquist Indices based on the *World Development Indicators*, FAO ResourceStat, FAO PopStat, and FAOSTAT.

ible explanation for this peculiar result. He argues that when there are no apparent changes in efficiency levels (i.e., when ECh = 1), in the case of developing countries in which extraordinarily low levels of inputs are used, then this may be interpreted as either no change, or a slight improvement, in the use of outdated technology. In the case of Egypt and Sudan, some improvements were registered in TCh in the 1980s and 1990s. This may reflect improvements in the agricultural extension services in those countries.

Of the West Asian countries sampled, the records of TFP (the measure of agricultural productivity) indicate that the "most productive" countries were Turkey and Jordan (in that order). In the Turkish case, the values of TCh were greater than one in most of the periods considered, indicating that innovation had occurred. In other words, in spite of stagnant scores of ECh, the production function of the Turkish agricultural sector had been shifting upwards, with a positive effect on agricultural productivity. Jordan recorded improvements in TCh, but ups and downs in ECh scores, indicating enhancements in the 1960s and 1970s, declines in the 1980s and 1990s and a recovery in the period 2000–2007.

Syria has not shown any improvement (relative to the other countries in the sample) in terms of agricultural efficiency (stagnant estimated values of ECh). However, it is outstanding that technical change registered values greater than one in all periods but 1961–70, which indicates technological innovations leading to improvements in agricultural productivity. In the Pakistan case, agricultural productivity increased from the 1990s onwards due to better use of existing technology (scores of ECh higher than one) and improved technology (TCh values higher than one). In the 1960s, 1970s and 1980s, agricultural productivity remained stagnant (TFP scores equal to one), with higher than one scores for ECh being offset by lower than one scores for TCh.

Yemen and Iran recorded the lowest scores for TFP in West Asia. The Yemeni TCh scores for the 1960s and 1970s (0.97 and 0.87 respectively) were low. These low records may reflect the socio-political problems which occurred in Yemen during those decades. The North Yemen Civil War from 1962 to 1970 disrupted economic activities and caused major damage to infrastructure throughout the country, affecting agricultural production, input supply and quantities of tradable outputs. In the 1980s, 1990s and the period 2000–2007, scores of TCh improved, pushing towards slight improvements in agricultural productivity. The Iranian case showed improvements in TFP for the 1900s and 2000–2007, but declines in agricultural productivity in all previous periods, which were explained by declines in ECh and TCh.

When we say that the technical change is said to be stagnant, it does not necessarily mean that no technical change has occurred at all. It may have occurred but at very low rates compared with those occurring in the best practice countries, such as Turkey and Tunisia (remember that each country's technical change performance was measured only relative to the best countries in the sample).

Recently Shahabinejad and Akbari (2010) also used DEA to undertake a comparative agricultural productivity study on Egypt, Iran, Pakistan and Turkey (among others) for the period 1993–2007. Focusing on the growth in TFP and its decomposition into technical and efficiency change components, they found (similar to the findings of this study) that TCh has been the main source of growth in TFP for Egypt, Iran, Turkey and, to a lesser extent, Iran. The study also noted that ECh has been a serious constraint in the achievement of high levels of TFP. With the current know-how in input use, such constraint has prevented these countries from further increases in agricultural output.

Fuglie (2010) has undertaken a worldwide comparative study on agricultural productivity indicators. For the estimation of TFP, Fuglie (2010) also used 1961–2007 FAO annual data on agricultural outputs and inputs. His results, unavailable for individual nations but grouped for West Asian and North African countries, suggest that accelerating TFP improvement was offset by decelerating input growth. Another paper by Ludena et al. (2007) also used the Malmquist index to calculate past and estimate future agricultural productivity growth for the period 1961–2001. This study was conducted on a global basis (i.e. 116 countries worldwide), but detail was lost as for presentation purposes results were grouped into blocs that included West Asian and North African countries. In general terms, their findings also suggest that technological diffusion has been an important driving force of agricultural productivity across regions.

5. Discussion

The above findings are quite important because they allow the ranking of the more and less productive countries, and have useful agricultural policy implications. Tables 2–5 are constructed in order to provide empirical support for the findings obtained using the Malmquist Index.

Table 2 Agricultural Value Added per Worker (Constant US$2,000), per Country and Time Period

Country	1961–70	1971–80	1981–90	1991–00	2001–07	Periodical growth rate (%)
Algeria	539.3	943.2	1,519.1	1,880.3	2,156.9	41.4
Tunisia	812.8	1,359.5	1,678.8	2,370.3	2,809.9	36.4
Iran	753.8	1,105.2	1,557.5	2,147.7	2,596.6	36.2
Jordan		683.0	1,246.2	1,415.9	1,605.0	32.9
Syria			2,228.2	2,780.6	3,674.0	28.4
Egypt	839.5	955.6	1,262.2	1,673.2	2,242.9	27.8
Pakistan	367.2	418.8	496.8	646.6	748.0	19.5
Morocco	920.8	1,007.5	1,150.2	1,341.1	1,837.1	18.8
Sudan	402.5	461.3	437.6	529.4	721.9	15.7
Yemen			279.0	296.2	343.6	11.0
Turkey	1,521.3	1,680.6	1,734.1	1,762.6	2,212.6	9.8
Ethiopia				155.8	169.4	8.8

Source: Own elaboration based on the FAO's FAOSTAT, *World Development Indicators*, and United States Department of Agriculture's online databases.

Table 2 shows that the agricultural value added per worker (as represented by the agricultural GDP) increased sharply in the sample period in three (Jordan, Algeria and Tunisia) out of the four more productive countries according to the Malmquist Index. In Turkey it did not grow substantially as the agricultural value added already had high values (the highest in the sample). Characteristic of those countries was a general increase in the use of modern inputs such as fertilizers (Table 3) and machinery (Table 4), and an increase in the area of irrigated land (Table 5). This suggests that the growth in agricultural productivity was due to an increased use of modern inputs (i.e., TCh), as well as to increments in agricultural efficiency (ECh).

Tables 3 and 4 show the use of fertilizer and machinery. Jordan and Turkey have invested heavily in these two important agricultural inputs. Their use of fertilizer grew noticeably from 10.6 and 8.3 kg/ha in the 1960s to about 400 and 87.7 kg/ha in the period 2001–07 respectively. The less productive countries Yemen, Ethiopia and Sudan have modestly

Table 3 Average Fertilizer Consumption (kg/ha), per Country and Time Period

Country	1961–70	1971–80	1981–90	1991–00	2001–07	1961–2007 average
Egypt	112.1	188.2	349.5	337.3	473.2	292.1
Jordan	10.6	21.3	42.8	54.5	400.6	105.9
Pakistan	7.6	32.7	73.7	112.4	147.3	74.7
Turkey	8.3	35.6	58.0	69.7	87.9	51.9
Iran	3.3	22.5	61.4	64.2	83.9	47.0
Syria	3.5	14.1	40.4	62.3	64.2	36.9
Morocco	8.5	20.6	32.4	32.4	41.3	27.0
Algeria	8.8	24.0	24.4	11.3	12.1	16.1
Tunisia	5.7	10.2	19.1	20.2	22.8	15.6
Yemen	0.1	3.6	11.0	9.3	8.7	6.5
Ethiopia	0.2	1.8	4.5	12.3	8.1	5.4
Sudan	2.6	4.4	5.4	3.7	3.7	4.0

Source: Own elaboration based on the FAOSTAT online database.

increased their use of mineral fertilizers (nitrogen, phosphate and potassium) over time. In 2001–07 they all consumed less than 9 kg/ha of fertilizers, which is a small amount from the viewpoint of soil fertility.

It is worth pointing out the increased use of fertilizers in Pakistan and Egypt. These countries, together with Mexico, India and the Philippines, participated actively in the 1960s and 1970s in the development of agricultural production that emphasized the use of hybrid seeds, fertilizers and mechanization of agriculture, which came to be called "The Green Revolution". The TCh scores for Egypt and Pakistan were higher than one in most periods, indicating the efforts at agricultural innovation (such as the use of genetically improved varieties, better irrigation systems, etc.) paid off for these countries.[3]

Iran has also substantially increased its fertilizer consumption and, in this study, improvements in technical change were observed in the 1980s, 1990s and the 2001–07 period (Table 1). These improvements might

3 It is generally considered that the extra food produced by the Green Revolution has reduced famine in India and Pakistan.

Table 4 Tractor Use per Hectare, per Country and Time Period

Country	1961–70	1971–80	1981–90	1991–2000	2001–07
Turkey	433.5	127.8	47.9	34.2	26.4
Egypt	181.6	119.7	51.7	39.9	35.8
Jordan	181.8	88.0	68.2	61.5	46.9
Syria	910.7	377.0	128.4	67.1	52.8
Pakistan	2,062.2	466.2	123.9	71.5	59.2
Iran	1,141.8	409.2	112.0	78.8	66.2
Algeria	215.2	174.2	111.5	86.4	83.2
Tunisia	300.8	198.2	188.5	149.6	126.7
Morocco	806.7	461.8	261.6	233.8	213.0
Yemen	1,782.6	491.3	266.1	261.3	243.5
Sudan	4,422.6	1,426.9	1,310.8	1,438.2	857.8
Ethiopia	20,669.1	3,816.0	3,567.3	3,572.6	4,271.6

Source: Own elaboration based on the FAOSTAT online database — ResourceStat, Machinery archive.

have been consequences from the 1963 land reform and the social and economic development programme known as the "White Revolution", which was introduced over a 15-year period. However, a reduction in ECh and stagnant TFP in Iran during the 1980s was observed. This might reflect the eight years of war against Iraq, which weakened its agricultural sector during this decade.

In Turkey, Jordan and Algeria (three out of the four most productive countries), the agricultural machinery use per hectare also rose very quickly. In Turkey one tractor was used to service 433.5 hectares on average, which decreased to 26.4 hectares per tractor in 2001–07. Likewise in Jordan and to a lesser extent in Algeria and Tunisia, the number of tractor-serviced hectares decreased over time. It is noticeable that Yemen, Ethiopia and Sudan (where agricultural productivity has not improved in relation to the other countries of the sample as estimated through the Malmquist Index), the number of tractor-serviced agricultural land still remains high.

As part of their strategies to increase agricultural output, three out of the four higher-ranked countries (Turkey, Algeria and Tunisia) continuously

Table 5 Irrigated Land (ha), per Country and Time Period

Country	Irrigated Land (ha)					Compounded Inter-periodical Growth Rate (%)
	1961–70	1971–80	1981–90	1991–97	2001–07	
Turkey	1,482,900	2,248,900	3,280,000	4,110,286	5,215,000	36.9
Algeria	233,500	245,500	324,900	527,857	816,000	36.7
Tunisia	110,000	204,300	291,200	380,143	347,750	33.3
Yemen	234,300	279,300	308,500	455,857	658,250	29.5
Syria	541,600	548,900	629,100	1,024,714	1,404,800	26.9
Jordan	32,500	35,800	51,700	68,714	78,400	24.6
Morocco	897,500	1,079,400	1,245,300	1,257,000	1,573,720	15.1
Iran	4,930,000	5,606,000	6,517,900	7,216,857	8,575,400	14.8
Pakistan	11,900,400	13,797,200	15,935,000	17,211,429	18,610,000	11.8
Egypt	2,680,100	2,702,700	2,531,900	3,162,571	N/D	5.7
Sudan	1,556,000	1,719,500	1,902,200	1,946,571	1,481,400	–1.2
Ethiopia	151,700	157,700	161,800	182,429	137,600	–2.4

Source: Own elaboration based on the 1961–97 data collected from the *Statistical abstract, Syrian Arabic Republic*, 1991–98 and *Annual agricultural statistic abstract of the Syrian Arabic Republic*, 1985–98. The 2001–07 data was collected from the FAOSTAT online database. No data (N/D) was found for Egypt in 2001–07.

increased their areas of irrigated land — e.g., between the periods 1961–70 and 2001–07, Turkey increased its irrigated land area at a compounded inter-periodical growth rate of 36.9 per cent. The areas of irrigated land in Algeria and Tunisia increased at compound rates of 36.7 and 33.3 per cent respectively (Table 5). As expected, the lowest-ranked countries (Sudan and Ethiopia) actually reduced their irrigated lands at negative compounded inter-periodical rate of –1.2 and –2.4 per cent respectively.

The number of people who depended on agriculture, fishing or forestry for their livelihoods decreased in three (Turkey, Tunisia and Algeria) out of the four most productive countries, while increasing slightly in Jordan. Fewer people working on agriculture is a characteristic of economies that experience economic growth and rural development. This characteristic is usually associated with the well-known phenomenon “economic tertiary”, where the agricultural labour force is absorbed by the tertiary sector (generally services). In Ethiopia, Sudan and Yemen (three of the least productive countries in the sample) the number of people who depend on agriculture for their livelihoods actually increased at 2.14%, 1.74% and 1.65% per year between 1961 and 2007 respectively. More people depending on agriculture is historically a characteristic of economic deterioration and decrease in agricultural labour productivity.

As can be seen from the tables and Figure 1, the four more productive countries increased their use of modern inputs such as fertilizer and machinery, whereas their use of traditional inputs such as land and labour grew slowly, or even decreased. On the other hand, in the less productive countries (Ethiopia, Yemen, Sudan and, to a lesser extent, Iran), the use of fertilizers and machinery increased at moderate rates (except in Iran, where the use of modern inputs increased at a significant rate), while the use of traditional inputs, especially agricultural labour, increased at considerable rates.

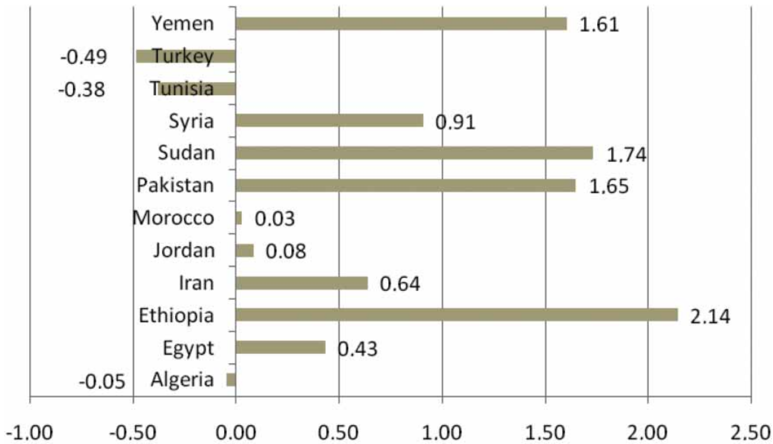
Further evidence on and insights into inter-country differences can be gained by comparing labour and land partial productivity among countries over successive time periods. In Figure 2, the "agricultural GDP per agricultural worker" was plotted against the "agricultural GDP per hectare of agricultural land", for the periods 1961–70, 1971–80, 1981–90, 1991–2000 and 2001–07.[4] Each co-ordinate point represents one country's position at one time period. For each country, data for successive periods are joined with a line indicating the pattern of agricultural performance over time. If such a line is parallel to the plotted 45° line, it indicates that "agricultural GDP per agricultural worker" and "agricultural GDP per hectare of agricultural land" are equal.

Figure 2 was constructed using the concept of partial productivity, which relates an aggregate of outputs to a single input (for example, agricultural GDP per agricultural worker on the figure's vertical axis). The problem with using this concept is that it assigns overriding significance to the average physical productivity of the single input factor (labour in this case). However, the concept is still useful because it provides insights into the historical performance of the sector.

The plotted line for Tunisia (one of the four most productive countries) has a steeper slope than the 45° line, meaning that the agricultural GDP growth per worker (vertical axis) contributed more than the agricultural GDP growth per hectare of land (horizontal axis) to the performance of the agricultural sector of this country. In the case of Turkey, the slope

4 Egypt was not included in Figure 2 because of a problem with scale. However, data for Egypt, as well as for the other 11 countries, are presented in Table 6.

Figure 1 Population Depending on Agriculture for Livelihoods



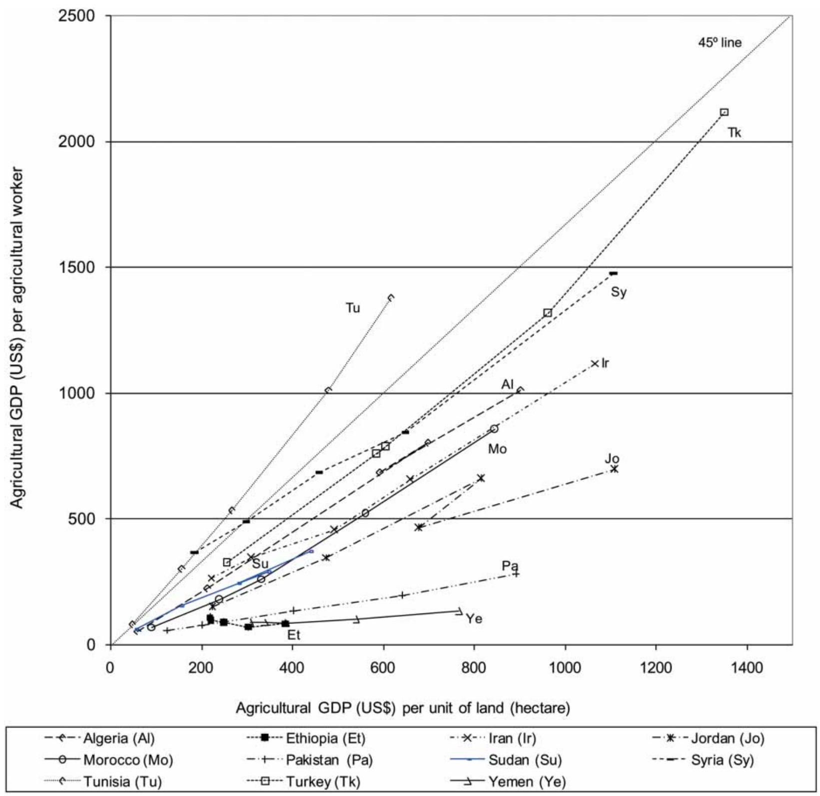
Source: Own elaboration based on the FAOSTAT online database (PopStat). The FAO defines "agricultural population" as all persons depending for their livelihoods on agriculture, hunting, fishing or forestry. This estimate comprises all persons actively engaged in agriculture and their non-working dependants.

changes from flatter than the 45° line in the first four decades (1960s, 1970s, 1980s and 1990s) to a steeper slope for the last period (2001–07), meaning that in the first decades agricultural GDP growth per hectare contributed more than the agricultural GDP growth per worker, but it reversed in the last period. In both cases, Tunisian and Turkish, faster growth of agricultural GDP per worker means increased agricultural workers' productivity.

The plotted lines for Algeria, Iran and Syria were slightly flatter to the 45° line, indicating a slightly faster growth of agricultural GDP per hectare of agricultural land in relation to agricultural GDP per worker. For the rest of the countries included in the sample, agricultural GDP grew as a result of more contribution of agricultural land in comparison to the contribution of agricultural workers, which indicates a relatively lower productivity of agricultural workers.

Data for Jordan showed a particular pattern. Both agricultural GDP per hectare and agricultural GDP per worker increased between the 1960s and 1980s (Figure 2). However, in the 1990s agricultural GDP per worker decreased in relation to the figure of the 1980s, and recovered again in

Figure 2 Agricultural GDP per Agricultural Worker and per Hectare of Agricultural Land



Source: Own elaboration based on the FAOSTAT and *World Development Indicators* online databases.

the 2000–07 period, which explains a “Z” shaped form of its agricultural GDP line over time.

The agricultural performance of Yemen and Sudan (two of the least productive countries) shown in Figure 2 illustrates that the contribution of agricultural GDP per worker was insignificant, denoting poor performance of agricultural labour productivity. In the Ethiopian case, the agricultural GDP per worker actually decreased from 1960 to 2007 (from US$108.5 to US$84.2 per agricultural worker as shown in Table 6). Data for Yemen indicated that agricultural GDP per worker marginally grew

Table 6 Agricultural GDP agricultural worker and unit of land

	Algeria		Egypt		Ethiopia		Iran	
Period	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)
1961–70	55.1	60.4	68.2	540.1	108.5	219.1	266.4	221.2
1971–80	224.5	213.7	126.5	1153.0	97.2	221.4	345.3	311.3
1981–90	801.9	698.0	250.1	2525.0	89.0	249.8	455.5	493.1
1991–00	684.1	593.3	421.1	3315.3	71.7	303.6	656.5	660.7
2001–07	1010.8	901.6	570.3	3989.9	84.2	384.6	1118.9	1067.6
	Jordan		**Morocco**		**Pakistan**		**Sudan**	
Period	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)
1961–70	151.4	223.5	71.2	91.2	59.0	126.3	59.6	54.5
1971–80	348.4	475.4	179.7	241.3	78.3	202.3	153.6	154.1
1981–90	661.2	816.8	262.5	334.1	134.9	403.3	290.3	346.4

(*Continues*)

Table 6. Continued

Period	Algeria		Egypt		Ethiopia		Iran	
	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)
1991–00	464.7	678.5	520.6	560.1	194.4	642.5	234.4	281.7
2001–07	646.9	1109.9	855.1	845.5	280.5	893.4	371.0	439.3

Period	Syria		Tunisia		Turkey		Yemen	
	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)	Agric. GDP (US$) per agricultural worker	Agricultural GDP per unit of land (ha)
1961–70	368.7	186.7	80.5	47.5	325.7	255.4	90.3	307.5
1971–80	489.7	298.2	301.2	156.6	788.1	606.0	91.2	339.9
1981–90	684.4	458.8	534.1	266.6	759.4	585.5	87.1	386.3
1991–00	843.7	647.9	1012.8	480.6	1316.4	963.0	102.2	540.0
2001–07	1478.4	1108.1	1377.9	616.6	2119.1	1351.9	133.6	766.9

Source: Own elaboration based on the *World Development Indicators* online databases, agricultural GDP and population variables.

from US$90.3 to US$133.6 in almost 50 years of agricultural history in that country (from the 1960s to the 2000–07 period).

6. General Discussion

Comparison of the agricultural TFPs of different countries, using the Malmquist Index, has revealed the diverse performances of the agricultural sectors of the 12 countries in the sample. The most productive countries were Turkey, Algeria, Tunisia and Jordan, in that order. Morocco, Egypt, Syria and Pakistan followed them. Finally, the agricultural sectors of Iran, Sudan, Yemen and Ethiopia were, in comparison, the least productive.

The decomposition of TFP growth into ECh and TCh provides indicators of the status of the production technology applied by particular countries. For example, this analysis, applied to Turkey and Tunisia, indicate that technical progress (i.e., TCh scores that were greater than one) has been occurring over time, and that existing technology has been used in such a way as to realize its potential significantly. The movement of the frontier over time also reflects the success of specific policies that aimed to facilitate the acquisition/development of foreign/local technologies. As noted by Kalirajan, Obwona and Zhao (1996), changes in ECh over time and across individual countries will indicate the level of success of a number of important dimensions of industrial or agricultural policies.

The TFP results for Morocco (i.e., TCh smaller than ECh scores) imply that policy actions should focus more on accelerating the rate of TCh (agricultural innovation) than the rate of ECh (technology diffusion). The opposite applies to the case of Jordan, where ECh scores tended to be smaller than TCh scores, indicating the need for strengthening policy actions focusing on accelerating the rate of agricultural services throughout the country.

The low values of ECh obtained for Iran, Pakistan and Syria (indicating an ineffective application of existing technologies), suggest that policy actions are needed to place more emphasis on extension programmes, without sidelining agricultural innovations (TCh). With regard to Egypt, all of its ECh scores were estimated to be one, indicating stagnant or no improvement in the use of existing technology which has not been used to its full potential. Agricultural productivity in this country has grown, thanks to improvements in TCh only. This reflects the need for strengthening agricultural extension services not only in the fertile Nile-surrounding areas of Egypt, but most importantly in highly populated southern parts of the country.

The results obtained for Ethiopia, Yemen and Sudan indicate that these countries were quite “far” from the production frontier for all the time periods considered. For these countries, which have adopted technologies that originated abroad, the TFP scores of less than one denote a failure to acquire/develop and adapt new technology, which implies a lack of shifts in the frontier over time. Inefficiency and lack of innovation may be due to the increasing number of agricultural workers in these countries. It implies that policy actions are necessary to absorb the high rates of population growth into other sectors of the economy. It can be interpreted as the establishment of rural-based factories, which in turn could create more off-farm employment opportunities. In general, chronic under-one scores in respect of both technical change and efficiency change in these three countries suggest that governments and national and international institutions should make greater efforts to strengthen agricultural research and extension services in these countries if food security and national well-being are to be improved.

7. Implications

The implication of this study is that national and international organizations need to increase their efforts to improve the performance of the agricultural sector in the least productive countries. This requires increased investment in agricultural research, improved infrastructure and supporting policies. Without such action, the livelihoods of the rural people and competitiveness of their agricultural sectors will remain marginal.

Yet the TFP results from countries like Turkey, Algeria, Tunisia and Jordan indicate some optimism about the prospects of agricultural productivity as a response to economic development. Over time, the TFP has grown quickly in some regions, showing that it might not necessarily take several years for the agricultural sector to respond to policy actions oriented at increasing agricultural output and food security. Nonetheless, the TFP results from Ethiopia, Yemen and Sudan indicate that they were unable to sustain productivity growth in agriculture, thus suffering from low levels of food security and rural well-being.

The fact that TCh has been the main driving force of TPF tells us that investing in agricultural research is the main lever to increase productivity. Yet it must be acknowledged that low values of ECh usually indicate that long time lags between agricultural research investments and productivity response exist. This indicates that spending on agricultural research must be accompanied by agricultural extension programmes that not only contribute to broaden the use of new technology, but to agricultural capital formation as well.

Also the fact that our TFP growth estimates have been uneven across countries suggest that rather than undertaking a comprehensive agricultural research investment per region, what is needed is a more selective criterion for a clear understanding of the baseline reasons for low agricultural productivity per country and per commodity. Then a relatively strong performance and better targeted investments per commodity group can be achieved.

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