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PRODUCTIVITY, EFFICIENCY AND TECHNICAL CHANGE IN WORLD AGRICULTURE: A FÄRE-PRIMONT INDEX APPROACH.

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Abstract

This paper makes a comparative analysis of the total factor productivity (TFP) estimations on the agricultural sector between the traditional Malmquist index and the new Färe-Primont index (FPI) proposed by O´Donnell. Moreover, the study makes some direct comparisons with previous traditional literature. In addition, it makes use of an improved measure of the capital stock, which showed important effects on the estimates of the agricultural productivity. The new FPI yields some lower growth of agricultural productivity and the use of the improved measure of the capital stock shows a very important effect on TFP gains.

JEL Classifications: C18, O47, Q11.

Keywords: Total Factor Productivity; Färe-Primont index; Malmquist index; agricultural productivity; technological and efficiency change.

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1. Introduction

The availability of good indicators of the evolution of total factor productivity (TFP) is essential to analyze the growth of an economy and the evolution of its supply and competitiveness. This is particularly relevant in the agricultural sector because its productivity has important consequences on food security and prices and is directly related to the use of natural resources and factor reallocation to other economic sectors. More realistic figures and adequate international comparisons may reveal the necessity of design better policies to improve agricultural productivity in some regions with a very scarce or null growth, as it is the case of Europe.

For these reasons, many efforts have been made to improve the quality of TFP indicators, which have been reflected in different applications in agricultural activity. During the last two decades, studies that try to measure the changes in TFP and international comparisons have proliferated. As Coelli and Rao (2005) indicate, this boom is due to two main reasons: the availability of new statistical information provided by the Food and Agriculture Organization (FAO) of the United Nations, and the appearing and diffusion of new techniques, such as Data Envelopment Analysis (DEA) and the parametric technique of Stochastic Frontier Analysis (SFA). These frontier approaches have several advantages for estimating TFP indexes over other techniques, such as the index numbers based on prices or the growth-accounting approach.[1]

[1] Among the indexes based on prices can be highlighted the widely used Tornquinst and Fisher indexes. The growth-accounting approach is used to estimate the world growth rates of TFP in works such as Fuglie (2012 a y b) and Avila and Evenson (2010).

First, no information about prices is required. Second, it is not necessary to assume that all economic units are efficient. Third, the economic units do not need to follow a profit-maximization or cost-minimization behavior. Finally, and perhaps most importantly, the DEA and SFA techniques permit the decomposition of TFP into technical change and technical efficiency, among other measures, depending on the index used.

Both methods have their pros and cons. The DEA analysis is more flexible because it does not need to impose a specific functional form and because no assumption is required about the distribution of the inefficiency component. Moreover, the most recent advances include measures of relative efficiency obtained from the Malmquist index (MI)[2], among others. In contrast, it does not identify the "noise" of the regression, and the indexes computed assume that any deviation of the productive behavior of an economic unit from the efficient frontier is an inefficiency, when it might be picking up an external shock or just measurement mistakes. Another disadvantage of the DEA methodology is that the common hypothesis tests in parametric models cannot be applied. In any case, the debate about the pros and cons of the parametric and nonparametric techniques remains open.[3]

Coelli and Rao (2005), CR from now on, apply DEA to the agricultural TFP between 1980 and 2000. The novelty of their work resides in the transversal dimension of the analysis and in the

[2] When we speak of the Malmquist index, we allude to the index attributed to Caves et al. (1982) and the decomposition suggested by Färe et al. (1994), which turns out the broadest spread up so far.

[3] In order to address the DEA, Coelli et al. (2005) and Fried et al. (2008) are recommended. Murillo (2004) reviews recent advances. Liu et al. (2013) analyze and demonstrate its exponential use, besides the most influential studies and the subsequent extensions.

technique used, based on the calculation and decomposition of the MI calculated with DEA estimations.[4]

Besides these advances, the availability of new information and access to new techniques have resulted in the emergence of new studies about TFP indicators. In particular, O'Donnell (2009, 2010) implements a new technique based on the advances achieved in O'Donnell (2008). This work starts from a critique of the traditional MI, of the kind attributed to Caves et al. (1982), which states that it is incomplete. Except in special cases, it is a partial measure of the productivity change, which implies that the decomposition of this MI in Färe et al. (1994) produces estimations of technical change and technical efficiency that are not very reliable. The main reason for this is the existence of some problems and restrictions of the MI, mainly because it is not an exhaustive index, that is, additive and multiplicative (O'Donnell, 2012a)[5]. Moreover, as Griffel-Tatje and Lovell (1995) demonstrate, the MI is a measure of productivity change that obtains systematically biased estimations, with the exception of the particular case in which this index equals the Moorsteen-Bjurek index[6]. In this case, constant returns to scale and an inverse homothetic technology are assumed.

Based on this criticism, O'Donnell (2010) uses the same statistical information as CR to analyse the efficiency in the agricultural sector and computes the Moorsteen-Bjurek index. He uses two outputs (crops and animals) and five inputs (land, labor, livestock, number of tractors and the

[4] Other similar studies are Ludena et al. (2007) and Ludena (2010), which also use the DEA technique and the MI in order to estimate and decompose the TFP for a wide group of countries, although their analysis is mainly focused on the Latin American region.

[5] O'Donnell (2008) explains the multiplicative and additive conditions.

[6] Following O'Donnell, we call it the Moorsteen-Bjurek index because it is an index developed by Bjurek (1996), although it is also known as the Hicks-Moorsteen index.

quantity of fertilizers). The Moorsteen-Burek index fulfills the multiplicative condition, so it is an improvement of the index introduced by CR[7]. However, the Moorsteen-Bjurek index, although it fulfils the multiplicative condition, presents several limitations due to its failure to meet Fisher's transitivity condition. The latter implies that only binary comparisons are valid, that it, they can be multilateral or multi-temporal, but not both at the same time (O'Donnell, 2011a). These limitations are overcome by the proposal of O'Donnell (2011a and 2012b), applying the Färe-Primont index (FPI), which does fulfil the transitivity and multiplicativity conditions, and allows multilateral and multi-temporal comparisons. For this reason, the FPI is considered to be an exhaustive and ideal index in that it satisfies all the relevant axioms and proofs in the index numbers theory (O'Donnell, 2011 a and b). This is the main reason for choosing the FPI and to apply it we choose the DEA methodology developed by O'Donnell (2010).[8]

The aforementioned reasons motivate our interest in estimating new indexes and comparing them with the traditional ones. Two analyses are worth carrying out. First, to evaluate the differences between the FPI and the MI, and to compare our results on the agricultural sector with those obtained by CR. Second, to incorporate an improved measure of the inputs used, following Burzer et al. (2010), who drew attention to the low quality of the common proxies used to measure the capital stock in the agricultural sector. The analysis incorporates the estimations with a new measure of the capital stock provided by the FAO.

[7] CR use a sample of 93 countries and the period from 1980 to 2000, while O'Donnell (2010) uses 88 countries and the period 1970 to 2001.

[8] O'Donnell named this index Färe-Primont because its calculation is based on two indexes developed by Färe and Primont (1995). It should be highlighted that another index with similar properties, the Lowe index, exists but its calculation needs information about prices.

The paper is organized as follows. In Section 2, we present the methodology used to estimate TFP, technical efficiency and technical change from the FPI. In Section 3, we compare the estimations from the MI and from those from the FPI, and we also compare our results with the ones obtained by CR and Headey et al. (2010). In Section 4, we offer the estimations of a new TFP index for a wide sample of countries during the period 1975-2007, and examine its evolution. Finally, in Section 5, we present the main conclusions.

2. Methodology

In this paper we apply the advances developed by O'Donnell (2008, 2010, 2011[a] and 2012 a) in order to measure the TFP, based on the DEA. We also compute the FPI suggested by O'Donnell (2012b) and its decomposition into an efficiency index and another one of technological index.[9]

The DEA methodology used, based on O'Donnell (2012b), has the advantage of not requiring the restrictive assumptions about the structure of the technology, the degree of competition in inputs and outputs markets, the use of prices as market signals, nor the optimizing behavior of the firm. It only requires an estimation of the production frontier which will allow us to calculate the TFP index and which is the basis of the decomposition into the technological index and efficiency index. TFP is defined as the relationship between outputs and inputs, which can be represented as:

$$\mathrm{TFP}_{it} = \frac{\mathrm{Q}_{it}}{\mathrm{X}_{it}} \tag{1}$$

[9] We have used the program DPIN 3.0 for the calculations, whose performance is explained in O'Donnell (2011b).

where $Q_{it} = Q(q_{it})$ and $X_{it} = X(x_{it})$ are the aggregate function of output and inputs, respectively, and Q(.) and X(.) are aggregate, lineally homogeneous, nonnegative and no decreasing functions.

In order to estimate the production function, two approaches can be adopted, using outputs or inputs. In the first case, the production function is constructed from the maximum output given some fixed factors. In the second case, the costs frontier is constructed with the lowest input endowment given a quantity of output.

In this paper, we consider the output approach due to the particularities of the agricultural sector because it requires an important amount of "sunk capital" such as machinery and land. As CR note, in the agricultural sector it is reasonable to assume the goal of maximizing the output, more than minimizing the production factors[10]. With this proposal, the distance function that represents the technology available in period t and which is output oriented can be written as:

$$D_0(x_{it}, q_{it}, t) = \left(q'_{it}\alpha\right)/\left(\gamma + x'_{it}\beta\right) \tag{2}$$

where $q\left(q_{1it}, \dots, q_{Jit}\right)'$ and $x_{it}(x_{1it}, \dots, x_{Kit})'$ indicate the output and input vectors respectively, for firm i and year t. The parameters α and β are nonnegative and the parameter γ captures the kind of scale returns which are assumed: $\gamma = 0$ represents constant returns to scale (CRS), $\gamma \geq 0$ represents decreasing returns to scale (DRS) and $\gamma \leq 0$ increasing returns to scale (IRS).

[10] For a detailed knowledge of this issue, Färe et al. (1994) or Kalirajan and Shand (1999) are recommended. Moreover, Murillo (2004), Coelli et al. (2003 and 2005) and Greene (2005 and 2008) address the approach of the production costs or inputs.

From equation (2), and by means of linear optimization, the parameters which minimize $D_0(x_{it}, q_{it}, t)^{-1}$ can be estimated and the general solution is shown in equation (3):

$$D_0(x_{it}, q_{it}, t)^{-1} = \min_{\alpha,\gamma,\beta}\{\gamma + x'_{it}\beta : \gamma l + X'\beta \geq Q'\alpha; q'_{it}\alpha = 1; \alpha \geq 0; \beta \geq 0\} \quad (3)$$

where Q is the observed matrix of outputs (J x M_t) and X is the observed matrix of inputs (K x M_t), and M_t is a column vector indicating the number of observations used to estimate the frontier in year t.

Given the advantages of FPI over the MI, we will use the FPI in the specific solution. The specific calculations applied to the case of FPI for both approaches (output and input) are represented by equations (4) and (5), respectively:

$$D_0(x_0, q_0, t_0)^{-1} = \min_{\alpha,\gamma,\beta}\{\gamma + x'_0\beta : \gamma l + X'\beta \geq Q'\alpha; q'_0\alpha = 1; \alpha \geq 0; \beta \geq 0\} \quad (4)$$

$$D_1(x_0, q_0, t_0)^{-1} = \max_{\emptyset,\delta,\eta}\{q'_0\phi - \delta : Q'\phi \leq \delta l + X'\eta; x'_0\eta = 1; \phi \geq 0; \eta \geq 0\} \quad (5)$$

The linear optimization of equations (4) and (5) yields the parameters $\alpha_0, \beta_0, \gamma_0, \phi_0, \delta_0, y\ \delta_0$, and t_0 defines the observations that are used to estimate the representative frontier.[11]

Additionally, the aggregate functions used to calculate the FPI are the following:

$$Q(q) = q'p_0^* \quad \text{with} \quad p_0^* \equiv \partial D_0(x_0, q_0, t_0)/\partial q_0 = \alpha_0/(\gamma_0 + x'_0\beta_0) \quad (6)$$

[11] The parameters $\phi_0, \delta_0, \delta_0$ are those corresponding to the ones already presented in equation (2) $\alpha_0, \beta_0, \gamma_0$, from the inputs perspective.

$$X(x) = x' w_0^* \quad \text{with} \quad w_0^* \equiv \partial D_1(x_0, q_0, t_0)/\partial x_0 = \eta_0/(q_0' \phi_0 - \delta_0) \qquad (7)$$

The FPI, as well as the MI, can be decomposed into two components[12]: one is technological component (TC) and another one of efficiency component (EC), as follows:

$$\mathrm{TFP_{it}} = \mathrm{TC_t} \,.\, \mathrm{EC_{it}} \qquad (8)$$

Moreover, the calculation of each index is obtained from:

$$TFP_{it} = {}^{Q_{it}}/_{X_{it}} \qquad (1)$$

$$TC_t = max_i \, {}^{Q_{it}}/_{X_{it}} \qquad (9)$$

$$EC_{it} = {}^{TFP_{it}}/_{TC_t} \qquad (10)$$

The technological component (TC) measures a shift of the production frontier during a period and is expressed by equation (9). Its calculation results from the identification of the economic unit i that shows the maximum level of TFP for a given period t.[13]

The efficiency change component measures a movement of the economic unit towards (or away from) the production frontier, which means an improvement (or worsening) in the efficient use of the production factors.

3. Färe-Primont vs. Malmquist

In this section, we estimate the PFI of agricultural TFP, as well as its two components of technological and efficiency change. The aim is to carry out a comparative analysis with the

[12] It is possible to decompose the TFP into other measures of efficiency, including the scale efficiency. However, due to the interest of this paper and for reasons of space, we will observe only the decomposition into TC and EC. For other different decompositions, see O'Donnell (2012b).

[13] In O'Donnel TC_t is TFP_t^*.

existing estimations, specifically, with those of CR based on the MI, which assumes technological reversal and constant returns to scale. The use of an index that does not fulfill the multiplicative nor the transitive conditions, such as the MI, can yield a biased measure of the agricultural TFP, which can be solved with the FPI.

For all our estimations we use data from Fuglie (2012 a y b)[14], who offer a new database which is the most complete agriculture database at the moment, except for the new variable of capital stock (*Gross Capital Stock*), which is extracted directly from FAOSTAT. In order to make the estimations as comparable as possible with those of CR, in this section we use the same sample of 93 countries over 1980-2000 as CR, as well as the same inputs and the same way of measuring the capital stock.

As our output, we will use gross agricultural output, that is, the sum of the value of production of crop and livestock commodities, valued at constant international dollars (2005 base year). It will be entered as a single variable in the model, not separately as in CR.

The four inputs used are *Agricultural Land*, *Labor*, *Ferlizer* and, as the capital factor, *Machinery and Livestock Heads as capital factor*. *Agricultural Land* is a rainfed-cropland equivalents measure, adjusted by quality obtained for the weighted sum of irrigated, rainfed cropland and permanent pasture lands. *Labor* is the total economically active adult population in agriculture. For the intermediate inputs, *Fertilizer* is the total metric tons of N, P_2O_5, K_2O fertilizer consumption measured in "N-fertilizer equivalents"[15]. The traditional measure of the capital stock is *Machinery,* or total stock of farm machinery, and *Livestock Heads,* or total livestock capital on farms in “cattle equivalents”.

[14] For a description of the methodology and data sources see http://www.ers.usda.gov/data-products/international-agricultural-productivity.aspx

[15] See, for example, Hayami and Ruttan (1970) and Fulginiti and Perrin (1977).

As has been demonstrated by Burzer et al. (2010), data on tractors are poor proxies for agricultural fixed capital. For this reason, we estimate two models: "model 1", which uses the variable *Capital Stock*, measured by the gross capital stock at constant 2005 US$ prices; and "model 2", which includes the traditional variables of *Machinery and Livestock Heads*. We think that model 1 is already an improvement on existing estimations because *Capital Stock* is a better proxy than just the number of tractors and livestock heads.

For "model 1", we estimate the FPI, and this result will bring together the multiplicative and transitive properties that allow the multilateral and multi-temporal comparisons, with an improved measure of the input capital. In order to detect biases for the use of an index without the mentioned properties, we also estimate the MI with the improved variable *Capital Stock* (MI-model 1).

In order to make the inter-annual comparisons, we calculate the geometric average of the productivity change, technological change and efficiency change of all economic units and each year. We assume technological reversal and constant returns to scale, both for the MI and the FPI. Following the recommendations of CR (2005), it is convenient to consider the size of each economy with its participation in the production value each year as a weight. Table 1 shows the annual average change in efficiency, technical change and TFP change using the weighted geometric average.

The estimations in Table 1 allow us to compute the average annual growth rate of the TFP, which is 2.32% for the MI-model 1, while CR obtained a value of 2.04%. The FPI yields 1.70% and 1.32% for models 1 and 2, respectively, which are much lower rates.

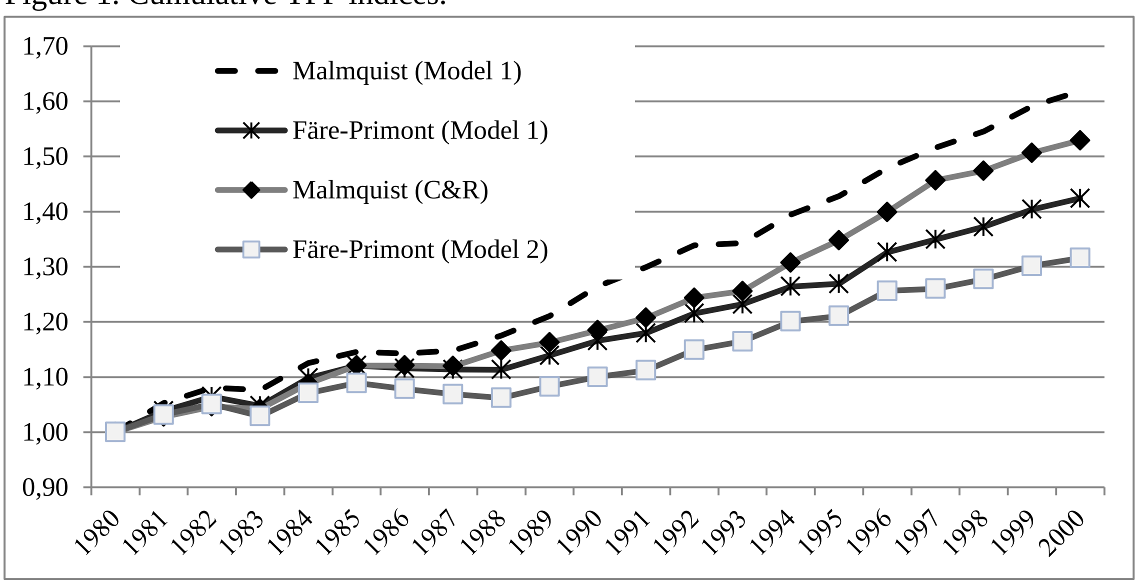
Table 1. Malmquist, Färe-Primont and Coelli & Rao (Malmquist) indices. Weighted annual mean efficiency change, technical change and TFP change, 1980-2000.

Model 1	Malmquist (Model 1)			Färe-Primont (Model 1)			Coelli & Rao -Malmquist			Färe-Primont (Model 2)		
Años	Efficiency	Tech	TFP	Efficiency	Tech	TFP	Efficiency	Tech	TFP	Efficiency	Tech	TFP
1980	1	1	1	1	1	1	1	1	1	1	1	1
1981	1.01	1.04	1.05	1.04	1.00	1.04	1.02	1.01	1.03	1.06	0.98	1.03
1982	0.99	1.04	1.03	1.00	1.02	1.03	0.99	1.03	1.02	1.01	1.01	1.02
1983	1.02	0.97	1.00	0.96	1.02	0.98	1.01	0.99	1.00	0.95	1.03	0.98
1984	1.04	1.00	1.05	1.02	1.02	1.05	1.02	1.02	1.04	1.06	0.98	1.04
1985	0.98	1.03	1.02	1.02	1.00	1.02	1.01	1.02	1.03	1.01	1.01	1.02
1986	1.00	1.00	1.00	1.02	0.98	1.00	1.00	1.00	1.00	1.02	0.97	0.99
1987	1.00	1.01	1.00	0.98	1.02	1.00	0.99	1.01	1.00	0.99	1.01	0.99
1988	0.98	1.05	1.02	1.00	1.00	1.00	1.02	1.01	1.03	1.00	0.99	0.99
1989	1.04	0.99	1.03	1.02	1.01	1.02	1.01	1.01	1.01	1.03	0.99	1.02
1990	1.02	1.03	1.04	1.02	1.01	1.02	0.99	1.03	1.02	1.03	0.99	1.02
1991	1.01	1.01	1.03	0.99	1.02	1.01	1.01	1.01	1.02	1.00	1.01	1.01
1992	0.97	1.06	1.03	0.99	1.04	1.03	1.04	1.00	1.03	1.00	1.03	1.03
1993	0.98	1.03	1.00	1.01	1.00	1.01	1.03	0.98	1.01	0.99	1.03	1.01
1994	1.06	0.98	1.04	1.04	0.98	1.03	1.03	1.01	1.04	1.05	0.99	1.03
1995	1.00	1.02	1.02	1.02	0.99	1.00	0.98	1.05	1.03	1.00	1.01	1.01
1996	1.01	1.03	1.04	1.01	1.03	1.04	1.03	1.01	1.04	1.03	1.01	1.04
1997	1.07	0.96	1.03	1.05	0.97	1.02	1.03	1.01	1.04	1.00	1.01	1.00
1998	0.98	1.04	1.02	1.00	1.01	1.02	1.00	1.01	1.01	1.03	0.99	1.01
1999	0.98	1.05	1.03	0.99	1.03	1.02	0.98	1.04	1.02	1.01	1.01	1.02
2000	1.00	1.02	1.02	1.01	1.00	1.01	1.00	1.02	1.02	1.01	1.00	1.01
Cumulative	1.15	1.42	1.62	1.22	1.17	1.42	1.20	1.28	1.53	1.29	1.02	1.32
Geometric mean of growth	0.69%	1.70%	2.32%	0.96%	0.73%	1.70%	0.86%	1.17%	2.04%	1.21%	0.10%	1.32%

In any case, we consider that the best estimation is the growth rate of 1.70%, obtained from the FPI-model 1, because it gathers the two improvements in the accuracy of calculation: one due to the virtues of the FPI already explained and the other because of the improvements in the quality of the information used.

Figures 1 to 3 show the cumulative growth rates from the estimations in Table 1. Figure 1 represents the cumulative change in the TFP. In both models, the MI is higher than the FPI and overestimates the growth of TFP in agriculture. The cumulative variation rate in 2000 according to the MI-model 1 is 1.62 and the value obtained by CR (MI-model 2) is 1.53, while the values for the FPI are 1.42 and 1.32, respectively. Moreover, it can be confirmed that the estimations of model 1, both for the MI and the FPI, yield estimations of the TFP growth rate that are higher than the ones for model 2. This indicates that a low quality measure of the capital stock results in an underestimation of the agricultural productivity performance. To sum up, the estimations made with the MI and a deficient measure of capital stock (model 2) result in an overestimation effect, due to the index properties, and an underestimation, due to the deficient measure of capital stock.

Figure 1. Cumulative TFP indices.



At the same time, there is an increasing divergence between the estimations of the MI themselves, and between these and the FPI figures. The cumulative growth rate for the FPI for the whole period is 42% in model 1 and 32% in model 2 while, for the MI, it is 62% in model 1 and 53% in the CR estimations (model 2). It can be deduced that, for the analyzed period, the overestimation generated by the MI is around 20% above the FPI (62-42% and 53-32%). And the underestimation produced for the same period and due to the different measures of the capital stock is around 10% (62-53% and 42-32%).

Figure 2 shows the estimations corresponding to the technical efficiency change, where two features can be stressed: first, the divergence between indexes and models are not as pronounced in the case of TFP; and second, the pattern of importance seems to be reversed because the values of the FPI are higher than those of the MI. Comparing Figures 2 and 3, it is shown that PFI gives more weight to the efficiency component and smaller to that of technological change.

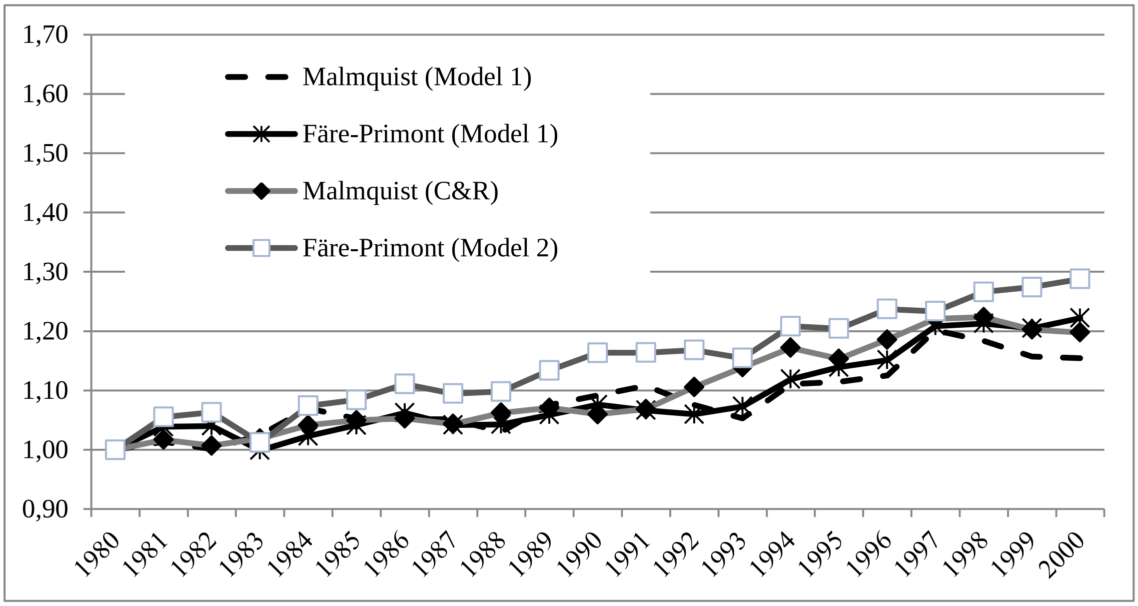
Looking at the differences caused by the capital stock measures used, the FPI-model 1 gives more weight to the technological component, with a cumulative growth of 17% while the FPI-model 2 yields only 2%. This is an interesting result because the FPI-model 1 is calculated with a richer capital measure which considers, among other things, the impact of the technology incorporated in the value of the capital good.[16]

The counterpart is that the FPI-model 2 gives more weight to the efficiency component. A similar divergence is confirmed when we compare the results of the MI, with a cumulative growth of 42% (model 1) compared to the 28% obtained by CR (model 2). For both indexes, in model 2, we

[16] Indeed, it has to be taken into account that, even if the only capital good used in the agricultural production were tractors, it would not be capturing the changes in the built-in technology either. Moreover, the jump in our estimations between 1993 and 1994 coincides with the international spreading of the use of new transgenic seeds, and all the associated changes in machinery and fertilizers, among other relevant transformations.

observe an underestimation of the technological component of about 15% for the whole period, which can be attributed to the differences in the capital stock measures.

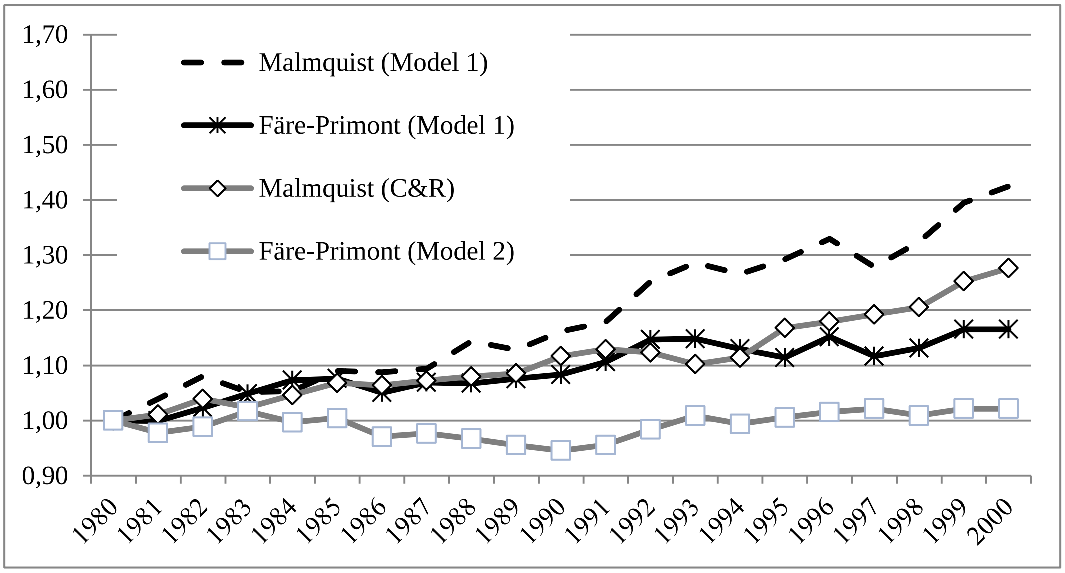
Figure 2. Cumulative Efficiency indices.



Comparing Figures 1 and 3, it can be highlighted that the technological component seems to be explaining the agricultural productivity growth during the whole period of analysis. The overestimation of the technological change is especially strong when the MI is used instead of the FPI. Furthermore, there exists a clear divergence between the estimations obtained with the two indexes since the 90s, a key moment due to the incorporation of important technical changes. The consideration of the new measure of capital stock (model 1) reveals the underestimation of the technological effect generated with the use of the traditional measure of the capital factor (model 2), both in the estimations obtained with the MI and with the FPI.

In this way, these results show that by improving only the measure of the capital stock but maintaining the use of the traditional MI, the average annual growth of the technological component is 1.70%, still overvalued for the effect of the index used. However, improving the measure of the capital stock and also using the new FPI, the improvement due to the technical change is reduced to an annual growth rate of 0.73%, which we consider to be a measure that adjusts better to reality.

Figure 3. Cumulative Tech indices.



To conclude, we compare our estimations with the recent ones of Headey et al. (2010). These authors estimate the MI with the traditional capital measure and state that the estimations based on SFA are preferable to those obtained by means of the DEA[17]. Based on Nin et al. (2003), these authors consider that the DEA estimations suffer from low average TFP growth, a large number of countries recording negative TFP growth, considerable volatility of year-to-year growth rates and weak or insignificant correlations with simple measures of productivity, such as labor productivity.

[17] These authors work with a simple of 88 countries and along the period 1970-2001. The variables used and the information sources are the same ones used by CR, as it is the DEA technique used.

Table 2 presents the main statistics to compare the different indicators of TFP growth and its correlation with each country's productivity growths. The first two columns correspond to the estimations made by Headey et al (2010) for SFA and DEA. The last two columns have been calculated from our estimations DEA with MI and FPI, in both cases for model 1, with the new variable *Capital Stock*. The comparisons have to be made with caution, because Headey et al (2010) use the same sample and data that CR, and present their statistics based on simple, unweighted averages. For greater comparability, we have calculated the simple averages based on our estimations. Moreover, they fit the individual productivities and this offers some interesting evidence.

Table 2. Comparition of SFA, Malmquist and Färe-Primont

Indirect indicators of plausibility of TFP growth results	SFA	DEA Malmquist	DEA Malmquist (model 1)	DEA Färe-Primont (model 1)
Average annual growth rate	1.7	1.4	2.0	1.4
Maximun annual growth rate	3.4	6.9	10.5	3.6
Mínimun annual growth rate	-1.5	-1.6	-4.3	-1.1
Average standard deviation of annual growth rate	3.8	10.3	11.3	6.8
Maximun of country-specific standard deviation of annual growth rate	12.1	62.7	60.7	23.2
Minimun of country-specific standard deviation of annual growth rate	0.9	3.2	3.2	2.0
Correlation with labor productivity	0.27	0.04	0.47	0.87
Correlation with land productivity	---	---	0.40	0.76
Correlation with capital productivity	---	---	0.48	0.98

Suorce: Headey et al. (2010) and autor´s calculations.

According to the average annual growth rate, the SFA technique yields growth figures somewhat higher than the DEA-Malmquist estimations (1.7% and 1.4%, respectively) in Headey et al. At the same time, our estimations show TFP growth rates higher with the DEA-MI than with the DEA-FPI. These comparisons of growth rates do not permit us to predict whether the magnitude of estimating the FPI with the SFA technique will be higher or lower.

However, the comparison of the dispersion measures can offer a more conclusive result. The international or inter-temporal deviations are much higher when the DEA is used compared to the SFA. This behaviour might be due exclusively to the effect of the random shocks that, in the case of the SFA, is absorbed by the residual of the regression.

In accordance with Headey et al., the SFA technique is more suitable than DEA, mainly because the correlation between the TFP growth rates and those of the labor productivity is higher. From our estimations, we obtain a correlation that is even higher, reaching 0.47 for MI-DEA with the new measure of the capital stock, which is similar to the correlation with the land productivity growth (0.40) and with the capital productivity growth (0.48). If we use not only the new measure of the capital stock but also the FPI, the correlations are even higher, namely, 0.87 with the labor productivity growth, 0.76 with the land productivity growth and 0.98 with the capital productivity growth.[18]

To sum up, the use of the FPI, together with the use of a more precise measure of capital stock, achieves a better adjustment in the TFP estimations. However, its comparison with the results obtained with the SFA technique requires a deeper analysis, which constitutes part of our future research agenda.

[18] The correlation coefficients are calculated between the series of estimated TFP growth rates and those of labor, land and capital productivities, measured in all cases as the relationship between the output and the factor endowment.

4. Färe-Primont results

In the previous section, we presented and analysed some of the main differences between the traditional MI and the new proposal of the FPI. The analysed period and the country sample used were adapted to allow us a direct comparison with one of the most cited works on this subject, that of CR. In this section, we use the information of the largest period available to offer the estimations that incorporate the improvements from both the new FPI and the more precise measure of capital stock provided by the FAO. In this way, the available information, where the main restriction is the existing data of the capital stock variable, allows us to construct a wide sample that covers the period 1975-2007. Although it would have been possible to widen the sample of countries, we have decided to maintain it at 93 countries to avoid introducing sample heterogeneity and to facilitate the comparison with the results presented before.

In Table 3, we show the estimations corresponding to the cumulative variation of the FPI for the TFP and the efficiency and technical change components, for the whole sample and for a group of regions classified in the same way as in CR. [19]

The average annual growth rate of the TFP (1.40%) is relatively reduced if we compare it with the 1.70% reported in Table 1. This result is due to the almost non-existent development between

[19] In Table 3, we present only one column for the technological change variable because this is the technological frontier and, given the construction of the FPI, it is fixed at a constant value. For this reason, we show only the result corresponding to the whole sample, and the same one is valid for all the geographical regions. We have also verified the possibility of a bias in our estimations from a different time dimension in the sample. In the Annex, we present a table with the results of cumulative growth rates for the period 1980-2000 obtained from the estimations with samples 1980-2000 and 1975-2007. It is shown that a 50% increase in the time dimension of the sample yields an insignificant effect, likely due to the lost of decimals in the calculations.

1975 and 1980, which produces a decline in the global product, as well as in the efficiency and technological change indexes.

Table 3. Cumulative Efficiency, Tech and TFP growth, and annual geometric mean of change. Färe-Primont indices.

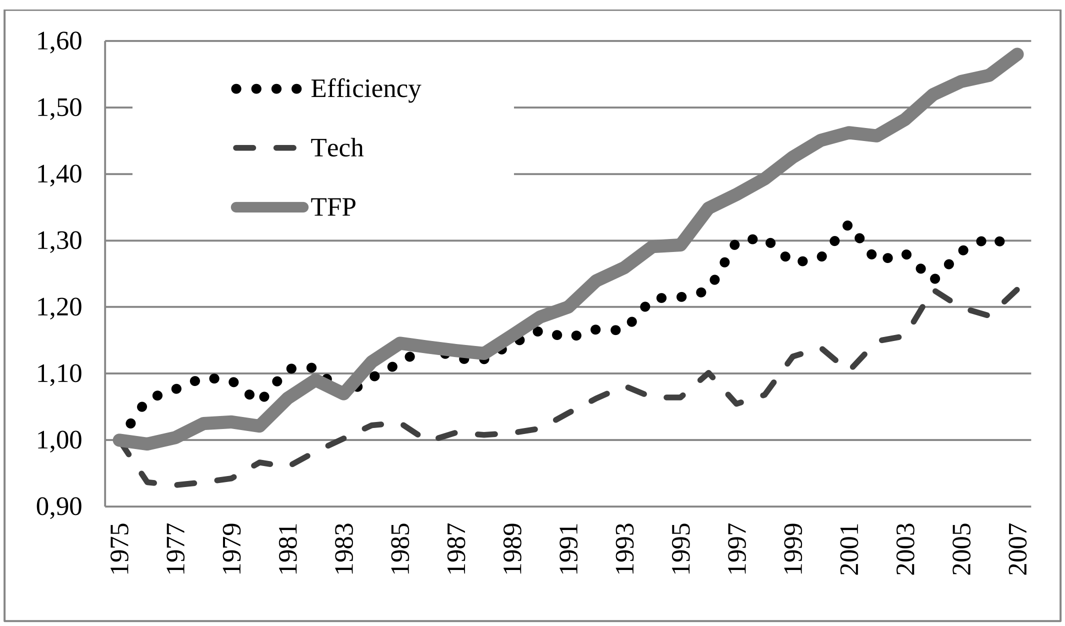
	All			Africa		Asia	
Years	Efficiency	Tech	TFP	Efficiency	TFP	Efficiency	TFP
1975	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1976	1.06	0.94	0.99	1.04	0.97	1.05	0.98
1977	1.08	0.93	1.00	1.03	0.96	1.05	0.98
1978	1.09	0.94	1.02	1.03	0.97	1.08	1.01
1979	1.09	0.94	1.03	1.02	0.96	1.04	0.98
1980	1.06	0.97	1.02	1.00	0.96	1.01	0.98
1981	1.11	0.96	1.06	1.02	0.98	1.05	1.01
1982	1.11	0.98	1.09	1.00	0.98	1.05	1.03
1983	1.07	1.00	1.07	0.97	0.97	1.05	1.05
1984	1.09	1.02	1.12	0.97	0.99	1.06	1.08
1985	1.12	1.03	1.15	1.03	1.06	1.07	1.09
1986	1.14	1.00	1.14	1.08	1.08	1.10	1.09
1987	1.12	1.01	1.13	1.08	1.09	1.05	1.07
1988	1.12	1.01	1.13	1.12	1.13	1.07	1.07
1989	1.14	1.01	1.16	1.16	1.17	1.07	1.09
1990	1.16	1.02	1.19	1.17	1.19	1.08	1.09
1991	1.15	1.04	1.20	1.24	1.29	1.06	1.10
1992	1.17	1.06	1.24	1.20	1.27	1.07	1.14
1993	1.16	1.08	1.26	1.20	1.30	1.11	1.21
1994	1.21	1.06	1.29	1.26	1.34	1.13	1.21
1995	1.21	1.06	1.29	1.27	1.35	1.14	1.21
1996	1.22	1.10	1.35	1.35	1.49	1.14	1.25
1997	1.30	1.05	1.37	1.39	1.47	1.21	1.28
1998	1.30	1.07	1.39	1.42	1.51	1.22	1.30
1999	1.27	1.13	1.43	1.37	1.54	1.17	1.32
2000	1.27	1.14	1.45	1.35	1.54	1.19	1.35
2001	1.33	1.10	1.46	1.41	1.55	1.25	1.37
2002	1.27	1.15	1.46	1.40	1.60	1.18	1.36
2003	1.28	1.16	1.48	1.45	1.68	1.21	1.40
2004	1.24	1.23	1.52	1.39	1.70	1.14	1.40
2005	1.28	1.20	1.54	1.46	1.75	1.18	1.41
2006	1.30	1.19	1.55	1.53	1.81	1.20	1.43
2007	1.29	1.23	1.58	1.45	1.78	1.20	1.47
Geometric Mean of Change	0.77%	0.62%	1.40%	1.13%	1.76%	0.54%	1.17%

Cont. Table 3

	Australasia		Europe		North America		South America	
Years	Efficiency	TFP	Efficiency	TFP	Efficiency	TFP	Efficiency	TFP
1975	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1976	1.12	1.05	1.05	0.99	1.09	1.02	1.07	1.01
1977	1.13	1.05	1.05	0.98	1.17	1.09	1.08	1.01
1978	1.24	1.16	1.07	1.00	1.15	1.07	1.10	1.03
1979	1.22	1.15	1.08	1.02	1.19	1.12	1.10	1.04
1980	1.13	1.09	1.07	1.03	1.13	1.09	1.07	1.03
1981	1.21	1.16	1.06	1.02	1.25	1.20	1.16	1.12
1982	1.14	1.12	1.08	1.06	1.26	1.24	1.15	1.13
1983	1.29	1.29	1.04	1.04	1.07	1.07	1.12	1.13
1984	1.23	1.26	1.06	1.09	1.17	1.19	1.11	1.14
1985	1.25	1.29	1.04	1.07	1.25	1.28	1.17	1.20
1986	1.29	1.29	1.07	1.07	1.26	1.26	1.15	1.14
1987	1.28	1.29	1.07	1.08	1.25	1.26	1.17	1.18
1988	1.33	1.34	1.06	1.06	1.17	1.18	1.21	1.22
1989	1.31	1.32	1.07	1.09	1.24	1.26	1.23	1.24
1990	1.34	1.37	1.11	1.13	1.30	1.33	1.24	1.26
1991	1.32	1.37	1.11	1.16	1.27	1.32	1.22	1.27
1992	1.35	1.43	1.12	1.19	1.31	1.40	1.21	1.29
1993	1.35	1.46	1.10	1.19	1.20	1.30	1.17	1.26
1994	1.27	1.36	1.09	1.16	1.39	1.48	1.23	1.31
1995	1.39	1.48	1.11	1.18	1.31	1.39	1.29	1.37
1996	1.43	1.58	1.12	1.23	1.33	1.46	1.26	1.39
1997	1.50	1.59	1.18	1.24	1.42	1.50	1.33	1.40
1998	1.53	1.63	1.18	1.26	1.43	1.52	1.33	1.42
1999	1.49	1.68	1.15	1.29	1.39	1.56	1.34	1.51
2000	1.45	1.66	1.14	1.30	1.41	1.60	1.31	1.49
2001	1.52	1.68	1.18	1.31	1.42	1.56	1.39	1.54
2002	1.34	1.54	1.14	1.31	1.34	1.54	1.37	1.57
2003	1.45	1.68	1.13	1.30	1.34	1.55	1.34	1.55
2004	1.34	1.65	1.15	1.40	1.37	1.67	1.27	1.56
2005	1.46	1.76	1.14	1.37	1.40	1.67	1.40	1.67
2006	1.37	1.62	1.14	1.35	1.38	1.64	1.44	1.71
2007	1.38	1.69	1.08	1.33	1.40	1.72	1.42	1.75
Geometric Mean of Change	0.97%	1.60%	0.24%	0.87%	1.02%	1.65%	1.08%	1.70%

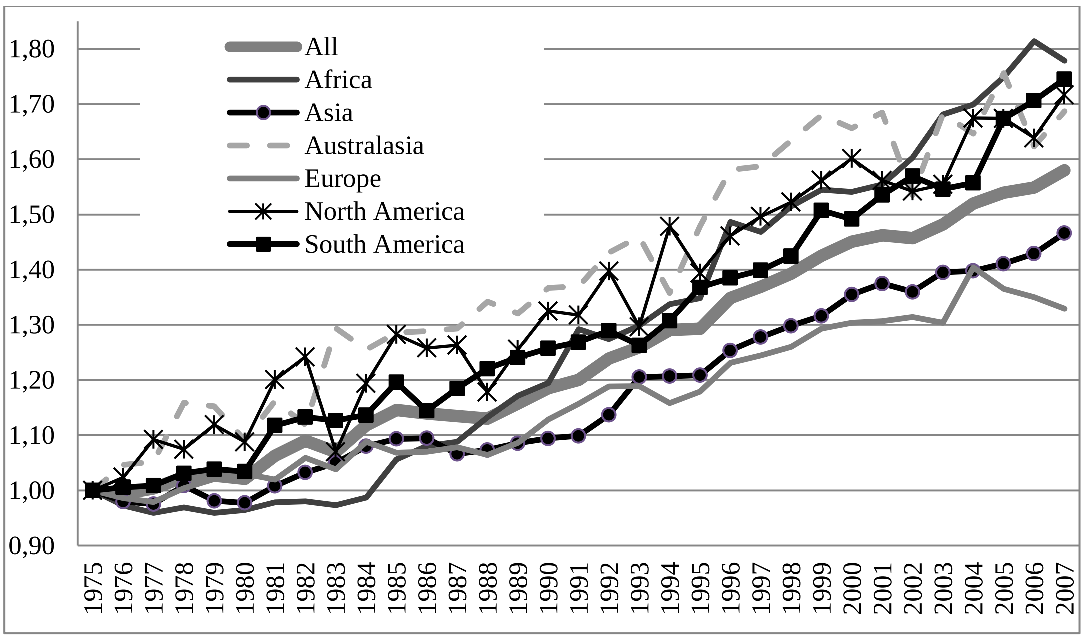
Figure 4 illustrates this fact, with a stagnation of the FTP from 1975 to 1980. At the same time, a technological deterioration takes place which can be due to an increase in the cost of oil inputs and a decline in the global demand, in such way that the output to input ratio falls. Moreover, the average increase in the efficiency index might be indicating a certain convergence process, which might be the result of the economic slow down of the leader countries and not so much to the progress of the catching-up countries. The following decades reveal an important boom for the agricultural economy, in which two stages can be identified. The first is led by efficiency improvements, likely due to the world economic opening-up which occurred from the late 80s and intensified during the 90s.The second starts in the mid 90s and is led mainly by technological improvements. This technological wave might be explained basically by the diffusion of the use of the direct seeding and the new developments in GM.

Figure 4. Cumulative Efficiency, Tech and TFP indices. All sample.



The two regions with the highest TFP growth rates are Africa and Latin America, with average rates of 1.76% and 1.70%, respectively (Table 3), closely followed by North America and Australasia, with rates of 1.65% and 1.60% respectively. Finally, Europe and Asia show a more moderate growth. Figure 5 shows the evolution of TFP by region. Africa has experienced an almost uninterrupted productivity growth since the middle 80s; this behaviour might be indicating some convergence towards the most advanced economies in the agricultural sector. Australasia and North America, particularly the latter, on the other hand, show a TFP growth with a "hand saw" outline with important fluctuations of the TFP. Meanwhile, South America shows a more continuous growth, with big leaps at specific moments. Finally, the European and Asian regions experience relatively poor advances in their TFPs.

Figure 5. Cumulative TFP indices by regions.



Some of our results are completely different from those of CR. Specifically, for these authors, the region with the best performance is Asia while, in our estimations, it has the lowest growth. Moreover, in our estimations, Africa is the region with the highest productivity growth while for CR its growth is below the average.

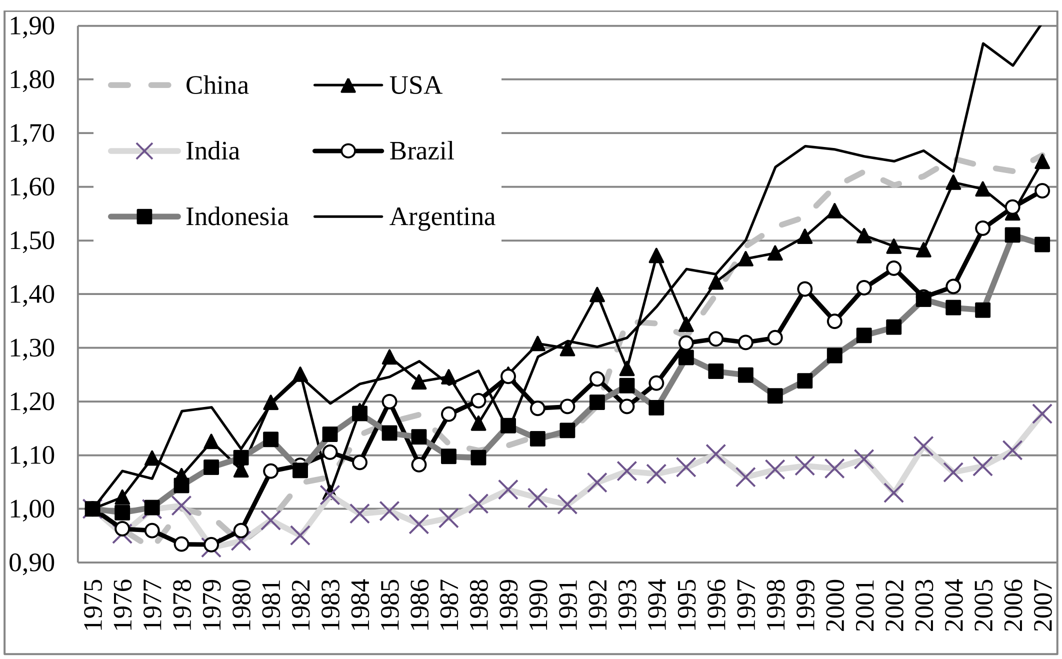
The same happens for South America which, in CR has the lowest growth of all regions while, in our estimations, it is one of the leaders, only surpassed by Africa. Among the remaining regions, the differences are not very large, especially in Australasia, with an evolution which is very similar to the average with a big productivity leap in 1994.

The dissimilarities are caused by the different indexes used and the different measures of capital stock, as well as the weights considered in the total index. In this way, a country such as India, with barely any productivity growth but which is the third food producer in the world, has a big incidence on the total weighted index. Here we would find a satisfactory explanation of the noticeable differences between our estimations and those of CR for the Asian region.

The same regional trends can be detected in Figure 6, which presents the evolution of the TFP for the six main economies in the world in terms of agricultural production.

In Asia, China and India have very different evolutions: China has one of the highest productivity growths, equal to that of the United States and only surpassed by Argentina, while India shows the lowest growth of the whole sample.

Figure 6. Cumulative TFP indices by specifics countries.



In general terms, there is a remarkable productivity growth at the beginning of the 90s in the main agricultural economies in the world, as is reflected in the total index. Two facts might be influencing that performance: one is the opening up process that occurred during that period, which would have affected the TFP by means of an improvement in the productive efficiency; and the other is the technological change produced by the genetic revolution, fostered by the genetically modified crops and the diffusion of the diffusion of the use of direct seeding, technological advances widely accepted and used in all of these economies.

5. Summary and conclusions

We have carried out new estimations of the TFP in the agricultural sector that are based on the most recent advances made by O'Donnell. This author suggests using the FPI in order to correct certain deficiencies of the traditional MI. The comparison of these two indexes shows that the MI systematically overestimates the TFP measurements and the FPI is more adjusted to the real evolution of agricultural productivity.

The improvements achieved in this study not only refer to the kind of index employed but also to the adjustment and quality of the variables used to compute the index. It has been verified that the estimations that use a more adequate measure of the capital stock, such as those provided by the FAO, obtain higher values of the TFP growth rates compared to those calculated with the traditional measures, such as the total stock of farm machinery and total livestock capital on farms in "cattle equivalents". This would be indicating that a bad quality measurement of the capital stock yields an underestimation of the productivity performance in the agricultural sector, a result that appears both in the estimations made with the MI and the ones made with the FPI.

For these reasons, the traditional estimations with the MI and a deficient measurement of the capital stock yield, at the same time, an overestimation effect, due to the index properties, and an underestimation effect, due to the poor quality of the capital stock variables.

When the TFP index is decomposed into the efficiency index and the technological change index, it can be observed that the MI is overestimating the technological change to the detriment of the efficiency component.

Moreover, the estimations including the improved measurement of the capital stock show a better performance of the technological component than those using the traditional measurements. Taking this result into account in the estimations of the FPI of TFP, it turns out that the technological change is the component that explains a significative part of the growth of global agricultural productivity during the whole period of analysis.

Finally, we have presented the estimations for the longest possible period of the FPI with the improved measure of the capital stock. The boom of the agricultural productivity after the beginning of the 90s in the main economies in the world can be highlighted. Two relevant facts might explain this performance: one is the global economic opening up that took place during that period and that might have affected the TFP by means of an improvement in productive efficiency; and the other might be the technological change produced by the genetic revolution caused by GM crops and the diffusion of use of direct seeding in all of these economies.

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Annex

Table 4. Cumulative Efficiency, Tech and TFP growth. Färe-Primont indices for Model 1, and 93 countries.

	Sample 1980-2000			Sample 1975-2007		
Year	Efficiency	Tech	TFP	Efficiency	Tech	TFP
1980	1	1	1	1	1	1
1981	1.04	1.00	1.04	1.05	0.99	1.04
1982	1.04	1.02	1.06	1.05	1.02	1.07
1983	1.00	1.05	1.05	1.01	1.04	1.05
1984	1.02	1.07	1.10	1.03	1.06	1.09
1985	1.04	1.08	1.12	1.06	1.06	1.12
1986	1.06	1.05	1.12	1.08	1.03	1.12
1987	1.04	1.07	1.11	1.06	1.05	1.11
1988	1.04	1.07	1.11	1.06	1.04	1.11
1989	1.06	1.08	1.14	1.08	1.05	1.13
1990	1.08	1.08	1.17	1.10	1.05	1.16
1991	1.07	1.11	1.18	1.09	1.08	1.18
1992	1.06	1.15	1.22	1.10	1.10	1.21
1993	1.07	1.15	1.23	1.10	1.12	1.23
1994	1.12	1.13	1.26	1.15	1.10	1.26
1995	1.14	1.11	1.27	1.15	1.10	1.27
1996	1.15	1.15	1.33	1.16	1.14	1.32
1997	1.21	1.12	1.35	1.23	1.09	1.34
1998	1.21	1.13	1.37	1.23	1.11	1.36
1999	1.20	1.17	1.40	1.20	1.17	1.40
2000	1.22	1.17	1.42	1.21	1.18	1.42

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