ARGUMENTA OECONOMICA
No 2 (49) 2022
ISSN 1233-5835; e-ISSN 2720-5088

Nada Trivić, Bojana Todić***

A DECOMPOSITION OF THE TOTAL PRODUCTIVITY FACTOR INTO TECHNICAL PROGRESS AND TECHNOLOGICAL EFFICIENCY – METHODOLOGICAL POSSIBILITIES

Total productivity as the basis for measuring economic efficiency is the initial presumption of this paper, and it is derived from the fact that it has a multiple importance of growing productivity, as an expression of production efficiency. The complex phenomenon of total productivity of factors is sometimes approached too simplistically, and even incorrectly. Productivity is treated as an isolated phenomenon, regardless of the numerous and various factors that condition it and the effects it has on other economic categories. The basis of the theoretical-methodological approach proposed in this paper, was the transcendental logarithmic production function (translog), as a clear interdependence between the maximum output vector and the production factor vector.

The paper discusses the methodological basis for decomposition of total productivity growth on technical progress and technological efficiency, and a specification of the deterministic marginal production function. Adequate decomposition enables the more precise identification of the causes of lags in productivity growth. The results of the empirical analysis, through appropriate categorisation, are useful in conducting economic policy because they indicate the direction of activities with the aim of increasing total productivity.

Keywords: efficiency, total productivity, translog production function, technical progress, decomposition

JEL Classification: C02, D24, O47, B21
DOI: 10.15611/aoe.2022.2.03

Quote as: Trivić, N., Todić, B. (2022). A decomposition of the total productivity factor into technical progress and technological efficiency – methodological possibilities. *Argumenta Oeconomica,* 2(49).

1. INTRODUCTION

Production efficiency and its interaction with the phenomenon of development is at the centre of attention when talking about the problems of modern socio-economic development in general, and economic development in particular (Baldwin & Wulong, 2008). Efficiency is measured by the degree of performance in the use of production

* Department of International Economics and Business, University of Novi Sad, Subotica, Serbia. ORCID: 0000-0002-3469-3322.

** Department of Probability and Mathematical Statistics, University of Belgrade, Belgrade, Serbia. ORCID: 0000-0002-4754-8087.

resources, and it is expressed by the ratio of production results to investments, hence productivity is one of the most expressive indicators of the economy, i.e. production efficiency. It is also an important indicator for comparing the quality of the economy between related business entities in the country, and between different countries as well. In order to clearly define and quantify the criteria of economic growth efficiency by applying comparative methods, precisely elaborated theoretical assumptions are necessary.

In economics there is in fact no single, generally accepted indicator that measures economic efficiency, although economic theory has mastered the analytical foundations of empirical research of productivity. At the same time, it should be taken into consideration that productivity growth generates multiple effects on economic development, because it is the basis for the more efficient production and improvement of economic conditions. Efficiency is most often expressed and measured by labour productivity (Balk, 2001). A deeper insight into the quantitative dimensions of economic growth and development is not possible without simultaneously including the capital productivity and many partial indicators of the economy, among which the indicator of total productivity is of special importance as an aggregate indicator of development, as well as the indicator of efficiency of transforming resources into products and services (Atkin et al., 2019). It is a complex and long-term phenomenon, essentially related to almost all elements that determine the dynamics of economic life. Measuring productivity is not a goal, but a tool that can serve as a basis for organizing, planning, and managing at different levels of the economy. Each of the productivity indicators in its own way reflects the changes in the observed phenomenon and has its advantages and disadvantages.

Modern conditions of development increasingly indicate the relevance of differentiating between technical progress and efficiency in the overall change of total productivity factors (Feder, 2017). The basis of the theoretical approach is represented by the production function, as a clear interdependence between the maximum output vector and the input vector. There are numerous papers in which the measurement and explanation of variations in total factor productivity is performed using marginal values (Coelli, Rao, O'Donnell, Battese, 2005). Although technical progress and efficiency start from a common methodological basis in the production function, their empirical analysis can be carried out as independent (Russell and Young, 1983).

The first part of this paper discusses the methodological basis for decomposition of total productivity growth on technical progress and technological efficiency. The second part specifies the deterministic marginal production function (Ghobadian and Husband, 1990).

2. PRIMARY GOALS AND METHODOLOGY

The primary goal of this paper is to examine the methodological basis by which the change of total productivity is decomposed into technical progress and changes in technological efficiency. At the same time, technical progress is seen as a change in the marginal value of the largest possible (potential) production, i.e. moving the boundaries of the possibility of production. The rate of change is measured directly through the deterministic marginal production function (Afriat, 1972). All other changes in productivity can be attributed to technical progress.

If the measured level of the total factor productivity is less than the potential, the difference represents the *technological inefficiency*. If the level of technology is given, explicit resource allocation is required to reach that potential level of technological efficiency in time (Munir Ahmad and Bravo-Ureta, 1996). It is an indisputable fact that productivity growth, with an adequate mastery of technology, is essential for development and can be more useful than technical progress (Fateh M. Mari and Heman Das Lohano 2007). It is also necessary to know how far the technological limit is on the time axis and how quickly it can be reached.

3. METHODOLOGICAL BASIS FOR DECOMPOSITION OF TOTAL PRODUCTIVITY FACTOR GROWTH

The initial assumption of the model represents a defined functional interdependence between output and input, which adequately expresses the production process of the business entity, for example, company

$$G\left[y(s,t);z(s,t);s,t\right]\leq 0, \tag{1}$$

where: $y(s, t)$ – output vector; the aggregate output index of company s at time t; $z(s, t)$ – input vector; the aggregate input index of company s at time t; s and t – in function G represent marginal factor productivity indicators company s at time t.

Suppose further that the output vector is separable from the input vector and that there is a corresponding aggregate output index. Then, the production interdependence can be represented as

$$y(s,t)\leq g\left[z(s,t);s,t\right]. \tag{2}$$

The assumption is that the necessary conditions of regularity are satisfied by function g. For any combination of outputs and inputs of the company, inequality (2) is satisfied if the company does not use its inputs at the maximum possible or 'most practical' productivity level. If $s,\hat{t}$ and $\hat{y}$ represent potential and 'most practical' productivity level and output volume for a 'possible' company, then inequality (2) is

$$y(s,t) = g\left[z(s,t);s,t\right] \le g\left[z(s,t);\hat{s};\hat{t}\right] = \hat{y}(s,t). \tag{3}$$

where function g is defined with s and t. This means that $\hat{y}(s,t) = y(\hat{s},\hat{t})$.

This relation expresses the initial assumption of the analysis, that a company that has adequate technology or behaves economically rationally, is still far from the possible (potential) production possibility frontier (Bravo-Ureta and Rieger, 2008).

The potential level of total productivity, in relation to the level of the current (actual) productivity, can be defined as the lowest possible coefficient of reduction of potential output that can be produced by the applied input level and the level of the current (actual) productivity, i.e. as the minimum reduction factor in potential output $\left[e(s,t)\,y(\hat{s},\hat{t})\right]$ produced by the applied input level and the actual productivity level as

$$e(s,t)\,\hat{y}(s,t) = g\left[z(s,t);s,t\right], (0 \le e \le 1). \tag{4}$$

Alternatively, $e(s, t)$ can be defined as the maximum coefficient of increase of output which can be produced at the applied input level and the potential level of productivity[1]

$$y(s,t)\,/\,e(s,t) = g\left[z(s,t);\hat{s},\hat{t}\right]. \tag{5}$$

By comparing these two definitions, index e is reduced to the ratio y and $\hat{y}$, at a defined level of the output with a given combination of input $z(s, t)$:

$$e(s,t) = y(s,t)\,/\,\hat{y}(s,t). \tag{6}$$

The first derivative of the logarithm of a given equation (3) with respect to t is

$$\dot{y}(s,t) = \dot{g}(z,s,t) + g_Z(s,t)\,\dot{z}(s,t) \tag{7}$$

hence the rate of change of total factors productivity for enterprise s can be expressed as

$$\dot{g}(z,s,t) = \dot{y}(s,t) - g_z(s,t)\,\dot{z}(s,t), \tag{8}$$

where $g_z(s, t)$ – the output elasticity vector with respect to each component z; the dot above the symbol indicates the logarithmic time derivative.

At the same time, from the first derivative of the logarithm of expression (5), it is obtained that

$$\dot{y}(s,t) = \dot{g}(z,\hat{s},\hat{t}) + g_z(z,\hat{s},\hat{t})\,\dot{z}(s,t) + \dot{e}(s,t) \tag{9}$$

[1] This definition was given by Malmquist (1953). The analysis of this index in comparison of productivity (Caves and Christensen, 1980).

then, it follows from (7) and (9) that

$$\dot{g}(z,s,t)+g_z(s,t)\dot{z}(s,t)=\dot{g}(z,\hat{s},\hat{t})+g_z(z,\hat{s},\hat{t})\dot{z}(s,t)+\dot{e}(s,t).$$

Thus the rate of change of the total productivity is

$$\dot{g}(z,s,t)=g_z(z,\hat{s},\hat{t})+\dot{e}(s,t)+\left[g_z(\hat{s},\hat{t})-g_z(s,t)\right]\dot{z}(s,t). \qquad (10)$$

In equation (10), *the rate of technological change* is defined by $\dot{g}(z,s,t)$ and represents the *boundaries of* (possible, potential) *production*, in terms of the actual rate. The boundaries of the production function for that group of companies represent the average level of applied technology. If that level of technology changes over time, that change should be distinguished from a change in the relative efficiency of the use of the applied technique. These effects are covered by $\dot{e}(s,t)$ in equation (10). By definition, $\dot{e}(s,t)$ represents the rate at which company *s* moves towards or away from production boundaries and represents *the rate of change in technological efficiency*. For a company that reached production equal to the potential ('most practical'), $\dot{e}(s,t)$ must be 0. In other cases, it has a positive or negative value and indicates a decrease or increase in the difference between potential and current (achieved) productivity (Dawson, 2008).

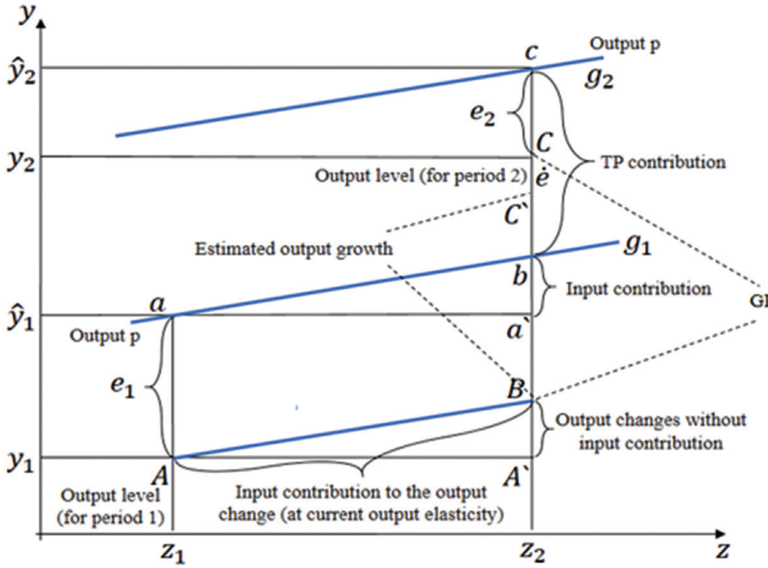
Finally, for a given input level, the company's effort to reach a potential output also requires changes in output elasticity, which is expressed by the last component in equation (10). This means that equation (10) decomposes the conventional measure of total productivity into three components:

1. technical progress,
2. changes in technological efficiency,
3. the difference between the marginal and achieved values of the elasticity output coefficient.

The comparison of the conventional approach to measuring the total productivity growth rate and the decomposition of that rate according to the presented methodology can be illustrated graphically (see Figure 1), where g_1 and g_2 are linearly homogeneous Cobb-Douglas marginal production functions with Hicks neutral technical progress for the two observed periods.

According to the methodology applied in this paper, *the contribution of technical progress* to the output growth is given by shifting the boundaries of the production function, as {**bc**}. For the company that applies the best technological solutions defined in g_1 and g_2, the difference between *potential output* {**a'c**} and the sum of the changes attributed to the growth of input {**a'b**} is equal to {**bc**}. BC' represents the output growth provided for the marginal production function (and is equal to {**bc**}). This change is smaller than the actual change BC. The difference CC' is the change in output that is attributed to the increased technology efficiency, $\dot{e}(s,t)$.

The conventional measurement of total factor productivity growth does not distinguish between *technical progress* and *technological efficiency*, although



where: y – per-capita output; z – capital-labour ratio; A and C – output level of y_1 and y_2 for the observed periods 1 and 2 (in logarithmic values); AB – the projection of input contribution to changes in the output based on current elasticity of the output; AB is parallel to function g_1, because the equality of elasticity of both potential and actual output with respect to inputs z is assumed; Aa and Cc – are e_1 and e_2, respectively; BC – *total productivity* that is measured conventionally and most often interpreted as the output growth attributed to technical progress; A'B – are changes in output without input contribution to those changes.

Fig. 1. Decomposing the growth rate of the total productivity

Source: Nishimizu and Page, 1982, p. 928.

analytically they differ significantly (Xueqing Wang, Yuan Chen, Bingsheng Liu, 2013). Their identification can have significant implications for the decision-making process. According to this methodology, *technical progress* is defined as the result of innovation and adaptation to new technology by the best manufacturers. The total factor productivity growth represents *the sum of the rates of technical progress* and *technological efficiency*. High rates of technical progress may coexist with decreasing technological efficiency (e.g. inadequate technology mastery or short-term adjustment to minimum costs in terms of quasi-fixed return on capital). In addition, a relatively low rate of technical progress can coexist with a rapid improvement in technological efficiency. The results of the empirical analysis of each specific economy will enable their appropriate categorisation (Arditi and Mochtar 2000). Activities aimed at increasing total productivity will be incorrect if they are aimed at accelerating the rate of innovation in conditions when the cause of lagging growth in total productivity is the low rate of mastery or application of modern technology.

4. SPECIFICATION AND EVALUATION OF MARGINAL PRODUCTION FUNCTION

When estimating the production boundary model, the conventional approach imposes very strict restrictions concerning the properties of the technology (Russell and Young, 1983). Empirical estimates of the production boundaries most often use different variants of the Cobb-Douglas form, which in addition to a number of attractive properties, place strict restrictions in terms of the nature and possibility of factor substitution, as well as the character of technical progress. The flexible functional form of the production function imposes relatively fewer a priori limitations in the structure of the production process. That flexible form, often used in recent empirical research, is the *transcendental logarithmic form of the production function* (Caves and Christensen, 1980), which is an approximation of the Taylor series of the second order to a doubly differentiable arbitrary production function. Outputs are defined as exponential functions of input logarithms with translog production functions (Heathfield and Wibe, 1987; Batiese, 1992).

The translog production function of relation (3) is[2]:

$$\begin{aligned}\ln y(s,t) = \alpha_0(s,t) + \sum_m \alpha_m(s,t)\ln z_m(s,t) + \\ \frac{1}{2}\sum_m\sum_n \beta_{mn} \ln z_m \ln z_m(s,t)\ln z_n(s,t),\end{aligned} \tag{11}$$

where

$$\alpha_0(s,t) = \alpha_0(s) + \alpha_t + 0{,}5\beta_{tt}(s)t^2\,, \tag{12}$$

$$\alpha_m(s,t) = \alpha_m(s) + \beta_{mt}(s)t\,,\ m = 1, 2, \dots, N. \tag{13}$$

Then, the output elasticity with respect to each of the inputs is

$$\frac{\sigma \ln y(s,t)}{\sigma \ln z_m(s,t)} = \alpha_m(s) + \beta_{mt}(s)t + \sum_m \beta_{mn}(s,t)\,,\ m = 1, 2, \dots, N. \tag{14}$$

Differences in *marginal factor productivity* by (s, t) are expressed with α_m and β_{mt}. The structure of factor substitution possibilities is expressed by β_{mn} and is independent with respect to (s, t). The growth rate of the total factor productivity is the change in the output elasticity over time, at constant input sizes, and then it is

$$\frac{\sigma \ln y(s,t)}{\sigma t} = \alpha_t(s) + \beta_{tt}(s)t + \beta_{mt}(s)\ln z_m(s,t)\,. \tag{15}$$

[2] The structure of the specified output of the selected functional form directly implies the properties of the index numbers used to measure output, input, and productivity.

Assuming that there is a company conducting the 'most practical production' (equal to the potential product), the *translog marginal production function* is

$$\ln \hat{y}(s,t) = \left(\hat{\alpha}_0 + \hat{\alpha}_t + 0,5\hat{\beta}_{tt}t^2\right) + \sum_m \left(\hat{\alpha}_m + \hat{\beta}_{mt}t\right)\ln z_m(s,t) + 0,5\sum_n\sum_m \hat{\beta}_{mn} \ln z_m(s,t)\ln z_n(s,t) \quad (16)$$

for which conditions (14) and (15) also apply. The coefficient of technical progress of a marginal company is $\hat{\alpha}_t$, as the rate of technical progress at the border point approaches the approximation of the Taylor series. Under normal economic conditions, this rate is non-negative. $\hat{\beta}_{tt}$ is the *rate of change of technical progress* and can have a positive, negative or zero value depending on whether there is an increasing, decreasing or constant rate of technical progress. $\hat{\beta}_{mt}$ are *changes in the output elasticity* with relation to each input and can have a positive, negative or zero value depending on changes in the technical progress of the m^{th} factor, which can be intense, slight or neutral.

The literature indicates three possible approaches to the estimation of the marginal production function: *deterministic*, *probabilistic*, and *stochastic*. The *probabilistic* and *stochastic* approaches are based on an attempt to reduce the sensitivity of the estimated limits to observational random errors. The *deterministic* assessment technique uses simple observation, but all observation points are spatially limited or are in front of the border. This technique roughly corresponds to the theoretical concept of borders, as the external borders of production determination, and is sensitive to errors in observations. It is an assessment technique that is most often used along the boundaries determined by the observation points of the input-output in the spatial position or in front of the boundaries of production.

For more precise results, the parameters of the production boundaries are possible to evaluate with a simple method of equations, by applying the translogarithmic form in the joint estimation of the production function and equations of factors' share (14). However, the use of factor share equations assumes the maximization of profits in the product market and all factors, with perfect competition, and requires equality between the factor income and output elasticity. The results show that this equality does not have to be valid for all sectors of the economy, which means that it is impossible to estimate the parameters based on an incorrect specification of the equations on the participation of factors in the marginal production function. It is then possible to use the method of a system of equations to estimate the *marginal production function*.

The choice of methods for estimating the parameters of the marginal production function depends on the critical examination of the assumptions about the distribution of errors. The procedure of maximum reliability for the evaluation of the parameters of the production function arises from the method which minimises the disturbance term or error variable. The statistical properties of this procedure are not always suitable, but they are appropriate for the specification of error distribution. The alternative is to minimise the sum of deviation from the production possibilities, with the aim of limiting all observations in front of the production possibilities. Such a procedure for estimating the parameter values can be accomplished by applying linear programming.

The objective function is to linearly minimize unknown parameters

$$\sum_{t=1}^{T}\sum_{s=1}^{S}\Big[\left(\hat{\alpha}_0+\hat{\alpha}_t t+0{,}5\hat{\beta}_{tt}t^2\right)+\sum_m\left(\hat{\alpha}_m+\hat{\beta}_{mt}t\right)\ln z_m(s,t)+ \\ 0{,}5\sum_m\sum_n\hat{\beta}_{mn}\ln z_m(s,t)\ln z_n(s,t)-\ln y(s,t)\Big], \tag{17}$$

$$S=1,2,\ \ldots,\ S;\ t=1,2,\ \ldots,\ T.$$

The limitations in the model arise from restrictions of the known observations of input-output combinations below the production boundaries

$$\left(\hat{\alpha}_0+\hat{\alpha}_t t+0{,}5\hat{\beta}_{tt}t^2\right)\sum_m\left(\hat{\alpha}_m+\hat{\beta}_{mt}t\right)\ln z_m(s,t)+ \\ 0{,}5\sum_m\sum_n\hat{\beta}_{mn}\ln z_m(s,t)\ln z_n(s,t)\geq\ln y(s,t), \tag{18}$$

$$s=1,2,\ \ldots,\ S;\ \ t=1,2,\ \ldots,\ T.$$

With the assumption of constant returns to scale, restrictions arise:

$$\sum_m\hat{\alpha}_m=1, \\ \sum_m\hat{\beta}_{mn}=0,\ n=1,2,\ldots,N, \\ \sum_m\hat{\beta}_{mt}=0. \tag{19}$$

The translog production boundary is neither monotone nor concave for a certain free area. Imposing the monotonicity of the minimum implies the restriction that $\hat{\alpha}_m$ and $\hat{\alpha}_t$ are non-negative

$$\hat{\alpha}_m>0,$$

$$\hat{\alpha}_t>0\cdot \tag{20}$$

This is a required but not sufficient condition for concavity, therefore it is necessary to limit the non-negativity of technical progress and the output elasticity for each input

$$\hat{\alpha}_m + \hat{\beta}_{mt} \sum_n \hat{\beta}_{mn} \ln z_n(s,t) \geq 0, \tag{21}$$

$$\hat{\alpha}_t + \hat{\beta}_{tt} t + \sum_m \hat{\beta}_{mt} \ln z_m(s,t) \geq 0, \; m = 1,2, \ldots N. \tag{22}$$

Due to monotonicity and constant returns to scale, the required and necessary condition of concavity can be presented as negative individual elasticity share expressed by the constraint

$$\beta_{mm} \leq 0, \; m = 1,2, \ldots, N. \tag{23}$$

The estimation of gross production function by sectors is possible if the inputs are: capital, labour and other material inputs. Data on gross product and material inputs should be at constant prices. The data series for capital represent net capital stocks reduced by replacement costs, also at constant prices. The labour input is expressed as the number of employees.

Since the translog production function is an approximation of the Taylor series of the second order of an arbitrary production function, the choice of the normalization point around which the Taylor series will expand is very important, because the sum of the initial relations significantly determines the quality of the approximation at the adjacent selected normalisation point. The normalisation point represents also a production point, as a rough approximation of the border, and its choice is important given the regional and sectoral dimension of the analysis.

The rates of technical progress (for economy, sector or region) are obtained by combining the estimated values of the parameters with the volume of inputs, as in equation (15) for each year, taking a simple average of consecutive pairs. The level of technological efficiency, defined by relation (6), is obtained by antilogarithmising the variables from constraint (18) in the linear model. The rate of change in technological efficiency is approximated by logarithmic differences of successive time periods. The rate of change in total productivity represents the sum of the rate of *technical progress* and the *rate of technological efficiency*.

CONCLUSION

Quantitative economic analysis, as a complex and compound field, has attracted the special attention of economic science scholars with the occurrence of its slow growth, lagging behind the development of some countries since the 1990s (Mao Zhi, Goh Bee Hua 2002). Effective programmes for the restructuring of these economies, the elimination of difficulties and the return of these economies to the path of development require answers to questions about the causes of developmental delays, i.e. the identification of the factors that have contributed the most to this state of affairs.

The conventional approach to the analysis of total factor productivity (with both parametric and non-parametric access to index numbers) equalises changes in total factor productivity with changes in output volume controlling the level of input, i.e. as a vertical shift of the production function. The results obtained in this way are useful in conducting economic policy, although often criticised (Chau, and Walker, 1988). However, such a methodological procedure does not allow for a distinction between technical progress and efficiency, therefore the concept of total productivity growth is often used as a synonym for technical progress in the literature regarding productivity.

According to this methodology, the growth of total factor productivity is the sum of *technical progress* and *technological efficiency*. High rates of technical progress may coexist with declining technological efficiency (e.g. failure to master technology) or a relatively low rate of technical progress, may coexist with rapid improvements in technological efficiency. The results of the empirical analysis for each specific economy allow for their appropriate categorisation (Ekanayake and Jayasuriya, 2008). Activities aimed at increasing total productivity will be misplaced if they are aimed at accelerating the rate of innovation when the cause of lagging growth in total productivity is a low level of mastery or the application of modern technology.

This indicates the necessity of the simultaneous qualitative analysis of functional solutions and the institutional structure of the economic system, in order to obtain documented knowledge about the causes of unsatisfactory trends in economic efficiency.

REFERENCES

Afriat, S. N. (1972). Efficiency estimation of production functions. *International Economic Review*, 13(3): 568-98. https://www.jstor.org/stable/2525845.

Arditi, D. and Mochtar, K. (2000). Trends in productivity improvement in the US construction industry. *Construction Management and Economics*, 18(1): 15-27.

https://doi.org/10.1080/014461900370915.

Atkin, D., Amit, K. K. & Adam, O. (2019). *Measuring productivity: lessons from tailored surveys and productivity benchmarking*. https://www.nber.org/papers/w25471

Batiese, E. G. (1992). Frontier production functions and technical efficiency: a survey of empirical applications in agricultural economics. *Journal of Agricultural Economics*, 7(3-4): 185-208. DOI: 10.1111/j.1574-0862.1992.tb00213.x

Baldwin, R. J., Wulong, G. (2008). Productivity: what is it? How is it measured? What has Canada's performance been over the period 1961 to 2012? *The Canadian Productivity Review*, 15-206-X (038): 1-29. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1507893

Balk, B. (2001). Scale efficiency and productivity change, *Journal of Productivity Analysis*, 15: 159-183. https://link.springer.com/article/10.1023/A:1011117324278

Bravo-Ureta, B. E. and Rieger, L. (2008). Alternative production frontier methodologies and dairy farm efficiency. *Journal of Agricultural Economics*, 41(2): 215-226. DOI: 1477-9552.1990.tb00637.x

Caves, D. W. and Christensen, L. R. (1980). Global properties of flexible functional forms. *American Economic Review*, 70(3): 422-432. https://www.jstor.org/stable/1805230?seq=1#metadata_info_tab_contents

Chau, K. W. and Walker, A. (1988). The measurement of total factor productivity of the Hong Kong construction industry. *Construction Management and Economics*, 6(3): 209-224. DOI: 10.1080/01446198800000019

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., Battese, G.E. (2005). An introduction to efficiency and productivity analysis. https://www.springer.com/gp/book/9780387242651.

Dawson, P. J. (2008). Measuring technical efficiency from production functions: some further estimates. *Journal of Agricultural Economics*, 36(1): 31-40. DOI: 10.1111/j.1477-9552.1985.tb00154.x

Ekanayake, S. A. B. and Jayasuriya, S. K. (2008). Measurement of firm-specific technical efficiency: a comparison of methods. *Journal of Agricultural Economics*, 38(1): 115-122. DOI: 10.1111/j.1477-9552.1987.tb01032.x

Fateh, M. Mari and Heman Das Lohano. (2007). Measuring production function and technical efficiency of onion, tomato, and chillie farms in Sindh, Pakistan. *Pakistan Development Review*, 46(4): 1053--1064. DOI: 10.30541/v46i4II

Feder, C. (2017). A Measure of total factor productivity with biased technological change, *Economics of Innovation and New Technology*. DOI: 10.1080/10438599.2017.1329697

Ghobadian, T. and Husband, A. (1990). Measuring total productivity using production functions. *International Journal of Production Research*, 28(8): 1435-1446. DOI: 10.1080/00207549008942803.

Heathfield, F. D. and Wibe, S. (1987). The translog function. [in:]An introduction to cost and production functions, pp 105-117. https://link.springer.com/chapter/10.1007%2F978-1-349-18721-8_6

Mao, Z., Goh Bee Hua, Shou Qing Wang and Ofori, G. (2002). Total factor productivity growth accounting in the construction industry of Singapore. *Construction Management and Economics*, 21(7): 707-718. https://doi.org/10.1080/0144619032000056126.

Munir, A. and Bravo-Ureta, B. E. (1996). Technical efficiency measures for dairy farms using panel data: a comparison of alternative model specifications. *Journal of Productivity Analysis*, 7(4): 399--415. DOI: 10.1007/BF00162049

Nishimizu, M. and Page, M. J. (1982). Total Factor Productivity Growth, Technological Progress and Technical Efficiency Change: Dimensions of Productivity Change in Yugoslavia, 1965-78. *The Economic Journal,* Vol. 92, Issue 368, pp. 920-936. https://doi.org/10.2307/2232675

Russell, Noel and Trevor Young (1983). Frontier production functions and the measurement of technical efficiency. *Journal of Agricultural Economics*, 34(2): 139-150. DOI: 10.1111/j.1477-9552.1983.tb00984.x

Xueqing Wang, Yuan Chen, Bingsheng Liu, Yinghua Shen and Hui Sun (2013). A total factor productivity measure for the construction industry and analysis of its spatial difference: a case study in China. *Construction Management and Economics*, 31(10): 1059-1071. https://doi.org/10.1080/01446193.2013.826371.

Received: February 2021, revised: October 2021