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Research Article

Using malmquist TFP index for evaluating agricultural productivity: Agriculture of Türkiye NUTS2 regions

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ABSTRACT

Agriculture is one of the main economic sectors in Türkiye. Therefore, a performance evaluation is essential for an improvement in agricultural sector. In this study, the productivity of Turkish agricultural sector was analyzed for the years between 2006-2015. A non-parametric technique, Data Envelopment Analysis (DEA) based Malmquist index method, was applied to calculate the Total Factor Productivity (TFP) indices for agriculture in 26 NUTS2 (The Nomenclature of Territorial Units for Statistics) regions of Türkiye for the selected 10-year period. Total agricultural production value is used as the output variable and six input variables are selected as: land, labor, machine, livestock and government investment. The analysis was conducted via the computer program DEAP2.1. The result reveals that agricultural TFP of regions has decreased by 2% annually on average. The maximum TFP growth in agriculture occurred between 2007 and 2008 with a mean increase of 12% in overall TFP of regions. On the other hand, the greatest regression in the overall TFP was observed in 2010-2011 period by a decrease of 13%.

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INTRODUCTION

Due to its economic importance, agricultural productivity and growth in agriculture have become among the essential research areas over the last five decades [1]. Researchers have examined both the sources of growth in productivity over time and of differences in productivity among countries and regions over the same period. As a result of the efforts for maintaining self-sufficiency in the agricultural sector on the country level and the attempts for the reconciliation in the international arena, agriculture and agricultural politics have been one of the major and crucial subjects of the scientific research and political debates. As in many other countries, agriculture is one of the main economic sectors in Türkiye, and the performance and efficiency of Turkish agriculture also consists of

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an essential research area. Türkiye, with its high potential in agricultural activity, is a prominent agricultural provider among developing countries. Although Türkiye has a long and heavy industrialization history, agriculture still maintains its importance, especially regarding its share in total GDP, the direct and indirect employment opportunities it provides to other sectors and the supply of agricultural products as raw materials to the industry [2]. In order to maintain its existing contributions to the economy and, above that, in order to have a sufficient growth rate, agricultural sector must be strong structurally, and have to develop and improve its performance.

Table 1 presents the development of agricultural sector in Turkish economy during the years 2006-2015 in terms of several economic indicators. The share of agriculture in total GDP shows a decrease in general. In this 10-year period, the growth rate of agriculture does not exhibit a consistent trend, as seen in Table 1. Although the growth rates are positive in almost all years, there is a significant regress in 2007. As from 2010 on, the agricultural sector has declined at smaller rates than the overall growth rates until 2015 in which the growth rate of agricultural sector surpassed the overall growth rate of Türkiye.

This situation necessitates the investigation of the agricultural performance of Türkiye. This study starts from this necessity and tries to investigate the agricultural performance of Türkiye.

Malmquist TFP Index is a technique widely used in evaluating the agricultural productivity of countries, regions or individual farms/enterprises. The related studies at country level mostly use Malmquist index method to evaluate the change in the agricultural productivity of a country over a period or comparing the performance of a group of countries. In studies ([1], [3-11]), Malmquist index method has been used to estimate the productivity growth in agriculture sector of developing and developed countries for different sample groups and for various time periods. In the literature, there are more specific studies that considers countries within a continent or a specific region. Thirtle et al. [12] used Malmquist TFP index method to evaluate the agricultural productivity of 22 Sub-Sahara countries between 1971-1986. Nin-Pratt et al. [13] compared the TFP of China and India in terms of their agricultural production over the period 1961-2006. Galanopoulos et al. [4] used sequential Malmquist TFP index method to analyze the agricultural productivity growth of 13 Mediterranean countries including Türkiye, between 1966-2002.

There are also studies at country level that evaluate the agricultural productivity change of OECD countries or EU countries for different time intervals [14-18]. Some of the studies use Malmquist TFP index method to estimate the agricultural productivity growth at regional level [19-23]. There are several studies in Türkiye that were conducted using Malmquist TFP index at regional and at province level [24-27].

The studies using Malmquist index for evaluating agricultural productivity of Türkiye were mostly conducted at country-level and there are a few studies at NUTS3 (provinces) [27] and NUTS1 (regions) levels [25]. So far there is no study evaluating the agricultural performance of NUTS2 regions. This is one the motivations behind deciding NUTS2 regions as the subject of the present analysis. Furthermore, NUTS2 level provides a quite appropriate scope for the analysis since it is not as aggregate as NUTS1 level and it is not as individual as NUTS3 provinces. A brief look to the area shows that the researches about agricultural productivity of Türkiye concluded so far do not include the recent years. The most recent researches at the country-level

Table 1. Economic Indicators for Türkiye Agriculture [28]

	GDP			Year-to-Year Growth Rate	
Year	**Total GDP (Current Buyers' Prices, in Thousands of TL)**	**GDP of Agriculture Sector (Current Buyers' Prices, in Thousands of TL)**	**Share of Agriculture Sector in the total GDP (%)**	**Overall Growth Rate (% by the constant prices of 1998)**	**Growth Rate of Agriculture Sector (% by the constant prices of 1998)**
2006	789,227,555	64,415,593	8.16	7.1	1.5
2007	880,460,879	66,197,107	7.52	5.0	−6.2
2008	994,782,858	74,451,345	7.48	0.8	4.5
2009	999,191,848	81,234,274	8.13	−4.7	4.1
2010	1,160,013,978	104,703,635	9.03	8.5	7.7
2011	1,394,477,166	114,838,169	8.24	11.1	3.4
2012	1,569,672,115	121,692,893	7.75	4.8	2.2
2013	1,809,713,087	121,709,079	6.73	8.5	2.3
2014	2,044,465,876	134,724,745	6.59	5.2	0.6
2015	2,337,529,940	161,146,448	6.89	6.1	9.1

analyze the data up to the year 2009, and the researches at the region-level up to 2010. There is no research regarding agricultural productivity of Turkish regions for the time passed since then.

In light of this information, the present study, differing from the previous studies with the selected time interval and the regions concerned, aims to evaluate 26 NUTS2 regions of Türkiye over the period 2006-2015, in terms of their agricultural TFP change using Malmquist TFP Index method. The contribution of this study to the field has two-fold: one is the selected input and output variables for NUTS2 level; and second is the period considered. This study aims to add a value to the existing study by preforming a comprehensive analysis by collecting data for seven variables for 26 regions and analyzing the productivity index of these regions. Another important contribution is providing the data sources utilized for such analyses.

In this study, we used DEA based Malmquist TFP Index where Malmquist TFP Index method uses the distance functions that are measured by DEA method to calculate the TFP changes and its components (technical efficiency change, technological change, pure technical efficiency change and scale efficiency change) between different time periods. Therefore, in Section 2, DEA is first introduced and then details for Malmquist TFP index are discussed as well as the research design and data. In Section 3, results obtained are provided. Some final remarks are discussed in Section 4.

METHODOLOGY

We used DEA-based Malmquist Index method to measure the change in TFP of agricultural activity of Türkiye regions between 2006-2010. Total agricultural production value is used as an output and six input variables, namely land, labor, machine, livestock, fertilizer and government investment, are selected as inputs. Since there is no study using the NUTS2 level, data for the inputs and outputs are collected and organized for each region. The analysis was conducted via the computer program DEAP2.1 [29].

Malmquist Index method uses distance functions to calculate the index of productivity change. Since the distance functions are calculated using Data Envelopment Analysis (DEA), a brief review of DEA is presented in the following section prior to the introduction of Malmquist TFP index method. Next presented are the details about the research design and the data choice.

Introduction to DEA

DEA, occasionally called frontier analysis, was first put forward by Charnes et al. [30]. It is a non-parametric, linear programming model used to analyze the relative efficiency of different decision-making units (DMU). Before discussing the details of DEA, we need to distinguish the terms: efficiency and productivity.

Efficiency and productivity are two different concepts which are generally confused with each other. Productivity basically depends on the quantities of inputs and outputs. In a simple way, the productivity is the ratio of outputs to the inputs, i.e. the unit output per input [31]. Another definition of productivity is the maximum output that can be obtained by using the minimum input [32]. Besides, productivity does not measure the relative performance of individual entities; instead, it enables to measure the performance of each production unit independently [33].

The other essential concept, efficiency has many definitions in the literature. Färe et al. [34] defines it as the ability of a DMU or a firm to achieve its behavioral objective. Efficiency concept does not just consider the quantities of input and outputs, but also the ability and behavior of DMUs in transforming the inputs to outputs. Koopmans [35] first introduced the concept of technical efficiency and it was further extended to a definition what is now referred to as Pareto-Koopmans Efficiency [36]: "The performance of a DMU is efficient if and only if it is not possible to improve any input or output without worsening any other input or output."

Debreu [37] and later Farrell and Pearson [38], developed the radial efficiency measurement concept based on the production frontiers. According to this frontier-based approach, the radial distance of an observed DMU to the production frontier gives the measure of its efficiency relative to the production technology that is used by all DMUs [39]. In this sense, the main contribution of Farrell and Person [38] was the assumption of the possibility of inefficient units under the frontier. The points along the production frontier are then defined as technically efficient [40].

DEA is based on the production frontier that is determined by the best technology. Instead of using the regression line passing through the center of production set, which is the approach of deterministic econometric models, it uses a piece-wise linear production frontier which is constructed by the observed data. The frontier envelopes all the observed data and the technical efficiency of DMUs are calculated relative to the frontier [36]. The name `data envelopment analysis' arise from this feature of the model. For the detailed explanation of DEA theory, we refer the readers to [41].

Distance functions as a tool for radial efficiency measurement have main advantages compared to other efficiency measurement techniques. The main advantages of DEA can be listed as:

- It can evaluate production systems with multiple input and multiple output.
- Since it is based on radial efficiency measurement technique, it is unit invariant.
- It does not require any weight assignment or price information.

Malmquist Index

Malmquist Index method uses the distance functions, estimated by DEA, to calculate the TFP change and its components between different time periods.

The productivity and efficiency measurements give the performance of an entity at a given time. Whereas, productivity change refers to a change in the productivity of a firm or a production unit from one period to another [31].

If we have a panel data, it is possible to estimate the change in TFP with several methods. Being a widely used method, advantage of Malmquist TFP Index can be summarized as:

- It does not use cost minimization or profit maximization assumptions. In this context, it does not require any price data.
- It defines explicitly the two components of the index, change in technology and change in technical efficiency [42].

These properties make Malmquist TFP Index a preferable strong method for performance evaluation of government institutions or non-profit organizations [31].

Malmquist TFP Index was first introduced by Caves et al. [43]. This index is constructed using the ratios of distance functions which were earlier used to construct quantity indexes by Malmquist [44]. Thereby, the resulting index is called Malmquist TFP index [42]. It estimates the change in productivity between two periods by calculating the radial distance of input-output combinations to the production frontier at a given period or in other words relative to a reference technology. The production technology, denoted by $\mathbf{S}^t$ for each time period $t = 1,...,T$, represents the transformation of input vector $\mathbf{x}^t$ to output vector $\mathbf{y}^t$; i.e. the technology envelopes the set of all feasible input and output vectors [42].

$$\boldsymbol{S}^t = ((\boldsymbol{x}^t, \boldsymbol{y}^t) : \boldsymbol{x}^t \ can\ produce\ \boldsymbol{y}^t) \tag{1}$$

Malmquist TFP index calculations are based on distance functions which also form a basis for the radial efficiency measurement of Farrel and Pearson [38]. Following Färe et al. [42], the input distance function at time t, which also characterizes the technology S^t, is defined as:

$$d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t) = \sup\{\lambda : (\boldsymbol{x}^t/\lambda, \boldsymbol{y}^t) \in \boldsymbol{S}^t)\} \tag{2}$$

The distance function $d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t)$ measures the largest possible contraction of inputs. The input distance function, $d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t) \geq 1$ if and only if $(\boldsymbol{x}^t, \boldsymbol{y}^t) \in \boldsymbol{S}^t$. Whereas, $d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t) = 1$ if only if (x^t, y^t) is on the border of production frontier, in Farrel's terminology when it is technically efficient.

In order to calculate input-based Malmquist index of productivity change, the distance functions should be defined with respect to two different periods, such as periods t and $t + 1$. The input distance function of the unit (x^{t+1}, y^{t+1}) relative to the technology in period t can be expressed as follows:

$$d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t) = \sup\{\lambda : (\boldsymbol{x}^t/\lambda, \boldsymbol{y}^t) \in \boldsymbol{S}^t)\} \tag{3}$$

Similarly, it is possible to define the distance function of (x^t, y^t) with respect to the technology at t+1 and this is denoted by $d_i^{t+1}(\boldsymbol{x}^t, \boldsymbol{y}^t)$. If the technology in period t is considered as the reference time, Malmquist index is defined as [30]:

$$M_{CCD}^t = \frac{d_i^t(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})}{d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t)} \tag{4}$$

Alternatively, if the technology in period t+1 is taken as reference, then Malmquist index is defined as:

$$M_{CCD}^{t+1} = \frac{d_i^{t+1}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})}{d_i^{t+1}(\boldsymbol{x}^t, \boldsymbol{y}^t)} \tag{5}$$

The input-based Malmquist TFP index between the period t and following period t+1 is defined as the geometric mean of these two indices [45].

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

Following Färe et al. [45], having the suitable panel data, four distance functions are required to estimate the input-based Malmquist TFP index of a DMU for two consecutive periods, t and t+1, which are listed as:

$d_i^t(\boldsymbol{x}^t, \boldsymbol{y}^t)$: The input distance function of (x^t, y^t) relative to S^t

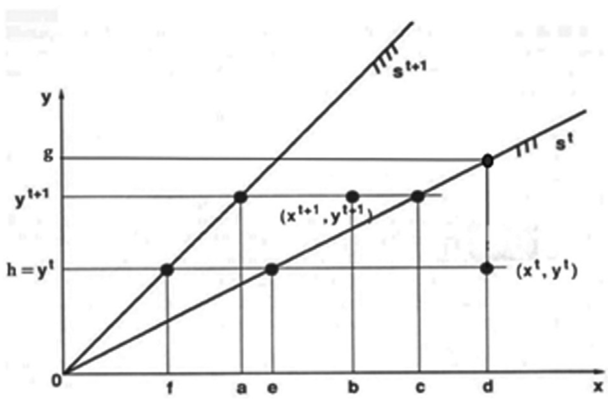

Figure 1. The Input Distance Function and the Malmquist Input-Based Index of TFP [45].

$d_i^{t+1}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})$: The input distance function of (x^{t+1}, y^{t+1}) relative to S^{t+1}

$d_i^{t}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})$: The input distance function of (x^{t+1}, y^{t+1}) relative to S^{t}

$d_i^{t+1}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})$: The input distance function of (x^{t}, y^{t}) relative to S^{t+1}

These distance functions can be calculated using DEA-like LP models. In this regard, four LP problems are required to measure the TFP change of a DMU.

When time is involved in the analysis of productivity change, we need to consider the concept of change in technology. Technological change is defined as the shift of the production frontier determined by the technology in corresponding time periods [42]. This is depicted in Figure 1 for a production with one output and one input. Period t and period t+1 represents the two production frontiers in different times. A change in the productivity of a DMU overtime may be caused not only by a change in its efficiency, but also by a change in its technology or by a combination of the two factors. In this regard, it is possible to express the input-based Malmquist TFP index as:

$$M_i = (\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1}, \boldsymbol{x}^{t}, \boldsymbol{y}^{t}) = \frac{d_i^{t+1}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})}{d_i^{t}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})} \times \left[\frac{d_i^{t}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})}{d_i^{t+1}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})} \frac{d_i^{t}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})}{d_i^{t+1}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})} \right]^{1/2} \quad (7)$$

The first factor on the right-hand side of the equation represents the change in technical efficiency between the two periods; whereas the second term, geometric mean, stands for the technological change between the periods [42].

$$\text{Technical Efficiency Change (TEC)} = \frac{d_i^{t+1}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})}{d_i^{t}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})} \quad (8)$$

$$\text{Technological Change (TC)} = \left[\frac{d_i^{t}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})}{d_i^{t+1}(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})} \frac{d_i^{t}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})}{d_i^{t+1}(\boldsymbol{x}^{t}, \boldsymbol{y}^{t})} \right]^{1/2} \quad (9)$$

or

$$M_i^{t,t+1} = TEC \times TC \quad (10)$$

A change in technology can be interpreted as a natural measure of innovation or a change in technology. Coelli et al. [31] illustrate this concept for an agricultural productivity analysis such that when all farms face a bad year in terms of, let's say rainfall, it causes the production frontier to shift downward and DEA-based Malmquist index method interpret this shift as a technological regress.

On the other hand, the efficiency change is related with the distance of DMUs to the frontier. It measures the degree of catching-up the efficient production frontier[1] [46]. In other words, it calculates how far the observed DMU is from the efficient frontier, the efficiency of using its inputs. This decomposition enables to observe the contributions of each index to the TFP change.

Additionally, the corresponding distance functions mentioned in Equation 7 can be illustrated by the distances measured in Figure 1 as:

$$M_i = (\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1}, \boldsymbol{x}^{t}, \boldsymbol{y}^{t}) = \left(\frac{0b}{0a}\right)\left(\frac{0e}{0d}\right)\left[\left(\frac{0b/0c}{0b/0a}\right) \times \left(\frac{0d/0e}{0d/0f}\right)\right]^{1/2} = \left(\frac{0b}{0a}\right)\left(\frac{0e}{0d}\right)\left[\left(\frac{0a}{0c}\right)\left(\frac{0f}{0e}\right)\right]^{1/2} \quad (11)$$

If the value of input-based Malmquist index, $M_i^{t,t+1}$, is greater than one, it indicates a regression; whereas a value less than one corresponds to a progress and a value equal to one indicates no change from period t to period $t + 1$ [45]. However, DEAP2.1 program displays the reciprocal of the input-based Malmquist index which is equivalent to the value of output-based Malmquist index under CRS assumption. So that, it is easier to interpret the index values in the common way, i.e. an index value greater than one indicates a progress and a value less than one corresponds to a regress for the present study.

Research Design and Data

For this analysis, an input-oriented Malmquist TFP index model was used under CRS assumption to measure the TFP change and its components for 26 regions in the period 2006-2015. We preferred an input-orientation referring to the suggestions that there is more control on the inputs than the outputs in agriculture. Likewise, CRS technology is assumed due to the aggregate region-level data used for the analysis. The results of Malmquist TFP Index provided TFP changes and its components for agriculture of 26 regions in Türkiye for the years between 2006 and 2015.

Data

So far in Türkiye, there is no study evaluating the agricultural performance of NUTS2 regions. This is one the motivations behind deciding 26 NUTS2 regions as the DMUs of the present analysis. The list of NUTS level regions and their official codes are presented in Table 2.

Most of the data used in this study was obtained from the database of TUIK, Regional Statistics TUIK [47]. Other data sources are T.R. Ministry of Development [2] and Ministry of Food Agriculture and Livestock.

Most of the studies about agricultural productivity are conducted using the variables listed as the fundamental

Table 2. NUTS levels of Türkiye

NUTS1-Regions	Region Number	NUTS2 Codes	NUTS2-Sub-regions	NUTS3-Provinces
Northeast Anatolia	1	TRA1	Erzurum Region	Erzurum, Erzincan, Bayburt
	2	TRA2	Ağrı Region	Ağrı, Kars, Iğdır, Ardahan
Middle east Anatolia	3	TRB1	Malatya Region	Malatya, Elazığ, Bingöl, Tunceli
	4	TRB2	Van Region	Van, Muş, Bitlis, Hakkari
Southeast Anatolia	5	TRC1	Gaziantep Region	Gaziantep, Adıyaman, Kilis
	6	TRC2	şanlıurfa Region	şanlıurfa, Diyarbakır
	7	TRC3	Mardın Region	Mardin, Batman, Şırnak, Siirt
İstanbul	8	TR10	İstanbul Region	İstanbul
West Marmara	9	TR21	Tekirdağ Region	Tekirdağ, Edirne, Kırklareli
	10	TR22	Balıkesir Region	Balıkesir, Çanakkale
Aegean	11	TR31	İzmir Region	İzmir
	12	TR32	Aydın Region	Aydın, Denizli, Muğla
	13	TR33	Manisa Region	Manisa,Afyon,Kütahya,Uşak
East Marmara	14	TR41	Bursa Region	Bursa, Eskişehir, Bilecik
	15	TR42	Kocaeli Region	Kocaeli, Sakarya, D´üzce, Bolu, Yalova
West Anatolia	16	TR51	Ankara Region	Ankara
	17	TR52	Konya Region	Konya, Karaman
Mediterranean	18	TR61	Antalya Region	Antalya, Isparta, Burdur
	19	TR62	Adana Region	Adana, Mersin
	20	TR63	Hatay Region	Hatay, Kahramanmaraş, Osmaniye
Middle Anatolia	21	TR71	Kırıkkale Region	Kırıkkale, Aksaray, Niğde, Nevşehir, Kırşehir
	22	TR72	Kayseri Region	Kayseri, Sivas, Yozgat
West Blacksea	23	TR81	Zonguldak Region	Zonguldak, Karabük, Bartın
	24	TR82	Kastamonu Region	Kastamonu, Çankırı, Sinop
	25	TR83	Samsun Region	Samsun, Tokat, Çorum, Amasya
East Blacksea	26	TR90	Trabzon Region	Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane

indicators of agricultural productivity by FAO (Food and Agriculture Organization of the United Nations). To draw an analogy with the other studies using DEA, similar input variables have been selected for the analysis.

In the analysis, total agricultural production value is used as the only output variable and six input variables are selected as: land, labor, machine, livestock, fertilizer and government investment. (See Table 3 for the statistical values of selected variables).

Output: The only output variable is the total value of agricultural production (in terms of 1000 TL). It is the sum of value of crop production, value of livestock and value of animal production. The values were deflated on the basis of Producer Price Index of Agricultural Products (Agriculture PPI) taking 2010=100 base (TUIK [48]).

Inputs:

- *Land:* This variable represents the total arable land (hectare) and total land under permanent crops (hectare).
- *Labor:* Labor represents the economically active population (male and female population older than 15) employed in agriculture.
- *Machine*: Machine variable is the total number of agricultural equipment and machinery. Besides four-wheel tractors and two-wheel tractors, the combine harvesters are also included in this variable, referring to the study Karacuka et al. [49]
- *Fertilizer*: This input variable is the sum of nitrogen, phosphorous and potash amounts contained in various fertilizers consumed by the regions under evaluation in metric tons.
- *Livestock:* The livestock input variable is the total number of live animals of different categories. These animals are bovine animals, calves, sheep, goat, horse, and poultry. The number of these different animals are converted to 'cattle equivalents' using conversion factors shown in Table 4.
- *Investment:* This variable is the value of annual fixed capital government investments outgoing for

Table 3. Description of Selected Variables

Variable	Unit	Mean	Min.	Max.
Production	1000 TL	6091104	705162	12520609
Land	Hectare	939457	70100	3486917
Labor	Number (Thousand persons)	211	11	587
Machine	Number	44219	4671	141303
Fertilizer	Metric tons	77905	4778	242423
Livestock	Number	491031	55213	1119395
Investment	1000 TL	128106	483	1401118

Table 4. Conversion Factors for Cattle-Equivalent Unit

Animal Species	Conversion Factors
Culture race Cattle	1.00
Native race Cattle	0.5
Hybrid race Cattle	0.75
Culture race heifer	0.6
Native race heifer	0.3
Hybrid race heifer	0.45
Buffalo	0.9
Young Buffalo	0.75
Bull	1.5
Ox	0.6
Horse	0.5
Hinny	0.4
Donkey	0.3
Sheep-Aries (native)	0.1
Sheep-Aries (merinos)	0.1
Goat	0.08
Goat (Angora)	0.08
Lamb-kid	0.04
Poultry	0.0034

agricultural sector in each region, provided in terms of 1000 TL.

RESULTS

In this analysis, Malmquist indices for each year-pair was estimated via DEAP2:1 program Coelli [29]. The three Malmquist indices are:

- Technical efficiency change (TEC)
- Technological change[2] (TC)
- Total factor productivity change (TFPC)

In this regard, the program DEAP2.1 first calculates and displays technical efficiency (TE)[3] scores of each region with respect to individual years one by one. Besides, it calculates the TE of each region with respect to the following year. Then it constructs the Malmquist indices of productivity change for a year-pair using the distance functions calculated with respect to two production frontiers that belong to two adjacent years. As mentioned earlier, TFPC is the product of TEC and TC where TEC measures the distance of each region to the frontier while TC represents an overall change affecting the agriculture. Table 5 presents the annual average indices of three categories for each region.

Table 5. Malmquist Index Summary of Region Means

Regions		TEC	TC	TFPC
1	TRA1	1.01	1.02	1.03
2	TRA2	1.02	1.02	1.04
3	TRB1	1.00	1.01	1.01
4	TRB2	1.00	1.00	1.00
5	TRC1	1.01	1.00	1.01
6	TRC2	0.99	0.98	0.98
7	TRC3	1.00	0.98	0.98
8	TR10	0.98	0.92	0.90
9	TR21	1.02	0.97	0.99
10	TR22	1.04	0.99	1.02
11	TR31	1.00	0.99	0.99
12	TR32	0.98	0.96	0.94
13	TR33	0.97	0.97	0.95
14	TR41	1.01	0.96	0.97
15	TR42	1.00	0.89	0.89
16	TR51	1.00	0.95	0.95
17	TR52	1.03	0.98	1.01
18	TR61	1.00	0.98	0.98
19	TR62	1.00	0.95	0.95
20	TR63	1.00	0.96	0.96
21	TR71	1.05	0.91	0.95
22	TR72	1.00	0.98	0.99
23	TR81	1.01	1.02	1.03
24	TR82	1.01	1.02	1.03
25	TR83	1.02	0.99	1.00
26	TR90	1.00	0.99	0.99
Mean*		1.01	0.98	0.98

*Note that all Malmquist index averages are geometric means [29].

The annual average TEC of all regions are given in Table 5. Efficiency change is an indicator for the usage of existing inputs in a more or in a less efficient way, in other terms it represents getting closer to or away from the best production frontier. For this reason, some researchers use the term 'catch-up factor' for the efficiency change index [46]. According to Table 5, 12 regions have a slight increase in their TE on the average by ratios changing between 1% and 5%. Kırıkkale Region (TR71) ranks first in terms of improving its technical efficiency by 5% on average. It is followed by Balıkesir Region (TR22), Konya Region (TR52) and Tekirdağ Region (TR21) with an increase in TE by 4%, 3% and 2% respectively. Over the 10-year period, TE of four regions have been regressed on the average: Sanlıurfa Region (TRC2), İstanbul Region (TR10), Aydın Region (TR32) and Manisa Region (TR33) with decreases of 1%, 2%, 2% and 3% respectively. Whereas, the remaining eleven regions with an index of 1, show no change on the average among these years. The mean value of TEC for all regions through 10-year was estimated as 1.01 which means a 1% increase in TE on the average.

The annual averages of TC index for all regions is also given in Table 5. TC refers to an innovation or a shift in the production frontier, i.e. an upward shift means production level is increased [46]. As seen from the results, there are only five regions that has a positive average TC. Erzurum (TRA1), Ağrı (TRA2), Zonguldak (TR81) and Kastamonu (TR82) Regions have an average TC index of 1.02, meaning an average technological improvement by 2%. On the other hand, Kocaeli Region (TR42) has the greatest average regression in technology by 11%. It is followed by Kırıkkale (TR71), İstanbul (TR10), Ankara (TR51) and Adana (TR62) Regions which also have regressions in technology by 9%, 8%, 5% and 5% respectively. The other regions exhibit technological regressions by relatively low percentages, below 4%. The mean annual TC index of all regions is 0.98, which indicates an average technological regression by 2% for agricultural production of whole country over 2006-2015 period.

Total factor productivity change (TFPC) is the multiplication of two indices TEC and TC. As seen in Table 5, the annual mean TFP change in agricultural production of the regions studied is found to be negative. On average, agricultural TFP of Türkiye has decreased by 2% annually. If we examine the regions individually, we see that Ağrı Region (TRA2) has the greatest average increase in TFP by 4% regarding its agricultural production. Zonguldak (TR81), Kastamonu (TR82), Erzurum (TRA1) and Balıkesir (TR22) Regions follow it by increases of between 2 to 3%. Besides, Malatya (TRB1), Gaziantep (TRC1) and Konya (TR52) Regions have annual TFP growth by 1% on average. Excluding Van (TRB2) and Samsun (TR83) Regions which have no change in TFP on average, all the other regions have a negative average TFPC index. However, Tekirdağ (TR21), Trabzon (TR90), _Izmir (TR31) and Kayseri (TR72) regions have a slight decrease in mean TFP by 1%. The greatest average regressions in TFP are observed for Kocaeli (TR42) and İstanbul (TR10) Regions by decreases of 11% and 10%, while the remaining regions experience 2% to 6% drops in their agricultural TFP on average.

Additionally, to compare and interpret the among NUTS2 regions in each year, one can refer to Figure 2, 3 and 4 which display TFPC of all regions through 2006-2015. (See Tables A1 and A2 for the exact values of TFPC, TEC and TC of all regions for each year-pair).

So far, the mean Malmquist indices for agricultural performance of all regions over 10-year period have been discussed. To examine the agricultural performance of all regions one by one for each year-pair, Malmquist index values are graphed for each region through 10-year period. The Malmquist index summaries of some regions with significant TFPC values are displayed in Figure 5, 6 and 7.

Ağrı Region (TRA2), with a value of 1.04, has the greatest average TFP growth through 2006-2015. If we examine Figure 5, TFP has decreased by almost 20% between 2008-2009 and approximately by 10% in periods, 2010-2011, 2011-2012 and 2012- 2013. However, the extreme TFP growth in 2009-2010 is above 70%. This and the approximate 10% increases in other 4 periods are the grounds for the maximum average TFPC value. The increase in TFP

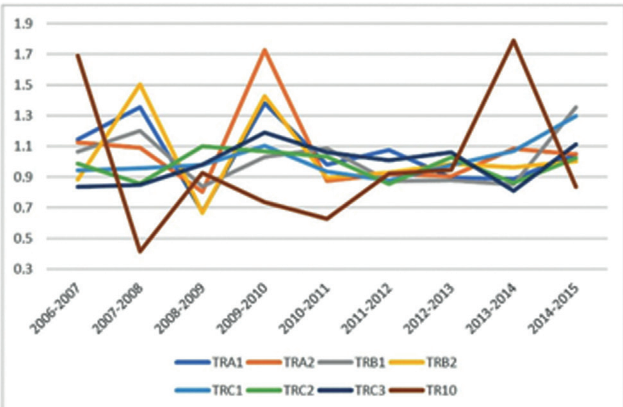

Figure 2. Malmquist index of TFPC for all regions over 2006–2015.

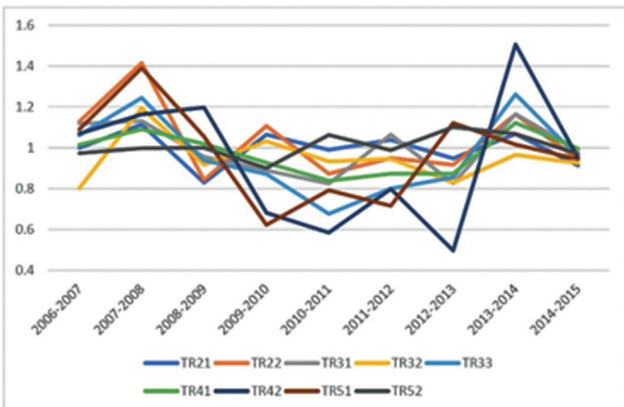

Figure 3. Malmquist index of TFPC for all regions over 2006–2015 (continue).

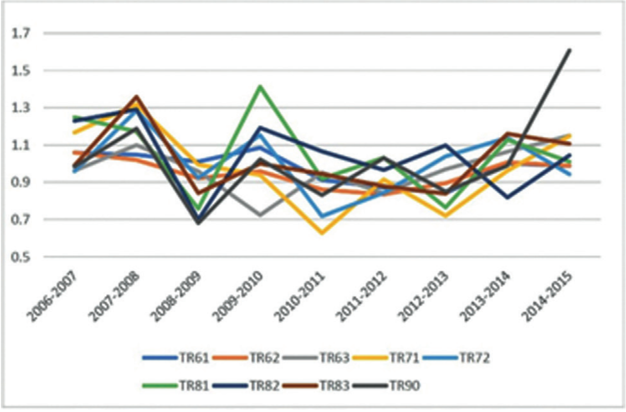

Figure 4. Malmquist index of TFPC for all regions over 2006–2015.

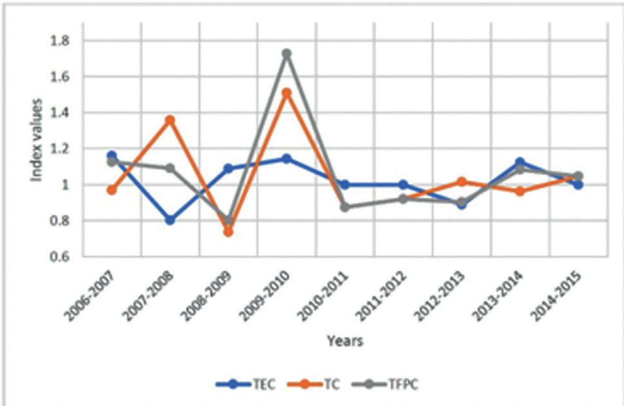

Figure 5. Malmquist Index Summary of Ağrı Region (TRA2).

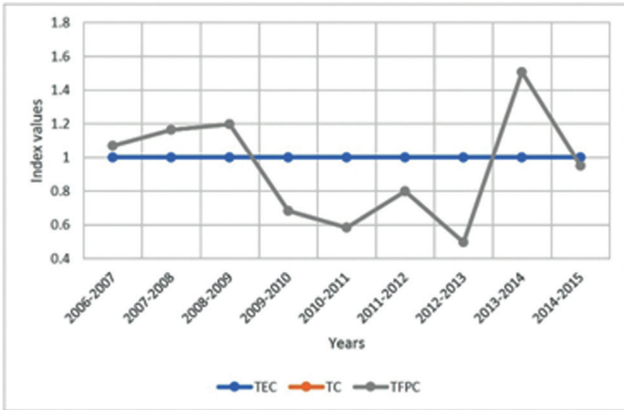

Figure 6. Malmquist Index Summary of Kocaeli Region (TR42).

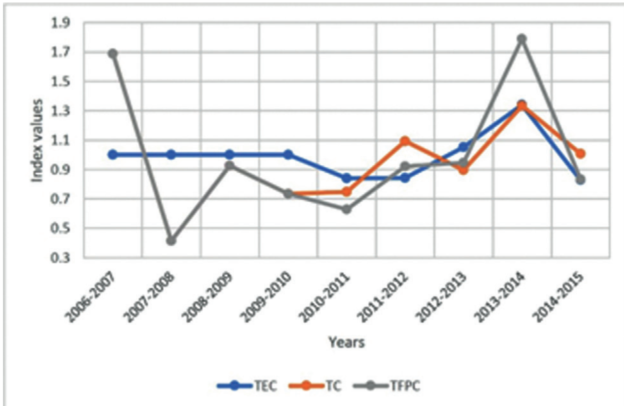

Figure 7. Malmquist Index Summary of Istanbul Region (TR10).

is highly related with the change in technology as seen in Figure 5.

Figure 6 displays the Malmquist index changes for Kocaeli Region (TR42) which has the greatest average TFP regression among NUTS2 regions. In Figure 6, TC and accordingly TFPC indices are identical, since all TEC indices are equal to 1 which indicates no change occurred in TE through the 10-year period. We can conclude that TFP change is caused by the change in technology. Besides, the major falls in TFP of TR42 take place between 2010-2011 and 2012-2013 by approximate 40% and 50% decreases respectively.

Istanbul Region (TR10) is found to have the maximum annual TFP growth, when we examine the TFPC index of all regions over 10-year period (See Tables A1 and A2). This growth in TFP of TR10 occurs in 2013-2014 by an index of 1.79. This means a 79% growth in TFP between these years and can also be observed in Figure 7 which presents the index summary for TR10. Both TC and TEC components have contributions to the increase in TFP almost at same level for 2013-2014 period. The change in TE is above 30%.

For the other years, TR10 has experienced a negative change in TFP except for 2006-2007. Furthermore, TR10 has the lowest TFPC index, having a value of 0.46, among all regions during 10-year period. There is a 54% decrease in TFP between 2007-2008. This is due to the regression in technology, since TEC index is 1 and TC index is 0.46 for these years. Despite the radical increases in 2006-2007 and 2013-2014, there is a 10% mean decrease in TFP over 10-year period (See Table 5).

It is also possible to observe how the average TFP and its components change from year to year. The overall TFP indices and its components for each year-pair are presented in Table 6 and graphed in Figure 8.

The results shown in Table 6 provide a brief opinion about how the total agricultural production performance

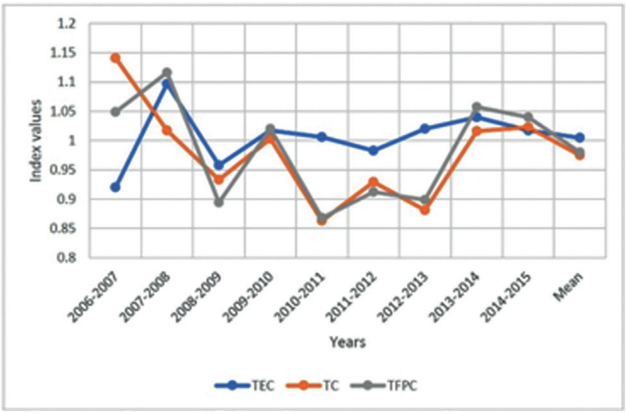

Figure 8. Malmquist Index Summary of Annual Means.

Table 6. Malmquist Index Summary of Annual Means

Years	TEC	TC	TFPC
2006–2007	0.92	1.141	1.049
2007–2008	1.097	1.017	1.116
2008–2009	0.958	0.933	0.894
2009–2010	1.017	1.003	1.02
2010–2011	1.006	0.863	0.868
2011–2012	0.983	0.929	0.912
2012–2013	1.02	0.881	0.899
2013–2014	1.04	1.016	1.057
2014–2015	1.017	1.023	1.04
Mean	1.005	0.975	0.98

has changed from year to year averagely. Accordingly, the greatest TFP growth occurred in period 2007-2008 by a 12% increase in overall TFP. The main contribution to TFP growth is by TEC which has a higher index value than TC for this year-pair. On the other hand, 2010-2011 period experienced the greatest regression in the overall TFP by a 13% decrease. The main cause of this regression can be interpreted as the negative technological change. Likewise, as shown in Figure 8, TC and TFPC lines are almost parallel to each other (except 2 year-pairs), which indicates that the main contribution to TFPC comes from a change in technology (TC). In other words, technological improvement or regression strongly affects TFP proportionally. This relation can be confirmed for the year-pairs, 2006-2007, 2010- 2011, 2011-2012 and 2012-2013 in Figure 8, where TEC indices are apart from TC and TFPC indices.

CONCLUSION

In this study, an application of DEA-based Malmquist TFP Index method is presented to evaluate the agricultural performance of 26 NUTS2 regions of Türkiye between 2006 and 2015.

The result of the analysis reveals that agricultural TFP of 26 regions has decreased by 2% annually over 2006-2015 on average. Average annual TEC and TC indices, the components of TFPC index, are found to be 1.01 and 0.98, respectively. This indicates an average improvement in technical efficiency by 1% and an average regression in technology by 2%. The main reason behind the average TFP regression seems to be overall 2% regression in technology.

When the annual means of Malmquist indices are examined, it is seen that the maximum TFP growth in agriculture occurred between 2007 and 2008 with a mean increase of 12% in overall TFP of regions. This is mainly due to an improvement in technical efficiency rather than an improvement in technology. On the other hand, the greatest regression in the overall TFP was observed in 2010-2011 period by a decrease of 13%. The main cause of this regression was found to be the negative technological change. Also, the period 2008-2009 has faced a similar decrease in overall agricultural TFP, by almost 11%, which was mainly caused by a 7% regression in technology. Considering all year-pairs, the technological change is found to be the main factor that contributes to TFP change in agriculture.

Technological regression may refer to an extreme climate change or general economic crisis which would have a noticeable impact on the agriculture sector as well as the other sectors. These kinds of undesirable events, all in all, may affect agricultural production negatively and may lead to a negative shift of the production frontier. To illustrate, one of the factors behind the technological regression between 2008-2009 may be the extreme drought that Türkiye faced during 2008.

On the other hand, a technological improvement, the positive shift of the production frontier, may be induced by many external factors such as an increase in average precipitation ratio, a general improvement in country economics and agricultural policies, or an increase in the level of using innovative equipment and methods for agriculture.

It is highly possible that other factors that were not included in the present analysis may have an impact on the agricultural efficiency, and productivity of Türkiye regions. For example, a common problem in agriculture of Türkiye is that agricultural entities are generally small-scale enterprises, and agricultural areas are composed of the large number of land parcels. This situation is one of the major factors behind the low productivity and inefficiency of using land for many regions. Kayseri Region (TR72) and Kırıkkale Region (TR71), having similar topographic and climate conditions, also suffer from these problems which are probably factors behind the decreasing productivity levels of these regions. One possible solution to this problem might be to encourage and support the activities for land consolidation. Additionally, these regions may improve their productivity, and efficiency by catching up the recent technology in terms of agricultural techniques, innovations and education.

For future research, other factors that may have an external impact on agricultural efficiencies, such as literacy rate, education level, and the share of agriculture in GDP or ratio of the households engaged in agricultural activities, can be analyzed via several different methods.

In Türkiye, there are a few studies that are using DEA method in agricultural efficiency and TFP analysis. Most of these studies are at the farm level and are conducted through interview surveys. The availability and accessibility of agricultural data is a key factor in increasing the extensity of such studies. In this context, FADN database should be developed and should be spread among the farmers. If the farmers would be able to use this database system widely and properly, it would make a great contribution to academic research, and government policies regarding agricultural improvement. Especially for farm-level studies, FADN database would provide a broad research field as well as data accessibility. With this system, more specific analysis such as sustainability, ecological and environmental efficiency analyses could be conducted at the farm level to investigate the most influential factors and provide farmers a path to enhance their techniques and regulate their input usage. Moreover, our experience during this study showed that there is a need for an improved system to aggregate all the agricultural data required to perform productivity analyses.

It should be mentioned that; the study does not prospect the reasons behind the negative TFPC of regions in depth. Although the findings of this research give clues for understanding the agricultural performance of Türkiye, there is still a need for further research to understand the results. More detailed analysis or interviews with experts should be conducted to understand the main reasons for low productivity measures. However, this study may contribute to the literature to provide information about the data sources utilized for the analyses. In addition, the results may serve as a reference in future work for the researchers examining agricultural efficiency in Türkiye.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

ENDNOTES

1 The efficient production frontier and accordingly all the technical efficiency measurements mentioned in the present analysis assumes constant return-to-scale (CRS). For detailed information about 'return-to-scale' concept, one can refer to Coelli et al. [31].

2 The term `Technical change' is used for `Technological change' in some studies (i.e., Coelli and Rao [1]; Fa¨re et al. [42]; Nin et al. [5].

3 TE is the technical efficiency estimated under CRS assumption.

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APPENDIX A – MALMQUIST INDEX SUMMARY FOR NUTS2 REGIONS OF TÜRKIYE

Table A.1. TFPC Index and its components for NUTS2 Regions of Türkiye over 2006–2015

	2006–2007			2007–2008			2008–2009		
Region	**TEC**	**TC**	**TFPC**	**TEC**	**TC**	**TFPC**	**TEC**	**TC**	**TFPC**
TRA1	1.19	0.97	1.14	0.92	1.48	1.35	0.88	0.76	0.67
TRA2	1.16	0.97	1.13	0.80	1.36	1.09	1.09	0.74	0.80
TRB1	1.02	1.05	1.06	1.00	1.20	1.20	0.93	0.90	0.84
TRB2	1.00	0.88	0.88	1.00	1.50	1.50	1.00	0.67	0.67
TRC1	0.87	1.08	0.94	0.92	1.04	0.96	1.01	0.97	0.98
TRC2	1.00	0.99	0.99	1.00	0.86	0.86	1.00	1.10	1.10
TRC3	0.99	0.84	0.83	1.01	0.84	0.85	1.00	0.98	0.98
TR10	1.00	1.69	1.69	1.00	0.42	0.42	1.00	0.93	0.93
TR21	0.68	1.47	1.00	1.57	0.71	1.11	0.85	0.98	0.83
TR22	0.99	1.13	1.13	1.22	1.16	1.42	0.91	0.93	0.84
TR31	1.00	1.12	1.12	1.00	1.13	1.13	1.00	0.96	0.96
TR32	0.73	1.10	0.80	1.08	1.10	1.19	0.96	0.95	0.92
TR33	0.79	1.34	1.06	1.22	1.02	1.24	0.87	1.07	0.94
TR41	0.85	1.20	1.01	1.13	0.97	1.09	1.06	0.96	1.02
TR42	1.00	1.07	1.07	1.00	1.16	1.16	1.00	1.20	1.20
TR51	0.67	1.63	1.09	1.50	0.93	1.39	1.00	1.05	1.05
TR52	0.72	1.36	0.97	1.13	0.89	1.00	1.05	0.95	1.00
TR61	1.00	1.06	1.06	1.00	1.05	1.05	1.00	1.01	1.01
TR62	1.00	1.06	1.06	1.00	1.02	1.02	1.00	0.92	0.92
TR63	0.81	1.20	0.96	1.24	0.89	1.10	1.00	0.96	0.96
TR71	0.90	1.29	1.17	1.81	0.73	1.32	0.97	1.02	1.00
TR72	0.74	1.29	0.96	1.13	1.13	1.29	0.98	0.94	0.92
TR81	1.09	1.15	1.25	1.00	1.17	1.17	0.88	0.86	0.76
TR82	1.19	1.04	1.23	1.06	1.22	1.29	0.76	0.92	0.70
TR83	0.85	1.16	0.99	1.28	1.06	1.36	0.79	1.06	0.84
TR90	1.00	0.98	0.98	1.00	1.19	1.19	1.00	0.68	0.68
Mean	0.92	1.14	1.05	1.10	1.02	1.12	0.96	0.93	0.89
Max.	1.19	1.69	1.69	1.81	1.50	1.50	1.09	1.20	1.20
Min.	0.67	0.84	0.80	0.80	0.42	0.42	0.76	0.67	0.67

Table A.2. TFPC Index and its components for NUTS2 Regions of Türkiye over 2006–2015

	2009–2010			2010–2011			2011–2012		
Region	**TEC**	**TC**	**TFPC**	**TEC**	**TC**	**TFPC**	**TEC**	**TC**	**TFPC**
TRA1	1.03	1.35	1.38	1.10	0.89	0.98	1.12	0.96	1.08
TRA2	1.14	1.51	1.73	1.00	0.88	0.88	1.00	0.92	0.92
TRB1	0.87	1.18	1.03	1.16	0.94	1.09	0.93	0.94	0.87
TRB2	1.00	1.43	1.43	1.00	0.89	0.89	1.00	0.93	0.93
TRC1	1.00	1.11	1.10	1.02	0.92	0.94	0.95	0.92	0.88
TRC2	1.00	1.07	1.07	1.00	1.03	1.03	1.00	0.85	0.85
TRC3	1.00	1.19	1.19	1.00	1.06	1.06	1.00	1.01	1.01
TR10	1.00	0.74	0.74	0.84	0.75	0.63	0.84	1.09	0.92
TR21	1.21	0.88	1.06	1.09	0.91	0.99	1.01	1.03	1.04
TR22	1.16	0.96	1.11	1.08	0.81	0.87	0.86	1.10	0.95
TR31	1.00	0.89	0.89	1.00	0.82	0.82	1.00	1.07	1.07
TR32	0.98	1.06	1.03	1.02	0.92	0.93	1.13	0.84	0.95
TR33	0.93	0.94	0.87	0.88	0.77	0.68	0.92	0.87	0.80
TR41	1.01	0.92	0.93	0.94	0.89	0.84	0.99	0.88	0.87
TR42	1.00	0.68	0.68	1.00	0.58	0.58	1.00	0.80	0.80
TR51	1.00	0.62	0.62	1.00	0.79	0.79	0.85	0.85	0.72
TR52	0.95	0.95	0.90	1.19	0.90	1.06	1.01	0.98	0.99
TR61	1.00	1.09	1.09	1.00	0.91	0.91	1.00	0.87	0.87
TR62	1.00	0.96	0.96	0.97	0.89	0.86	0.98	0.85	0.84
TR63	0.77	0.95	0.72	1.05	0.90	0.95	0.97	0.87	0.84
TR71	1.04	0.91	0.94	0.86	0.73	0.63	1.17	0.78	0.92
TR72	1.36	0.85	1.15	0.86	0.84	0.72	0.88	0.96	0.84
TR81	1.11	1.27	1.41	0.99	0.92	0.92	1.03	1.00	1.03
TR82	1.09	1.09	1.19	1.15	0.93	1.07	0.98	0.98	0.97
TR83	0.97	1.04	1.00	1.08	0.88	0.94	1.02	0.86	0.88
TR90	1.00	1.02	1.02	1.00	0.83	0.83	1.00	1.03	1.03
Mean	1.02	1.00	1.02	1.01	0.86	0.87	0.98	0.93	0.91
Max.	1.36	1.51	1.73	1.19	1.06	1.09	1.17	1.10	1.08
Min.	0.77	0.62	0.62	0.84	0.58	0.58	0.84	0.78	0.72

Table A.3. TFPC Index and its components for NUTS2 Regions of Türkiye over 2006–2015

	2012–2013			2013–2014			2014–2015		
Region	**TEC**	**TC**	**TFPC**	**TEC**	**TC**	**TFPC**	**TEC**	**TC**	**TFPC**
TRA1	0.91	0.98	0.90	1.00	0.89	0.89	0.98	1.07	1.05
TRA2	0.89	1.02	0.90	1.12	0.96	1.08	1.00	1.05	1.05
TRB1	0.92	0.95	0.88	0.94	0.91	0.85	1.29	1.05	1.35
TRB2	1.00	0.98	0.98	1.00	0.96	0.96	1.00	1.00	1.00
TRC1	1.00	0.98	0.98	1.13	0.95	1.07	1.28	1.02	1.30
TRC2	1.00	1.03	1.03	0.99	0.87	0.86	0.93	1.11	1.02
TRC3	1.00	1.06	1.06	1.00	0.81	0.81	1.00	1.11	1.11
TR10	1.05	0.90	0.95	1.34	1.34	1.79	0.83	1.01	0.84
TR21	0.95	1.00	0.95	1.20	0.89	1.07	0.90	1.01	0.91
TR22	1.12	0.82	0.92	1.04	1.12	1.16	1.00	0.94	0.94
TR31	1.00	0.83	0.83	1.00	1.17	1.17	1.00	0.99	0.99
TR32	1.18	0.70	0.83	0.84	1.15	0.97	0.99	0.93	0.92
TR33	1.15	0.75	0.86	1.09	1.16	1.26	1.01	0.95	0.96
TR41	1.07	0.82	0.87	1.07	1.05	1.12	1.00	1.00	1.00
TR42	1.00	0.50	0.50	1.00	1.51	1.51	1.00	0.95	0.95
TR51	1.13	1.00	1.12	1.05	0.97	1.02	1.00	0.94	0.94
TR52	1.11	0.99	1.10	1.17	0.91	1.07	1.00	0.97	0.97
TR61	1.00	0.84	0.84	1.00	1.00	1.00	1.00	0.99	0.99
TR62	1.04	0.86	0.89	1.02	0.99	1.01	1.00	0.99	0.99
TR63	1.00	0.97	0.97	1.10	0.97	1.06	1.15	1.00	1.15
TR71	0.91	0.80	0.72	0.95	1.02	0.96	1.13	1.01	1.15
TR72	1.20	0.86	1.04	1.09	1.05	1.14	0.94	1.01	0.94
TR81	0.80	0.96	0.76	1.26	0.90	1.13	0.98	1.03	1.01
TR82	1.14	0.96	1.10	0.82	1.00	0.82	1.00	1.04	1.04
TR83	1.09	0.77	0.84	1.01	1.15	1.16	1.15	0.97	1.11
TR90	1.00	0.85	0.85	1.00	0.99	0.99	1.00	1.61	1.61
Mean	1.02	0.88	0.90	1.04	1.02	1.06	1.02	1.02	1.04
Max.	1.20	1.06	1.12	1.34	1.51	1.79	1.29	1.61	1.61
Min.	0.80	0.50	0.50	0.82	0.81	0.81	0.83	0.93	0.84