TOTAL FACTOR PRODUCTIVITY AND SUSTAINABLE AGRICULTURAL DEVELOPMENT

Katerina Melfou1, Athanasios Theocharopoulos2, Evangelos Papanagiotou3

TEI of Western Macedonia, Greece1, Aristotle University of Thessaloniki, Greece2,3

Total factor productivity (TFP) growth is a widespread quantitative economic instrument used to evaluate the performance and sustainability of agricultural systems over time, which has proven valuable for policy measures geared towards fostering agricultural development. Yet, there are more dimensions to be accounted for when aiming for sustainable agricultural development than the production side of an agricultural system namely, the issues of environmental protection and resource use together with the question of social responsibility. Consequently, objections have risen in the recent decades, regarding the suitability of TFP growth to reveal whether a rural system is progressing in a sustainable course and alternative tools that attempt to remove the bias in measuring changes in productivity have been proposed. The objective of this paper is twofold; to review the conventional approaches in the measurement of TFP growth and to discuss the necessary amendments in TFP measurement so that it can be a more comprehensive index of sustainable growth and thus conducive to agricultural development. The amendments which incorporate externalities and resource quality issues in productivity measurement, produce alternative measures to TFP namely, ‘total resource productivity’ and ‘social’ total factor productivity. Another approach is to construct sustainability and productivity indices separately, and then join them together so as to broaden the evaluation of agricultural systems.

Key words: total factor productivity, sustainability, total resource productivity, agricultural development, externalities.

JEL Classification System: O47, D24, Q01

Introduction

The issue of factor productivity remains still significant in the agricultural sector of most countries. Observing the trend in total factor productivity indices and most importantly being able to disentangle the relative contribution of a variety of factors in determining this growth rate, is a key issue that helps shape policies aiming at agricultural development.

However, an ongoing issue is how this should be done in a way to reflect whether resources are being used in a sustainable manner or are being misused and allowed to degenerate faster than their ability for self restoration. The point is that intensive agriculture along with market table outputs produces negative externalities as well. The productivity measures that have been widely used for many years were restricted to the factors of production and the outputs for which there was a price in a well defined market. Non-marketed externalities such as water pollution from agricultural chemicals for example, were largely ignored. In the last decades this became an essential issue and a lot of effort has been made to incorporate externalities in productivity measurement (Fare et al, 1989; Hailu and Veeman, 2001; Ball et al, 2005).

A bias occurs whenever externalities or social outputs are not included in the conventional measures of productivity growth. In order to reflect social responsibility alternative productivity growth measures are needed, which integrate the external or social output into a generalized productivity measure (Ball et al, 2005).

Conventional approaches to TFP measurement

The term productivity is defined as the rate of output produced per unit of input used in the production process. Total factor productivity (TFP) is a more comprehensive term that relies in a measurement of productivity based on aggregate outputs and inputs. According to production theory the rate of output depends on the state of technology, the quantity and quality of the factors of production used and the efficiency with which these factors are employed. Any divergence in TFP measurement over time or across firms in cross section data may come as the result of differences in the state of technology, the scale of pro-
duction or efficiency (Capalbo and Antle, 1988). Two general approaches can be distinguished in the measurement of TFP, the non-parametric and the econometric to which we now turn.

**Non-parametric approach to the measurement of TFP growth. The Tornqvist-Theil Index.** On the basis of the Tornqvist-Theil index lies the idea that the growth in total output can be explained by the growth in total factor input, provided there is no technological change. In order to calculate the TFP index in this way data on outputs and inputs must be aggregated by means of an indexing method the choice of which depends on the assumptions made regarding the underlying production technology. The Laspeyres index implies a linear production function in which all inputs are perfect substitutes or a Leontief production function in which all inputs are used in fixed proportions. The geometric index is exact for a Cobb-Douglas production function and the Tornqvist-Theil index which is an approximation to the Divisia index is exact for a homogeneous translog production function (Antle and Capalbo, 1988). The Divisia indexes for aggregate output and input are defined as proportional rates of growth. The proportional rate of TFP growth is:

\[
\text{TTFP} = \frac{Q - X}{Q_{t-1} - X_{t-1}}
\]

where

\[
\ln \frac{Q}{Q_{t-1}} = \ln \frac{X}{X_{t-1}}
\]

This shows by how much output(s) \(y\) can be increased given a quantity of input(s) \(x\), such that \(x\) and \(y\) remain in the production set. An input distance function can similarly be defined and under constant returns its value is the reciprocal to the output distance function. The reference technology set \(s^k\) consists of observations of all decision making units in time period \(k\).

To construct the Malmquist index, it is necessary to define distance functions with respect to two different time periods \(k\) and \(k+1\) as:

\[
D_o^k(x^{k+1}, y^{k+1}) = \left( \max \{ \theta : (x^{k+1}, \theta y^{k+1}) \in s^k \} \right)^{-1}
\]

\[
D_o^{k+1}(x^k, y^k) = \left( \max \{ \theta : (x^k, \theta y^k) \in s^{k+1} \} \right)^{-1}
\]

The distance function specified by the first equation measures the maximum proportional change in output required to make \((x^{k+1}, y^{k+1})\) feasible in relation to the technology used in period \(k\). Similarly, the distance function specified by the second equation measures the maximal proportional change in output required to make \((x^k, y^k)\) feasible in relation to the technology set \(s^{k+1}\) used in period \(k+1\).

Denneu et al (1981) offer a decomposition of the rate of productivity change into two separate components measuring the rate of technical change and returns to scale. Nishimitzu and Page (1982) identified technical change and change in technical efficiency as two distinct components of productivity change.

Efficiency difference between period \(k\) and \(k+1\) is measured as:

\[
\text{TEM}_{k} = D_o^{k+1}(x^{k+1}, y^{k+1}) - D_o^{k}(x^{k+1}, y^{k+1})
\]

where the numerator is the distance function, equation (8)

Efficiency difference between period \(k\) and \(k+1\) is measured as:

\[
\text{E}_{o}^{k+1}(x^{k+1}, x^{k+1}, y^{k+1}, x^k) = \frac{D_o^{k+1}(x^{k+1}, y^{k+1})}{D_o^k(x^k, y^k)}
\]

where the numerator is the distance function, equation, measured for time \(k+1\).

Technical difference between time period \(k\) and \(k+1\) is:

\[
\text{T}_{o}^{k+1}(x^{k+1}, x^{k+1}, y^{k+1}, x^k) = \left[ \frac{D_o^k(x^{k+1}, y^{k+1})}{D_o^{k+1}(x^{k+1}, y^{k+1})} \right] \times \left[ \frac{D_o^{k+1}(x^{k+1}, y^{k+1})}{D_o^k(x^{k+1}, y^{k+1})} \right] \times \left[ \frac{D_o^k(x^{k+1}, y^{k+1})}{D_o^{k+1}(x^{k+1}, y^{k+1})} \right]
\]

The Malmquist productivity index is the product of the efficiency index and the technical index:

\[
M_{o}^{k+1} = \text{E}_{o}^{k+1} \times \text{T}_{o}^{k+1}
\]

The Malmquist productivity index was later integrated in the Data Envelopment Analysis (DEA) framework by Fare et al (1992) using a constant returns to scale technology for a benchmark. Subsequently, Fare et al (1994) extended the decomposition to a variable returns to scale technology. Ray and Desili (1997) pointed out an
inherent contradiction in the Fare et al (1994) decomposition and offered an alternative.

**Econometric approach.** What is generally meant by productivity is the increase in output that can not be attributed to the corresponding increase in input use. In other words, it is the increase in output over and above the increase that can be achieved by an equivalent raise in the factors of production. This ‘unexplained residual output growth’ was recognized as early as the 50’s (Abramovitz, 1956). In the following decades, the residual TFP growth was ascribed to the following factors: the rate of change of technological progress, the influence of scale economies, productive efficiency and the effect of the lack of adjustment of quasi-fixed inputs to their long-term equilibrium levels. These factors’ relative contribution to TFP growth - positive or negative- was disentangled by means of either the primal approach, which is the econometric estimation of production functions, or the dual approach which involves the estimation of cost and profit functions. Although the primal and dual approach are two distinct but equivalent ways to analyze the production technology the dual approach has dominated empirical work (Capalbo and Antle, 1988).

The primal approach focuses on the way in which the factors of production are combined in order to produce the final output as described by the production function. In fact, the production function is a set of possible relationships between inputs and outputs at a particular technological level and can be used for modeling and measuring productivity growth. Apart from the Cobb-Douglas production function the transcendental logarithmic function which is a flexible functional form has been used to model productivity (Beattie and Taylor, 1985).

In the recent decades production theory turned from production functions to duality theory and relied more on cost and profit functions. In the context of duality theory the producer’s objective function can be described by a cost or profit function. Hence, factor demand and output supply equations compatible with profit maximization or cost minimization on behalf of the producers, may be readily derived. This is due to the particular properties of the dual relationships known as the Hotelling lemma and Shephard’s lemma as they characterize the profit and cost function, respectively. The developments in duality theory have contributed to the formulation of economic models that do not require an ex ante knowledge of the existent production technology (Diewert, 1974).

At the same time, a number of different flexible functional forms were proposed to capture firm behavior and describe the underlying technology. Some of them that are more often used to analyze the agricultural sector are presented in what follows.

Even though all flexible forms can interpret complex types of factor substitution the most widely used is the transcendental logarithmic function (translog) developed by Christensen, Jorgenson & Lau (1973):

\[
\ln C = \alpha_0 + \sum \alpha_i \ln P_i + \frac{1}{2} \sum \sum \alpha_{ij} \ln P_i \ln P_j + \sum \beta_i \ln Q + \sum \delta_i \ln Q_i \ln Q_j + \frac{1}{2} \sum \sum \beta_{ij} \ln Q_i \ln Q_j + \sum \phi_i \ln P_i + \sum \rho_i \ln Q \cdot t + \alpha \cdot t
\]  

where, \( \alpha, \alpha_i, \beta_i, \delta_i, \mu_i, \rho_i, \alpha \) are the estimated parameters, \( P \) are the prices of variable factors of production, \( Q \) is the output quantity and \( t \) is time.

The reasons for its popularity are that its logarithmic form facilitates empirically the imposition of homogeneity restrictions and the calculation of elasticities. It is also flexible since it permits to test statistically technology characteristics such as the returns to scale. The Cobb-Douglas function that is also used is a special case of the translog function and assumes constant elasticity of substitution between the factors of production and homothetic technology. It is possible to statistically test whether the underlying technology is best described by a Cobb-Douglas, by examining the estimated parameters of the translog.

The generalized Leontief proposed by Diewert (1971) has also been established as another functional form extensively used to analyze production technology in the long run:

\[
C = Q \left[ \sum \sum \beta_i P_i \ln P_i^{1/2} + \sum \phi_i P_i t \right]
\]  

where \( \beta_i, \phi_i \) are the estimated parameters.

Another function that is used to approximate production technology is the Normalized Quadratic (Heady & Dillon, 1962):

\[
C = Q \left[ \sum \alpha_i P_i + \left( \frac{1}{2} \right) \sum \sum \alpha_{ij} P_i P_j + \sum \phi_i P_i t \right]
\]  

where, \( \alpha_i, \alpha_{ij}, \phi_i \) are the estimated parameters. In this case, prices \( P \) are normalized. All these flexible functional forms are used as second order Taylor approximations of a cost function.

**Amendments in TFP measurement and sustainability**

The assessment of economic performance by means of the TFP measures, as they were briefly discussed in the previous sections do not include any external effects economic activity might have on the environment. Externalities are the side effects of economic activity that are not being compensated for. Externalities can be ‘good’ or ‘bad’ and are termed positive or negative, respectively. If, for example, the runoff from the use of agrochemicals in an area with agricultural holdings pollutes a lake, fishermen are negatively affected because of the
reduction in fish population. A negative externality is present provided fishermen are not compensated for the worsening of their situation. On the other hand, if a property owner takes actions to improve his property, the value of other properties in the area also increase despite the fact their owners undertook no actions to improve them. If this landowner receives no compensation for his activities, we have the presence of a positive externality. The conventional measures of total factor productivity do not take into account externalities that are the by-products of most production processes.

Another characteristic of the conventional measures for total factor productivity growth is that they do not reflect changes in resource stock levels and flows which is a shortcoming, particularly for the agricultural industry which relies heavily in the use of natural resources.

In order for agricultural development to be sustainable the measurement of productivity and hence the evaluation of agricultural systems should embrace all these issues. The assessment of productivity growth should accommodate both the occurrence of externalities from agricultural activities and the potential depletion of natural resource stocks and flows.

**Incorporating externalities in TFP measurement.**

The most relevant problem is how to measure the economic value of an externality. Positive externalities should receive a positive social value and negative externalities should have a negative social value. Agricultural externalities are more complex because they are not associated with an identified specific source but instead the sources of the externality are widespread to a large number of farm units. For example, agricultural chemicals leach and pollute the underground water but it is difficult to assign a particular level of pollution to any specific farm in the catchment’s area. This type of pollution is the collective responsibility of all production units in the area hence it is termed a ‘non-point’ source of pollution.

The usual TFP measures include all marketed outputs and inputs but ignore non-marketed outputs and externalities. This omission causes distortions in the assessment of productivity, especially in the agricultural industry, where the production process has significant environmental effects.

Two terms that have been suggested and reflect the addition of non-marketable inputs-outputs and externalities in productivity measurement, are Total Resource Productivity (TRP) and ‘Social’ Total Factor Productivity (social-TFP), (Gollop and Swinand, 1998; Barnes 2002).

Gollop and Swinand (1998) compared estimates of TRP growth and TFP growth for the US agricultural sector over the period 1972-1993. The environmental regulations for pesticides that were imposed on the farm sector are accounted for in the measurement of TRP. A welfare maximization model is used to derive the estimates and the effect of pesticides on ground water is captured by shadow prices. TRP growth rates are lower than TFP growth rates during the period of increased groundwater pollution from pesticides. The estimates are reversed during the periods of pollution reduction whereby TRP growth rates exceed conventional TFP estimates. Thus, in this case TFP growth rates overestimate productivity growth when pollution is rising and underestimate it when pollution is reduced.

The finding that conventional measures of productivity are biased upward when the production of negative externalities is escalating and biased downward when externalities in production are declining is also confirmed by Ball et al (2005) for the US agricultural sector. They estimate productivity growth using a generalised measure adjusted to encompass social responsibility for environmental protection. Specifically, they use a state-by-year panel of the sector which includes data on the environmental risk imposed by intensive farming due to pesticide leaching and runoff. The typical handicap of non-availability of price data for externalities or social outputs that can be a restrictive factor in measuring productivity growth with the usual growth accounting and index number approaches is overcome. Interestingly, joint production of output and the external effect are modelled without requiring any data on the shadow price of the externality.

The productivity bias is also detected by Hailu and Veeman (2001) in the case of the Canadian pulp and paper industry where conventional productivity measures consistently underestimate productivity growth when compared to environmentally adjusted measures. They estimate a parametric input distance function that incorporates both desirable outputs and two undesirable water pollutant outputs. The estimates show that measures of productivity change that disregard the externalities underestimate considerably the performance of the industry. The productivity improvement, from society’s point of view has been bigger than conventional measures would imply, the reason being that conventional measures do not take into account the reduction in pollution achieved by this industry through investment in pollution abatement capital.

A ‘social’ TFP Tornqvist index is used to measure productivity in the U.K. agriculture, which includes two bad outputs, pesticide and nitrogen pollution and gives diverging results when compared to the regular TFP growth index (Barnes, 2002). In the ‘70s the environmentally adjusted measure reduces TFP growth while from the 80’s onwards there is a growth in social-TFP as pesticide and nitrogen use is falling. Rising estimates of social-TFP may be expected if other public goods beyond pollution abatement, such as potential contributions towards sustainable agricultural development, are included in the productivity calculations.
**Sustainability and economic performance.** When sustainability is analyzed from the point of view of natural sciences the emphasis is on its biophysical dimensions. In that context the aim is to preserve the productive capacity of resources in the long-run. Such biophysical measures of sustainability are for example, crop yields on the output side or indicators of soil and water quality on the input side. However, these measures of sustainability seem to be confined to one aspect of the problem, because yields must not be interpreted in isolation but in relation to input use and any indicators of resource quality must be related to productivity (Byerlee and Murgai, 2001). We can not rely on biophysical indicators of sustainability alone and ignore factors that affect the economic performance of a farming system. Nambari et al (2001) propose an agricultural sustainability index (ASI) that includes economic and social indicators along with biophysical and chemical ones and apply it to the coastal zone of China. The index is as follows:

\[
ASI = N \times Y \times S \times M \times Q \times B \times I \times E
\]  

where \( N \) is the agricultural nutrient balance, \( Y \) the crop yield, \( S \) the soil quality, \( M \) the agricultural management, \( Q \) the agri-environmental quality, \( B \) the agricultural biodiversity, and \( E \) is the agricultural net energy balance.

The indicator \( I \), is the economic and social viability expressed as real net output per unit of land, income per worker and change in managerial skills. The rating of each indicator, including \( I \), affects the size of the overall ASI index. Results indicate substantial changes in sustainability during the 90’s between regions within the coastal zone of China. As pointed out, the index is sensitive to the ratings chosen for the various indicators and must be tested to determine whether statistically significant differences can be detected after its application in different agricultural systems. In addition, it is more appropriate to rely on total factor productivity rather than on the productivity of a single factor of production, land in this case, given the possibilities for factor substitution and economies of scale.

The perspective of social sciences is the economic viability of farming in the long-run and TFP was considered a suitable measure of output which determines sustainability. A non-negative trend in TFP over time was taken as an indication that a system was sustainable since output appeared to be increasing at least as fast as inputs. Whilst a negative trend in TFP seemed to imply that resources are being misused (Lynam and Herdt, 1989). The adjustment of TFP measures to account for externalities improves their ability to assess economic performance that is compatible with sustainable development. Total Resource Productivity (TRP) and ‘Social’ Total Factor Productivity (social-TFP) are indexes that accommodate non-marketable inputs and outputs and externalities in the measurement of productivity. Hence, it is a non-negative trend in total resource productivity over time that is now taken to be a measure of a sustainable agricultural system. A criticism extended to both measures is that the analysis is performed at an aggregate level as TFP and TRP are usually applied to a sector or state level. Either one, as an overall index does not identify particular production systems and regions with potential sustainability problems, especially given that these problems tend to affect particular locations. Instead, the farming systems level has been suggested as the appropriate level of analysis, where parallel activities are carried out in terms of crops grown, livestock raised and inputs used.

The issue of resource stocks and flows must also be considered for the evaluation of economic performance with a focus on sustainability. Intertemporal comparisons of TFP measures that incorporate and set a value to the resource stocks and flows can reveal whether an agricultural system is sustainable or not. Equally, interspatial all inclusive TFP measures can be used to compare two alternative farming systems at a certain point in time. Ehui and Spencer (1993), adjust the ‘Denny and Fuss’ interspatial and intertemporal TFP measures to account for changes in resource stocks and flows in four cropping systems in Nigeria, looking at the changes in the stock of soil nutrients in particular. The TFP measures are derived from a dual variable cost function which besides the standard variables of crop output \( Y \) and input prices \( W \) has as additional arguments the change in resource stock levels \( Z \) and the resource stock abundance level \( B \).

\[
G_{it} = G (Y_{it}, W_{it}, Z_{it}, B, T, D)
\]

Where \( T \) is the intertemporal and \( D \) the interspatial efficiency difference indicators. Their results show that the TFP measures are sensitive to changes in soil nutrient stocks and flows. More specifically, in those cases where the soil nutrients are important for the cropping system, conventional and modified TFP measures produce different results. The extension of the time span of analysis beyond the two years examined in this case and the addition of more environmental variables such as water quality, erosion etc. will enhance further the evaluation of agricultural systems in terms of their sustainability.

A third approach combines the previous two, i.e. one that focuses on indicators of resource quality and the other that points to productivity measures (Byerlee and Murgai, 2001). In order to assess the sustainability of agricultural systems, we have to define separate indicators of agro-ecosystems health and consequently relate them to TFP trends. The idea is to develop useful and cost-effective indicators to monitor long-term changes in resource quality and ways to relate these, to changes in...
productivity. In that context, the assessment of developments in sustainability can be carried out by means of a production function that will integrate, economic, agronomic and resource quality variables. Along with the conventional inputs it should include non-conventional inputs such as education, agricultural technology variables, weather variables, resource degradation variables such as soil erosion and nutrient status in the soil and in the watersheds.

Criticism has been extended regarding the use of sustainability indicators that cover economic, social and environmental data, by Hueting and Reijnders (2004). The additive nature of these indicators with the composing elements being added up, with or without weighing, is being questioned. A further point that is made concerns the incorporation of economic and social data in the sustainability indicators given that no credible causal relation seems to exist between socioeconomic data and a system’s sustainability. The latter is being defined as that production level that safeguards the living standards of generations to come and depends on the availability of the fundamental functions of ecosystems in the long run. The suggestion that follows is that economic and social data should be accessible as separate and distinct indicators, whereas the physical indicators for sustainability should focus on the processes that operate in natural ecosystems.

Concluding remarks

This paper reviewed the main parametric and non-parametric methods used to estimate total factor productivity (TFP) growth which is an important instrument in assessing the performance and sustainability of agricultural systems over time. However, the belief that a non-negative trend in TFP growth implies that a system is sustainable, in view of the fact that output appears to increase at least as fast as inputs, is questioned. There are other aspects as well to consider in the assessment of the performance of a rural system, besides production, such as the treatment of externalities generated by agricultural activity or the way natural resources may be depleting.

The question to address is therefore, by which instrument the sustainability of a rural system should be measured in the course of time. The long term trends in TFP may serve by giving an indication of biophysical sustainability only when a negative growth rate is observed continuously over a period of time. In the other cases conventional TFP growth indexes appear to be biased either underestimating or overestimating productivity developments in the presence of externalities. For that reason alternative measures are used such as ‘total resource productivity’ and ‘social’ TFP that can remove the bias in measuring changes in productivity growth.

A theoretical counter argument that is suggested is to determine separate indicators of agro-ecosystem quality and relate them to trends in productivity so as to broaden the evaluation of agricultural systems. This should be done at a disaggregate level and over a long period of time to allow for variations in space and time that characterize agricultural production, as long as the problem of data availability, which is a major constraint, can be overcome.

Provided that social outputs and externalities ought to be included for a more comprehensive productivity assessment, it is preferable to use the non-negative trend in total resource productivity instead of conventional TFP as a measure of a sustainable agricultural system. When there is availability of data on resource stocks and flows it is essential to expand the productivity index to accommodate this information.

Either way, taking into account that the sustainable use of agricultural resources is an objective that lies in the center of any policy to promote agricultural development, productivity growth measurement should reveal the change in both good and ‘bad’ outputs and inputs and the change in resource quality. As long as the TFP growth index is amended in a way that reflects the environmentally undesirable impacts of agricultural activities, it will be a satisfactory indicator of sustainability to be used in the pursuit of agricultural development.

References


