



*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

# Production Structure Characteristics and Adaptations of Productivity Growth Measures : A Survey

*Lassaad LACHAAL*

**Caractéristiques de la production et des marchés et mesures de la croissance de la productivité : une revue de la littérature**

**Mots-clés :**  
productivité globale des facteurs, approches traditionnelles, caractéristiques de la production et des marchés, adaptations des mesures standard

***Production Structure Characteristics and Adaptations of Productivity Growth Measures: A Survey***

**Key-words :**  
total factor productivity, traditional measures, technical and market characteristics, measurement adaptations

**Résumé** – L'objectif de cet article est double. D'une part, il propose une revue, non exhaustive, de la littérature sur les méthodes de mesure et d'analyse de la productivité d'une entreprise ou d'un secteur. A cette fin, les diverses approches non paramétriques et économétriques généralement utilisées pour mesurer la productivité globale des facteurs sont présentées, ce qui permet de mettre en évidence les hypothèses usuelles qui les sous-tendent. D'autre part, cet article passe en revue quelques extensions possibles des approches traditionnelles permettant d'assouplir certaines hypothèses usuelles et d'améliorer la mesure et l'interprétation de l'évolution de la productivité globale des facteurs. Ces adaptations visent à prendre en compte certaines caractéristiques techniques de production et certaines spécificités de marché dans l'analyse et l'évaluation de la productivité, en particulier (i) impact de la présence d'économies d'échelle ; (ii) impact de structures de concurrence imparfaite ; et (iii) impact des inefficacités de production. Ces extensions possibles des approches usuelles ne constituent en aucun cas une liste exhaustive des caractéristiques de la production et des marchés à considérer, mais reflètent plutôt quelques-uns des problèmes majeurs auxquels on est confronté lorsque l'on désire mesurer la productivité d'une entreprise ou d'un secteur. Il ressort de la discussion qu'il existe un réel besoin d'un cadre théorique élargi capable de prendre en compte explicitement les effets de ces caractéristiques de production et de marché dans les analyses et les évaluations de l'évolution de la productivité. Ainsi, le développement d'un tel cadre semble une voie d'approfondissement nécessaire pour améliorer notre compréhension et interprétation de cet indicateur de performance. L'article propose également quelques directions de recherche pour le futur telles que la prise en compte de l'impact de la recherche-développement (R&D), des politiques tarifaires et des politiques de prix dans l'analyse et l'évaluation de l'évolution de la productivité.

**Summary** – Non-parametric index number and parametric econometric techniques for productivity growth measurement and interpretation are reviewed in this paper. Procedures to account for technical and market characteristics which affect productivity growth and are ignored in traditional measures are presented. Adaptations to traditional measures include the effect of scale economies, imperfect competition in output market, and inefficiency in production. The main conclusion is that a comprehensive framework that accounts for these and other characteristics is much needed. Pursuing ways to develop such a framework to refine and extend our understanding and interpretation of productivity growth has perhaps the greatest potential to tackle these and other issues found in the productivity growth literature. Along these lines, future research areas that seem to provide a strong potential direction for future work include, the effect of R&D, the effect of tax policies, and the role of government price policies on productivity growth measurements.

\* Department of Agricultural Economics, National Agricultural Research Institute of Tunisia (INRAT), Rue Hédi Karray, 2049 Ariana, Tunisia.

PRODUCTIVITY growth is often cited as one of the major factors contributing to the continued economic growth of a nation (Huffman, 1993). As a result, measures and analysis of productivity change have been an area of great interest for both economists and policy makers. This interest has been for at least two purposes. First, productivity measures can be used for comparative purposes. That is, to compare productivity levels among different periods as well as different regions (Hayami and Ruttan, 1985; Ball, 1985). Second, they can be used to account for the different sources of growth related to various changes in the production process, including technical efficiency, scale economies and technological change (Fan, 1991; Capalbo, 1988). Of particular interest has been the influence of research expenditures (both private and public), extension and schooling on productivity growth (Evenson, 1988; Huffman and Evenson, 1992).

During the late seventies to early eighties, most industrialized countries experienced large productivity fluctuations and slowdown<sup>(1)</sup>. As a result, a large body of the literature was developed to provide the kind of explanations sought for these fluctuations. However, measurement analysis alone of existing productivity measures did not seem to provide good insights into the reasons underlying productivity growth fluctuations. To overcome these difficulties, methodological developments in productivity growth research have taken new directions to account for technical and market characteristics which affect productivity growth and were typically ignored in traditional measures.

The objectives of this paper are twofold. The first is to review the literature on current methods related to productivity growth measurement and explanation. In doing so, we show the need to understand the assumptions underlying traditional measures and which must be considered in interpreting the findings of productivity studies. Further, procedures for adjustments for technical and market characteristics which are typically ignored in traditional productivity growth computations are presented. These include: presence of scale economies, imperfect competition in output markets, and inefficiency in the production process. The second objective is to outline future research areas that seem to provide a strong potential direction for new insights. This relates to the effect of R&D, the impact of tax policies, and the role of government price policies on productivity growth measurement. Concluding comments are provided in the last section.

---

<sup>(1)</sup> See the papers presented in a symposium on "The slowdown in productivity growth", *Journal of Economic Perspectives*, Fall, 1988.

## PRODUCTIVITY MEASUREMENTS

The basic concept in productivity measurement is total factor productivity (*TFP*), the ratio of an index of aggregate output to an index of aggregate input. Two formal approaches for deriving total factor productivity indexes have been identified in the literature: the growth accounting (index number) approach and the econometric approach.

### The Growth Accounting Approach

The starting point of this approach is the view that, in the presence of technological progress, growth in total factor inputs do not explain total output growth. The residual growth in output not accounted for by the growth in factor inputs is associated with productivity growth (Domar, 1961). Thus, procedures for measuring productivity growth are based on this fundamental concept of residual output (Kendrick, 1961; Jorgenson and Griliches, 1967).

When using this approach however, heterogenous inputs and outputs need to be aggregated. For this purpose, a number of index formulas have been developed and applied in the literature. However, from a conceptual point of view, the *divisia index* (Diewert, 1976) has been the most widely accepted method of aggregation for use in productivity analysis. A measure of *TFP* growth based on this index is given as follows:

$$TFP = \dot{Y} - \dot{X} \quad (1)$$

where aggregate outputs and inputs indexes,

$$\dot{Y} = \sum_j \frac{P_j Y_j}{R} \dot{Y}_j \text{ and } \dot{X} = \sum_i \frac{w_i X_i}{C} \dot{X}_i,$$

are defined in terms of proportional rates and weighted by their average revenue shares and cost shares, respectively.

The proportionate rate of growth of total factor productivity as defined in (1) is expressed in terms of instantaneous changes and applies only exactly to data generated continuously. To make this index operational a discrete approximation is needed<sup>(2)</sup>. The most commonly used

---

<sup>(2)</sup> For a long time, approximation to divisia input index was done in an ad-hoc manner. However, in his seminal article, Diewert (1976) was able to identify the economic assumptions about the underlying aggregation functions that are implicit in the choice of an index number. For example, the use of Laspeyres index number implies the assumption of either a linear production function in which all inputs are substitutes, or a Leontief production function in which all inputs are used in fixed proportions. The geometric index number implies an underlying Cobb-Douglas specification for the production function. Finally, the Tornqvist-Theil index number has been shown to be exact for a homogenous translog production function.

discrete approximation to the continuous Divisia index is provided by the Tornqvist-Theil quantity index (Hulten, 1973). First, we define the Tornqvist-Theil approximation to the Divisia indexes of aggregate outputs and inputs as:

$$\begin{aligned}\Delta \text{Ln} Y &= \text{Ln} \left( \frac{Y_t}{Y_{t-1}} \right) = 1/2 \sum_j (R_{jt} + R_{j,t-1}) \text{Ln} \frac{Y_{jt}}{Y_{j,t-1}} \\ \Delta \text{Ln} X &= \text{Ln} \left( \frac{X_t}{X_{t-1}} \right) = 1/2 \sum_i (S_{it} + S_{i,t-1}) \text{Ln} \frac{X_{it}}{X_{i,t-1}}\end{aligned}\quad (2)$$

where  $R_{jt}$  and  $S_{it}$  are the revenue share of output  $Y_j$  in total revenue and the cost share of input  $X_i$  in total cost in period  $t$ . Then, a discrete approximation to (1) is provided by the following:

$$\Delta TFP = \Delta \text{Ln} Y - \Delta \text{Ln} X \quad (3)$$

By choosing the index to equal 100 in a particular year and accumulating the measure in accordance to (3), we obtain one estimate of the conventional index of total factor productivity.

Interpretation of this index requires some care when the implicit assumptions of neutral technical change, constant returns to scale and perfectly competitive markets are not met. With departure from the above assumptions, this residual includes not only the effect of technical change but also the effects of many economic phenomena including, non-constant returns to scale and market imperfections.

An alternative framework for making index number measurements of productivity growth without having to approximate a concept specified with respect to continuous time was proposed in Caves, Christensen and Diewert (1982). The novelty of their approach was to use the notion of distance functions to define the Malmquist productivity index. However, it was not until 1992 that Färe *et al.* (1992) first provided the foundation to empirically estimate the Malmquist productivity index. Since then, this index has enjoyed an increased popularity which can be attributed to several factors. Namely, (i) the Malmquist index has the advantage that it can be constructed from quantity data only; (ii) the index requires less restrictive assumptions than other traditional index numbers; and (iii) no econometric estimation is needed for its construction.

Given the recent developments in this area, we present here a brief description of the Malmquist productivity index. The exposition is based on output distance functions, which are reciprocals of non-parametric Farrell (1957) radial efficiency measures. A parallel approach based on an input-oriented measure, however, can also be developed.

To illustrate, let  $X^t = (X_1^t, \dots, X_n^t) \geq 0$  and  $Y^t = (Y_1^t, \dots, Y_m^t) \geq 0$  denote vectors of inputs and outputs in period  $t$ ,  $t = 1, \dots, T$ . Further, let  $P^t(X^t)$  denote the technology set of all output vectors  $Y^t$  obtainable

from input vectors  $X^t$ . As in Färe, Grosskopf and Lovell (1994), this set is assumed to exhibit constant returns to scale and free disposability of outputs and inputs. Following Shephard (1970), the output distance function representation of the technology is defined as:

$$D_0^t(X^t, Y^t) = \inf \left\{ \theta : \frac{Y^t}{\theta} \in P^t(X^t) \right\}, \quad \theta > 0 \quad (4)$$

Introducing observations from two periods,  $t$  and  $t + 1$ , and corresponding technology sets, the output-based Malmquist index is given by the ratio of two distance functions (Caves *et al.*, 1982, eq. 33):

$$M_0^t(X^t, Y^t, X^{t+1}, Y^{t+1}) = \frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)}, \quad t = 1, \dots, T \quad (5)$$

where  $D_0^t(\cdot)$  is the output distance function relative to the technology set for period  $t$ . The Malmquist index in (5) is interpreted as a measure of productivity change and can take values greater than, equal to or less than unity according whether productivity increases, remains the same or declines between periods  $t$  and  $t + 1$ .

As noted above, Färe *et al.* (1992) provided a way for computing the Malmquist productivity index. Applying linear programming techniques as in data envelopment-type analysis, they computed the distance function (4) for each observation  $k$  ( $k = 1, \dots, K$ ) at each period  $t$  as the solution to program (6) below. In fact the solution calculates output-based Farrell measures of technical efficiency. An output distance function for each observation  $k$  is obtained by the reciprocals of the solutions to the following:

$$\begin{aligned} [D_0^t(X^{kt}, Y^{kt})]^{-1} &= \max \theta \\ \text{subject to: } \theta Y_j^{kt} &\leq \sum_k \lambda^{kt} Y_j^{kt}, \quad j = 1, \dots, J \\ X_i^{kt} &\geq \sum_k \lambda^{kt} X_i^{kt}, \quad i = 1, \dots, I \\ \lambda^{kt} &\geq 0, \quad k = 1, \dots, K \end{aligned} \quad (6)$$

where  $\lambda^{kt}$  denotes intensity variables familiar from activity analysis. In addition, similar computations of mixed periods distance functions  $D_0^t(X^{t+1}, Y^{t+1})$  and  $D_0^{t+1}(X^t, Y^t)$  are required to obtain the Malmquist productivity change index defined as the geometric mean of two adjacent-period indices:

$$M_0^{t+1} = \left[ \frac{D_0^t(X^{t+1}, Y^{t+1}) D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t) D_0^{t+1}(X^t, Y^t)} \right]^{1/2} \quad (7)$$

Bureau *et al.* (1995), in an empirical application comparing the Malmquist productivity index in (7) to other non-parametric productivity measures, found the Malmquist index to yield *TFP* measurements consistent with the Fisher and Hulten indices. The main limitation,

they note, is that the proposed non frontier approach does not identify the role of technical inefficiency.

Färe, Grosskopf, Norris and Zhang (1994) proposed a frontier analogue to the above and extended the Caves *et al.* Malmquist productivity index to allow for technical inefficiency. By introducing the notion of inefficient observations, the authors were able to decompose the Malmquist output index of productivity change into two components. The first component measures the change in efficiency relative to own period technology while the second component measures technical change. Decomposition of *TFP* change into these components is obtained from the geometric mean of period  $t$  and  $t + 1$  indices as follows:

$$M_0^{t+1} = \left[ \frac{D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)} \right] \left[ \frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^{t+1}(X^{t+1}, Y^{t+1})} \frac{D_0^t(X^t, Y^t)}{D_0^{t+1}(X^t, Y^t)} \right]^{1/2} \quad (8)$$

While having the definite advantage of not requiring the specification of a particular parametric model, the above approach, being non-parametric and deterministic, precludes hypothesis testing regarding certain features of the technology (e.g., returns to scale). To remedy this situation, Atkinson and Cornwell (1998), proposed an alternative econometric cost frontier framework to decompose productivity change into technical change and change in firm efficiency relative to the frontier. The authors developed an input based distance measure of productivity change which they decomposed using the Nishimizu and Page (1982) type of productivity growth decomposition framework.

## The Econometric Approach

The econometric approach to productivity measurement is based on econometric techniques to estimate the production function, the cost function associated with the production function, or the output supply and factor demand equations associated with the profit function. These parametric techniques used to measure total factor productivity growth are found appealing mainly because they are statistical. The following develops the links between production theory and the conventional *TFP* growth measure (Solow, 1957; Ohta, 1974).

Assume the following single output technology:  $Y = f(X, t)$ , where  $t$  represents technical progress. Taking the logarithmic time derivative of both sides of this relationship gives:

$$\dot{Y} = \sum_i \frac{\partial f(X, t)}{\partial X_i} \frac{dX_i}{Ydt} + \frac{\partial \ln f(X, t)}{\partial t} \quad (9)$$

Defining the rate of technical change as  $TC = \partial \ln f(X, t) / \partial t$ , and assuming cost minimization,  $\partial f / \partial X_i = w_i / (\partial C / \partial Y)$ , equation (9) yields:



$$\dot{Y} = \sum_i \varepsilon_{CY}^{-1} \frac{w_i X_i}{C} \dot{X}_i + \dot{T}C \quad (10)$$

where  $\varepsilon_{CY}$  is the elasticity of cost with respect to output. Substituting the index of aggregate inputs as defined above, we obtain:

$$\dot{T}C = \dot{Y} - \varepsilon_{CY}^{-1} \dot{X} \quad (11)$$

Or using the conventional measure of *TFP* growth defined in (1), we write:

$$\dot{TFP} = \dot{T}C + (\varepsilon_{CY}^{-1} - 1) \dot{X} \quad (12)$$

We now can see the effect of a departure from the assumption of constant returns to scale on *TFP* growth measure. Thus, only by assuming constant returns to scale ( $\varepsilon_{CY} = 1$ ), that the econometric approach yields a measure of the growth rate of *TFP* identical to the growth rate of technical change. Without this assumption, this measure of *TFP* includes the dynamic effects of technical change as well as the static scale effects.

A parallel approach, leading to a dual measure of productivity growth can be carried out using an aggregate cost function,  $C = C(Y, w, t)$ . Taking the natural logarithm of both sides of this function and totally differentiating it with respect to time yields:

$$\frac{dC}{dt} \frac{1}{C} = \frac{\partial \ln C}{\partial Y} \frac{dY}{dt} + \sum_i \frac{\partial \ln C}{\partial w_i} \frac{dw_i}{dt} + \frac{\partial \ln C}{\partial t} \quad (13)$$

Defining the dual rate of technical change as,  $\dot{T}C_d = \partial \ln C(Y, w, t) / \partial t$ , arranging terms and making use of Shephard's lemma, equation (13) can be rewritten as:

$$\dot{T}C_d = \dot{C} - \sum_i \frac{w_i X_i}{C} \dot{w}_i - \varepsilon_{CY} \dot{Y} \quad (14)$$

Consider now differentiating both sides of the cost equation  $C = \sum w_i X_i$  logarithmically with respect to time and rearranging yields:

$$\dot{C} - \sum_i \frac{w_i X_i}{C} \dot{w}_i = \sum_i \frac{w_i X_i}{C} \dot{X}_i \quad (15)$$

Substituting into equation (14) yields:

$$- \dot{T}C_d = \varepsilon_{CY} \dot{Y} - \dot{X} \quad (16)$$

Or else, using the conventional measure of *TFP* growth in (1) yields:

$$\dot{TFP} = - \dot{T}C_d + (1 - \varepsilon_{CY}) \dot{Y} \quad (17)$$

Note that, in the absence of scale economies or diseconomies, this dual concept of productivity growth is equivalent to the primal specification of productivity growth measure outlined in equation (12) above.

Recently, developments in productivity growth measurement have focused on developing a framework that allows a decomposition of productivity growth into the different impacts resulting from scale economies and other technical and market characteristics. Morrison and Dievert (1990) observe that imperfect competition in output market appears to be the one that have much impact on productivity measure. The following section outlines a procedure to refine the above framework and incorporate market power into productivity growth measure.

## INCORPORATING MARKET POWER INTO PRODUCTIVITY MEASUREMENTS

Market power affects costs and therefore measured productivity growth in important ways. Indeed, for regulated industries, the assumptions of constant returns to scale and perfect competition are inappropriate. As Denny *et al.* (1981) observe, "*Monopolistic elements and cross-subsidization practices imply existence of non-marginal cost pricing of output*". The following cost-oriented framework recognizes the need to account for non-marginal cost pricing for regulated industries.

Assume that technology can be represented by the following aggregate cost function:

$$C = C(Y_1, \dots, Y_J, w_1, \dots, w_F, t) \quad (18)$$

Totally differentiating the above function with respect to time and rearranging terms yields:

$$-TC_d = \sum_j \epsilon_{CYj} \dot{Y}_j - \sum_i \frac{w_i}{C} \dot{X}_i \quad (19)$$

where  $TC_d$  denotes dual technical change and measures the proportionate shift in the cost function. Note that aggregate output index is defined as:  $\dot{Y}^p = \sum_j (P_j Y_j / R) \dot{Y}_j$ . Using cost elasticities as weights rather than revenues shares, output growth can also be defined as:

$$\dot{Y}^c = \sum_j [\epsilon_{CYj} / \sum_j \epsilon_{CYj}] \dot{Y}_j = [\sum_j \epsilon_{CYj}]^{-1} [\sum_j \epsilon_{CYj} \dot{Y}_j] \quad (20)$$

Note that under marginal cost pricing,  $\epsilon_{CYj} = \frac{Y_j}{C} \frac{\partial C}{\partial Y_j} = \frac{P_j Y_j}{C}$ , or else  $\sum_j \epsilon_{CYj} = \sum_j \frac{P_j Y_j}{C}$ . Therefore,  $\dot{Y}^c = \sum_j [P_j Y_j / \sum_j P_j Y_j] \dot{Y}_j = \dot{Y}^p$

Now making use of equation (20), we can write equation (19) as follows:

$$-TC_d = (\sum_j \epsilon_{CYj}) \dot{Y}^c - \dot{X} = (\sum_j \epsilon_{CYj} - 1) \dot{Y}^c + (\dot{Y}^c - \dot{Y}^p) + (\dot{Y}^p - \dot{X}) \quad (21)$$

Recalling that  $TFP = \dot{Y}^p - \dot{X}$ , the above equation can be rearranged to yield:

$$TFP = [-T'C_d] + [(1 - \sum_j \varepsilon_{CYj}) \dot{Y}^c] + [(\dot{Y}^p - \dot{Y}^c)] \quad (22)$$

which decomposes  $TFP$  growth rate into the contributions due to: (i) shifts in the cost function or technical change, (ii) movements along the cost function or scale economies, and (iii) non-marginal cost pricing. This last term can be interpreted as the effect on  $TFP$  growth rate of a departure from the marginal cost pricing assumption implicit in the standard index number approach.

## ADAPTATION OF PRODUCTIVITY MEASUREMENTS TO NON EFFICIENT PRODUCTION PROCESSES

Traditional productivity theory assumes perfect efficiency in production. That is, total production growth consists of movements along the production surface (increased input use) plus the increase in output due to shifts in the production surface (technological change). As a result, technical change was assumed to be the only source of productivity growth. If this assumption of continuously technically efficient production is relaxed, one can attribute total production growth to at least three separate factors: efficiency improvement, increased inputs use and technological change. Therefore, the rate of total factor productivity growth can be decomposed into the contributions due to technical change, scale economies and efficiency effects (Nishimizu and Page, 1982; Bauer, 1990).

### Production Function Approach to $TFP$ Decomposition

Let  $Y^* = f(X, t)$  represent the maximum output that can be produced with vector  $X$  at time  $t$ ; let  $Y$  denote actual production ( $Y \leq Y^*$ ). Define the Farrell (1957) output based measure of technical efficiency as:

$$TE = \frac{Y}{f(X, t)}, \quad \text{where } 0 < TE \leq 1 \quad (23)$$

Taking the logarithmic time derivative of both sides of equation (23) yields:

$$TE = \dot{Y} - \sum_i \frac{\partial \ln f(X, t)}{\partial X_i} \frac{dX_i}{dt} - \frac{\partial \ln f(X, t)}{\partial t} \quad (24)$$

Substituting the primal rate of technical change,  $TC$ , as defined above, equation (24) becomes:

$$Y = TE + TC + \sum_i \frac{\partial f(X, t)}{\partial X_i} \frac{X_i}{f(X, t)} X_i \quad (25)$$

Under cost efficiency,  $\frac{\partial f}{\partial X_i} = \frac{w_i}{\partial C / \partial Y}$ , equation (25) can be rearranged as:

$$Y = TE + TC + \sum_i \varepsilon_{CY}^{-1} S_i X_i \quad (26)$$

where,  $\varepsilon_{CY}$  is the cost elasticity with respect to output, and  $S_i$  is the cost share of factor  $i$ . Using the definition of the divisia index of  $TFP$  growth, one can write the following:

$$TFP = TE + (\varepsilon_{CY}^{-1} - 1) X + TC \quad (27)$$

This decomposition can be illustrated using production frontiers  $F_1$  in period 1 and  $F_2$  in period 2 (figure 1). Growth in  $TFP$  can be decomposed into: (i) an improvement in technical efficiency depicted by a movement from point  $A$  to  $B$ ; (ii) an increase in the scale of production depicted by a movement from point  $B$  to  $C$ ; and (iii) technological change resulting from a shift of the production frontier and depicted by a movement from point  $C$  to  $D$ .

Figure 1.  
A Production  
Function Approach  
to  $TFP$   
Decomposition

## Cost Function Approach to $TFP$ Decomposition

Again, a parallel analysis has been developed based on an aggregate cost function. Assume technology can be represented by the following dual cost function:  $C^* = C(Y, w, t)$ , where  $C^*$  represents the most efficient cost given  $(Y, w, t)$ . Following Farrell, define the input based overall measure of cost efficiency as follows:

$$CE = \frac{C(Y, w, t)}{C}, \quad \text{where } 0 < CE \leq 1 \quad (28)$$

where  $C$  is actual cost. Note that cost efficiency can be defined as the product of technical ( $TE$ ) and allocative efficiency ( $AE$ ). Or else,  $CE = TE + AE$ . Taking the logarithmic time derivative of both sides of equation (28) yields:

$$\dot{CE} = \frac{\partial \ln C}{\partial Y} \frac{dY}{dt} + \sum_i \frac{\partial \ln C}{\partial w_i} \frac{dw_i}{dt} + \frac{\partial \ln C}{\partial t} - \dot{C} \quad (29)$$

Arranging terms and making use of Shephard's lemma, equation (29) can be rewritten as:

$$\dot{C} - \sum_i \frac{w_i X_i}{C} \dot{w}_i = \varepsilon_{CY} \dot{Y} - \dot{CE} + \dot{TC}_d \quad (30)$$

making use of equation (15) above and assuming allocative efficient firms, we write:

$$\dot{TFP} = \dot{TE} + (1 - \varepsilon_{CY}) \dot{Y} + [-\dot{TC}_d] \quad (31)$$

The above decomposition can be illustrated using cost frontiers (figure 2). The increase in  $TFP$  between periods 1 and 2, that is from the initial position A to the final position D, can be decomposed into three effects as before. The first component represents technical efficiency and is depicted by a movement of the firm from A to B. The second, represents scale efficiency and is depicted by a movement from B to C. The third, represent technological change and is depicted by a shift of the average cost curve downward moving the firm from point C to D.

Figure 2.  
A Cost Function  
Approach to TFP  
Decomposition

The methodological development, in this paper, has been based primarily on considering procedures for adjustment to relax some of the assumptions inherent in the conventional measure of productivity growth. These extensions to the theory and measures of productivity growth are

by no means an exhaustive list of production characteristics that must be accounted for when measuring productivity growth. Rather, the discussions dealt with the most common issues encountered when measuring firm productivity<sup>(3)</sup>. Ignoring these technical and market characteristics yields biased estimates of firm or industry performance.

The burgeoning literature in the area of productivity growth measurement and explanation includes important contributions dealing with these issues. However, while our understanding of the determinants of productivity growth has been considerably advanced, other related areas still lack theoretical guidance and measurement refinements and thus provide some potential direction for future work.

## **FUTURE RESEARCH AGENDA**

### **Measurements of Productivity Growth and R&D**

A first line of research which promises to be a good field of new insights is related to the impact of R&D on economic growth. Indeed, while the literature dealing with the subject has provided strong empirical evidence linking R&D and productivity growth (Griliches, 1988; Nadiri and Bitros, 1980), potential problems of measurements and valuation of R&D still persist. These problems arise mainly due to difficulties faced in specifying R&D expenses in an appropriate manner or to impute correct benefits to earlier R&D. Extensions to the standard framework generally included R&D as an input into the production process. Nevertheless, indirect spillover effects which should also be accommodated are not easy to determine. Thus, future research into this area seem to be an urgent need to refine R&D measurements techniques and provide stronger evidence on the effects of R&D on productivity growth.

### **Measurements of Productivity Growth and Tax Policies**

The effects of tax policies on productivity growth measurement and explanation is another line of research that promises potential insights into this area. Indeed, while empirical evidence shed some light on the effects of tax policies on productivity growth, these effects are often difficult to quantify and the mechanisms by which they affect productivity are not well understood. Boskin (1988) points out that the 1970's United States tax policy which raised real effective tax rates on capital income may have

---

<sup>(3)</sup> Other determinants of cost and therefore production include capital obsolescence, R&D expenditures, advertising.

contributed to low investment and thus to low economic growth. The author further argues that the improvement in the 1980's productivity growth may well find its origin in the 1981 and 1986 tax reforms. Tolley and Shear (1984), on the other hand, provided an international comparison of tax rates and their effects on growth in national income. In both studies, though, these effects were difficult to quantify.

## **Measurements of Productivity Growth and Price Policies**

Agricultural price policies have often been seen by economists as a powerful instrument for directing and enhancing agricultural productivity growth<sup>(4)</sup>. Nevertheless, empirical evidence on the role of this instrument on productivity growth in the literature is rather limited. Recently, a handful of empirical studies have tried to investigate the role of government price policies on agricultural productivity growth.

Huffman and Evenson (1992) investigated the impact of US milk and crop price supports on technical change and hence productivity growth in both the crop and livestock sectors. The authors concluded that price effects on productivity growth are quite weak. Fulginiti and Perrin (1993) examined the relationship between price protection and technical change. They estimated a meta production function for 18 developing countries where output was a function of a set of conventional inputs and expected prices. The authors found that protectionist policies have a significant positive effects on productivity growth through greater innovation. Lachaal (1994) examined the role of price protectionism in the form of program subsidies on technical efficiency and hence productivity growth. The author applied Mundlak's (1988) concept of endogeneity to technical efficiency and generalized it within a dual framework. Empirical evidence from the US dairy sector suggested that protection policies can be growth retarding by encouraging technical inefficiencies.

The above studies, while providing useful information with respect to the nature of the relationship between price policies and productivity growth, are subject to some limitations. The most important of which is that they all consider the effects of price policies either on efficiency or on technical change. Thus, more work in this area is needed to provide stronger evidence and more guidance on the role of price policies on productivity growth.

---

<sup>(4)</sup> Antle (1988) argues that price support policies tend to positively affect technical change. Schultz (1979) claims that high prices reduce uncertainty and tend to drive technical innovations. Thus over-protected agricultural commodities are likely to display higher productivity growth rates. Farrel and Runge (1983) argue that agricultural price supports tend to promote more rapid technical progress.

## CONCLUSIONS

Measurement analysis of economic performance and, in particular, productivity growth is a wide ranging topic that have enjoyed a great deal of interest among researchers. Of particular importance have been the new methodological advances in productivity growth research to account for technical and market characteristics which affect productivity growth and were ignored in traditional measures.

The present paper reviews the literature on productivity growth measurements and provides insights on methodological extensions to relax the assumptions inherent in traditional growth measures. These extensions are simply a suggestive list of the most common issues encountered in productivity measurement research. As we have seen, recognizing the different technical and market characteristics results in adjustments to productivity growth measures that facilitate the analysis and interpretations of productivity fluctuations and/or slowdowns.

Our main conclusion is that while these adaptations provide insights about the impact of some determinants on productivity growth measure and decomposition, much remains to be done in the way of a comprehensive framework to accommodate these and other determinants and facilitate a better interpretation and analysis. Pursuing ways to develop such a framework to refine and extend our understanding and interpretation of productivity growth has perhaps the greatest potential to tackle these and other issues found in the productivity growth literature. These include, among others, the impact of research and development on productivity growth measurement and the effects of tax policy on economic growth. Within the same context, a related line of research that has been overlooked in the productivity literature appertains to the role of government price policies on the measurement of productivity growth in agriculture. Empirical evidence in the literature with regard to this issue is rather limited and more work in this area is needed to guide policy options.

## REFERENCES

- ANTLE (J. M.), 1988 — Dynamics, causality, and agricultural productivity, in: CAPALBO (S. M.) and ANTLE (J. M.) eds, *Agricultural Productivity Measurement and Explanation*, Washington, Resources for the Future.
- ATKINSON (S.) and CORNWELL (C.), 1998 — Estimating radial measures of productivity growth: Frontier vs non-frontier approaches, *Journal of Productivity Analysis*, 10, pp. 35-46.



- BAUER (P. W.), 1990 — Decomposing *TFP* growth in the presence of cost inefficiency, non-constant returns to scale, and technological progress, *Journal of Productivity Analysis*, 1, pp. 287-299.
- BALL (E.), 1985 — Output, input, and productivity measurement in US agriculture: 1948-1979, *American Journal of Agricultural Economics*, 67, pp. 475-486.
- BOSKIN (M. J.), 1988 — Tax policy and economic growth: lessons from the 1980's, *The Journal of Economic Perspectives*, 4, pp. 71-98.
- BUREAU (J.-C.), FÄRE (R.) and GROSSKOPF (S.), 1995 — A comparison of three nonparametric measures of productivity growth in European and United States agriculture, *Journal of Agricultural Economics*, 46, pp. 309-326.
- CAPALBO (S. M.), 1988 — Measuring the components of aggregate productivity growth in US agriculture, *Western Journal of Agricultural Economics*, 13, pp. 53-62.
- CAVES (D. W.), CHRISTENSEN (L. R.) and DIEWERT (E. W.), 1982 — The economic theory of index numbers and the measurements of input, output and productivity, *Econometrica*, 50(6), pp.1393-1414.
- DENNY (M.), FUSS (M.) and WAVERMANN (L.), 1981 — The measurement and interpretation of total factor productivity in regulated industries, an application to Canadian telecommunications, in: COWLING (T. G.) and STEVENSON (R. E.) eds, *Productivity Measurement in Regulated Industries*, New York, Academic Press, pp. 179-218.
- DIEWERT (E. W.), 1976 — Exact and superlative index numbers, *Journal of Econometrics*, 4, pp. 114-145.
- DOMAR (E.), 1961 — On the measurement of technological change, *Economics Journal*, 7, pp. 709-729.
- EVENSON (R.), 1988 — Research extension and US agricultural productivity: A statistical decomposition analysis, in: CAPALBO (S. M.) and ANTLE (J. M.) eds, *Agricultural Productivity Measurement and Explanation*, Washington, Resources for the Future.
- FAN (S.), 1991 — Effects of technological change and institutional reform on production growth in Chinese agriculture, *American Journal of Agricultural Economics*, pp. 266-275.
- FÄRE (R.), GROSSKOPF (S.), LINDGREN (B.) and ROOS (P.), 1992 — Productivity changes in Swedish pharmacies 1980-1989: A non-parametric Malmquist approach, *Journal of Productivity Analysis*, 3, pp. 81-97.

- FÄRE (R.), GROSSKOPF (S.) and LOVELL (C. A. K.), 1994 — *Production Frontiers*, Cambridge, Cambridge University Press.
- FÄRE (R.), GROSSKOPF (S.), NORRIS (M.) and ZHANG (Z.), 1994 — Productivity growth, technical progress, and efficiency change in industrialized countries, *American Econometric Review*, 84(1), pp. 66-83.
- FARREL (K.) and RUNGE (T.), 1983 — Institutional innovation and technical change in American agriculture: The New Deal, *American Journal of Agricultural Economics*, 65, pp. 1168-1173.
- FARRELL (M. J.), 1957 — The measurement of productive efficiency, *Journal of Royal Statistical Society*, General Series A, 120, part 3.
- FULGINITI (L. E.) and PERRIN (R. K.), 1993 — Prices and productivity in agriculture, *Review of Economics and Statistics*, 75, pp. 471-482.
- GRILICHES (Z.), 1988 — Productivity puzzles and R&D: Another non-explanation, *The Journal of Economic Perspectives*, 2, pp. 9-22.
- HAYAMI (Y.) and RUTTAN (V. W.), 1985 — *Agricultural Development*, Baltimore, John Hopkins University Press.
- HUFFMAN (W. E.), 1993 — Productivity Indexes and Returns to Research, Paper presented at the AAEEA meeting, Orlando, Florida.
- HUFFMAN (W. E.) and EVENSON (R. E.), 1992 — Contributions of public and private science and technology to US agricultural productivity, *American Journal of Agricultural Economics*, pp. 751-756.
- HULTEN (C. R.), 1973 — Divisia index numbers, *Econometrica*, 41, pp. 1017-1025.
- JORGENSEN (D.) and GRILICHES (Z.), 1967 — The explanation of productivity change, *Review of Economic Studies*, 34, pp. 249-283.
- KENDRICK (J. W.), 1961 — *Productivity Trends in the United States*, Princeton NJ, Princeton University Press for the National Bureau of Economic Research.
- LACHAAL (L.), 1994 — Subsidies, endogenous technical efficiency and the measurement of productivity growth, *Journal of Agriculture and Applied Economics*, 26, pp. 299-310.
- MORRISON (C.) and DIEWERT (W. E.), 1990 — New techniques in the measurement of multifactor productivity, *Journal of Productivity Analysis*, 1, pp. 267-285.
- MUNDLAK (Y.), 1988 — Endogenous technology and the measurement of productivity, in: CAPALBO (S. M.) and ANTLE (J. M.) eds,

*Agricultural Productivity Measurement and Explanation*, Washington, Resources for the Future.

NADIRI (M. I.) and BITROS (G. C.), 1980 — Research and Development expenditures and labor productivity at the firm level: A dynamic model, *in*: KENDRICK (J. W.), BEATRICE (N. V.) eds, *New Development in Productivity Measurement and Analysis, Studies in Income and Wealth*, The University of Chicago Press, pp. 387-418.

NISHIMIZU (M.) and PAGE (J. M.), 1982 — Total factor productivity growth, technological progress and technical efficiency change: Dimensions of productivity change in Yugoslavia, 1965-78, *The Economic Journal*, 92, pp. 920-936.

OHTA (M.), 1974 — A note on the duality between production and cost functions: Rate of return to scale and rate of technical progress, *Economic Studies Quarterly*, 25, pp. 63-65.

SCHULTZ (T. W.), 1979 — *Distortions of Agricultural Incentives*, Bloomington, Indiana University Press.

SHEPHARD (R.), 1970 — *Theory of Cost and Production Function*, Princeton University Press.

SOLOW (R.), 1957 — Technical change and the aggregate production function, *Review of Economics and Statistics*, 39, pp. 312-320.

TOLLEY (G. S.) and SHEAR (W. B.), 1984 — International comparison of tax rates and their effects on national income, *in*: KENDRICK (J. W.), ed, *International Comparisons of Productivity and Causes of the Slowdown*, Ballinger Publishing Company and the American Enterprise Institute, pp. 197-226.