Using Data Envelopment Analysis and Malmquist Total Factor Productivity Index for Agriculture of Turkish Regions

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

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Zeynep ŞIŞMAN

Abstract

Agriculture is one of the main economic sectors in Turkey besides its essential role in meeting the food demand of an increasing population. It is a simple fact that, for an improvement in agricultural sector, a performance evaluation is necessitated. Efficiency and productivity measurements are key concepts in performance evaluation and widely used in many studies conducted on agricultural performance analysis. With this regard, in this study, the productivity and efficiency of Turkish agricultural sector were analyzed for the years between 2006-2015. As being a non-parametric efficiency measurement technique, Data Envelopment Analysis (DEA) and Malmquist Total Factor Productivity (TFP) Index methods were used to examine the agricultural efficiency and productivity of 26 NUTS2 (The Nomenclature of Territorial Units for Statistics) regions of Turkey for the selected 10-year period. In this study, 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 results of the first analysis provided the Malmquist index values for TFP change and its components (technical efficiency change, technological change, pure technical efficiency change and scale efficiency change) in agriculture of 26 regions in Turkey for the selected time period. 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%. As a further analysis, DEA was applied for each year between 2006-2015 to investigate the input usage of regions that were found to be inefficient and to examine the possible ways of improving their efficiency in the corresponding years through the results of DEA.

Keywords: Data Envelopment Analysis, Malmquist TFP Index, Technical Efficiency, Agriculture

Türkiye Bölgelerinin Tarımsal Performansının Veri Zarflama Analizi ve Malmquist Toplam Faktör Verimliliği Endeksi ile Değerlendirilmesi

Zeynep ŞIŞMAN

Öz

Tarım, artmakta olan nüfusun yiyecek ihtiyacını karşılamadaki önemli rolünün yanında, Türkiye'nin temel ekonomik sektörlerinden biridir. Tarım alanında gelişme sağlanması için performans değerlendirmesi önemli bir ihtiyaçtır. Etkinlik ve verimlilik ölçümleri, performans analizinde kullanılan temel kavramlardır ve tarım alanındaki performans analizi çalışmalarında yaygın olarak kullanılmaktadır. Bu bağlamda, bu çalışmada Türkiye'deki tarım sektörünün 2006-2015 yılları arasındaki etkinlik ve verimliliği analiz edilmiştir. Türkiye'nin NUTS2 bölgelerinin etkinlik ve verimliliğini, belirlenen 10 yıllık süre içerisinde değerlendirmek üzere parametrik olmayan bir etkinlik ölçme tekniği olarak Veri Zarflama Analizi (VZA) ve Malmquist Toplam Faktör Verimlilik (TFV) Endeksi kullanılmıştır. Bu çalışmada, 'toplam tarımsal üretim değeri' çıktı değişkeni olarak belirlenmiş ve altı girdi değişkeni de alan, işgücü, makine, canlı hayvan, gübre ve kamu yatırımı olarak seçilmiştir. Analizlerde DEAP2.1 bilgisayar programı kullanılmıştır.

Birinci analiz, Türkiye'deki 26 bölgenin tarım sektörü icin TFV değişimi ve bileşenlerinin (teknik etkinlik değişimi, teknolojik değişimi, saf teknik etkinlik ve ölçek etkinlik değişimi) belirlenen dönemdeki Malmquist endeks değerlerini vermektedir. Sonuçlara göre bölgelerin tarımsal TFV'si yıllık ortalama %2 azalmıştır. Tarımdaki maksimum TFV yükselmesi ortalama %12'lik bir artışla 2007-2008 yılları arasında meydana gelmiştir. TFV'deki en fazla gerileme ise ortalama %13'lük bir düşüş ile 2010-2011 yılları arasında gerçekleşmiştir. Buna ek olarak, etkin olmayan bölgelerin girdi kullanımlarını incelemek üzere 2006-2015 arasındaki tüm yıllar için VZA uygulanmıştır. Ve bu bölgelerin ilgili yıllardaki etkinliklerini artırmaya yönelik hedeflere ve yöntemlere değinilmiştir.

Anahtar Sözcükler: Veri Zarflama Analizi, Malmquist Toplam Faktör Verimlilik İndeksi, Teknik Etkinlik, Tarım

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I cannot pass this page without mentioning a few more names.I appreciate for the helps of my cousin Rumeysa and my aunt for their assistance in proofreading.

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Contents

List of Figures

List of Tables

Abbreviations

DEA	**D**ata **E**nvelopment **A**nalysis
TFP	**T**otal **F**actor **P**roductivity
CRS	**C**onstant **R**eturn to **S**cale
VRS	**V**ariable **R**eturn to **S**cale
NUTS	**N**omenclature of **T**erritorial **U**nits for **S**tatistics
TE	**T**echnical **E**fficiency
SE	**S**cale **E**fficiency
DMU	**D**esicion **M**aking **U**nit
SFA	**S**tochastic **F**rontier **A**nalysis
TEC	**T**echnical **E**fficiency **C**hange
TC	**T**echnological **C**hange
PEC	**P**ure **T**echnical **E**fficiency **C**hange
SEC	**S**cale **E**fficiency **C**hange
TFPC	**T**otal **F**actor **P**roductivity **C**hange
CCR	**C**harnes, **C**ooper, **R**hodes
BCC	**B**anker, **C**harnes, **C**ooper
TUIK	**T**ürkiye **İ**statistik **K**urumu
FADN	The **F**arm **A**ccountancy **D**ata **N**etwork
ÇMVA	**Ç**iftik **M**uhasebe **V**eri **A**ğı
FAO	**F**ood and **A**griculture **O**rganization of the United Nations
OECD	**O**rganization for **E**conomic **C**o-operation and **D**evelopment

Chapter 1

Introduction

Agriculture is defined as the economic activity, which uses land and seed to produce crop and animal products and to obtain more valuable goods from these products. However agriculture is not only an economic activity, it is also a social process that has a significant role in sustaining balance in social, cultural, regional, ecological and health issues [5]. In addition to major agricultural production in its own, agricultural sector has an important role in terms of its contribution to other sectors in the economy at the same time. As a result, by supplying the essential needs of people, agriculture is an indispensable sector in almost every country and for this reason covers much of the long-term economic plans [6].

Due to its economic importance, agricultural productivity and growth in agriculture have become among the essential research areas over the last five decades [7]. 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 Turkey, and the performance and efficiency of Turkish agriculture also consists of an essential research area. Turkey, with its high potential in agricultural activity, is a prominent agricultural provider among developing countries. Although Turkey 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 [6]. 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 1.1 presents the development of agricultural sector in Turkish economy during the years 2006-2015 in terms of several economic indicators. The overall GDP shows a continuous increase over 2006-2015. Likewise, the GDP of agricultural sector has increased considerably over the 10-year period. However, the share of agriculture in total GDP shows a decrease in general, except the years between 2008 and 2011. The reason for the reductions can be explained by higher increases in GDP of other sectors in the corresponding years. The share of agriculture in total GDP of Turkey has especially decreased from 9.03 in 2010 to 6.89 in 2015.

Table 1.1: Economic Indicators for Turkey Agriculture [4]

	GDP			Year-to-Year Growth Rate	
Year	Total GDP (At Current Basic Prices, in Thousands of TL)	GDP of Agriculture Sector (At Current Basic Prices, in Thousands of TL)	Share of Agriculture Sector in the total GDP (\%)	Overall Growth of Output (2009=100 Chained Value, \% Change)	Growth of Output of Agriculture Sector (2009=100 Chained Value, \% Change)
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

In this 10-year period, the growth rate of agriculture does not exhibit a consistent trend, as seen in Table 1.1. Although the growth rates are positive in almost all years, there is a significant de-growth 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 Turkey.

As observed through the economic indicators, despite the continuous increase in GDP of agriculture there are inconsistent decreases in the growth rate of agriculture in Turkey.

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

There are several studies evaluating agricultural performance of Turkey comparing it with other countries, i.e. EU member states or OECD countries. In general, the studies regarding agricultural efficiency of Turkish agricultural production were mostly conducted at farm-level some of which are mentioned in Section 2.4. However, there are just a few studies analyzing the agricultural efficiency and productivity of provinces or NUTS1 regions of Turkey and there is no research on NUTS2 level before. NUTS (The Nomenclature of Territorial Units for Statistics) is a classification system established by the EU to divide up economic territorial regions in the EU countries and this system is also used in Turkey. The three NUTS levels of Turkey are: NUTS1 that consists of 12 regions, NUTS2 that consists of 26 sub-regions and NUTS3 including 81 provinces of Turkey.

A brief look to the area shows that the researches concluded so far do not include recent years. The most recent researches at the country-level analyze the data up to the year 2009, and the researches at the region-level up to 2010. There is no research regarding agricultural efficiency 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 measure the agricultural production efficiency and total factor productivity (TFP) change of NUTS2 regions in Turkey over the period 2006-2015. So, our study differs from previous researches by evaluating NUTS2 level regions that enables to observe the smaller territories and as a result less aggregate than NUTS1. The scope of the research ends with the year 2015 due to the availability of data. For the time being, 2015 is the most recent year for which the data of variables are available.

In this thesis, 26 NUTS2 regions of Turkey were evaluated over the period 2006-2015, in terms of their agricultural efficiency and TFP using Data Envelopment Analysis (DEA) and Malmquist TFP Index methods. DEA is a non-parametric, linear programming model used to analyze the relative efficiency of different decision-making units (DMU). On the other hand, 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. Both analyses were conducted via the computer program DEAP2.1.

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. The results of Malmquist TFP Index provided TFP changes and its components for agriculture of 26 regions in Turkey for the years between 2006-2015, as well as the technical efficiency of each region in all years. The result of the first analysis reveals that agricultural TFP of 26 regions has decreased by 2% annually on average. This regression is mainly caused by the regression in technology. 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%.

As a further analysis, DEA was applied for each year between 2006-2015 to investigate the input usage of regions that were found to be inefficient. Beside measuring technical efficiency, DEA also provides a method and a path towards efficiency. In this regard, the DEA results were then interpreted to show the possible ways of improving their efficiency in the corresponding years. And the results of the research are analyzed concerning this end.

In the first section of Chapter 2, the conceptual background of the methods used is presented with brief definitions of efficiency and productivity. In Sections 2.2 and 2.3, the mathematical formulations of DEA and Malmquist TFP Index methods were explained briefly. Then, a literature review is provided in Section 2.4 concerning the application of these methods in agricultural performance evaluation. Chapter 3 includes the basic information about the data, description of variables used in the analysis and the results of the analysis. The empirical results of two analysis, results of Malmquist TFP analysis and DEA, are presented in Section 3.2. The last chapter presents a summary of the whole study and possible ideas for future research.

Chapter 2

Background and Literature Review

In the first section of this chapter, the fundamental concepts related to efficiency and productivity will be discussed. In the following sections, the mathematical models of DEA and Malmquist Total Factor Productivity Index method will be discussed briefly. In Section 2.4, we will focus on the literature which includes applications of DEA and Malmquist TFP Index method in the agricultural sector.

2.1 Conceptual Framework

It is important for entities to analyze their production performance which is mainly related to the inputs and outputs. In this study, we will focus on some of the most commonly used methods for measuring the performance of production units, DEA and the Malmquist TFP Index. To get a better understanding of these measurement techniques; first, we need to clarify some terminology including fundamental concepts related to production, brief definitions of efficiency types and productivity.

2.1.1 Production Function and Production Frontier

Production is the process of transforming inputs into outputs. The *production function* is defined as the functional relationship between the inputs (or the factors of production) used within a production system and the outputs that can be produced with these inputs [1].

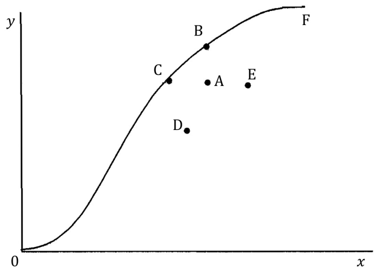

FIGURE 2.1: Production possibility set (Production feasible set) [1]

The set of all possible combinations of inputs-outputs under an existing production technology is defined as the *feasible production set* or *production possibility set* (PPS) [2]. Figure 2.1 illustrates a PPS for one input, one output production system, where x and y represent the input and output. A, B, C, D and E are the production units functioning in this production system. $0F$ curve is called the production frontier. In other words, the production frontier is the boundary of the PPS and is a piece-wise linear isoquant determined by the observed production units. The frontier also represents the production technology. For this reason, the production may occur below the production frontier but cannot occur above it [1].

Farrel [8] is the first one to empirically analyze the production functions as the production frontier. After his study, the production frontier was considered as a reference concept for efficiency measurements of homogeneous decision-making units. A *decision-making unit* (DMU) is a concept introduced by Charnes *et al.* [9] in the seminal work 'Measuring the efficiency of decision-making units'. It is defined as one of the production units (say firms or entities) that use similar inputs to produce similar outputs and process under the same production goal and with similar technology.

2.1.2 Efficiency vs 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 [1]. Another definition of productivity is the maximum output that can be obtained by using the minimum input [10]. Besides, productivity does not measure the relative performance of individual entities; instead, it enables to measure the performance of each production unit independently [11].

By this definition, it is possible to calculate the ratio of single output to single input or the ratio of all outputs to all inputs involved in a production process. The former is called the partial productivity, whereas the latter is called the total factor productivity (TFP). The basic ratio calculation in partial productivity measurement is not sufficient for multiple input-output production systems. TFP is a concept introduced to overcome this issue. TFP can be defined as the ratio of the aggregate output to the aggregate input [1]. These aggregate output and input values (also referred to as virtual input-output) can be considered as the weighted sum of all outputs and the weighted sum of all inputs respectively [2].

The other essential concept, *efficiency* has many definitions in the literature. Färe *et al.* [12] defines it as the ability of a DMU or a firm to achieve its behavioral objective. In other words, 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 [13] first introduced the concept of *technical efficiency* in 1951 and it was further extended to a definition what is now referred to as Pareto-Koopmans Efficiency [2]:

> "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 [14] and later Farrell [8], developed the radial efficiency measurement concept based on the production frontiers in 1951 and 1957 respectively. 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 [1, 15]. In this sense, the main contribution of Farrell [8] was the assumption of the possibility of inefficient units under the frontier. The points along the production frontier are then defined as technically efficient [16].

Figure 2.2 illustrates the difference between productivity and technical efficiency. The curve $0F$ is the production frontier of production system with one input and one output. The productivity of a specific DMU is measured as the slope of the line from the origin to that point (y/x), where x is used for input and y is for output. The productivity will

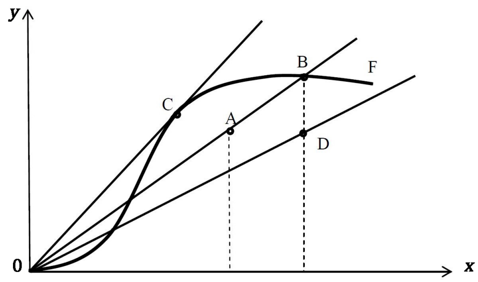

Figure 2.2: Productivity and Efficiency [1]

increase as the slope of the line increases. In order to clarify this graph, lets consider all DMUs (A, B, C and D) in this production system:

- A and B are at the same productivity level, since they have the same slope. However, A is not efficient whereas B is efficient (being on the frontier).
- D is an inefficient unit and is less productive when compared to A and B. D produces less output than B using the same amount of input.
- Points B and C are both efficient. However C has higher productivity, since it has a greater slope.
- The line passing through C is tangent to the production frontier, so this line represents the maximum possible productivity. And the point C is called the (technical) optimal scale, where the productivity and the technical efficiency is at maximum level.
- Other points on the production frontier are considered as less productive. So, a DMU might be efficient but not productive enough when compared with other DMUs relative to the same production function [1].

Along with the new approach to production frontiers, Farrel [8] has developed some terminology for production efficiency and new concepts in efficiency measurements through the seminal work "Measurement of Productive Efficiency" in 1957 [8]. As a new aspect, Farrell has demonstrated that the overall efficiency of a DMU operating under a specific technology can be decomposed into technical efficiency and allocative (or price) efficiency.

Technical efficiency is the capability of an entity to produce the maximum output with the existing inputs. Whereas, allocative efficiency can be defined as the success of a firm in using its inputs in the best way with its existing technology and respective input prices [8]. In other words, allocative efficiency measures how close is an entity to the optimum combination of its inputs at which the production cost is kept at the lowest level [17]. Farrell also demonstrated an efficiency measurement technique which is uses the radial uniform distances from inefficient DMUs to the production frontier [16].

One thing to be stressed is that when building a production frontier, there are two main scale assumptions: Constant return to scale (CRS) and variable return to scale (VRS). The concept of return to scale and its relationship with efficiency and productivity will be discussed in the next section.

2.1.3 Return to Scale: CRS vs VRS

Return-to scale is the relation between the change in inputs and the change in outputs. This concept can also be explained by answering the question: how close is the productivity to the scale of the DMU. Assuming the technical efficiency for a DMU is constant, if the productivity increases as the scale increases, then the production technology exhibits *increasing-return-to scale* (IRS). In other words, IRS is observed when an increase in inputs of a DMU results in more increase in outputs relative to its inputs. Similarly, it exhibits *decreasing-return-to scale* (DRS), if the productivity increases as the scale decreases. These two concepts are considered together as the *variable return-to-scale* (VRS). If the relation between the change in productivity and scale is linear, then the production technology is referred to be *constant-return-to scale* (CRS) [1, 18].

It is easy to understand the scale effect graphically in a simple one-input and one-output case, but it is difficult to illustrate it graphically for multi-input and multi-output cases [1]. Thus, the former case is depicted in Figure 2.3 to explain the relation between scale, technical efficiency and productivity.

If we consider all DMUs in the Figure 2.3 individually, we see that the DMU operating at point B has the greatest productivity indicating that it operates at the *most productive scale size* (MPSS) or in other words technically at the optimal productive scale. It should be noted that DMUs, A and C are both technically efficient with respect to VRS frontier, but they are not technically efficient with respect to CRS frontier. The productivity of A can be increased by increasing its scale, i.e. moving along the frontier (without a

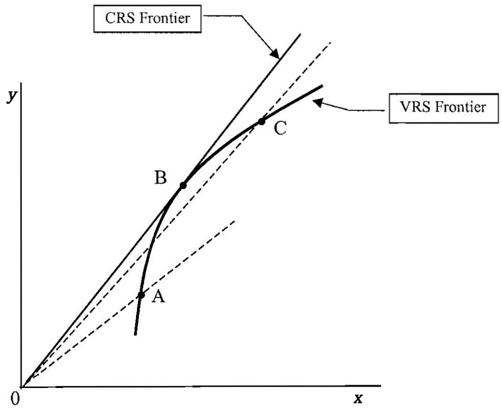

FIGURE 2.3: The effect of scale on productivity and efficiency [1]

change in its technical efficiency), toward the point B which is referred to as optimal scale. This behavior is called IRS. On the other hand, unit C is in a region of DRS, since the productivity of C increases with a decrease in its scale, i.e. moving along the efficient frontier toward B.

Based on the assumption that IRS, DRS and CRS regions can all be observed in one production function, this type of production is defined by the concept of VRS.

Up to now, we have discussed the efficiency and productivity concepts regarding the different production frontiers. After determining whether a DMU is efficient or not, the next issue to be considered is the calculation of technical efficiency. Technical efficiency measurements can be done in two ways: input-oriented and output-oriented which will be discussed in the next section.

2.1.4 Input and Output-Oriented Efficiency Measures

The input-oriented technical efficiency measure indicates how much input can proportionally be reduced while attaining the current amount of output. On the other hand, the output-oriented technical efficiency measure indicates how much output can proportionally be expanded while keeping the current input amount [19].

Figure 2.4 points out the different approaches used to calculate the technical efficiency with input and output-orientations for a simple case with single input and single output under CRS assumption. If we consider DMU A, the output-oriented technical efficiency is calculated by the ratio:

$$\text{TE}_o = y_1/y_2 \tag{2.1}$$

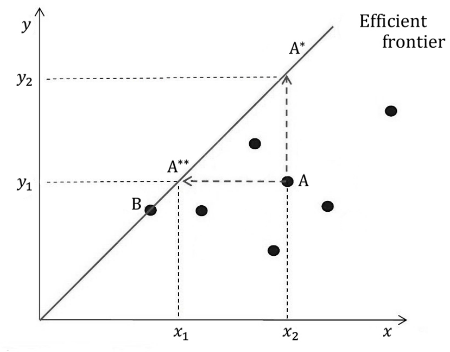

FIGURE 2.4: Input and output-oriented efficiency measures

While the input-oriented technical efficiency of A is calculated by the ratio:

$$\mathrm{TE}_i = x_1/x_2 \tag{2.2}$$

Where x and y denote inputs and outputs; x_1 and x_2 are the input values of A^{**} and A; y_1 and y_2 are output values of A and A^{*} respectively. If we consider the efficiency of DMU A, the distance $(y_2 - y_1)$ indicates the proportional increase in output, whereas the distance $(x_2 - x_1)$ indicates the proportional reduction in input which are required to achieve efficiency. They also represent the inefficiency of A.

In fact, output and input orientations determine which point on the efficient frontier is to be taken as a benchmark. DMU A can only increase its output by $(y_2 - y_1)$ and catch-up the frontier where DMU A^{*} stands. Likewise, it can only reduce its input by $(x_2 - x_1)$ to reach one of the efficient DMUs, A^{**}. Note that technical efficiency obtained by input and output orientations have the same value in Figure 2.4. This is due to the CRS assumption for the frontier.

On the other hand, the input and output-oriented efficiency measures would yield different values for a VRS frontier. Furthermore, a DMU may have different efficiency values under different scale assumptions. To clarify this, we consider a simple production system with one input and one output shown in Figure 2.5.

Figure 2.5 compares VRS and CRS frontiers of a production set and shows efficiency calculations using input-orientation. DMU B is technically efficient according to both frontiers, since it is at the optimal scale. Whereas, E is considered as technically efficient only under VRS assumption. It is inefficient under CRS assumption, since it is below CRS frontier. Similarly, F is only CRS efficient. The figure also displays the different

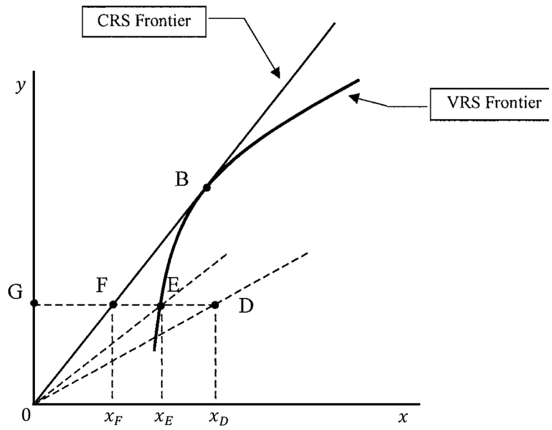

FIGURE 2.5: TE-CRS, TE-VRS and Scale efficiency [1]

distance ratios used to measure the efficiency rate of an inefficient DMU with respect to CRS and VRS frontiers. If we consider DMU D, the efficiency under CRS and VRS assumptions are calculated by the Equations 2.3 and 2.4 respectively:

$$\text{TE}_i\text{-CRS} = x_F/x_D \tag{2.3}$$

$$\text{TE}_i\text{-VRS} = x_E/x_D \tag{2.4}$$

Where x_F, x_E and x_D are the input values of the DMUs; F, E and D respectively.

Note that TE-VRS of D is greater than its TE-CRS. This difference in efficiencies represent another important concept, scale efficiency. The *scale efficiency* (SE) is defined as the the ratio of CRS efficiency to VRS efficiency, which provides an ease in the calculations [1]

$$\text{SE} = \frac{\text{TE-CRS}}{\text{TE-VRS}} \tag{2.5}$$

$$\text{TE-CRS} \leq \text{TE-VRS} \tag{2.6}$$

SE can be regarded as the success of a DMU to produce at the optimum scale. SE of unit D, by using Equations 2.3 and 2.4, can be expressed by the ratio:

$$\text{SE} = x_F/x_E \tag{2.7}$$

Where the ratio, x_F/x_E is an indicator of how distant are two frontiers for D, DMU under evaluation.

Up to now, we have discussed production functions with only one input and one output. However in real cases, production functions generally involve multi-inputs and multi-outputs. It is possible to represent the production technology by a production frontier in two dimensions only if it exhibits CRS. Note that, only production functions with two inputs and one output, or vice versa -two outputs and one input-, can be visualized graphically as seen in Figures 2.6 and 2.7.

The original illustration of Farrell's input efficiency measure is presented in Figure 2.6, in which production function and production frontier are represented for a simple case with two inputs and one output assuming CRS.

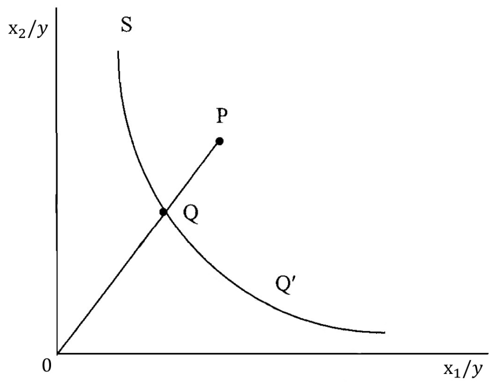

FIGURE 2.6: Input-oriented efficiency measure of Farrel [1]

In this figure, x_1 and x_2 are two input variables and y is the only output variable. The axis represent the ratios of inputs to outputs (x_1/y and x_2/y) which construct the S curve, the production frontier. The inefficiency of a DMU operating at point P could be measured as the radial distance QP, which represents the amount of all inputs that can be reduced proportionally without a change in the amount of output produced. The percentage of the reduction in input quantity can be expressed by the ratio $QP/0P$. So, input-oriented technical efficiency (TE_i) can be measured by the following equation:

$$\text{TE}_i = 0Q/0P \tag{2.8}$$

The numerical value of the technical efficiency of a DMU will always be between zero and one. A value of one means a fully efficient DMU that lies on the efficient frontier [8]. In this case, point Q is technically efficient.

The output-oriented technical efficiency measure of Farrel is illustrated in Figure 2.7 by a simple case where production involves two outputs (y_1 and y_2) and single input (x). Z curve represents the production frontier.

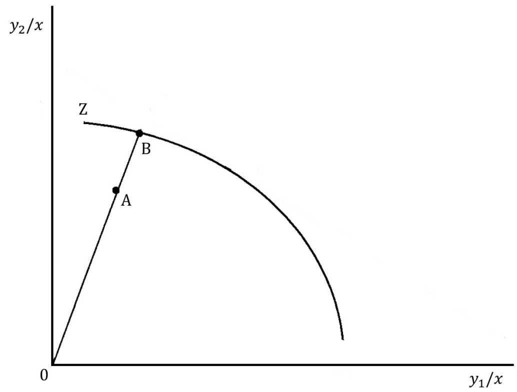

FIGURE 2.7: Output-oriented efficiency measure of Farrel [1]

The inefficiency of a DMU operating at point A is measured as the radial distance to the frontier, AB, which represents the maximum possible proportional expansion in all outputs while attaining the quantity of inputs used. The percentage of the expansion in outputs can be expressed by the ratio $AB/0B$. So, the output technical efficiency (TE_o) can be calculated by (1- inefficiency) and is stated as [1]:

$$\mathrm{TE}_o = 0A/0B \tag{2.9}$$

For the production systems with more then two inputs or two outputs, it is not possible to represent the production frontier with a two-dimensional graph. Also, the basic distance ratios used to calculate the efficiency in the previous cases would not be applicable. Instead another ratio, the ratio of weighted sum of outputs to the weighted sum of inputs namely TFP, is used to estimate the efficiency score of a DMU that belongs to such a production system. The details of TFP will be explained in Section 2.2.1. For an extensive discussion on radial efficiency measurements and productivity, one can refer to Coelli *et al.* [1] and Färe *et al.* [15].

2.1.5 Models for efficiency analysis based on production frontiers

The efficiency measures mentioned so far are based on production frontiers. In this context, Farrel's [8] demonstrations on efficiency measurement act as a benchmark in the literature. After his study, several techniques are developed for estimation of the production frontier and calculation of technical efficiency of production units. There are two main models for efficiency analysis based on production frontiers: the parametric (or econometric) and non-parametric models which are referred to as *Stochastic Frontier Analysis* (SFA), *Data Envelopment Analysis* (DEA) respectively.

Parametric models require a functional form for the production technology (which determines the relation between inputs and outputs) before the estimation of the production frontier [1]. This property is usually considered as a disadvantage due to the restrictions in obtaining specifications of a production technology for most cases. On the other hand, in non-parametric models, functional form is determined during the estimation process based on the sample observations [20]. So, it does not require any functional form for the technology a priori.

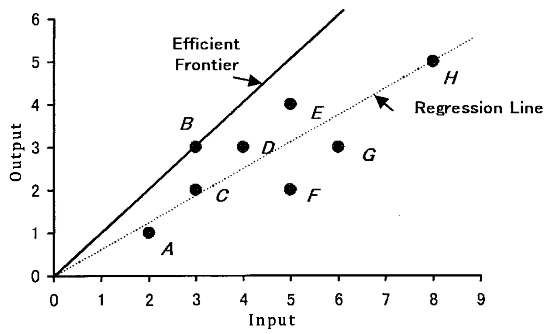

FIGURE 2.8: Production possibility set, Regression line and Efficient Production frontier [2]

According to the parametric approach, the best performance is assumed to be on the regression line of the production set (see Figure 2.8). The points on the regression line are assumed as efficient, whereas the outliers are considered as inefficient. Another important assumption of the parametric approach is that there will always be a random error due to the regression line which is not a concern of non-parametric approach because of its deterministic nature [20, 21].

As a parametric model, SFA will not be considered in this study. We will only give an insight into DEA and DEA-based Malmquist TFP index methods in the following sections, as they are non-parametric, frontier-based models used in the present study.

2.2 Data Envelopment Analysis (DEA)

Data envelopment analysis (DEA), occasionally called frontier analysis, was first put forward by Charnes, Cooper and Rhodes in 1978 [9]. They first called this model *'ratio'* model which was input oriented under CRS assumption. Later on this model is referred by the initials of the researchers (CCR). It is a non-parametric, linear programming model used to estimate the relative technical efficiency of DMUs. Charnes *et al.* [9] coined the term data envelopment analysis (DEA). Now what is known as DEA has been enhanced by the contribution of several models to CCR model such as BCC model which assumes VRS frontier [18]. The other developed models are 'multiplicative' model and the 'additive' model [1] which are beyond the scope of this study.

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 [2]. The name *'data envelopment analysis'* arise from this feature of the model.

The model uses the frontier approach which was first introduced by Farrel [8]. It assumes that DMUs may not always be fully efficient. It calculates the radial distances of inefficient units below the production frontier through linear programming (LP) models and the solutions yield the value of technical efficiency of individual DMUs relative to all other DMUs in the sample [1, 2]. Farrel evaluated the efficiency of production units with one output and multiple inputs and he used linear programming for efficiency measurement for the first time. In this sense, the contribution of DEA is the ability to evaluate DMUs that produce multiple outputs with using multiple inputs [22].

As another advantage of the method, since it is based on radial efficiency measurement technique, it is *unit invariant* which means it can evaluate DMUs with multiple input and outputs which have different units of measurement. For example, let one input be the land area which is measured in hectares, whereas another input can be labor which is expressed only by number. So, any change in the unit of measurement (to change hectare to meter square or to use labor work hour instead of number of workers) does not change the efficiency score of the production unit under evaluation [1]. Additionally, being a non-parametric model, DEA does not require a functional form for the production technology that relates input and outputs. It determines its functional form by the given set of input-output [19].

As mentioned earlier, productivity is the ratio of the weighted sum of all outputs to the weighted sum of all inputs of a DMU, say a firm. For a firm, this ratio cannot be calculated without using weights assigned to individual outputs and inputs. Weight assignment is a crucial problem for most of the efficiency measurements since this process requires the answer to the question: which input (or output) has more significance in the overall efficiency of a production unit. In other multi-criteria decision methods, these weights are determined before the analysis by the decision makers. DEA differs in this regard by not requiring weight or price information of input and outputs. Instead of this, the estimated production frontier derives the input and output weights which are calculated by a linear optimization problem through DEA [22]. Furthermore, for inefficient units, DEA provides a path that leads to efficiency by means of constructing peer groups for each inefficient unit which relates the weights of each input and output to the DMUs [23].

As in efficiency measurement techniques, the DEA model can either be input- or output-oriented. Input-oriented measures determine by how much can input quantities be reduced keeping output quantity constant. Whereas output-oriented measure indicates by how much can output quantities be increased by keeping the value of inputs fixed. The two orientations are also referred to as input minimization problem or output maximization problems respectively. The choice of orientation should be made considering which variables (inputs or outputs) the decision-makers have the most control over. Coelli [1] suggests that the choice of orientation has a poor effect on the obtained efficiency scores.

Our discussion on DEA will continue with brief descriptions of CCR and BCC models and their mathematical representations.

2.2.1 CCR Model

In this section, we will give a brief description of the mathematical formulation of CCR model which was proposed by Charnes *et al.* in 1978 [9]. In DEA models, usually, we evaluate n production units (DMUs) each using m inputs that produce s outputs. The efficiency rate of a production unit, say kth DMU, can be estimated through the TFP of that DMU which is expressed as the ratio of the weighted sum of all outputs to the weighted sum of all inputs as expressed in the equation.

$$TFP_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \tag{2.10}$$

In Equation 2.10 the nominator and the denominator is also defined as the virtual output and virtual input respectively [2], since the weights u and v are yet unknown and the optimal values of weights will be determined by solving the following fractional LP model (FLP). The objective function of the FLP model for kth DMU is the maximization of the ratio, virtual outputs/virtual inputs and it is stated as follows:
FLP:

$$\max \quad h_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \tag{2.11}$$

$$s.t. \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1, ..., n \tag{2.12}$$

$$v_i \geq 0 \quad u_r \geq 0 \qquad i = 1, ...m, \quad r = 1, ..., s \tag{2.13}$$

Indexes:
j: index for DMUs (there are n DMU)
i: the index for inputs (there are m inputs)
r: the index for outputs (there are s output)
Parameters:
x_{ij}: represents the value of ith input of jth DMU
y_{rj}: represents the value of rth output of jth DMU
Note that X_{ik} and Y_{rk} represent the ith input and rth output of the kth DMU respectively.
Variables:

v_i: represents the weight of the ith input

u_r: represents the weight of the rth output

The same notations will be used throughout the study as mentioned above.

In this optimization problem, the variables are the weights that will be assigned to input i and output r by the kth DMU. The $\mathrm{DMU_k}$ will choose its weights such that they will maximize its total factor productivity. In other words, the optimal weights may vary from one DMU to another DMU.

As discussed before, efficiency scores lie between 0 and 1. $\mathrm{DMU_k}$ is considered as technically efficient, if the optimal objective value of h_k is 1; whereas inefficient when h_k is less than 1. The first constraint provides the condition that the efficiency of any other DMU must not exceed 1, when they use the weights assigned by kth DMU. Also, the efficiency score of kth DMU should be normalized with respect to the efficiency values of other DMUs [1]. The weights of all inputs and outputs must be greater than zero and this condition is satisfied by the second constraint set[22].

A problem caused by this ratio formulation is that, it has infinitely many numbers of solutions for the variables u_r and v_i and it is a non-linear model. To linearize the model a new constraint is added [1]:

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \tag{2.14}$$

And the model FLP, for an input-oriented optimization problem is transformed into a LP model which is referred to as the primal CCR model [2, 24] and it is shown as:
$M_i(1)$:

$$\begin{aligned}
\max \quad & h_k = \sum_{r=1}^{s} u_r y_{rk} && (2.15)\\
s.t. \quad & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \qquad j = 1, ..., n && (2.16)\\
& \sum_{i=1}^{m} v_i x_{ik} = 1 && (2.17)\\
& v_i \geq 0 \quad u_r \geq 0; \qquad i = 1, ...m; \quad r = 1, ..., s && (2.18)
\end{aligned}$$

The LP model above is also called the multiplier model of CCR in the literature and can be denoted by $M_i(1)$, where the index i represents the model is input-oriented.

The transformation of FLP to $M_i(1)$ is also called 'Charnes-Cooper transformation' in fractional programming which enables to take the dual of the primal model. The dual of $M_i(1)$, also called the envelopment model, is stated as follows [2]:
$E_i(1)$:

$$\min \quad \theta_k \tag{2.19}$$

$$s.t. \quad \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rk} \quad ; \quad r = 1, ..., s \tag{2.20}$$

$$\theta_k x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \quad ; \quad i = 1, ..., m \tag{2.21}$$

$$\lambda_j \geq 0 \quad j = 1, ..., n \tag{2.22}$$

$$\theta_k \text{unrestricted} \tag{2.23}$$

where $\lambda_j \geq 0$ is a dual variable assigned to each DMU. The variable θ_k should have the same value with h_k in $M_i(1)$ because of the duality between the two models. θ_k gives the relative technical efficiency score of the kth DMU, so does h_k .

The envelopment model is generally preferred to multiplier model, since it has less constraint $(m + s < n + 1)$. To estimate the efficiency of all DMUs in a sample, the LP models $M_i(1)$ or $E_i(1)$ should be solved for each DMU. This means to construct n different models.

The calculations provide efficiency scores between 0 and 1 for each DMU. If $\theta < 1$, the corresponding DMU is considered as relatively inefficient and needs a proportional reduction in its inputs. Whereas, the DMUs having $\theta = 1$ are technically efficient units and (this indicates these DMUs are operating on the production frontier) they together form the efficient production frontier according to Farrel's [8] definition of efficiency [1].

2.2.1.1 Slacks included in Envelopment CCR model

Another issue about the LP models is the slacks associated with the input and output variables. Considering model $E_i(1)$, it may have both input and output slack values which can be stated as:

$$s_r^+ = \sum_{j=1}^{n} \lambda_j y_{rj} - y_{rk} \qquad ; \qquad r = 1, ..., s \tag{2.24}$$

$$s_i^- = \theta_k x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \qquad ; \qquad i = 1, ..., m \tag{2.25}$$

where s_r^+ and s_i^- represents output and input slacks respectively. However, Equations 2.24 and 2.25 may not yield all the non-zero slacks due to the possibility of multiple optimal solutions [25]. So, to determine the non-zero slacks after the model $E_i(1)$ is solved, the following LP model is used. This model is also referred to as *Phase II* DEA in which slacks are maximized [2], whereas model $E_i(1)$ which is used by Farrel [8] is regarded as *Phase I*.

$PhaseII$:

$$\max \qquad \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \tag{2.26}$$

$$s.t. \qquad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k x_{ik} \qquad ; \qquad i = 1, ..., m \tag{2.27}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \qquad ; \qquad r = 1, ..., s \tag{2.28}$$

$$\lambda_j \geq 0 \qquad ; \qquad j = 1, ..., n \tag{2.29}$$

The slacks obtained by model $PhaseII$ are defined as DEA slacks. And θ_k is the efficiency score obtained by $E_i(1)$, in other words in $PhaseI$. Actually, models $E_i(1)$ and $PhaseII$ are together considered as a two-stage DEA process and are joined in a single objective function which is presented in the following DEA model [25].

$Two-stage \quad DEA$:

$$\min \qquad \theta - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+) \tag{2.30}$$

$$s.t. \qquad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k x_{ik} \qquad ; i = 1, ..., m \tag{2.31}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \qquad ; r = 1, ..., s \tag{2.32}$$

$$\lambda_j, s_r^+, s_i^- \geq 0 \qquad j = 1, ..., n \tag{2.33}$$

In the seminal work of Charnes, Cooper and Rhodes [9], a DMU is considered to be *fully efficient* if it satisfies the two conditions below:

1. $\theta_k = 1$
2. All slack variables are zero.

The first condition implies the radial efficiency of Farrel's [8] or in other terms, technical efficiency, whereas the two conditions together imply *CCR-efficiency*. These conditions are also described by *Pareto-Koopmans efficiency* [9].

To obtain more detailed perspective about CCR models with slack variables, one can refer to [2, 9, 23].

2.2.1.2 DEA models with vector-matrix notation

The models $M_i(1)$ and $E_i(1)$ can also be expressed in vector-matrix notation by constructing an input and an output matrix as follows:

$$\mathbf{X} = \left[x_{ij}, \quad i = 1, 2..., m; \quad j = 1, 2..., n\right] \qquad \text{input matrix}(m \times n) \tag{2.34}$$

$$\mathbf{Y} = \left[y_{rj}, \quad r = 1, 2..., s; \quad j = 1, 2..., n\right] \qquad \text{output matrix}(s \times n) \tag{2.35}$$

The multiplier model$M_i(1)$ for $\mathrm{DMU_k}$ can be expressed in a vector- matrix notation (with Cooper's expression[2]) as follows:
$M_i(2)$:

$$\max_{u,v} \quad h_k = \mathbf{u}\mathbf{y}_k \tag{2.36}$$

$$s.t. \quad \mathbf{uY} - \mathbf{vX} \leq 0 \tag{2.37}$$

$$\mathbf{v}\mathbf{x}_k = 1 \tag{2.38}$$

$$\mathbf{u} \geq 0, \quad \mathbf{v} \geq 0 \tag{2.39}$$

Where $\mathbf{u}$ is a $(s \times 1)$ vector representing output weights and $\mathbf{v}$ is a $(m \times 1)$ vector representing input weights. The envelopment model with vector- matrix notation is expressed as follows:

$E_i(2)$:

$$\min_{\theta,\lambda} \quad \theta_k \tag{2.40}$$

$$s.t. \quad -\mathbf{y}_k + \boldsymbol{\lambda}\mathbf{Y} \geq 0 \tag{2.41}$$

$$\theta_k \mathbf{x}_k - \boldsymbol{\lambda}\mathbf{X} \geq 0 \tag{2.42}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.43}$$

Where $\boldsymbol{\lambda}$ is a $(n \times 1)$ vector of constants and θ_k is a scalar, being the efficiency score of the kth DMU.

In the envelopment model $E_i(2)$, $\boldsymbol{\lambda}\mathbf{X}$ and $\boldsymbol{\lambda}\mathbf{Y}$ can be interpreted as inputs and outputs of a virtual DMU which is presumed to be efficient. If $\mathrm{DMU_k}$ (the unit under evaluation) is found to be inefficient, then $\boldsymbol{\lambda}\mathbf{X}$ and $\boldsymbol{\lambda}\mathbf{Y}$ are linear input-output combinations of other DMUs and have better input-output values than $\mathrm{DMU_k}$. So, it is expected that, $\boldsymbol{\lambda}\mathbf{X} \leq \mathbf{x}_k$ for the inputs of the virtual unit and $\boldsymbol{\lambda}\mathbf{Y} \geq \mathbf{y}_k$ for the outputs [22]. The problem tries to reduce the input vector $\mathbf{x}_k$ radially as much as possible, while staying within the feasible production set. Because of this reduction in the input vector, a projected value $(\boldsymbol{\lambda}\mathbf{X}, \boldsymbol{\lambda}\mathbf{Y})$ is obtained on the frontier [1]. In other words, $\boldsymbol{\lambda}$ constitutes a reference set for $\mathrm{DMU_k}$ which provides a formula to catch-up the efficiency [22].

The CCR model assumes constant return to scale and can be used for both input and output-oriented efficiency measurements. All models mentioned above are input-oriented. The output-oriented CCR model is constructed in a similar way, regarding the aim to maximize the output while maintaining the input quantities. The output-oriented envelopment LP model to measure the efficiency of kth DMU is expressed as [23]:
E_o:

$$\max_{\phi,\lambda} \quad \phi \tag{2.44}$$

$$s.t. \quad \mathbf{x}_k - \boldsymbol{\lambda}\mathbf{X} \geq 0 \tag{2.45}$$

$$-\phi \mathbf{y}_k + \boldsymbol{\lambda}\mathbf{Y} \geq 0 \tag{2.46}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.47}$$

In model E_o , $1 \leq \phi \leq \infty$ and $\phi - 1$ is the proportional increase in outputs that could be achieved by kth DMU, while keeping the inputs fixed. It should be noted that output-oriented efficiency value is defined by $1/\phi$ which takes values between zero and one. For more information about the output-oriented CCR models one can refer to [2, 23]. Another thing to mention is that the efficiency scores obtained by input and output-oriented models will have the same value, since CCR model assumes constant return to scale.

2.2.2 BCC Model

The most important feature of DEA is the flexible approach and ability to adapt to new circumstances of production units. Within this perspective, many additions have been made to basic CCR model. The main contribution to CCR model is about the scale economics. CRS assumes that all the DMUs operate at optimum scale. However, in real life there are many factors such as financial limitations, government policies or imperfect competition that all might prevent DMUs to work at optimum scale [1]. In such cases, CRS assumption would be inappropriate. Färe *et al.* [12], Byrnes *et al.* [26] and Banker *et al.* [18] have enhanced CCR model in a way that it will be used for DMUs working relative to a VRS technology [20].

BCC (Banker, Charnes, Cooper) model which has been proposed by the researchers that give its name to it [18], assumes VRS and the efficiency score obtained by this model is also called *pure technical efficiency* [18]. The relation between technical efficiency obtained by CCR (TE-CCR) and obtained by BCC models (TE-BCC) and the scale efficiency (SE) is same with the relation between efficiency under CRS and VRS assumptions and scale efficiency. This relation can be expressed as follows [1].

$$\text{TE-CCR} = \text{SE} \times \text{TE-BCC} \tag{2.48}$$

$$\text{TE-BCC} \leq \text{TE-CCR} \tag{2.49}$$

According to their return to scale assumptions, BCC frontier will always be under CCR frontier as shown in Figure 2.3. Therefore, efficiency scores obtained by BCC model will be lower than the ones obtained by CCR model, in case the DMU under evaluation is not performing at the optimum scale (in other words if it is scale inefficient). If the DMU is scale efficient, then both BCC and CCR efficiency will have the same scores. This relation is also expressed in the Equations 2.48 and 2.49.

BCC model differ from CCR model by addition of the *convexity constraint* in the dual (envelopment) model which is stated as follows:

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{2.50}$$

With this regulation, the input-oriented BCC model is constructed as follows:
$E_i(3)$:

$$\min_{\theta,\lambda} \quad \theta_k \tag{2.51}$$

$$s.t. \quad \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rk} \quad ; \qquad r = 1, ..., s \tag{2.52}$$

$$\theta_k x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \qquad ; \quad i = 1, ..., m \tag{2.53}$$

$$\sum_{j=1}^{n} \lambda_j = 1; ; \qquad j = 1, ..., n \tag{2.54}$$

$$\lambda_j \geq 0 \tag{2.55}$$

$$\theta_k \quad \text{is unrestricted} \tag{2.56}$$

The envelopment model $E_i(3)$ can be expressed in vector-matrix notation as:
$E_i(4)$:

$$\min_{\theta,\lambda} \quad \theta_k \tag{2.57}$$

$$s.t. \quad -\mathbf{y}_k + \boldsymbol{\lambda}\mathbf{Y} \geq 0 \tag{2.58}$$

$$\theta_k \mathbf{x}_k - \boldsymbol{\lambda}\mathbf{X} \geq 0 \tag{2.59}$$

$$\sum \boldsymbol{\lambda} = 1 \tag{2.60}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.61}$$

The convexity constraint guaranties the comparison is made only between an inefficient DMU and DMUs with similar scale (similar size). This feature of DEA is known as *benchmarking* the inefficient DMUs. Hereby, the virtual target of an inefficient DMU (the projected point on the frontier) will be the convex combination of efficient DMUs [1]. In the dual model, if the DMU_k is efficient, then θ_k and λ_k will be equal to 1. Otherwise, the values of θ_k and λ_k will be less than 1.

The input-oriented primal BCC model can be stated as follows:
$M_i(3)$:

$$\max \quad h_k = \sum_{r=1}^{s} u_r y_{rk} - \mu_0 \tag{2.62}$$

$$s.t. \quad \sum_{r=1}^{s} u_r y_{rj} - \mu_0 - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \qquad j = 1, ..., n \tag{2.63}$$

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \tag{2.64}$$

$$v_i \geq 0 \quad u_r \geq 0; \qquad i = 1, ...m; \quad r = 1, ..., s \tag{2.65}$$

$$\mu_0 \quad \text{is unrestricted} \tag{2.66}$$

μ_0 variable in the primal model $M_i(3)$ is unrestricted and expressed as in the last constraint 2.66. The positive and negative value of μ_0 indicates that the DMU operates under decreasing return to scale and in increasing return to scale respectively. $\mu_0 = 0$ means the DMU works under constant return to scale [2]. Banker and Thrall [27] has shown that the above interpretations about μ_0 and the direction of return to scale are acceptable if and only if the optimal solution is unique. There are several proposals for alternative solutions of μ_0 in the same study.

2.2.3 DEA Calculations Using the Computer

All CCR and BCC models presented above can be solved by means of Excel-solver for each DMU. But it would take a lot of time to construct the LP model for each DMU. So, several softwares are developed to run DEA models such as DEAFrontier and DEAP2.1. DEAFrontier which is a Microsoft Excel add-in developed by Zhu [25], is a common tool for solving DEA models. Whereas, the software DEAP2.1 developed by Coelli [28] is used for both DEA and Malmqusit TFP index measurements. Since DEA is a linear programming model, the relative efficiency measurements can also be conducted through optimization programs such as GAMS, LINDO etc. Also, special DEA programs which is suitable for Windows (Frontier Analyst, Warwick DEA Softwares etc.) can be used for technical efficiency analysis. For a deeper insight into these tools, one can refer to [23] and [1].

2.3 Malmquist TFP Index

In efficiency measurements, how efficiency changes within a specific time is an important issue to be considered. So far, we observe that productivity or efficiency analysis does not have time dimension. The productivity and efficiency measurements give the performance of a firm 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 [1].

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 [3]. This is depicted in Figure 2.9 for a production with two outputs and one input. Period t_1 and period t_2 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 scale efficiency or by a combination of these three factors.

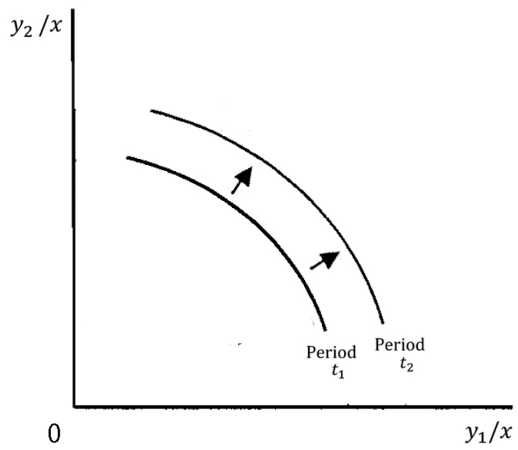

FIGURE 2.9: Technological Change (Shift of Production Frontier)

If we have a panel data (data for multiple variables over a specific time) of DMUs, it is possible to estimate the change in *Total Factor Productivity* (TFP) with several methods.

Tornquist/Fisher is one of the methods which assumes the aim is either maximization of revenue or minimization of cost. In contrast, Malmquist TFP Index method does not assume any of them. Thus, there is no need for collecting price data for Malmquist technique which is necessary for Fisher method. This property makes Malmquist TFP Index a preferable strong method for performance evaluation of organizations that belongs to government or are not interested in profit [1].

The 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. [3].

There are two main methods to calculate the change in TFP. The first one is non-parametric DEA which is a linear programming method. And the second one is parametric SFA method which use econometric methods. As a common property, both methods, DEA and SFA, use Malmquist TFP Index to estimate change in TFP [1].

Malmquist TFP Index was first introduced by Caves, Christensen and Diewert in 1982 [29]. This index is constructed using the ratios of distance functions which were earlier used to construct quantity indexes by Sten Malmquist in 1953 [30]. Thereby, the resulting index is called Malmquist TFP index [3].

Malmquist TFP Index 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. Accordingly, Malmquist index calculations are based on distance functions. The radial distance measurements can be input-oriented or output-oriented which cause a difference in orientation of Malmquist indices. Technologies with multiple-output and multiple-input can be represented by distance functions which only require data of input and output values [3].

2.3.1 Distance Functions used in Efficiency Measurement

As presented in the study of Färe *et al.* [3], $\mathcal{S}^t$ denotes the production technology for each time period $t = 1, \ldots, T$, which also 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.

$$\mathbf{S}^t = \Big\{ \big(\mathbf{x}^t, \mathbf{y}^t \big) : \mathbf{x}^t \quad \text{can produce} \quad \mathbf{y}^t \Big\} \tag{2.67}$$

Output distance function at time t, which also characterizes the technology S^t is defined as [3]:

$$d_o^t(\mathbf{x}^t, \mathbf{y}^t) = min\Big\{ \theta : \big(\mathbf{x}^t, \mathbf{y}^t/\theta \big) \in \mathbf{S}^t \Big\} \tag{2.68}$$

If (x^t, y^t) belongs to production possibility set which is defined by technology $\mathcal{S}^t$, i.e. $(x^t, y^t) \in S^t$ then,

$$d_o^t(\mathbf{x}^t, \mathbf{y}^t) \leq 1$$

If $d_o^t(\mathbf{x}^t, \mathbf{y}^t) = 1$, it means (x^t, y^t) is on the efficient production frontier or on the boarder of $\mathcal{S}^t$ technology. In Farrel's [8] terminology, it indicates a technically efficient production unit [1]. Figure 2.10 illustrates the relation between distance functions and Farrel's radial efficiency for a simple case with single input and single output under CRS assumption. In this example, the observed DMU has input and output values $(\mathbf{x}^t, \mathbf{y}^t)$ and is below the frontier, in other words technically inefficient under CRS assumption [3].

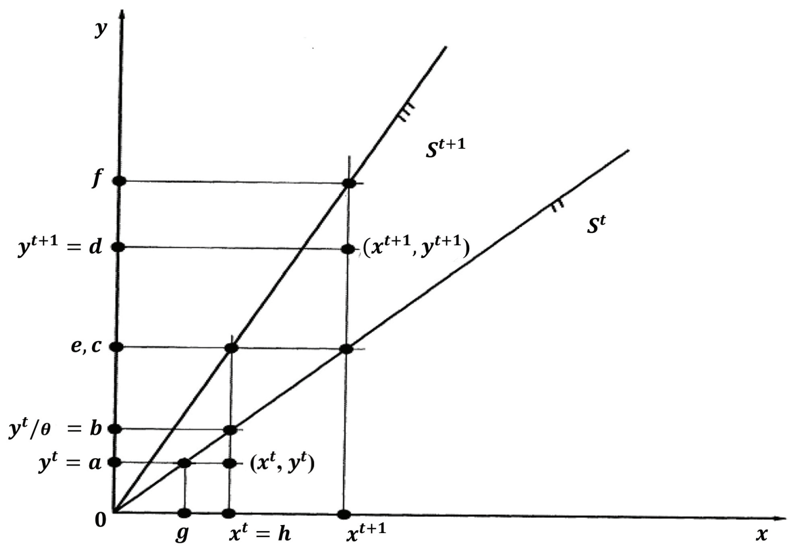

FIGURE 2.10: The Distance Functions and the Malmquist Output-Based Index of TFP [3]

The output distance measure is the reciprocal the ratio of the greatest proportional expansion in the output quantity to make $(\mathbf{x}^t, \mathbf{y}^t)$ efficient relative to the technology $\mathcal{S}^t$ (i.e. vertical distance to the frontier) to the current output quantity, while attaining the current input level. Note that, the output distance measure is equal to the radial output efficiency measure of Farrel's, which we will denote by TE_o and can be expressed as [1]:

$$TE_o = d_0^t(\mathbf{x}^t, \mathbf{y}^t) \tag{2.69}$$

In Figure 2.10, for the unit (x^t, y^t) under evaluation, these measures are given as:

$$TE_o = \theta = 0a/0b = d_o^t(\mathbf{x}^t, \mathbf{y}^t) \tag{2.70}$$

As discussed before, different orientations result in different efficiency measurements. The orientation choice makes difference also in distance functions which forms a basis for the radial efficiency measurements. Thus, the input distance function is defined as:

$$d_i^t(\mathbf{x}^t, \mathbf{y}^t) = max\Big\{\delta : \big(\mathbf{x}^t/\delta, \mathbf{y}^t\big) \in \mathcal{S}^t\Big\} \tag{2.71}$$

If (x^t, y^t) belongs to the production possibility set which defined by technology S^t, i.e. $(x^t, y^t) \in \mathcal{S}^t$, then

$$d_i^t(\mathbf{x}^t, \mathbf{y}^t) \geq 1$$

As same with the output distance functions, $d_i^t(\mathbf{x}^t, \mathbf{y}^t) = 1$ if (x^t, y^t) is on the efficient production frontier. The radial input efficiency (TE_i) of a production unit can be expressed in terms of the input distance function as follows:

$$TE_i = 1/d_i^t(\mathbf{x}^t, \mathbf{y}^t) \tag{2.72}$$

In Figure 2.10, for (x^t, y^t), this relation is illustrated as:

$$TE_i = 1/\delta = 0g/0h \quad \text{and} \quad d_i^t(\mathbf{x}^t, \mathbf{y}^t) = \delta = 0h/0g \tag{2.73}$$

Note that, under CRS technology, the output distance function is the reciprocal of the input distance function. So, we can state that

$$d_o^t(\mathbf{x}^t, \mathbf{y}^t) = 1/d_i^t(\mathbf{x}^t, \mathbf{y}^t) \tag{2.74}$$

for all x and y in S^t under CRS. In Figure 2.10, it is easy to show that $0a/0b = 0g/0h$

2.3.2 The Malmquist TFP Index Formulation

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

$$d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}) = \left\{\theta : \left(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}/\theta\right) \in \mathcal{S}^t\right\} \tag{2.75}$$

As seen in the Figure 2.10, (x^{t+1}, y^{t+1}) lies above the production frontier $\mathcal{S}^t$. In this sense, the output distance function of (x^{t+1}, y^{t+1}) relative to $\mathcal{S}^t$ is greater than 1 and is represented by the ratio, $0d/0e$. 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 $d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)$. If the technology in period t is considered as the reference time, Malmquist index which is defined by Caves et.al [9] is expressed as:

$$M_{CCD}^t = \frac{d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^t(\mathbf{x}^t, \mathbf{y}^t)} \tag{2.76}$$

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

$$M_{CCD}^{t+1} = \frac{d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \tag{2.77}$$

Following the study of Färe *et al.* [3], the output based Malmquist TFP index between the period t and following period $t+1$ is defined as the geometric mean of these two indices [3].

$$M_o(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) = \left[\frac{d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^t(\mathbf{x}^t, \mathbf{y}^t)} \frac{d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)}\right]^{1/2} \tag{2.78}$$

It is also possible to write this index as:

$$M_o(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) = \frac{d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^t(\mathbf{x}^t, \mathbf{y}^t)} \times \left[\frac{d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})} \frac{d_o^t(\mathbf{x}^t, \mathbf{y}^t)}{d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)}\right]^{1/2} \tag{2.79}$$

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, stand for the technological change between the periods [3]. These two components of TFP are shown as:

$$\text{Technical Efficiency Change (TEC)} = \frac{d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^t(\mathbf{x}^t, \mathbf{y}^t)} \tag{2.80}$$

$$\text{Technological Change (TC)} = \left[\frac{d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})} \frac{d_o^t(\mathbf{x}^t, \mathbf{y}^t)}{d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \right]^{1/2} \tag{2.81}$$

or

$$M_o^{t,t+1} = \text{TEC} \times \text{TC} \tag{2.82}$$

A change in technology indicates a shift in efficient production frontier overtime as seen in Figure 2.9. It can be interpreted as a natural measure of innovation or a change in technology [3]. Coelli [1] illustrates this concept for an agricultural productivity analysis such that when all farms face a bad year in terms of, lets say rainfall, it causes the production frontier to shift downward and DEA-based Malmquist 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 under CRS assumption [31]. 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 2.79 can be illustrated by the distances measured in Figure 2.10 as: :

$$\begin{aligned} M_o(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) &= \left(\frac{0d}{0f}\right)\left(\frac{0b}{0a}\right)\left[\left(\frac{0d/0e}{0d/0f}\right) \times \left(\frac{0a/0b}{0a/0c}\right)\right]^{1/2} \\ &= \left(\frac{0d}{0f}\right)\left(\frac{0b}{0a}\right)\left[\left(\frac{0f}{0e}\right)\left(\frac{0c}{0b}\right)\right]^{1/2} \end{aligned} \tag{2.83}$$

If the value of $M_o^{t,t+1}$ is greater than one, it indicates a positive TFP growth; whereas a value less than one means a TFP decline and a value equal to one indicates no change in TFP from period t to period $t+1$ [1].

Following Färe *et al.* [3], having the suitable panel data, four distance functions are required to estimate the Malmquist TFP index of a DMU for two consecutive periods, t and $t+1$, which are listed as:

$d_o^t(\mathbf{x}^t, \mathbf{y}^t)$: The output distance function of (x^t, y^t) relative to $\mathcal{S}^t$
$d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$: The output distance function of (x^{t+1}, y^{t+1}) relative to $\mathcal{S}^{t+1}$
$d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$: The output distance function of (x^{t+1}, y^{t+1}) relative to $\mathcal{S}^t$
$d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)$: The output distance function of (x^t, y^t) relative to $\mathcal{S}^{t+1}$

These distance functions can be calculated using DEA-like LP models. In this regard, to measure the TFP change of kth DMU between period t and $t+1$, four LP problems are required. The required LPs, which correspond to the distance functions mentioned above, are presented in the same order as:

$$\left[d_o^t(\mathbf{x}^t, \mathbf{y}^t)\right]^{-1} = \max_{\phi,\lambda} \quad \phi \tag{2.84}$$

$$s.t. \quad -\phi\mathbf{y}_{k,t} + \boldsymbol{\lambda}\mathbf{Y}_t \geq 0 \tag{2.85}$$

$$\mathbf{x}_{k,t} - \boldsymbol{\lambda}\mathbf{X}_t \geq 0 \tag{2.86}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.87}$$

$$\left[d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})\right]^{-1} = \max_{\phi,\lambda} \quad \phi \tag{2.88}$$

$$s.t. \quad -\phi\mathbf{y}_{k,t+1} + \boldsymbol{\lambda}\mathbf{Y}_{t+1} \geq 0 \tag{2.89}$$

$$\mathbf{x}_{k,t+1} - \boldsymbol{\lambda}\mathbf{X}_{t+1} \geq 0 \tag{2.90}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.91}$$

$$\left[d_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})\right]^{-1} = \max_{\phi,\lambda} \quad \phi \tag{2.92}$$

$$s.t. \quad -\phi\mathbf{y}_{k,t+1} + \boldsymbol{\lambda}\mathbf{Y}_t \geq 0 \tag{2.93}$$

$$\mathbf{x}_{k,t+1} - \boldsymbol{\lambda}\mathbf{X}_t \geq 0 \tag{2.94}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.95}$$

$$\left[d_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)\right]^{-1} = \max_{\phi,\lambda} \quad \phi \tag{2.96}$$

$$s.t. \quad -\phi \mathbf{y}_{k,t} + \boldsymbol{\lambda} \mathbf{Y}_{t+1} \geq 0 \tag{2.97}$$

$$\mathbf{x}_{k,t} - \boldsymbol{\lambda} \mathbf{X}_{t+1} \geq 0 \tag{2.98}$$

$$\boldsymbol{\lambda} \geq 0 \tag{2.99}$$

It should be noted that, the ϕ parameter do not need to be greater than or equal to one as it must be in the LP problem for output-oriented technical efficiency (See model E_o in Section 2.2.1). This indicates a production point may lie above the production frontier. This case is mostly observed when a production point from time $t + 1$ is compared to the technology of an earlier period, t.

Another point to be stressed is the scale assumption used in the analysis. Färe *et al.* [3] assumes CRS in their study. So, the distance functions, accordingly the change in technical efficiency, are calculated under CRS assumption. For an analysis under VRS assumption, the TEC index can also be decomposed into two indices, pure efficiency change (PEC) and scale efficiency change (SEC). And the multiplication of PEC and SEC indices gives the TEC index [32]. Here PEC is the efficiency change calculated under VRS[1]. For an extensive discussion on Malmquist TFP Index one can refer to the studies of Färe *et al.* [3] and Coelli [1] and Thanassoulis [32].

2.4 DEA and Malmquist TFP Index Approaches in Agriculture

In this section, first we discuss the main steps in building DEA model especially for studies regarding agriculture. Afterwards, a literature review is provided in terms of different aspects of studies involving applications of DEA and Malmquist TFP Index methods in evaluating the performance of agriculture sector.

[1]Calculation of PEC and SEC requires additional LP problems: $d_o^t(\mathbf{x}^t, \mathbf{y}^t)$ and $d_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$ relative to VRS technology [3].

2.4.1 Design of DEA models for Agricultural Efficiency Measurements

There are three main steps in building a DEA model: Determining the DMUs to be analyzed, selection of appropriate input and output variables to evaluate the efficiency of specified DMUs and determining the specifications of DEA model that is suitable for the analysis. In this section, we will give brief explanations for each step and present the applications of these steps in several papers about the agricultural efficiency measurements.

2.4.1.1 Determining the Decision-making Units

To apply DEA, the first step is to determine the decision-making units (DMUs) to be evaluated. Any production unit that transforms inputs to outputs can be regarded as a DMU. Ahn [33] specifies two principles for selecting DMUs:

- Each DMU should be defined as a production unit responsible from the resources it uses and outputs it produces.
- The number of DMUs in the sample should be large enough to avoid the insignificance in the efficiency frontier analysis.

It is also important that these DMUs should be functioning homogeneously, i.e operate under same goal and producing similar outputs using the similar inputs.

DEA is widely used to measure the relative technical efficiency of various units that belong to different sectors such as educational institutions [34, 35], hospitals [21, 36], airports [37], banks [38, 39] or any specific industrial sector such as power plants [40]. For agriculture sector, DMUs studied can be mainly grouped as individual farms, agricultural enterprises, the agricultural activity of regions within a country or agricultural performance of countries. This categorization for agriculture is explained by examples from literature in more detail in Section 2.4.2.

2.4.1.2 Selection of Variables

Selection of variables is the next crucial step in application of DEA since this process effects the comparison between DMUs and is highly correlated with the scope of the study. Although there is no functional form required for DEA, the choice of variables for a sample of DMU would cause a significant difference in the efficiency scores. For example, to evaluate the performance of a group of hospitals, inputs can be selected as hospital size, number of full-time staff, total assets and supply (operational expenses) and outputs are adjusted discharges, total outpatient visit and training full-time equivalents as in the study [36]. Whereas, for small business, say a sample of stores, one may simply use only sales and employee as single output and input respectively.

FAO (Food and Agriculture Organization of the United Nations) determined the fundemental indicators of agricultural productivity in their report published in 2003 as: land use (arable area, irrigated area, cultivated area), tractors, chemicals (pesticides and fertilizers), labor force, live animal, value of agricultural production, GDP and agricultural investment [41]. Most of the studies about agricultural productivity are conducted using these variables. Among these variables, the most common inputs are arable area, labor force, number of machines, livestock and the gross value of agricultural production is used frequently as the output. In literature, several studies consider two outputs separately as crop production and animal production as in [42, 43], whereas many evaluate the total agricultural production [44, 45].

Labor force is defined as the active population engaged in agriculture and is generally measured in numbers as in studies [44–46], while most of the farm-level studies prefer the annual work unit (AWU) or hours of work for labor variable such as in [47–49]. Machine variable usually includes only tractors which are total number of wheel and crawler tractors.

Another crucial thing is to decide the output, whether it will be the production value in monetary units or the amount of production in tons. This choice is also accompanied with the same decision for inputs, whether to use the monetary value or the amounts of inputs. This issue is highly related with the data source used for the analysis and the scope of the study. Farm-level studies mostly use amounts of the inputs. However, studies that use farm accountancy data network databases can reach the financial accounts of individual farms and this enables to use the monetary value of all inputs such as fertilizers, seeds, pesticides etc.

Additionally, the selected inputs vary by specific efficiency measurements in agricultural production. For example, environmental and energy use efficiency analysis requires the data of nitrogen and carbon amounts in all fertilizer types and amount of seeds, as well as the amount of fuel consumed for the machines used in agriculture as seen in studies [50–55]. On the other hand, a study evaluating the irrigation water use efficiency would require different variables such as in [56]. In this farm level study [56], in addition to common input variables, they used two other specific characteristics: available water supply of soils and average annual precipitation in the regions. As seen, these specific inputs are highly depended on the focus of the study.

Some variables such as literacy rate and age of farmers, government policies, income, agricultural investments are mostly used for the regression analysis after DEA measurement is conducted. Brief review of such applications is presented in Section 2.4.2

It should be noted that the number of input and output variables should not be determined arbitrarily. To use huge number of input and output variables would lead to a less discriminative analysis. For the analysis of a sample containing n DMUs that use m inputs to produce s outputs, the relation between the numbers of DMUs and input-output variables is determined by Sherman (d56) as $n > m + s$. However, Charnes and Cooper [57] suggest that the number of DMUs (n) should be, at least, three times the total number of input and output variables ($m + s$) to have a discriminatory DEA analysis [58].

2.4.1.3 Determining the model

In TFP and efficiency measurements, return-to scale property of the technology used is another important issue. After selection of appropriate variables, input or output-oriented DEA model with different scale assumptions can be built in accordance with the aim of the study. The choice of model should reflect the nature of the production system that is evaluated. It is appropriate to use BCC model, which assumes variable-return-to scale (VRS), when the production units are not working at the optimal scale and when there may be imperfect competition. To avoid the conflict in scale efficiency, VRS is suggested by several studies from previous literature [15, 18]. Alternatively, CCR model which assumes constant-return-to scale (CRS), can be used when all production units are operating at optimal scale in a perfectly competitive environment [15, 18].

In agricultural studies both of the scale assumptions exist. Some of the farm-level studies [56, 59] preferred to use VRS technology assuming that farms usually do not operate at their optimal scale because of possible factors such as imperfect competition and financial constraints. In this case, assuming CRS would mean a lack of scale efficiency which would result in an incorrect efficiency measurement [28]. On the other hand, many of the agricultural efficiency analysis that are conducted at country or regional level use CRS technology [7, 45, 60]. It is suggested to use CRS technology for these studies, due to the aggregate country-level or region-level data that are used for such analysis [7]. Besides these, there are many studies [47, 48, 61–63] that use both of the scale assumptions and compare the different results.

The choice of orientation should be made considering which variables (inputs or outputs) the decision-makers have the most control over. This highly varies in studies that analyze agricultural efficiency. In literature, input-oriented DEA models are more preferred [47, 48, 55, 56, 61] due to the assumption that farmers have more control on inputs more than on outputs. On the other hand, in some studies [7, 45, 60, 64], use of output-oriented DEA model is explained by the aim of maximizing the agricultural production for the given input set. It should be noted that input and output-oriented efficiency measures provide the same values under CRS assumption as in the studies [7, 45, 60, 64]. Another reason to prefer an input-oriented DEA model is that it requires fewer constraint [1].

2.4.2 Related Studies

DEA use in agricultural sector differs from each other in accordance with the scope and aim of the study. These studies can be categorized according to the subject of interest such as evaluating total factor productivity, irrigation efficiency, effect of government policies on the production efficiency or environmental efficiency etc. Accordingly, different models of DEA (CCR or BCC), with different choice of orientations have been applied in these studies by taking into consideration the scope and the variables .

The methodological variations in using DEA also depend on the input-output selection and the decision-making-units which will be analyzed. It is deduced from the literature that the studies about agricultural productivity or efficiency are conducted at country level, regional level or at farm/enterprise level. In addition, source of data for the analysis is highly dependent on the scope of the study i.e. whether the analysis at regional, country or farm level.

The related studies at country level mostly use Malmquist index method to evaluate the change in the agricultural performance of a country over a period or comparing the performance of a group of countries. In studies [7, 65–68], DEA-based 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. The common conclusion of these studies is the productivity growth in developing countries are negative, whereas it is positive in the western countries. And the increase in TFP in western countries is mainly due to the technological improvement rather than an increase in efficiency [7, 65, 67].

In the literature, there are more specific studies that considers countries within a continent or a specific region. Thirttle, Hadley and Townsed [69] used Malmquist TFP index method to evaluate the agricultural productivity of 22 Sub-Sahara countries between 1971-1986. Ninn-Prat *et al.* [70] compared the TFP of China and India in terms of their agricultural production over the period 1961-2006. Galanopoulos *et al.* [65] used sequential Malmquist TFP index method to analyze the agricultural productivity growth of 13 Mediterranean countries including Turkey between 1966-2002. They also investigated the convergence of TFP values of these countries by cross-sectional and time series convergence tests. The empirical results show that the increase in the productivity of Turkey mainly caused by the progression in efficiency rather than an improvement in technology over the period. The annual average technical change for Syria, Greece, Jordan and Turkey are found to be low (no more than 0.3%), whereas the highest technological progress (by more than 1%) have been seen in Cyprus, Libya and Spain.

Further studies at country level compare the efficiencies of OECD countries or EU countries for different time intervals. Data sets for most of these studies are obtained from the database of Food and Agriculture Organization of the United Nations (FAO). Hoang and Alauddin [55] used input-oriented DEA to analyze the economic, environmental and ecological efficiency in agricultural production of 30 OECD countries. The empirical results show that to increase environmental and ecological efficiencies, better combinations of inputs should be used rather than improving the technology. Also for a more sustainable agriculture, OECD countries should consider better input combinations with less nutrient contents.

Tunca and Deliktaş [64] also measured the technical efficiencies of 29 OECD countries in terms of their agricultural performance over the period 1966-2007. They used dynamic DEA which is rarely seen among the agricultural efficiency measurement methods in literature. In [71], Deliktaş *et al.* used the same approach (dynamic DEA) and compared the agricultural efficiency of Turkey with 26 European Union (EU) countries over the period 1992-2006. They observed that dynamic agricultural efficiency of more developed members of EU are higher than the less developed ones. The results indicate that the static factors have more impact on the inefficiency of Turkey. When the total static inefficiency is examined, it is seen that the allocative inefficiency has a greater role than the technical inefficiency. According to the findings of the study, the uncertainty in the short-term decision-making mechanisms play a great role in the static inefficiency of Turkey which also indicates a less developed market structure.

In another study, [72], 17 EU countries and Turkey (as a candidate) are evaluated in terms of the change in their agricultural total factor productivity over the period of 1962-2006. Also, the convergence of TFP values were investigated. One of the main results of the study indicates that the average change in TFP values are mainly caused by the technical change. Among the countries under evaluation, Denmark and England have the greatest improvement in TFP, whereas Turkey has the greatest regression in the TFP change. The only periods that Turkey has technological improvement in agriculture were found to be between 1981-1990 and 1991-2006.

Cankurt *et al.* [73] also estimated the change in technical efficiency and agricultural productivity of 17 EU countries and Turkey over the period 1961-2007 and searched for the effect of global crises on the efficiency change and productivity growth. The results indicate that a negative change in TFP is generally caused by a decrease in technological change. The period between 2000-2009 exhibits an improvement in technology and accordingly in TFP of agriculture in Turkey, although there is a regression in technical efficiency. The study concludes that this improvement is a result of the support policies applied by the government at the beginning of 2000s. The effect of the support policies on the agricultural productivity of Turkey was analyzed over 1980-2009 in another study [74] at national level.

DEA is frequently used in comparing agricultural efficiencies of the regions or the provinces within a country. Some of the studies also uses DEA-based Malmquist TFP index method to estimate the productivity growth in these regions over specific periods such as in [43, 75–77]. Millan and Aldaz [43] evaluated the agricultural productivity growth of 17 regions in Spain over the period 1977-1988. They also analyzed the possible effects of other non-conventional inputs such as geographic and institutional conditions on productivity growth. Kiani [75] analyzed the change in agricultural productivity of NWFP (Punjab province in Pakistan) between the period 1970-2004. Thirtle *et al.* [76] has compared the productivity growth of 18 regions of Botswana in terms of their agricultural productivity. Nghiem and Coelli [77] computed the TFP change of rice productions in 8 regions of Vietnam over the period 1976-1997.

Further studies such as [42, 78, 79] include different applications of DEA method. In [42], Aldaz and Milan measured the technical efficiencies of 17 regions of Spain by applying DEA to the panel data which is the same data set used in [43]. Then, a time series approach is applied to DEA panel data to calculate the technical change in agricultural production of the same regions over the same period as in [43]. The results of the two studies [43] and [42] were compared and no significant differences were observed. One of the DEA-panel assumptions, the lower bound of the technical change is zero, was found to be insignificant in this empirical study. However DEA-panel method was found to be more discriminative, thus it is sufficient to analyze non-radial inefficiency over time. In [78], intertemporal-DEA method was used to analyze the agricultural productivity of 19 European Union regions over 1982-97. In [79], Panel-DEA and bootstrapping methods were used to estimate the agricultural efficiencies of 4 regions in Thailand over the period 2008-2012.

There are several studies in Turkey that were conducted using DEA and Malmquist index methods at regional or at province level [45, 46, 63, 80, 81]. The data sets for these researches were mainly obtained from SIS (Turkey State Institute of Statistics) and Republic of Turkey Ministry of Food Agriculture and Livestock. In [45], DEA-based Malmquist TFP index method was used to estimate the technical efficiencies and TFP changes in agricultural activity of 4 provinces in South Marmara region of Turkey over the period 1993-2002. Armağan *et al.* [46] evaluated NUTS1 level regions in Turkey in terms of their crop production performance for the period 1994-2003. The mean scores of all the regions indicate that there is a decrease in TFP due to a decrease in technical change, or in other terms technological regression over the period. In [81], agricultural efficiency and TFP change of Turkey provinces were evaluated through the period 1998-2003.

Kaya and Aktan [80] evaluated the agricultural productivity change of 81 provinces in Turkey for the period 2000-2009. When the mean scores of all provinces are examined, the highest growth rate of TFP was observed in 2001 and the increase in TFP followed with lower values until 2005. Between 2005 and 2009 there was a decrease in TFP change. By means of decomposing of Malmquist TFP index values, the main cause of the increase and decrease in TFP growth rates were found to be the change in technological progress. In a further study, Aktan and Samut [63] used DEA to estimate the agricultural efficiencies of 81 provinces in Turkey for the year 2009. In this study, the Tobit-regression model was applied, as a second stage after DEA, to evaluate the relation between the technical efficiencies and the other external variables that might have effect on the agricultural productivity such as number of households, literacy rates, roads and precipitation rates. The results indicate that these variables have significant role in the technical efficiencies, while other variables used in Tobit model such as government, GDP and credit were found to have not much influence on the efficiency scores.

Using DEA in efficiency analysis at farm level appear frequently in literature. Most of the farm level studies are based on the data obtained through interview surveys such as in [47, 48, 59, 61]. Another source of data is the databases of the local/national farm management associations as used in studies [49, 56]. As observed from the literature, the data sets, both in terms of quantities and input-output selection, are more detailed and reliable in farm level studies. Other than these, in many studies the data are obtained through Ministries of Agriculture and the relevant associations in the country of application.

Lilienfeld and Asmild [56] estimated the irrigation water use efficiencies of 43 farms in Kansas over the period between 1992 and 1999 using DEA. Iraizoz *et al.* [49] compared the two approaches for measuring the technical efficiency in horticultural production, one being the parametric method SFA and the other is non-parametric DEA methods. The technical efficiencies of 46 tomato and asparagus growing horticultural farms in Navarra (Spain) were calculated by both methods and the results show that there is no significant difference between them. In [82], Malmquist TFP index method was used to calculate the agricultural efficiency and productivity change of the farms in 46 states of USA between 1960-1996.

In many studies regarding agricultural efficiency using DEA, some regression models have been used to identify the several factors underlying the inefficiencies or evaluating the other variables that might have impact on the efficiency scores such as in [44, 47–49, 61–63]. Guzma'n and Arcas [62] measured the technical efficiency of 247 agricultural cooperatives in Spain using non-parametric DEA technique. They used Tobit regression to determine if DEA method is complementary to the traditional economic ratio analysis method (factor analysis) which is conducted separately. The results show that DEA is an appropriate complement to the economic analysis regarding the financial accounts of the cooparatives. In [61], DEA was used to estimate the technical efficiencies of organic and conventional coffee farms in Nepal. Tobit regression analysis was used to determine the characterizations of farms that effect the inefficiencies.

As one of the core studies in Turkey, Deliktaş and Candemir [44] has measured the technical efficiencies of Turkish state enterprises using DEA. By computing Malmquist TFP indices, a comparison was made in terms of the changes in technical efficiencies and the total factor productivity over the period 1999-2003. The primary data for the study was obtained from the 5 years accounting records of 37 state-owned agricultural enterprises which serve under Turkey General Directorate of Agricultural Enterprises. As a second stage, regression analysis has been used to determine the factors effecting the production efficiencies. The mean annual scores indicate that the decrease in TFP growth over the period was mainly caused by the negative technical progress.

Studies [47, 48, 59, 60, 83] are some examples of farm efficiency measurements in different regions of Turkey. Alemdar and Ören [47] computed the technical efficiency of 193 wheat growing farms in Adıyaman province in Southeastern Region of Turkey. After regression analysis, the main factor affecting the technical inefficiencies was found to be land fragmentation. In [48] used DEA in measuring agricultural efficiency of 70 rice farms located in Edirne and Balıkesir, two provinces in Marmara Region of Turkey. Binici *et al.* [59] measured the agricultural efficiency of 54 cotton growing farms in Harran Plain of Şanlıurfa province in Turkey using DEA method. As a different approach, they evaluated the farms which are already producing at a high level of efficiency and estimated the inefficiencies in using the inputs. Candemir *et al.* [60] used DEA to estimate the technical efficiency of Hazelnut Agricultural Sales Cooperatives Unions (HASCUs) in Turkey and computed the change in agricultural productivity by using DEA-based Malmquist index method over the period 2004-2008.

Another common source of data, for farm efficiency measurements, is national/local Farm Accountancy Data Network (FADN) databases. It is a well processed system in Europe in which financial accounts of individual farms are reported detailly in the databases of relevant countries and used in many studies to analyze farm performance such as in [49, 56]. This system appears as *Çiftlik Muhasebe Veri Ağı* (ÇMVA) and is recently applied in Turkey by Ministry of Food Agriculture and Livestock. However, due to lack of clear data and accessibility to the new system, it is difficult to conduct a study using the data source in Turkey. However, there is one study in Turkey by Atıcı and Podinovski [83] in which they evaluated the agricultural efficiency of 347 farms from 12 regions of Turkey. The novelty of the study is the application of DEA with production trade-offs approach for the first time in a real-world agriculture problem: low discrimination in efficiency analysis of farms with different specializations (different type of crops is produced in individual farms). To overcome the low efficiency discrimination in the results obtained by conventional DEA, they established the production trade-off relationships between the several outputs.

Chapter 3

Analysis and Results

In this chapter, we will briefly present the aim and the scope of the study, the variables selected for the analysis, the data sources, the methods used for the analysis and the empirical results.

With this analysis, we aimed to evaluate the agricultural production performance for 26 NUTS2 regions of Turkey between 2006 and 2015. The non-parametric DEA-based Malmquist TFP Index method was used to measure the efficiency and productivity change in agricultural production of Turkey 26 regions over the period 2006-2015. This analysis provides Malmquist indices of TFP change and its components for agricultural production of NUTS2 regions over the specified period. Then a further efficency analysis was conducted by using two-stage DEA method for each year to obtain a detailed information about the input usage and to investigate the ways to improve efficiency of inefficient regions in the corresponding years.

3.1 Selected Variables and Data used in the Analysis

As discussed in the previous chapter, selection of variables is one of the important steps in building DEA model. In this section, we present the descriptions of selected variables, the sources of data used and the limitations and difficulties we have faced during data gathering process.

26 NUTS2 regions of Turkey are considered as the DMUs of the analysis. The list of NUTS level regions and their official codes are presented in Table 3.1.

The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system that was established by EU to divide up the economic territory of the EU for reducing the development differences among territorial regions. European Union (EU) regional statistics are organized according to this classification and it serves as a reference for socio-economic analysis of the regions. The NUTS classification is only used by EU member countries. The version used in Turkey, as a candidate country, is called statistical regions (SR-İBBS). However, in international studies, the abbreviation 'NUTS' is used also for Turkey, since İBBS is determined in accordance with the criteria of the NUTS classification system.

As seen in Table 3.1, Turkey NUTS classification consists of three levels. The third level includes 81 provinces. The second level consists of 26 territorial regions that are determined according to the size of population regarding the economic, social, cultural, geographical and other factors. At the first level, NUTS2 regions are aggregated into 12 NUTS1 territorial regions, regarding the same criteria used for the second level [84].

In literature, the studies regarding agricultural productivity of Turkey, if we exempt the farm-level studies, were mostly conducted at country-level and there are a few studies at NUTS3 (provinces) [45, 81] and NUTS1 (regions) levels [46]. So far there is no study evaluating the agricultural performance of NUTS2 regions. This is one the motivations behind deciding NUTS2 regions as DMUs of the 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 NUTS1 provinces.

3.1.1 Variables used in the Analysis

The most common variables used for assessment of agricultural productivity were discussed in Chapter 2. These variables mostly determined by FAO. To draw an analogy with the other studies using DEA, similar input variables have been selected for the present analysis. Total production value was considered as the only output variable. And six input variables were selected: land, labor, machine, livestock, fertilizer and investment. Table 3.2 lists the variables, their units and the statistical values associated with them.

Output

Table 3.1: NUTS levels of Turkey

NUTS1-Regions	**Region Number**	**NUTS2 Codes**	**NUTS2-Subregions**	**NUTS3-Provinces**
Northeast Anatolia	1	TRA1	Erzurum Region	Erzurum, Erzincan, Bayburt
	2	TRA2	Ağrı Region	Ağrı, Kars, Iğdır, Ardahan
Middleeast 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	Ä°zmir Region	Ä°zmir
	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'uzce, 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

Table 3.2: 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 (Cattle-equivalents)	491031	55213	1119395
Investment	1000 TL	128106	483	1401118

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 data of production values of all regions for 10-year period was obtained from TUIK database, then the values were deflated on the basis of Producer Price Index of Agricultural Products [1] (Agriculture PPI) taking 2010=100 base [85].

Inputs

- *Land:* This variable represents the total arable land (hectare) and total land under permanent crops (hectare), since all types of crop production are covered in the present analysis. Total arable land includes the cultivated lands, fallow lands and land used for vegetable (The land for vegetable and fruit production under protective cover is also included). Land under permanent crops represents the areas of perennial crops that do not need to be replanted after each harvest. This category includes vineyard areas, area of olive trees and areas of fruits beverage and spices crops but excludes the area of forest grown for wood or timber. In this input variable, land under permanent meadows and pastures are not included. All the required data was obtained from the TUIK database, Regional Statistics [86].

- *Labor:* Labor represents the economically active population (male and female population older than 15) employed in agriculture. The data is obtained from the Ministry of Food, Agriculture and Livestock.

- *Machine:* Machine variable is the total number of agricultural equipment and machinery. In most study regarding agricultural efficiency, tractor is the only machinery that is considered. However, in this analysis, besides four-wheel tractors and two-wheel tractors we preferred also to include the combine harvesters, referring to the study [71]. The data was obtained from the TUIK database, Regional Statistics.

[1] Agricultural Producer Price Index (Agriculture PPI) has been constructed in accordance with the methodology for Agricultural Price Statistics of EU. Year 2010 was considered as the base year, and it was created according to the NACE Rev.2 classification. So, Agriculture PPI was calculated separately for the activities under agriculture, forestry, fishery and hunting sectors, which were in the scope of Producer Price Index previously, and they are not included in PPI anymore.

- *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. The necessary data of fertilizers and their proportion of ingredients were obtained from The Ministry of Food Agriculture and Livestock.

- *Livestock:* The livestock input variable is the total number of live animals of different categories which are used for breeding, milking, egg laying, wool production, and to provide animal traction. 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 3.3. This method enables to measure total livestock of regions homogeneously, where species are weighted by their respective size. The conversion factors for the mentioned animals were obtained from The Pasture Regulations that were promulgated in the Official Gazette number 23419 in 31.07.1998. Thereby, all livestock values were represented by a single unit.

Table 3.3: 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

- *Investment:* This variable is the value of annual fixed capital government investments outgoing for agricultural sector in each region, provided in terms of 1000 TL. The data was obtained from the database of Ministry of Development [87].The current prices of fixed capital government investments were converted to 2017 prices using 2017 deflators for fixed capital investments which were determined and published by Ministry of Development.

3.1.2 Data

Most of the data was obtained from the database of TUIK, Regional Statistics [86]. The database of Ministry of Development is another source of data. Though, there were some difficulties in obtaining and organizing the panel data of 26 regions for 10-year period. The fact that analysis was conducted on region basis has created a limitation in finding data.

The data of some variables used in the analysis was not available online. For example the amounts of fertilizers or labor data by sectors are not found in TUIK database at NUTS2 level. So these variables were specially requested from the Ministry of Food Agriculture and Livestock.

Another problem is about the scope of some variables. The data requested for labor variable represents the total economically active population in agriculture. A major problem for this variable was the impossibility of decomposing it by production types. For example, if we could obtain the number of people active in livestock production and crop production individually, we would be able to conduct a more delicate analysis in terms of different types of production.

In this analysis, precipitation ratios of the regions and irrigation water amounts were not considered as input variables, since the difference among the regions would lead an indiscriminative result. Since all types of crops are included in the analysis and different kinds of crops require different amount of rain fall and irrigation methods, using these variables would lead a false comparison between productivity of regions.

Agricultural pesticides and seed amounts are other variables that could be used in the analysis. The data for each region could be requested from The Ministry of Food, Agriculture and Livestock. However due to time limit and slow communication conditions with the Ministry, this data could not be obtained and so it is not included in the analysis. Additionally, considering the constraints that relates the number of variables and the DMU number, to include high number of variables would lead an unhealthy analysis.

3.2 Empirical Results

In this section, we present the empirical results of two main analysis which were conducted to evaluate the agricultural performance of Turkey regions between 2006 and 2015. For these analysis we used DEA and Malmquist TFP index methods which were discussed theoretically in the previous chapter. For both of the analysis, each of 26 NUTS2 regions was accepted as a DMU. And both analysis were conducted via the computer program DEAP2.1.

In the first part, Malmquist TFP index method was used to estimate the TFP change and its components for NUTS2 regions over the period 2006-2015. A brief review of the theoretical background of the method is presented. The empirical results of the analysis were interpreted regarding the annual and region mean values of TFPC indices, beside evaluating the changes in some significant regions individually.

In the second part, we applied two-stage DEA for each year between 2006-2010 to examine the technical efficiency of regions in a more detailed way. With this regard, we presented the DEA results for three years which have significant values among the 10-year period. Besides, we analyzed some of the regions in terms of their input usage and the possible ways to improve their efficiency through explaining the results displayed by the program DEAP2.1

3.2.1 Results of Malmquist Index TFP Analysis

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 that is used for the present analysis referring to the study [7]. However, it should be stressed that Malmquist indices are constructed using the distance functions which are calculated with respect to both CRS and VRS assumptions [28]. So, in this part of the analysis the scale assumption has no influence on the results.

The technical efficiency scores and Malmquist indices for each year-pair was estimated via DEAP2.1 program [28]. Beside the efficiency scores with respect to both CRS and VRS assumptions and with respect to each period, there are five indices calculated by the program:

- Technical efficiency change (TEC)
- Pure technical efficiency change (PEC)
- Scale efficiency change (SEC)
- Technological change[2] (TC)
- Total factor productivity change (TFPC)

TC and TEC are two components of TFP change. Also, it is possible to observe the change in pure technical efficiency (PEC) which is calculated using the VRS efficiencies (TE-VRS) with respect to each year. Additionally, the scale efficiency change (SEC) for each year pair is provided, since scale efficiency is already calculated as the ratio of TE-CRS and TE-VRS. In this regard, the program DEAP2.1 first calculates and displays TE-CRS and TE-VRS values of each region with respect to individual years one by one. Besides, it calculates the TE-CRS of each region with respect to the following year. Then it constructs the five Malmquist indices for a year-pair using the distance functions calculated with respect to CRS frontier.

Table 3.4 presents the agricultural efficiency values relative to CRS technology (TE-CRS) for NUTS2 regions with respect to each year between 2006-2015.

Efficiency scores lie between 0 and 1, where 1 represents a efficient region and values less than 1 means inefficiency. In this 10-year period, the fully efficient regions are Van Region (B2), İzmir Region (TR31), Kocaeli Region (TR42), Antalya Region (TR61) and Trabzon Region (TR90) since they have TE score of 1 for all years. When we look at the average TE-CRS of each region over the 10-year period, it is observed that Şanlıurfa Region (TRC2), Mardin Region (TRC3) and Adana Region (TR62) are ranked as the second efficient group which have mean TE-CRS values greater than 0.99. On the other

[2]The term 'Technical change' is used for 'Technological change' in some studies such as [3, 7, 66]

Table 3.4: TE-CRS Scores of NUTS2 Regions in Turkey for 2006-2015

	Years										
Regions	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Avg.**
TRA1	0.83	0.98	0.90	0.79	0.81	0.89	1.00	0.91	0.91	0.89	0.89
TRA2	0.86	1.00	0.80	0.87	1.00	1.00	1.00	0.89	1.00	1.00	0.94
TRB1	0.98	1.00	1.00	0.93	0.81	0.94	0.87	0.81	0.76	0.97	0.91
TRB2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TRC1	0.81	0.71	0.65	0.66	0.66	0.67	0.63	0.64	0.72	0.92	0.71
TRC2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.92	0.99
TRC3	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR10	1.00	1.00	1.00	1.00	1.00	0.84	0.71	0.75	1.00	0.83	0.91
TR21	0.72	0.49	0.76	0.65	0.78	0.85	0.86	0.81	0.97	0.88	0.78
TR22	0.73	0.72	0.88	0.80	0.93	1.00	0.86	0.96	1.00	1.00	0.89
TR31	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR32	1.00	0.73	0.79	0.76	0.74	0.75	0.85	1.00	0.84	0.83	0.83
TR33	0.92	0.73	0.89	0.77	0.72	0.63	0.58	0.66	0.72	0.73	0.73
TR41	0.92	0.78	0.88	0.93	0.93	0.88	0.87	0.93	1.00	1.00	0.91
TR42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR51	1.00	0.67	1.00	1.00	1.00	1.00	0.85	0.95	1.00	1.00	0.95
TR52	0.80	0.57	0.64	0.68	0.64	0.76	0.77	0.86	1.00	1.00	0.77
TR61	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR62	1.00	1.00	1.00	1.00	1.00	0.97	0.95	0.98	1.00	1.00	0.99
TR63	1.00	0.81	1.00	1.00	0.77	0.81	0.78	0.78	0.85	0.98	0.88
TR71	0.61	0.55	0.99	0.96	1.00	0.86	1.00	0.91	0.86	0.97	0.87
TR72	0.65	0.48	0.54	0.53	0.72	0.62	0.55	0.66	0.71	0.67	0.61
TR81	0.92	1.00	1.00	0.88	0.98	0.97	1.00	0.80	1.00	0.98	0.95
TR82	0.60	0.71	0.75	0.57	0.63	0.72	0.71	0.81	0.66	0.66	0.68
TR83	0.72	0.61	0.78	0.62	0.60	0.64	0.66	0.71	0.72	0.82	0.69
TR90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Avg.	0.89	0.83	0.89	0.86	0.87	0.88	0.86	0.88	0.91	0.92	0.88
Min.	0.60	0.48	0.54	0.53	0.60	0.62	0.55	0.64	0.66	0.66	0.61
Max.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

hand, the most inefficient region was found to be Kayseri Region (TR72) by a mean TE-CRS score of 0.61 over 10-year. It is followed by Kastamonu Region (TR82), Samsun Region (TR83) and Gaziantep Region (TRC1) by mean TE-CRS scores less or equal than 0.70. Besides, the mean agricultural TE-CRS of all NUTS2 regions over the period 2006-2015 is 0.88.

In Table 3.4, we can observe the fluctuations and the change of TE-CRS through the years. We can conclude that there is not a steady increase or decrease in TE-CRS for any of the regions. However, we can observe some extreme falls or rise between some year-pairs. For example, TE-CRS from 2006 to 2007 exhibits a significant fall for 11 regions, whereas there are 8 regions that experience a jump in TE-CRS scores from 2007 to 2008. The changes in TE-CRS with respect to each year-pair will be discussed in detail with Malmquist index results.

The program DEAP2.1 also estimates the pure technical efficiency (TE-VRS) of regions with respect to each year. TE-VRS scores of NUTS2 regions are presented in Table 3.5.

Table 3.5: TE-VRS Scores of NUTS2 Regions in Turkey for 2006-2015

	Years										
Regions	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Avg.**
TRA1	0.83	0.98	0.90	0.79	0.81	0.89	1.00	0.91	0.91	0.89	0.89
TRA2	0.86	1.00	0.80	0.87	1.00	1.00	1.00	0.89	1.00	1.00	0.94
TRB1	0.98	1.00	1.00	0.93	0.81	0.94	0.87	0.81	0.76	0.97	0.91
TRB2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TRC1	0.81	0.71	0.65	0.66	0.66	0.67	0.63	0.64	0.72	0.92	0.71
TRC2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.92	0.99
TRC3	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR10	1.00	1.00	1.00	1.00	1.00	0.84	0.71	0.75	1.00	0.83	0.91
TR21	0.72	0.49	0.76	0.65	0.78	0.85	0.86	0.81	0.97	0.88	0.78
TR22	0.73	0.72	0.88	0.80	0.93	1.00	0.86	0.96	1.00	1.00	0.89
TR31	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR32	1.00	0.73	0.79	0.76	0.74	0.75	0.85	1.00	0.84	0.83	0.83
TR33	0.92	0.73	0.89	0.77	0.72	0.63	0.58	0.66	0.72	0.73	0.73
TR41	0.92	0.78	0.88	0.93	0.93	0.88	0.87	0.93	1.00	1.00	0.91
TR42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR51	1.00	0.67	1.00	1.00	1.00	1.00	0.85	0.95	1.00	1.00	0.95
TR52	0.80	0.57	0.64	0.68	0.64	0.76	0.77	0.86	1.00	1.00	0.77
TR61	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TR62	1.00	1.00	1.00	1.00	1.00	0.97	0.95	0.98	1.00	1.00	0.99
TR63	1.00	0.81	1.00	1.00	0.77	0.81	0.78	0.78	0.85	0.98	0.88
TR71	0.61	0.55	0.99	0.96	1.00	0.86	1.00	0.91	0.86	0.97	0.87
TR72	0.65	0.48	0.54	0.53	0.72	0.62	0.55	0.66	0.71	0.67	0.61
TR81	0.92	1.00	1.00	0.88	0.98	0.97	1.00	0.80	1.00	0.98	0.95
TR82	0.60	0.71	0.75	0.57	0.63	0.72	0.71	0.81	0.66	0.66	0.68
TR83	0.72	0.61	0.78	0.62	0.60	0.64	0.66	0.71	0.72	0.82	0.69
TR90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Avg.	0.89	0.83	0.89	0.86	0.87	0.88	0.86	0.88	0.91	0.92	0.88
Min.	0.60	0.48	0.54	0.53	0.60	0.62	0.55	0.64	0.66	0.66	0.61
Max.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TE-VRS is also considered as the technical efficiency devoid of the scale efficiency (SE) effects. SE can be calculated by estimating both TE-CRS and TE-VRS and looking at the difference in scores. The VRS technology is less restrictive than the CRS. This yields usually to a more number of efficient units and also higher efficiency scores among all DMUs (See Figure 2.3 in Section 2.1.3). There are nine regions that have TE-VRS score of 1.00 in all years as seen in Table 3.5. These are Van (TRB2), Şanlıurfa (TRC2), Mardin (TRC3), İstanbul (TR10), İzmir (TR31), Kocaeli (TR42), Antalya (TR61), Zonguldak (TR81) and Trabzon (TR90) Regions. Among these TRC2, TRC3, TR10 and TR81 were found to be inefficient on average according to CRS technology. This means that these four regions have a scale inefficiency which is the cause of low TE-CRS scores. On the other hand, TRB2, TR31, TR42, TR61 and TR90 are scale efficient regions, since TE-CRS and TE-VRS scores both are equal to 1.00.

Kayseri Region (TR72) has the lowest average TE-VRS value among all regions like it had the lowest average TE-CRS. This inefficiency is followed by Samsun (TR83) and Gaziantep (TRC1) Regions which have TE-VRS values of 0.70 and 0.79 respectively. Tekirdağ (TR21), Aydın (TR32), Manisa (TR33), Konya (TR52) and Kastamonu (TR82) Regions have average TE-VRS scores changing between 0.82 and 0.86. Whereas, the remaining regions have relatively high efficiency above 0.90.

When we compare the values in Table 3.4 and the values in Table 3.5, it is obvious that all of the TE-VRS scores of a specific year are greater than or equal to the TE-CRS scores of the same year. This is due to the nature of VRS and CRS frontiers that are used as a reference for the distance function calculation.

To evaluate the scale efficiency of regions in a specific year we can compare TE-CRS and TE-VRS values that belong to the corresponding year, because the Malmquist TFP method used in the program DEAP2.1 does not present the calculated scale efficiency scores of regions. However, it uses them in estimating SEC index. When we run the program DEAP2.1, it provides Malmquist index summary for each year as shown in Table 3.6. Since Malmquist index method measures the change in various efficiency types and TFP between two consecutive periods, i.e. consecutive years such as 2006 and 2007, the first index summary is given for year 2. This means there is no change to calculate for year 1, since there is no information for the years prior to year 1. The present analysis was conducted for the years between 2006-2015. Thus, the first index summary is for 2006-2007 (year2 = 2007) which is shown by Table 3.6.

The abbreviations used within the program DEAP2.1 are slightly different from the ones used in the literature. As seen in Table 3.6, 'effch' refers to technical efficiency change (relative to CRS technology), which is denoted by TEC in this analysis. 'Techch', 'pech', 'sech' and 'tfpch' refers to technological change, pure technical efficiency change (relative to a VRS technology), scale efficiency change and total factor productivity change respectively and denoted by TC, PEC, SEC, TFPC in this analysis as mentioned at the beginning of this section. In Table 3.6, the column under 'firm' heading, represents

Table 3.6: Malmquist Index Summary for 2006-2007

Malmquist Index Summary for Year=2					
firm	**effch**	**techch**	**pech**	**sech**	**tfpch**
1	1.19	0.97	1.13	1.05	1.14
2	1.16	0.97	1.10	1.05	1.13
3	1.02	1.05	1.00	1.02	1.06
4	1.00	0.88	1.00	1.00	0.88
5	0.87	1.08	0.82	1.07	0.94
6	1.00	0.99	1.00	1.00	0.99
7	0.99	0.84	1.00	0.99	0.83
8	1.00	1.69	1.00	1.00	1.69
9	0.68	1.47	0.98	0.69	1.00
10	0.99	1.13	1.05	0.95	1.13
11	1.00	1.12	1.00	1.00	1.12
12	0.73	1.10	0.73	0.99	0.80
13	0.79	1.34	1.00	0.79	1.06
14	0.85	1.20	0.92	0.92	1.01
15	1.00	1.07	1.00	1.00	1.07
16	0.67	1.63	1.00	0.67	1.09
17	0.72	1.36	0.90	0.79	0.97
18	1.00	1.06	1.00	1.00	1.06
19	1.00	1.06	1.00	1.00	1.06
20	0.81	1.20	0.99	0.81	0.96
21	0.90	1.29	1.25	0.72	1.17
22	0.74	1.29	0.78	0.95	0.96
23	1.09	1.15	1.00	1.09	1.25
24	1.19	1.04	1.06	1.12	1.23
25	0.85	1.16	0.92	0.92	0.99
26	1.00	0.98	1.00	1.00	0.98
Mean	0.92	1.14	0.98	0.94	1.05

the DMUs, which in our case are the 26 NUTS2 regions as given with the corresponding numbers in Table 3.1.

An index value represents the change between two periods meaning it can represent an increase or decrease in efficiency, technology or TFP. An index value can be greater than one contrary to an efficiency score, meaning a positive change. Likewise, an index value less than one means a negative change and index value of one stands for no change between the two periods. If we consider TC index of 9th region in Table 3.6, we can say an increase in technology has occurred from 2006 to 2007 by 47%. The percentage of the increase in a specific efficiency type or TFP is calculated by subtracting 1 from the corresponding index value and multiplying the result with 100. Likewise, the percentage of a decrease can be calculated by subtracting the corresponding index from 1 and multiplying the result with 100. For example, TFP of 4th region has been regressed by 12% from 2006 to 2007.

Including the index summary shown in Table 3.6, there exist nine Malmquist index summaries for 9 year-pairs in total, which are all presented in the Appendix A. Since there are many fluctuations through the years for each region, it is reasonable to begin with interpreting the 10-year mean values of Malmquist indices for all regions. Table 3.7 presents the annual average indices of five categories for each region.

Table 3.7: Malmquist Index Summary of Region Means

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

[a]Note that all Malmquist index averages are geometric means [28]

The annual average TEC of all regions are given in Table 3.7. 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 [31]. According to Table 3.7, 12 regions have a slight increase in their TE-CRS 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, although its average TE-CRS is less than 1 over the 10-year period. It is followed by Balıkesir Region (TR22), Konya Region (TR52) and Tekirdağ Region (TR21) with an increase in TE-CRS by 4%, 3% and 2% respectively. Over the 10-year period, TE-CRS of four regions have been regressed on the average: Şanlıurfa 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-CRS on the average.

The annual averages of TC index for all regions is also given in Table 3.7. TC refers to an innovation or a shift in the production frontier, i.e. an upward shift means production level is increased [31]. 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 3.7, the annual mean TFP change in agricultural production of the regions studied is found to be negative. On average, agricultural TFP of Turkey 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 averge, all the other regions have a negative average TFPC index. However, Tekirdağ (TR21), Trabzon (TR90), İzmir (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.

Pure efficiency change (PEC) and scale efficiency change (SEC) are the other two indices calculated and presented in Table 3.7. As discussed in Chapter 2, technical efficiency (TE-CRS) can be decomposed into 'pure' technical efficiency (TE-VRS) and scale efficiency (SE). In other terms, SE is expressed as the ratio of TE-CRS to TE-VRS. The calculation of TE-VRS enables to estimate the SE effects on technical efficiency. In this regard, the Malmquist indices for PEC and SEC are also considered as two components of TEC and these indices are useful to understand how TE-CRS has been changed, is it caused by a change in SE or TE-VRS.

Additionally, to compare and interpret the changes among NUTS2 regions, one can refer to Figure 3.1 which displays the mean index values of five categories (TEC, TC, PEC, SEC and TFPC) for all regions.

As seen in Figure 3.1, almost all regions (except TR32 and TR33) have mean PEC indices greater than or equal to 1, meaning that they have experienced a non-negative annual change in TE-VRS on the average. Whereas, the mean SEC indices of NUTS2 regions change between 0.98 and 1.01 indicating an average decrease of 2% and an average increase of 1% in scale efficiency of corresponding regions which are İstanbul Region (TR10) and Konya Region (TR52) respectively.

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 are displayed in Figure 3.2, 3.3, 3.4 and 3.5.

Ağrı Region (TRA2) has the greatest average TFP growth through 2006-2015. If we examine Figure 3.2, 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 is highly related with the change in technology as seen in 3.2. This could be a result of a higher production with a better use of machine and investment.

On the other hand, SEC indices are around 1 for almost every period which means there is not much change in scale efficiency of TRA2 during 10-year period. This also means TE-CRS and TE-VRS values are close to each other. It is also possible to observe the

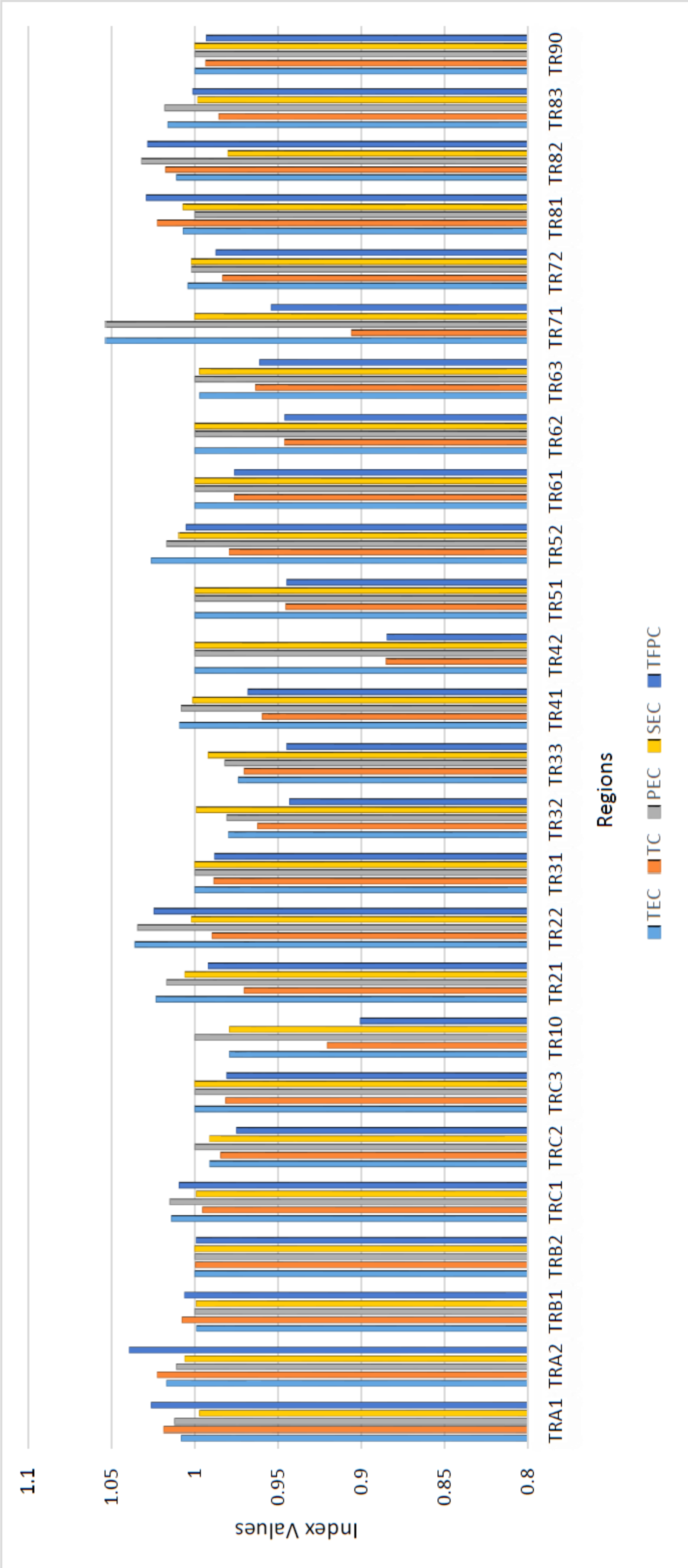

Figure 3.1: Malmquist Index Summary of Region Means

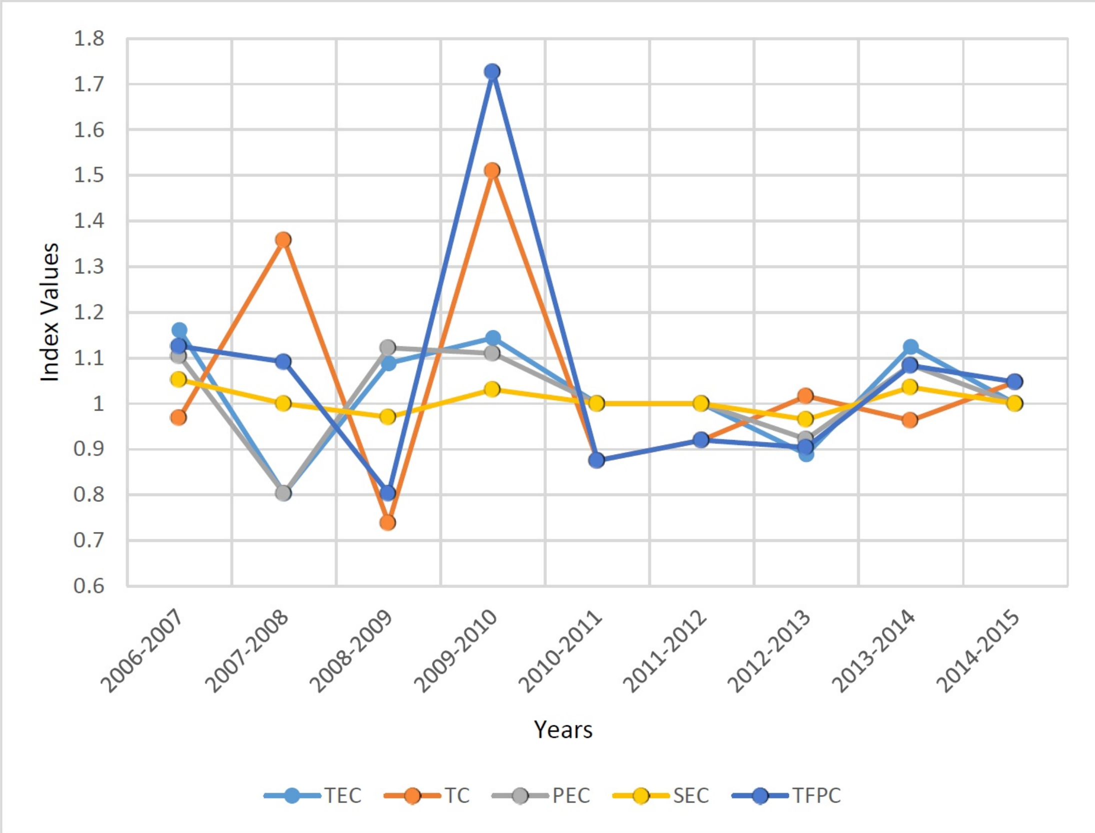

Figure 3.2: Malmquist Index Summary of Ağrı Region (TRA2)

proximity between TEC and PEC indices through the years in Figure 3.2. Besides, the maximum fall in TE-CRS of TRA2 (by a 20%) has occurred between 2007 and 2008.

Figure 3.3 displays the index changes through 10-year period for Kocaeli Region (TR42) which has the greatest average TFP regression among NUTS2 regions. Although TR42 is fully efficient in all years (See Table 3.4), its agricultural TFP has been changed. Figure 3.3, TC and accordingly TFPC indices are identical, since all TEC indices are equal to 1 which indicates no change occurred in TE-CRS through the 10-year period. We can conclude that TFP change is caused by the change in technology. PEC and SEC indices are also equal to 1, meaning TE-VRS and SE values are same for all years. Besides, the major falls in TFP of TR42 take place between 2010-2011 and 2012-2013 by approximate 40% and 50% decreases respectively.

İstanbul 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 in Appendix A). 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 3.4 which presents

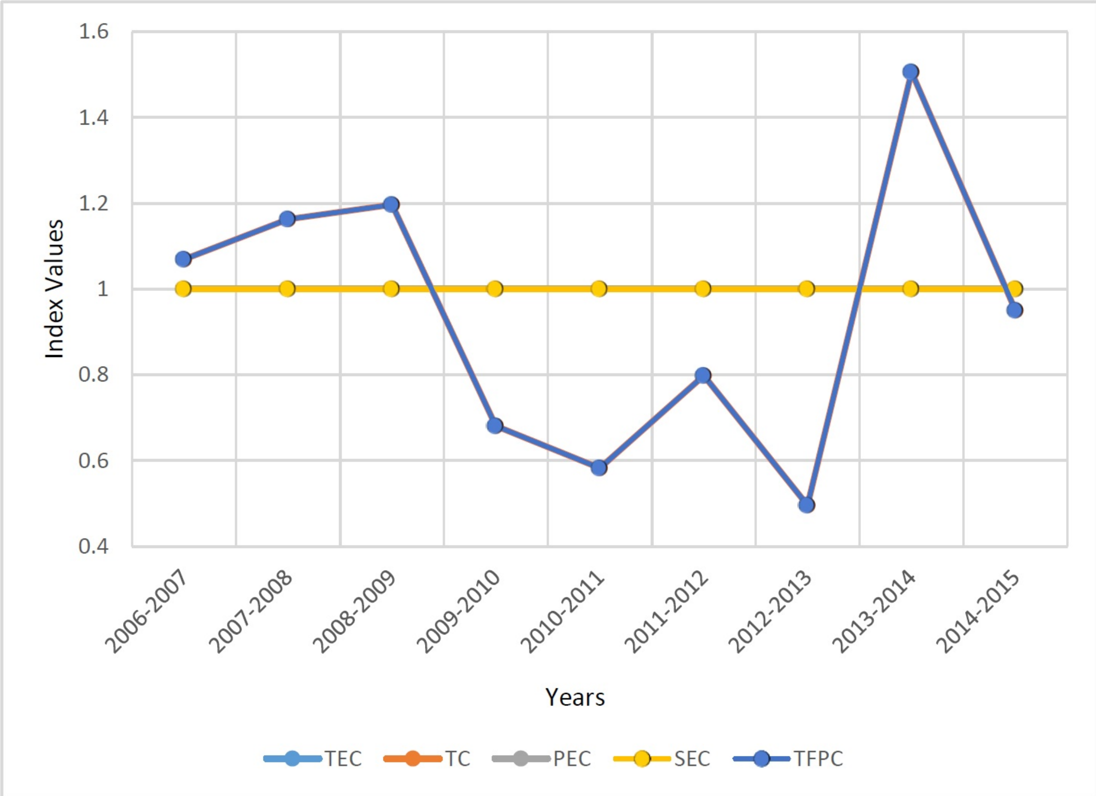

Figure 3.3: Malmquist Index Summary of Kocaeli Region (TR42)

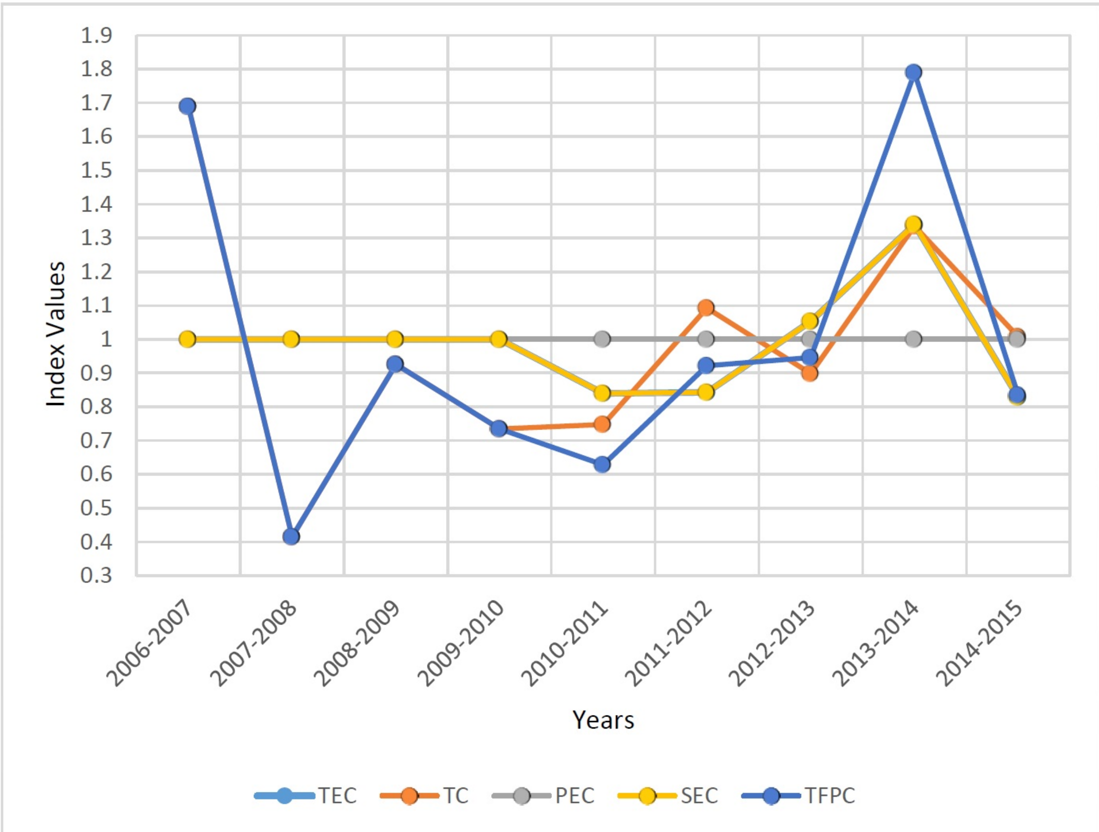

Figure 3.4: Malmquist Index Summary of İstanbul Region (TR10)

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-CRS is above 30%, same as the change in SE, while there is no change in TE-VRS in this period.

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 (See Table A.1 in Appendix). 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 3.7).

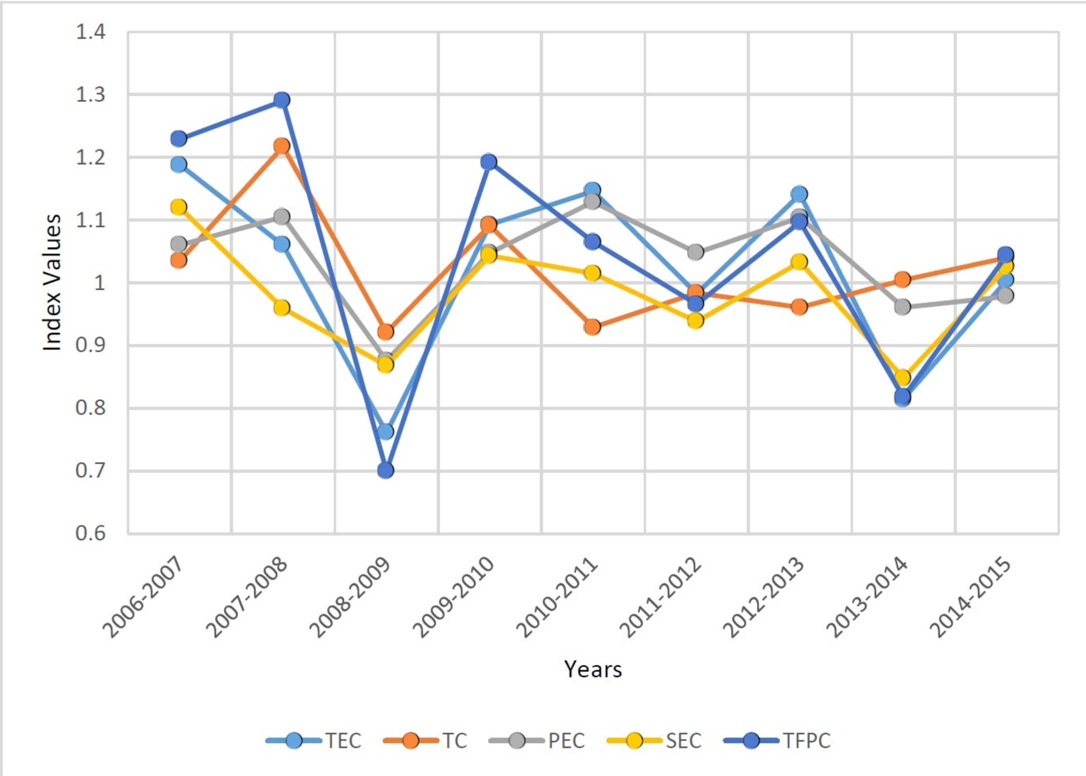

Figure 3.5: Malmquist Index Summary of Kastamonu Region (TR82)

Contrary to TR10, Kastamonu Region (TR82) has an average TFP growth of 2.9%, one of the regions that have a positive mean TFPC index. As seen in Figure 3.5, there are two extreme falls of TFPC indices in 2008-2009 and 2013-2014. However, during the other years agricultural TFP has increased accompanied with changes in TE more than in technology, since TEC indices follow a similar path with TFPC indices. Additionally, fluctuations of SEC and PEC indices throughout the years points out the existence of scale effects on the technical efficiency of TR82.

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 3.8 and graphed in Figure 3.6.

Table 3.8: Malmquist Index Summary of Annual Means

Years	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**
2006-2007	0.92	1.141	0.981	0.938	1.049
2007-2008	1.097	1.017	1.027	1.068	1.116
2008-2009	0.958	0.933	0.981	0.976	0.894
2009-2010	1.017	1.003	1.008	1.009	1.02
2010-2011	1.006	0.863	1.001	1.005	0.868
2011-2012	0.983	0.929	0.998	0.985	0.912
2012-2013	1.02	0.881	1.023	0.997	0.899
2013-2014	1.04	1.016	1.023	1.017	1.057
2014-2015	1.017	1.023	1.02	0.997	1.04
Mean	1.005	0.975	1.007	0.999	0.98

The results shown in Table 3.8, provide a brief opinion about how the total agricultural production performance has changed from year to year averagely. Accordingly, the greatest TFP growth occured 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 3.6, TC and TFPC lines are almost parallel to each other (except 2 year-pairs), which indicates that the main contribution to TFPC comes from 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 3.6, where TEC indices are apart from TC and TFPC indices.

Another extreme finding in Figure 3.6 is about the fluctuations in TEC, SEC and PEC indices during the first 3 years. Although overall TFP has been increased from 2006 to 2007, there is an average decrease in all efficiency types within this period. In the following period, 2007-2008, TEC, SEC and PEC indices are greater than 1 meaning a positive change. For the following years, these indices are slightly changing around 1, indicating a relatively stable efficiency on average.

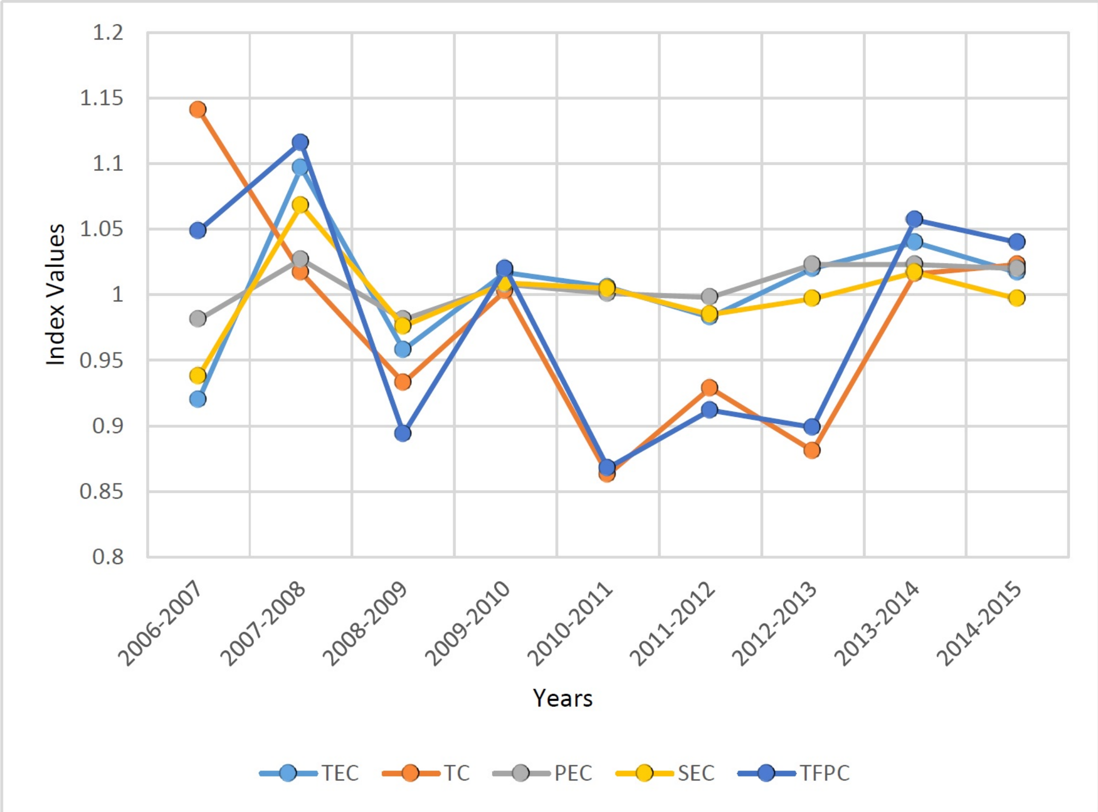

Figure 3.6: Malmquist Index Summary of Annual Means

3.2.2 DEA Results

Malmquist indices are helpful to observe the TFP changes or efficiency changes throughout a specific period. However, they do not give a detailed information about the cause of inefficiencies. For example, the mean TFP of all regions has increased between 2006 and 2007 by 5% as seen in Table 3.8. Since TEC and TC are two components of TFPC, we may only comment on the contribution of each of these indices. For 2006-2007, the technological improvement, by an index of 1.14, seems to be the cause of TFP growth, since TEC index for this year-pair is 0.92. Furthermore, this is the lowest mean TEC index among 10-year period, which indicates 8% decrease in TE-CRS of all regions on average. Additionally, when the TE-CRS values of all regions in each year from 2006 to 2015 are scanned, year 2007 seems to have the lowest average TE-CRS score (See Table 3.4). To investigate the reasons behind the inefficiencies of regions in year 2007 and ways to supress them, an individual DEA analysis can be conducted for the data of 2007.

The basic (one-stage) DEA model may be used to calculate the technical efficiency of each region for a specific year, but TE-CRS values were already obtained by Malmquist index method. Regarding this part of the study, it is more reasonable to use two-stage DEA method which additionally estimates the necessary radial input-output reductions to overcome inefficiency, the input-output slacks and the projected input and output values for each region.

Considering the properties mentioned above, we conducted DEA analysis for each year between 2006-2015 to evaluate the input usage and inefficiencies in agricultural production of NUTS2 regions. We used an input-oriented DEA model under CRS assumption. The variables used in the analysis are same with the ones used in Malmquist TFP analysis. With this regard, input slacks are calculated using two-stage DEA technique that is integrated within the computer program we used, DEAP2.1. Due the broad scope of the analysis, in this part, we will only present the summary of the DEA analysis for three years which exhibit significant changes or extreme TE values. Then we will explain how to interpret the result screens displayed by the program DEAP2.1.

One thing to be mention is that, in the following pages of this section, we will use the abbreviation, 'TE', for technical efficiency relative to CRS (TE-CRS), since all efficiency calculations are conducted under CRS assumption.

A summary of the DEA analysis conducted for 2007 is presented in Table 3.9 and it includes TE scores of all regions and all the slacks associated with each input. Output slacks are not included here, because they were found to be zero for all regions. Efficiency scores lie between 0 and 1. If TE is equal to 1 it means that region is technically efficient, whereas a value less than 1 indicates an inefficient region. As seen in Table 3.9, 15 regions are technically inefficient, while the the other 11 regions are technically efficient.

To provide a deeper evaluation, the program also displays projection summaries for each region such as shown in Table 3.10. This summary belongs to Kayseri Region (TR72) which seems to have the lowest TE with a score of 0.48 among all regions (See Table 3.9). In Table 3.10, 'radial movement' represents the required radial input reduction amounts which are the main cause of inefficiencies and can also be calculated manually by multiplying the corresponding original input value with the inefficiency of that region. Inefficiency of TR72 is 0.52 meaning that reducing all original input values by 52% would lead to an efficient production. In other words, the amounts specified for each input by radial movement is 52% of the original value of that input.

Table 3.9: DEA Result Summary for 2007

	Regions	TE-CRS	Input Slacks					
			Land (Hectare)	Labor (Thousand person)	Machine (Number)	Fertilizer (Metric tons)	Livestock (Number)	Investment (1000TL)
1	TRA1	0.98	60174	3	0	0	0	0
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	1.00	0	0	0	0	0	0
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.71	315355	34	0	0	0	26517
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	0.99	523215	0	0	29378	138206	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.49	167159	0	5471	15865	0	24273
10	TR22	0.72	0	19	707	0	0	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.73	216990	0	9816	0	0	19295
13	TR33	0.73	556534	92	29798	0	0	0
14	TR41	0.78	328741	0	17248	0	0	11176
15	TR42	1.00	0	0	0	0	0	0
16	TR51	0.67	640229	0	4094	9164	22536	16468
17	TR52	0.57	977014	7	0	0	0	110134
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	0.81	165906	42	0	5358	0	0
21	TR71	0.55	654711	21	11034	0	0	0
22	TR72	0.48	718520	0	3868	0	14223	9673
23	TR81	1.00	0	0	0	0	0	0
24	TR82	0.71	34688	0	7515	0	0	0
25	TR83	0.61	394386	114	17379	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.83						

Table 3.10: 2007 DEA Projection Summary of TR72

Results for region : 22 (TR72)
Technical efficiency = 0.48

Variables	Orijinal Value	Radial Movement	Slack Movement	Projected Value
production	5090891	0	0	5090891
land	2027734	-1053965	-718520	255249
labor	150	-78	0	72
machine	57870	-30079	-3868	23923
fertilizer	81183	-42197	0	38986
livestock	598403	-311035	-14223	273145
investment	105285	-54724	-9673	40887

LISTING OF PEERS:

peer	lambda weight
8	0.86
11	0.56

This model also determines the necessary slack movements for inputs as well as the input targets for each inefficient region to achieve a more efficient production. The radial movement for inputs indicates the reduction in inputs towards the efficient production frontier, whereas the slack movement represents a further step along the production frontier towards a virtual efficient point which use less inputs. Considering these indicators, the possible ways to enhance technical efficiency is to proceed these reductions in the specified inputs. Since the model we used is input-oriented, i.e. the aim is to reduce the inputs while attaining the output level, the radial reduction is only for inputs.

One point should be stressed that, different definitions of technical efficiency may lead to a confusion. The result of radial movements provides a TE score of 1 and it means technical efficiency is satisfied according to Farrel's [8] definition for radial efficiency measurement. However, it is not considered as CCR-efficient (according to Koopman's [13] definition) unless all slacks are equal to zero[3].

Considering these, if we evaluate TR72, it has input slacks for land, machine, livestock and investment. TR72 should further reduce these four inputs by the specified amounts, presented by the slack movement, to achieve CCR-efficiency. Thereby, we can say that the 'projected values' mentioned in the results are the input targets for CCR-efficiency. In this regard, for Kayseri Region, the main cause of inefficiency seems to be the inappropriate use of land beside the excess use of other inputs. To be clear, Kayseri region should reduce its land use approximately by 87% , investment by 61% and other inputs by almost 50% to achieve CCR-efficiency. It means that the same output can be obtained by using %87 less land , %61 less investment. In other words, Kayseri Region should use its land in a better way. The findings of the present analysis is consistent with the another report [88]. In this report it is also reported that Kayseri Region is not using its land in a efficient way due to the small sized land parcels. One suggestion to improve the efficiency could be selecting the right product for the region and consolidate the land.

The projection summaries also provide the peer groups for each region and lambda (λ) weights associated with them as shown in Table 3.10. Peer groups are helpful to determine a path towards an efficient production. For example, peer group of TR72 is composed of İstanbul Region (TR10) and İzmir region (TR31). The lambda weights are estimated as 0.86 and 0.56 respectively. The multiplication of lambda weights with the

[3] Further discussions on slacks included in efficiency measurements can be found in [1, 2, 9].

input values of the corresponding regions in the peer group gives the projected input values for the inefficient region that is examined. If we subtract the radial reduction amount from the total reduction required to achieve the projected value, we obtain the input slacks. This is how target (or projected) input values and accordingly slacks are calculated.

If we evaluate Table 3.9 again, the efficient regions seems to be also CCR-efficient, since they all have zero input slacks. The projection summary for Şanlıurfa Region (TRC2),as being one of the 11 efficient regions, is presented in Table 3.11. There is neither radial nor slack movement required, since TRC2 is already CCR-efficient. Also there is no peer determined except the region itself. The other CRR- efficient regions are Ağrı (TRA2), Malayta (TRB1), Van (TRB2), İstanbul (TR10), İzmir (TR31), Kocaeli (TR42), Antalya (TR61), Adana (TR62), Zonguldak (TR81) and Trabzon (TR90) regions.

Table 3.11: 2007 DEA Projection Summary of TRC2

Results for region: 6 (TRC2)				
Technical efficiency = 1.00				
Variable	Original value	Radial movement	Slack Movement	Projected value
production	6676464	0	0	6676464
land	1821987	0	0	1821987
labor	111	0	0	111
machine	22310	0	0	22310
fertilizer	184968	0	0	184968
livestock	421397	0	0	421397
investment	107748	0	0	107748
LISTING OF PEERS:				
peer	lambda weight			
6	1.00			

On the other hand, it seems that Tekirdağ (TR21), Kırıkkale (TR71), Konya (TR52), Samsun (TR83) and Ankara (TR51) regions have relatively low TE in 2007, below 0.70 (See Table 3.9). For a more efficient production, radial input reductions by 51%, 45%, 43%, 39% and 33% are needed for these regions respectively. The slacks associated with each input differ from region to region. TR71 and TR83 have slacks for land, labor and machine, whereas TR21 has slacks for land, machine, fertilizer and investment. TR51 has also livestock slack.

TE values of Gaziantep (TRC1), Balıkesir (TR22), Aydın (TR32), Manisa (TR33), Bursa (TR41) and Kastamonu (TR82) regions lie between 0.70 and 0.80. And for a better agricultural performance they require 29%, 28%, 27%, 27%, 22% and 29% reductions in all their inputs respectively.

As seen from Table 3.9, land variable is the most frequent input slack among the regions which indicates the problem of inappropriate use of agricultural land. It is followed by machine, labor and investment variables. At this point, one possible question is how reduction in land or labor can lead to an efficient agricultural production. The answer can be explained by the initial assumptions of the analysis. Since this is an input-oriented analysis, we are investigating the excess usage of inputs for the given amounts of outputs which are the cause of inefficiency.

To observe the inputs slacks in other years, DEA analysis for agricultural production is conducted for each year which can be found in the Appendix B. In addition to analysis for 2007, only DEA analysis for 2008 and 2015 are presented in this part due to significant TE values and changes in these years. 2007-2008 was found to have the highest average TEC index among all year-pairs (see Figure 3.6). This means the maximum change in TE has occurred from 2007 to 2008. Table 3.12 presents a summary of DEA analysis for 2008.

The average TE of NUTS2 regions has been increased from 0.83 to 0.89 between 2007-2008. The number of efficient regions were increased to 13 in 2008 and only three regions have TE below 0.70. Kayseri region (TR72) has the lowest TE (0.54) among the regions in 2008, like in 2007. However, there is an obvious improvement for TR72 from 2007 to 2008. TE has increased by 12% and the number of inputs that have slack were reduced to three; land, labor and machine.

Table 3.10 and Table 3.13 enable to compare the input usage in two consecutive years, 2007 and 2008, for TR72. It is seen that land, fertilizer and investment usage have been decreased approximately by 8%, 30% and 17% respectively, from 2007 to 2008. The only increased input is labor, by almost 6%. The other inputs have been used almost at the same level. Whereas, the production has increased almost by 10%. The obvious decrease in input usage accompanied with an increase in output seems to be one of the factors that may lead to an improvement in the efficiency score. However, it is important not

Table 3.12: DEA Result Summary for 2008

	Regions	TE-CRS	Input Slacks					
			Land (Hectare)	Labor (Thousand person)	Machine (Number)	Fertilizer (Metric tons)	Livestock (Number)	Investment (1000TL)
1	TRA1	0.90	139551	41	653	0	0	0
2	TRA2	0.80	1504	31	0	0	0	3352
3	TRB1	1.00	0	0	0	0	0	0
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.65	223549	10	0	0	0	8679
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.76	0	0	13718	39493	0	0
10	TR22	0.88	33640	0	6494	0	0	11325
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.79	245865	18	12033	0	0	13541
13	TR33	0.89	633596	37	46253	0	0	0
14	TR41	0.88	422442	0	27905	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	0.64	923160	0	5137	0	0	41142
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	1.00	0	0	0	0	0	0
21	TR71	0.99	1300053	19	30178	16307	0	0
22	TR72	0.54	737116	7	4858	0	0	0
23	TR81	1.00	0	0	0	0	0	0
24	TR82	0.75	129879	0	7555	0	0	2284
25	TR83	0.78	498025	146	26637	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.89						

to forget that the other regions' performance, that constitute the production frontier in this year, is the other main determinant in estimating the relative efficiency of TR72.

During 2007-2008 Kırıkkale Region (TR71) has experienced the highest increase in its TE by 81% (See Table A.1). In 2008, TR71 is too close to be technically efficient with a TE value of 0.99. However, it has slacks for land, labor, machine and fertilizer. The amounts for input slacks presented in Table 3.12 are greater than the amounts calculated for 2007 input slacks. This indicates that higher TE scores do not always mean slack amounts will be reduced. Since DEA calculates relative TE values of regions for each year individually, the amounts of input slacks for a specific year depend on the original input and output values of each region in the corresponding year that is under evaluation, as well as the corresponding TE scores. For example, TR71 has decreased all inputs except

Table 3.13: 2008 DEA Projection Summary of TR72

2008 Results for region: 22 (TR72)
Technical efficiency = 0.54

Variable	original value	radial movement	slack movement	projected value
production	5628993	0	0	5628993
land	1889592	-861142	-737116	291334
labor	163	-74	-7	82
machine	58151	-26501	-4858	26791
fertilizer	56447	-25725	0	30722
livestock	603290	-274937	0	328353
investment	87346	-39806	0	47540

LISTING OF PEERS:

peer	lambda weight
15	0.05
23	0.04
11	0.74

machine from 2007 to 2008, while there is a slight reduction in output by 0.8%. This change shows parallelism with the enhancement in TE. However, TR71 still requires radial and slack movement to catch-up the CCR-efficiency, which totally depend on the values of efficient regions which construct the production frontier for 2008.

Tekirdağ Region (TR21), by 57%, has the second greatest TE increase among all regions in 2007-2008 period in which TE was increased from 0.49 to 0.76. In 2008, it has still machine and fertilizer slacks. This change is followed by Ankara Region (TR51) by 50% increase in TE. Furthermore, TR51 achieved CCR- efficiency in 2008 by having no input slacks. It is possible to compare 2007 and 2008 input amounts used by TR51 by the projection summaries showed in Table 3.14 and 3.15.

Table 3.14: 2007 DEA Projection Summary of TR51

2007 Results for region: 16 (TR51)
Technical efficiency = 0.67

Variable	original value	radial movement	slack movement	projected value
production	3434696	0	0	3434696
land	1205337	-399120	-640229	165987
labor	40	-13	0	27
machine	30054	-9952	-4094	16008
fertilizer	64824	-21465	-9164	34195
livestock	225943	-74816	-22536	128591
investment	26230	-8685	-16468	1077

LISTING OF PEERS:

peer	lambda weight
8	2.23

Table 3.15: 2008 DEA Projection Summary of TR51

2008 Results for region: 16 (TR51)
Technical efficiency = 1.00

Variable	original value	radial movement	slack movement	projected value
production	3759256	0	0	3759256
land	1196497	0	0	1196497
labor	27	0	0	27
machine	30094	0	0	30094
fertilizer	49378	0	0	49378
livestock	223939	0	0	223939
investment	23663	0	0	23663

LISTING OF PEERS:

peer	lambda weight
16	1

When the original output and input values of TR51 for 2007 and 2008 are compared, all inputs -except machine- has been decreased (land by 0.7%, labor by 32.5%, fertilizer by 23.8%, livestock by 0.8% and investment by 0.7%), while the production value increased by 9.4%. It is obvious that using less input while producing a higher amount of output would result in higher TE. However, it should be stressed that the conditions of other regions directly affect the estimated TE scores for that year. In other words, if other regions had a better agricultural performance than they did in 2008, then with the same input usage and production, TR51 might have been scored as inefficient in 2008.

The other inefficient regions in 2008 are Erzurum (TRA1), Ağrı (TRA2), Balıkesir (TR22), Aydın (TR32), Manisa (TR33), Bursa (TR41), Kastamonu (TR82) and Samsun (TR83) regions having TE scores changing between 0.70 and 0.90, as seen in Table 3.12.

The next analysis we present is for 2015, in which the average TE of all regions takes the maximum value throughout 2006-2015 (See Table 3.4). Also, 2015 as being the most recent year, provide more information about the recent status of agricultural production performance of each region. The summary of DEA analysis for 2015 is presented in Table 3.16.

The mean TE score in 2015 is 0.92 which is the highest average TE score throughout 2006-2015. As seen in Table 3.16, there are 12 technically efficient regions which are Ağrı (TRA2), Van (TRB2), Mardin (TRC3), Balıkesir (TR22), İzmir (TR31), Bursa (TR41), Kocaeli (TR42), Ankara (TR51), Konya (TR52), Antalya (TR61), Adana (TR62) and

Table 3.16: DEA Result Summary for 2015

			Input Slacks					
Regions		**TE-CRS**	Land (Hectare)	Labor (Thousand person)	Machine (Number)	Fertilizer (Metric tons)	Livestock (Number)	Investment (1000TL)
1	TRA1	0.89	76830	0	0	0	0	2304
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	0.97	149224	0	0	0	0	40018
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.92	265925	0	0	9476	0	4598
6	TRC2	0.92	711141	0	0	84665	0	791661
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	0.83	0	0	0	13225	12613	0
9	TR21	0.88	0	0	21168	64200	0	28925
10	TR22	1.00	0	0	0	0	0	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.83	127563	0	5025	0	0	0
13	TR33	0.73	296888	0	21937	0	0	0
14	TR41	1.00	355950	0	43721	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	1.00	0	0	0	0	0	0
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	0.98	55562	0	0	94058	0	3299
21	TR71	0.97	638040	0	24969	4246	0	0
22	TR72	0.67	486040	0	0	0	0	6150
23	TR81	0.98	23792	93	15014	0	0	15689
24	TR82	0.66	68315	5	7854	0	0	4955
25	TR83	0.82	468209	0	42532	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.		0.92					

Trabzon (TR90) regions. Having no input slacks, they are also CCR-efficient. On the other hand, Kastamonu Region (TR82) has the lowest TE score (0.66), followed by Kayseri (TR72) and Manisa (TR33) regions.

Malatya (TRB1), Gaziantep (TRC1), Şanlıurfa (TRC2), Hatay (TR63), Kırıkkale (TR71) and Zonguldak (TR81) regions has relatively high TE values changing between 0.92 and 0.98. Whereas, the other five regions have TE values between 0.80 and 0.90. These are Erzurum (TRA1), İstanbul (TR10), Tekirdağ (TR21), Aydın (TR32) and Samsun (TR83) regions.

As seen in Table 3.16, there are very few slacks for labor and livestock, which indicates a radial reduction would be enough to achieve CCR-efficiency. On the other hand, land is the most frequent slack variable among all the regions in 2015. It is possible to examine each region in terms of the radial and slack movements they require to reach to the efficient production frontier. Also, it is possible to learn the peer groups for each region that act as a guide towards efficiency. For illustration, we will only examine the least efficient region in 2015, Kastamonu Region (TR82). Table 3.17 presents the projection summary of TR82.

Table 3.17: 2015 DEA Projection Summary of TR82

2015 Results for region: 24 (TR82)
Technical efficiency = 0.66

Variable	original value	radial movement	slack movement	projected value
production	2813949	0	0	2813949
land	451732	-154246	-68315	229171
labor	135	-46	-5	84
machine	36105	-12328	-7854	15922
fertilizer	22069	-7536	0	14533
livestock	367215	-125388	0	241827
investment	99378	-33933	-4955	60490

LISTING OF PEERS:

peer	lambda weight
2	0.12
18	0.20

Radial movement is the amount of inputs that should be reduced to reach the production frontier. In other words, the reduction ratio in all inputs is the inefficiency ratio of the region under evaluation. Considering these, TR82 should reduce all inputs by 34% which are the amounts presented for radial movement. However, the main cause of inefficiency seems to be the land and machine, since these have the highest amounts among the input slacks. Thus, TR82 requires further reduction in land and machine by 15% and 22% respectively to become CCR-efficient. Slacks for labor and investment are relatively low, 4% and 5% of the original values. Ağrı region (TRA2) and Antalya Region (TR61), which are among the efficient regions, are determined as peers for TR82. This indicates the combination of input usage of these two regions constitute a target for TR82.

To clarify how peer groups constitute a reference set, we present the basic calculations for the projected input values of TR82 as an example in Table 3.18.

Regions numbered 2 and 18 are estimated as peers for TR82 (Region 24) with weights, $\lambda_2 = 0.12$ and $\lambda_{18} = 0.20$ respectively. As seen in Table 3.18, lambda weights are

Table 3.18: Calculation of Projected Values for TR82

	Original Values		Projected Values of Region 24
Inputs	Region 2	Region 18	$\lambda_2 \mathbf{X}_2 + \lambda_{18} \mathbf{X}_{18}$
land	682667	732213	229171
labor	233	278	84
machine	22624	66526	15922
fertilizer	15842	63757	14533
livestock	1045718	567349	241827
investment	109704	237746	60490

multiplied with the inputs of corresponding regions, i.e. λ_2 with the inputs of Region 2, X_2 and λ_{18} with the inputs of Region 18, X_{18}. The sum of the weighted inputs of Region 2 and Region 18 gives the projected input values for Region 24.

When we examine all the years through 2006-2015, we see that the most frequent slacks are land and machine followed by investment and labor in descending order (see Appendix B). There are very few slacks for livestock and fertilizer. This indicates that excess use of land and machine, as having the highest input slacks, can be considered as one of the major factors behind the technical inefficiency in agricultural production for the regions under evaluation. Also it is important to take in consideration other input slacks such as investment and labor for an improvement in efficiency by constituting a more efficient way of using them, avoiding unnecessary usage.

Chapter 4

Conclusion and Future Work

Agriculture is one of the main economic sectors in Turkey. Although Turkey has a long and heavy industrialization history, agriculture still maintains its importance. However, recent statistics depict that despite the continuous increase in GDP of agriculture there are inconsistent decreases in the growth rate. In order to have a sufficient growth rate, agricultural sector must be strong structurally, and have to develop and improve its performance. This situation necessitates the investigation of the agricultural performance of Turkey. This thesis started from this necessity and aimed to investigate the agricultural performance of Turkey within a recent time interval and with using DEA and DEA-based Malmquist TFP methods.

In this study, an application of DEA and DEA-based Malmquist TFP Index methods is presented to evaluate the agricultural performance of 26 NUTS2 regions of Turkey between 2006 and 2015. In the first analysis, Malmquist TFP indices for agricultural production of NUTS2 regions were estimated for the period 2006-2015. Then a further analysis was conducted by using two-stage DEA method for each year to obtain detailed information about the input usage and to investigate the ways to improve efficiency of inefficient regions in the corresponding years.

The result of the first 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 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 mean values of TFP index for each region are examined, it is seen that, among all regions, agriculture of Kocaeli Region (TR42) has the greatest regression in TFP on average with a mean decrease of 11% over 10-year period. This decrease is due to the negative change in technology, since TR42 is technically efficient in all years which yields a TEC index equal to 1. These findings indicate that TR42 has been using its inputs in an efficient way during the 10-year period. However the productivity level has been decreased due to technological regression averagely.

On the other hand, the maximum average TFP growth is observed in agriculture of Ağrı Region (TRA2) with a mean increase of 4% over 10-year period. It is followed by Zonguldak (TR81), Kastamonu (TR82), Erzurum (TRA1) and Balıkesir (TR22) Regions which have mean TFP growths at 3%, 2.8%, 2.6% and 2.4% levels respectively.

İstanbul (TR10) has the maximum TFPC index considering all TFP changes in each year. This corresponds to the increase of 80% in TFP of TR10 between 2013 and 2014. However, there is a mean decrease of 10% in TFP of TR10 over 10-year period.

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 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 change is defined as the shift of the production frontier. An upward shift indicates the technological improvement, whereas the downward shift means a negative change in technology. Technological regression may refer to an extreme climate change or general economic crisis which would have an observable impact on agriculture sector as well as the other sectors. These kind of undesirable events, all in all, may affect the 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 Turkey 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.

To investigate the input usage of regions in more detail, as a further step, two-stage DEA analysis was conducted for each year. The average technical efficiency of all regions is estimated as 0.88. The average TE-CRS of all regions in 2007, which was measured as 0.83, is the lowest TE-CRS value throughout the 10-year period. However, only the results of DEA analysis for years 2007, 2008 and 2015 were presented, regarding the significant TE-CRS values of these years. The projection summaries of some inefficient regions in these years are presented to observe their input usage and the possible paths to improve their technical efficiency. The projection summaries show the calculated radial and slack movement amounts for each input that are required to achieve CCR-efficiency. Also, paired comparisons, which are conducted for several regions by taking a reference set to constitute the target input values for an inefficient region, were discussed.

As may be concluded, through this thesis, which investigates the agricultural efficiency of regions in Turkey over the 2006-2015 years, some prominent results have been reached. It should be always remembered that DEA is a relative efficiency measurement technique and it is essential to point that the agricultural performance of other regions would directly take role in building the production frontier and so directly affect one specific region's efficiency score.

The result of DEA analysis could be used to determine the problematic areas in agriculture in Turkey and to suggest some paths to improve efficiency. The analysis performed in the present study shows that the main reason behind the inefficiency of regions are improper use of land and machine. These inputs are followed by investment and labor. These findings indicate that the inappropriate use of land and labor, in other words excess use of them, is one of the main reasons behind the inefficiency of regions.

The main question need to be answered is how to use the land in a better way or how to enhance other input usage. One of the possible solutions to this question may be to choose the right products according to the land specifications. Another suggestion for regions might be to increase tendency towards high value products. Also, as a general problem in agriculture of Turkey, the problem of small land parcels used in agriculture can be handled by promoting land consolidation. To raise the awareness for the use of recent technology can be another path toward increasing agricultural productivity and efficiency by means of introducing and extending new techniques and machines used in agriculture. The role of government and policy-makers is essential in informing and promoting the farmers about the proper way of doing agriculture. In this manner, an important step in improving agricultural efficiency can be having the right investments for the regions and right policies that would regulate agricultural production and direct the farmers towards a better production system.

4.1 Future Work and Discussions

It should be stressed that the efficiency scores obtained by DEA analysis should not be considered as absolute efficiency values of DMUs, since DEA measures the TE of DMUs relative to each other. In this regard, if a region uses same amounts of inputs and produces same amount of output in two specific year, it would not yield the same TE scores for these years. Since DEA method measures the relative TE of DMUs in a specific period, i.e. year in this case, the input-output data of other regions accordingly affects the TE score of a region in the year analyzed.

Another issue to be mentioned is that the variables selected for the present analysis are not the only factors affecting the technical efficiency of agricultural production. There are many different variables for measuring agricultural efficiency other than used in the present analysis. In this regard, the results of this DEA analysis should be interpreted considering only the variables selected for the study. Otherwise, it may lead to a contradiction with the results obtained by other studies using different indicators as their variables.

It is highly possible that other factors that were not included in the present analysis may have impact on the agricultural efficiency and productivity of Turkey regions. For example, a common problem in agriculture of Turkey is that agricultural entities are generally small scale enterprises and agricultural areas are composed of large number of land parcels. This situation is one of the major factor behind the low productivity and inefficiency of using land for many regions. Kayseri Region (TR72) and Kırıkkale Region (TR71), having the similar topographic and climate conditions, also suffer from these problems which are probably one of the 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.

Another critical issue about the agricultural performance analysis is the labor data. In Turkey most of the agricultural activity is based on small scale enterprises and mostly family-owned business. This situation is usually accompanied by unpaid work of family members who are not registered to statistical databases as actively working population in agriculture. Thus, labor data for several regions may be under-investigated. This is another factor that may affect the agricultural performance analysis in general.

For future research, other factors that may have external impact on agricultural efficiency 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.

Another possible future work may be to evaluate the agricultural productivity and technical efficiency of NUTS2 and NUTS1 regions of Turkey regarding different production types, crop production and animal production, using the same methods, DEA and Malmqusit TFP Index. However, in order to be able to conduct an appropriate and consistent analysis, a more dissociated data is required, for example a decomposed labor data for crop and animal production or data for the land area of permanent meadows.

In Turkey, there are a few studies that are using DEA method in agricultural efficiency and TFP analysis. Most of these studies using this method are at farm-level and are conducted through interview surveys. The availability and accessibility of agricultural data is a key factor to increase 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, then this would make a great contribution to academic researches as well as the government policies regarding the agricultural improvement. Especially for farm-level studies, FADN database would provide a broad research field as well as accessibility to data. With this system, more specific analysis such as sustainability, ecological and environmental efficiency analysis could be conducted at farm-level to investigate the most influential factors and provide farmers a path to enhance their techniques and regulate their input usage.

It should be mentioned that, the study does not prospect the reasons behind the inefficiencies of regions in depth. Although the findings of this research give clues for understanding the agricultural performance of Turkey, there is still need for further research. However, this study may contribute to the literature in terms of providing information about the data sources utilized for the analysis, and the limitations faced during data gathering. And the results of the analysis may serve as a reference in future work for the researchers examining agricultural efficiency in Turkey. Furthermore, we hope this study may provide a path to policy-makers to develop more effective policies and regulate the investments on each region by taking the findings of this analysis into consideration.

Appendix A

Malmquist TFP Index Summary of NUTS2 Regions

Malmquist Index Summary of 26 NUTS2 Regions are presented for each year between 2006-2015.

Table A.1: TFPC Index and its components for NUTS2 Regions of Turkey over 2006-2015

	2006-2007					**2007-2008**					**2008-2009**				
Region	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**
TRA1	1.19	0.97	1.13	1.05	1.14	0.92	1.48	0.96	0.96	1.35	0.88	0.76	0.88	1.00	0.67
TRA2	1.16	0.97	1.10	1.05	1.13	0.80	1.36	0.80	1.00	1.09	1.09	0.74	1.12	0.97	0.80
TRB1	1.02	1.05	1.00	1.02	1.06	1.00	1.20	1.00	1.00	1.20	0.93	0.90	1.00	0.93	0.84
TRB2	1.00	0.88	1.00	1.00	0.88	1.00	1.50	1.00	1.00	1.50	1.00	0.67	1.00	1.00	0.67
TRC1	0.87	1.08	0.82	1.07	0.94	0.92	1.04	1.07	0.86	0.96	1.01	0.97	1.10	0.92	0.98
TRC2	1.00	0.99	1.00	1.00	0.99	1.00	0.86	1.00	1.00	0.86	1.00	1.10	1.00	1.00	1.10
TRC3	0.99	0.84	1.00	0.99	0.83	1.01	0.84	1.00	1.01	0.85	1.00	0.98	1.00	1.00	0.98
TR10	1.00	1.69	1.00	1.00	1.69	1.00	0.42	1.00	1.00	0.42	1.00	0.93	1.00	1.00	0.93
TR21	0.68	1.47	0.98	0.69	1.00	1.57	0.71	1.03	1.52	1.11	0.85	0.98	0.84	1.01	0.83
TR22	0.99	1.13	1.05	0.95	1.13	1.22	1.16	1.29	0.95	1.42	0.91	0.93	0.94	0.96	0.84
TR31	1.00	1.12	1.00	1.00	1.12	1.00	1.13	1.00	1.00	1.13	1.00	0.96	1.00	1.00	0.96
TR32	0.73	1.10	0.73	0.99	0.80	1.08	1.10	1.20	0.90	1.19	0.96	0.95	0.90	1.07	0.92
TR33	0.79	1.34	1.00	0.79	1.06	1.22	1.02	1.00	1.22	1.24	0.87	1.07	1.00	0.87	0.94
TR41	0.85	1.20	0.92	0.92	1.01	1.13	0.97	1.03	1.09	1.09	1.06	0.96	1.07	0.99	1.02
TR42	1.00	1.07	1.00	1.00	1.07	1.00	1.16	1.00	1.00	1.16	1.00	1.20	1.00	1.00	1.20
TR51	0.67	1.63	1.00	0.67	1.09	1.50	0.93	1.00	1.50	1.39	1.00	1.05	1.00	1.00	1.05
TR52	0.72	1.36	0.90	0.79	0.97	1.13	0.89	0.83	1.36	1.00	1.05	0.95	1.17	0.90	1.00
TR61	1.00	1.06	1.00	1.00	1.06	1.00	1.05	1.00	1.00	1.05	1.00	1.01	1.00	1.00	1.01
TR62	1.00	1.06	1.00	1.00	1.06	1.00	1.02	1.00	1.00	1.02	1.00	0.92	1.00	1.00	0.92
TR63	0.81	1.20	0.99	0.81	0.96	1.24	0.89	1.01	1.23	1.10	1.00	0.96	1.00	1.00	0.96
TR71	0.90	1.29	1.25	0.72	1.17	1.81	0.73	1.27	1.43	1.32	0.97	1.02	0.98	0.99	1.00
TR72	0.74	1.29	0.78	0.95	0.96	1.13	1.13	1.08	1.05	1.29	0.98	0.94	0.97	1.02	0.92
TR81	1.09	1.15	1.00	1.09	1.25	1.00	1.17	1.00	1.00	1.17	0.88	0.86	1.00	0.88	0.76
TR82	1.19	1.04	1.06	1.12	1.23	1.06	1.22	1.11	0.96	1.29	0.76	0.92	0.88	0.87	0.70
TR83	0.85	1.16	0.92	0.92	0.99	1.28	1.06	1.19	1.07	1.36	0.79	1.06	0.77	1.03	0.84
TR90	1.00	0.98	1.00	1.00	0.98	1.00	1.19	1.00	1.00	1.19	1.00	0.68	1.00	1.00	0.68
Mean	0.92	1.14	0.98	0.94	1.05	1.10	1.02	1.03	1.07	1.12	0.96	0.93	0.98	0.98	0.89
Max.	1.19	1.69	1.25	1.12	1.69	1.81	1.50	1.29	1.52	1.50	1.09	1.20	1.17	1.07	1.20
Min.	0.67	0.84	0.73	0.67	0.80	0.80	0.42	0.80	0.86	0.42	0.76	0.67	0.77	0.87	0.67

Table A.2: TFPC Index and its components for NUTS2 Regions of Turkey over 2006-2015 (Continue)

	2009-2010					2010-2011					2011-2012				
Region	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**
TRA1	1.03	1.35	1.03	0.99	1.38	1.10	0.89	1.12	0.99	0.98	1.12	0.96	1.03	1.09	1.08
TRA2	1.14	1.51	1.11	1.03	1.73	1.00	0.88	1.00	1.00	0.88	1.00	0.92	1.00	1.00	0.92
TRB1	0.87	1.18	0.92	0.95	1.03	1.16	0.94	1.09	1.06	1.09	0.93	0.94	0.97	0.96	0.87
TRB2	1.00	1.43	1.00	1.00	1.43	1.00	0.89	1.00	1.00	0.89	1.00	0.93	1.00	1.00	0.93
TRC1	1.00	1.11	0.98	1.02	1.10	1.02	0.92	0.93	1.10	0.94	0.95	0.92	0.92	1.03	0.88
TRC2	1.00	1.07	1.00	1.00	1.07	1.00	1.03	1.00	1.00	1.03	1.00	0.85	1.00	1.00	0.85
TRC3	1.00	1.19	1.00	1.00	1.19	1.00	1.06	1.00	1.00	1.06	1.00	1.01	1.00	1.00	1.01
TR10	1.00	0.74	1.00	1.00	0.74	0.84	0.75	1.00	0.84	0.63	0.84	1.09	1.00	0.84	0.92
TR21	1.21	0.88	1.20	1.00	1.06	1.09	0.91	1.16	0.94	0.99	1.01	1.03	1.03	0.99	1.04
TR22	1.16	0.96	1.06	1.09	1.11	1.08	0.81	1.00	1.08	0.87	0.86	1.10	0.92	0.93	0.95
TR31	1.00	0.89	1.00	1.00	0.89	1.00	0.82	1.00	1.00	0.82	1.00	1.07	1.00	1.00	1.07
TR32	0.98	1.06	0.94	1.04	1.03	1.02	0.92	1.02	1.00	0.93	1.13	0.84	1.19	0.95	0.95
TR33	0.93	0.94	0.91	1.02	0.87	0.88	0.77	0.71	1.23	0.68	0.92	0.87	0.89	1.03	0.80
TR41	1.01	0.92	1.00	1.01	0.93	0.94	0.89	0.94	1.01	0.84	0.99	0.88	1.03	0.96	0.87
TR42	1.00	0.68	1.00	1.00	0.68	1.00	0.58	1.00	1.00	0.58	1.00	0.80	1.00	1.00	0.80
TR51	1.00	0.62	1.00	1.00	0.62	1.00	0.79	1.00	1.00	0.79	0.85	0.85	0.88	0.96	0.72
TR52	0.95	0.95	0.90	1.06	0.90	1.19	0.90	1.31	0.90	1.06	1.01	0.98	1.14	0.89	0.99
TR61	1.00	1.09	1.00	1.00	1.09	1.00	0.91	1.00	1.00	0.91	1.00	0.87	1.00	1.00	0.87
TR62	1.00	0.96	1.00	1.00	0.96	0.97	0.89	0.98	1.00	0.86	0.98	0.85	0.98	1.00	0.84
TR63	0.77	0.95	0.82	0.93	0.72	1.05	0.90	1.04	1.02	0.95	0.97	0.87	0.96	1.01	0.84
TR71	1.04	0.91	1.02	1.02	0.94	0.86	0.73	0.89	0.96	0.63	1.17	0.78	1.12	1.04	0.92
TR72	1.36	0.85	1.44	0.94	1.15	0.86	0.84	0.81	1.06	0.72	0.88	0.96	0.88	0.99	0.84
TR81	1.11	1.27	1.00	1.11	1.41	0.99	0.92	1.00	0.99	0.92	1.03	1.00	1.00	1.03	1.03
TR82	1.09	1.09	1.05	1.04	1.19	1.15	0.93	1.13	1.02	1.07	0.98	0.98	1.05	0.94	0.97
TR83	0.97	1.04	0.97	1.00	1.00	1.08	0.88	1.08	1.00	0.94	1.02	0.86	1.01	1.01	0.88
TR90	1.00	1.02	1.00	1.00	1.02	1.00	0.83	1.00	1.00	0.83	1.00	1.03	1.00	1.00	1.03
Mean	1.02	1.00	1.01	1.01	1.02	1.01	0.86	1.00	1.00	0.87	0.98	0.93	1.00	0.99	0.91
Max.	1.36	1.51	1.44	1.11	1.73	1.19	1.06	1.31	1.23	1.09	1.17	1.10	1.19	1.09	1.08
Min.	0.77	0.62	0.82	0.93	0.62	0.84	0.58	0.71	0.84	0.58	0.84	0.78	0.88	0.84	0.72

Table A.3: TFPC Index and its components for NUTS2 Regions of Turkey over 2006-2015 (Continue)

	2012-2013					**2013-2014**					**2014-2015**				
Region TEC	**TC**	**PEC**	**SEC**	**TFPC**	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**	**TEC**	**TC**	**PEC**	**SEC**	**TFPC**	
TRA1	0.91	0.98	1.00	0.91	0.90	1.00	0.89	1.00	1.00	0.89	0.98	1.07	0.98	1.00	1.05
TRA2	0.89	1.02	0.92	0.97	0.90	1.12	0.96	1.09	1.04	1.08	1.00	1.05	1.00	1.00	1.05
TRB1	0.92	0.95	0.96	0.96	0.88	0.94	0.91	0.99	0.95	0.85	1.29	1.05	1.09	1.19	1.35
TRB2	1.00	0.98	1.00	1.00	0.98	1.00	0.96	1.00	1.00	0.96	1.00	1.00	1.00	1.00	1.00
TRC1	1.00	0.98	1.01	0.99	0.98	1.13	0.95	1.09	1.04	1.07	1.28	1.02	1.29	0.99	1.30
TRC2	1.00	1.03	1.00	1.00	1.03	0.99	0.87	1.00	0.99	0.86	0.93	1.11	1.00	0.93	1.02
TRC3	1.00	1.06	1.00	1.00	1.06	1.00	0.81	1.00	1.00	0.81	1.00	1.11	1.00	1.00	1.11
TR10	1.05	0.90	1.00	1.05	0.95	1.34	1.34	1.00	1.34	1.79	0.83	1.01	1.00	0.83	0.84
TR21	0.95	1.00	0.89	1.07	0.95	1.20	0.89	1.21	0.99	1.07	0.90	1.01	0.90	1.01	0.91
TR22	1.12	0.82	1.04	1.07	0.92	1.04	1.12	1.04	1.00	1.16	1.00	0.94	1.00	1.00	0.94
TR31	1.00	0.83	1.00	1.00	0.83	1.00	1.17	1.00	1.00	1.17	1.00	0.99	1.00	1.00	0.99
TR32	1.18	0.70	1.10	1.07	0.83	0.84	1.15	0.85	0.98	0.97	0.99	0.93	0.98	1.01	0.92
TR33	1.15	0.75	1.18	0.97	0.86	1.09	1.16	1.22	0.89	1.26	1.01	0.95	1.02	0.99	0.96
TR41	1.07	0.82	1.04	1.03	0.87	1.07	1.05	1.07	1.00	1.12	1.00	1.00	1.00	1.00	1.00
TR42	1.00	0.50	1.00	1.00	0.50	1.00	1.51	1.00	1.00	1.51	1.00	0.95	1.00	1.00	0.95
TR51	1.13	1.00	1.12	1.01	1.12	1.05	0.97	1.01	1.04	1.02	1.00	0.94	1.00	1.00	0.94
TR52	1.11	0.99	1.00	1.11	1.10	1.17	0.91	1.00	1.17	1.07	1.00	0.97	1.00	1.00	0.97
TR61	1.00	0.84	1.00	1.00	0.84	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99
TR62	1.04	0.86	1.04	1.00	0.89	1.02	0.99	1.01	1.01	1.01	1.00	0.99	1.00	1.00	0.99
TR63	1.00	0.97	0.99	1.01	0.97	1.10	0.97	1.08	1.02	1.06	1.15	1.00	1.15	1.00	1.15
TR71	0.91	0.80	0.98	0.93	0.72	0.95	1.02	0.93	1.02	0.96	1.13	1.01	1.10	1.03	1.15
TR72	1.20	0.86	1.20	1.00	1.04	1.09	1.05	1.10	0.99	1.14	0.94	1.01	0.92	1.02	0.94
TR81	0.80	0.96	1.00	0.80	0.76	1.26	0.90	1.00	1.26	1.13	0.98	1.03	1.00	0.98	1.01
TR82	1.14	0.96	1.10	1.03	1.10	0.82	1.00	0.96	0.85	0.82	1.00	1.04	0.98	1.03	1.04
TR83	1.09	0.77	1.10	1.00	0.84	1.01	1.15	1.01	1.00	1.16	1.15	0.97	1.19	0.96	1.11
TR90	1.00	0.85	1.00	1.00	0.85	1.00	0.99	1.00	1.00	0.99	1.00	1.61	1.00	1.00	1.61
Mean	1.02	0.88	1.02	1.00	0.90	1.04	1.02	1.02	1.02	1.06	1.02	1.02	1.02	1.00	1.04
Max.	1.20	1.06	1.20	1.11	1.12	1.34	1.51	1.22	1.34	1.79	1.29	1.61	1.29	1.19	1.61
Min.	0.80	0.50	0.89	0.80	0.50	0.82	0.81	0.85	0.85	0.81	0.83	0.93	0.90	0.83	0.84

Appendix B

Tables for DEA Result Summary

Table B.1: DEA Result Summary for 2006

	Regions	TE-CRS	Input Slacks					
			Land	**Labor**	**Machine**	**Fertilizer**	**Livestock**	**Investment**
1	TRA1	0.83	73038	9	0	0	0	0
2	TRA2	0.86	121554	0	440	0	35255	8628
3	TRB1	0.98	194724	0	0	0	0	11853
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.81	334299	0	477	0	0	25675
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.72	0	0	9079	22512	0	20399
10	TR22	0.73	0	24	376	0	0	25608
11	TR31	1.00	0	0	0	0	0	0
12	TR32	1.00	0	0	0	0	0	0
13	TR33	0.92	606142	138	35698	0	0	0
14	TR41	0.92	421762	0	24345	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	0.80	1648843	0	453	0	0	169598
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	1.00	0	0	0	0	0	0
21	TR71	0.61	604156	5	9885	0	0	0
22	TR72	0.65	1005462	0	4343	0	0	45260
23	TR81	0.92	0	72	5419	0	0	14170
24	TR82	0.60	9194	10	4651	0	0	6389
25	TR83	0.72	247940	86	10914	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.89						

Table B.2: DEA Result Summary for 2007

			Input Slacks					
Regions		**TE-CRS**	Land (Hectare)	Labor (Thousand person)	Machine (Number)	Fertilizer (Metric tons)	Livestock (Number)	Investment (1000TL)
1	TRA1	0.98	60174	3	0	0	0	0
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	1.00	0	0	0	0	0	0
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.71	315355	34	0	0	0	26517
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	0.99	523215	0	0	29378	138206	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.49	167159	0	5471	15865	0	24273
10	TR22	0.72	0	19	707	0	0	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.73	216990	0	9816	0	0	19295
13	TR33	0.73	556534	92	29798	0	0	0
14	TR41	0.78	328741	0	17248	0	0	11176
15	TR42	1.00	0	0	0	0	0	0
16	TR51	0.67	640229	0	4094	9164	22536	16468
17	TR52	0.57	977014	7	0	0	0	110134
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	0.81	165906	42	0	5358	0	0
21	TR71	0.55	654711	21	11034	0	0	0
22	TR72	0.48	718520	0	3868	0	14223	9673
23	TR81	1.00	0	0	0	0	0	0
24	TR82	0.71	34688	0	7515	0	0	0
25	TR83	0.61	394386	114	17379	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.83						

Table B.3: DEA Result Summary for 2008

	Regions	TE-CRS	Input Slacks					
			Land (Hectare)	Labor (Thousand person)	Machine (Number)	Fertilizer (Metric tons)	Livestock (Number)	Investment (1000TL)
1	TRA1	0.90	139551	41	653	0	0	0
2	TRA2	0.80	1504	31	0	0	0	3352
3	TRB1	1.00	0	0	0	0	0	0
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.65	223549	10	0	0	0	8679
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.76	0	0	13718	39493	0	0
10	TR22	0.88	33640	0	6494	0	0	11325
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.79	245865	18	12033	0	0	13541
13	TR33	0.89	633596	37	46253	0	0	0
14	TR41	0.88	422442	0	27905	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	0.64	923160	0	5137	0	0	41142
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	1.00	0	0	0	0	0	0
21	TR71	0.99	1300053	19	30178	16307	0	0
22	TR72	0.54	737116	7	4858	0	0	0
23	TR81	1.00	0	0	0	0	0	0
24	TR82	0.75	129879	0	7555	0	0	2284
25	TR83	0.78	498025	146	26637	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.89						

Table B.4: DEA Result Summary for 2009

			Input Slacks					
Regions		TE-CRS	Land	Labor	Machine	Fertilizer	Livestock	Investment
1	TRA1	0.79	16143	48	0	0	0	12391
2	TRA2	0.87	60592	37	0	0	100891	0
3	TRB1	0.93	181882	13	0	0	0	94665
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.66	209983	0	98	0	0	106308
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.65	0	0	12470	43155	0	0
10	TR22	0.80	27709	0	24	0	0	34508
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.76	217305	0	10450	0	0	21952
13	TR33	0.77	397557	0	37074	1525	0	0
14	TR41	0.93	0	0	24442	0	0	363
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	0.68	377121	0	0	0	0	88056
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	1.00	0	0	0	0	0	0
21	TR71	0.96	1201486	0	30456	53506	0	0
22	TR72	0.53	674069	0	1232	0	0	1722
23	TR81	0.88	26055	146	5328	0	0	8890
24	TR82	0.57	113492	3	3462	0	0	30247
25	TR83	0.62	252902	57	15636	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.86						

Table B.5: DEA Result Summary for 2010

	Regions		Input Slacks					
	Regions	TE-CRS	Land	Labor	Machine	Fertilizer	Livestock	Investment
1	TRA1	0.81	3007	43	0	0	0	16478
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	0.81	93644	30	0	0	0	97229
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.66	178857	0	0	0	0	65688
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.78	0	0	16816	57551	0	49219
10	TR22	0.93	117043	0	12300	0	97912	58939
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.74	125323	0	11948	0	0	27176
13	TR33	0.72	225518	0	27504	0	0	0
14	TR41	0.93	0	0	29087	13330	0	31013
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	0.64	380760	0	0	21911	0	0
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	0.77	93764	24	0	0	0	31362
21	TR71	1.00	0	0	0	0	0	0
22	TR72	0.72	932436	0	5113	0	56408	47114
23	TR81	0.98	12886	107	8004	0	0	11472
24	TR82	0.63	21685	0	7738	0	0	28464
25	TR83	0.60	301676	0	18632	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.87						

Table B.6: DEA Result Summary for 2011

			Input Slacks					
Regions		**TE-CRS**	**Land**	**Labor**	**Machine**	**Fertilizer**	**Livestock**	**Investment**
1	TRA1	0.89	21491	0	0	0	10987	18326
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	0.94	71200	37	196	0	0	113628
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.67	142583	0	1005	2198	0	0
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	0.84	0	0	1481	3578	1578	5682
9	TR21	0.85	34206	0	34421	35038	0	0
10	TR22	1.00	0	0	0	0	0	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.75	77411	0	7487	0	106319	0
13	TR33	0.63	2071	0	22011	0	112871	0
14	TR41	0.88	114898	0	38543	38	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	0.76	622106	0	17719	14105	0	0
18	TR61	1.00	0	0	0	0	0	0
19	TR62	0.97	204979	0	0	82993	0	0
20	TR63	0.81	167366	13	0	43049	0	46759
21	TR71	0.86	365935	0	20390	17920	0	0
22	TR72	0.62	729720	0	1781	0	45569	0
23	TR81	0.97	7568	128	9270	0	0	16517
24	TR82	0.72	6988	17	11569	0	0	35132
25	TR83	0.64	299934	0	19294	0	64545	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.88						

Table B.7: DEA Result Summary for 2012

	Regions	TE-CRS	Input Slacks					
			Land	**Labor**	**Machine**	**Fertilizer**	**Livestock**	**Investment**
1	TRA1	1.00	0	0	0	0	0	0
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	0.87	47603	23	0	0	0	63167
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.63	200944	0	153	10188	0	93431
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	0.71	0	0	0	6096	0	12073
9	TR21	0.86	7581	0	33734	46202	0	15103
10	TR22	0.86	132532	0	14783	0	51522	26552
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.85	112816	58	1375	0	0	0
13	TR33	0.58	165544	0	19270	0	0	0
14	TR41	0.87	0	0	28271	2365	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	0.85	551116	0	12882	5711	0	18376
17	TR52	0.77	687170	0	13265	21311	0	115430
18	TR61	1.00	0	0	0	0	0	0
19	TR62	0.95	156956	0	0	105456	0	0
20	TR63	0.78	131400	14	0	58079	0	78237
21	TR71	1.00	0	0	0	0	0	0
22	TR72	0.55	691034	0	0	0	0	8057
23	TR81	1.00	0	0	0	0	0	0
24	TR82	0.71	18855	0	9555	0	0	31820
25	TR83	0.66	9954	0	16903	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.87						

Table B.8: DEA Result Summary for 2013

	Regions	TE-CRS	Input Slacks					
	Regions	TE-CRS	Land	Labor	Machine	Fertilizer	Livestock	Investment
1	TRA1	0.91	172891	0	0	0	255030	69795
2	TRA2	0.89	0	10	1935	0	239673	11738
3	TRB1	0.81	13489	70	0	0	0	33994
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.64	161303	0	0	4892	0	0
6	TRC2	1.00	0	0	0	0	0	0
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	0.75	0	0	93	10654	14904	0
9	TR21	0.81	67173	0	30952	51908	0	6543
10	TR22	0.96	0	0	26431	0	331137	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	1.00	0	0	0	0	0	0
13	TR33	0.66	90856	0	38880	0	0	0
14	TR41	0.93	297224	52	41368	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	0.95	689156	0	15778	16781	0	80803
17	TR52	0.86	780001	0	25887	32140	0	147719
18	TR61	1.00	0	0	0	0	0	0
19	TR62	0.98	220721	0	507	118535	0	3295
20	TR63	0.78	142742	0	0	62858	0	0
21	TR71	0.91	713053	0	24918	0	0	0
22	TR72	0.66	698275	0	8663	0	121154	64188
23	TR81	0.80	0	81	7142	0	17453	11830
24	TR82	0.81	166378	0	12910	0	176133	60179
25	TR83	0.71	246592	0	37421	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.88						

Table B.9: DEA Result Summary for 2014

	Regions	TE-CRS	Input Slacks					
	Regions	**TE-CRS**	**Land**	**Labor**	**Machine**	**Fertilizer**	**Livestock**	**Investment**
1	TRA1	0.91	82925	0	0	0	0	43357
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	0.76	58753	0	0	0	0	28533
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.72	122206	0	0	0	0	19679
6	TRC2	0.99	722108	0	0	78521	0	873578
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	1.00	0	0	0	0	0	0
9	TR21	0.97	0	0	27449	58782	0	0
10	TR22	1.00	0	0	0	0	0	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.84	119097	0	10729	0	0	0
13	TR33	0.72	230514	0	29918	0	0	0
14	TR41	1.00	122079	0	39469	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	1.00	0	0	0	0	0	0
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	0.85	0	0	0	50140	0	3996
21	TR71	0.86	354680	0	17996	1787	0	0
22	TR72	0.71	398804	0	1166	0	0	31528
23	TR81	1.00	0	0	0	0	0	0
24	TR82	0.66	75383	0	7666	0	0	18216
25	TR83	0.72	445043	6	29241	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.	0.91						

Table B.10: DEA Result Summary for 2015

	Regions	TE-CRS	Input Slacks					
			Land (Hectare)	Labor (Thousand person)	Machine (Number)	Fertilizer (Metric tons)	Livestock (Number)	Investment (1000TL)
1	TRA1	0.89	76830	0	0	0	0	2304
2	TRA2	1.00	0	0	0	0	0	0
3	TRB1	0.97	149224	0	0	0	0	40018
4	TRB2	1.00	0	0	0	0	0	0
5	TRC1	0.92	265925	0	0	9476	0	4598
6	TRC2	0.92	711141	0	0	84665	0	791661
7	TRC3	1.00	0	0	0	0	0	0
8	TR10	0.83	0	0	0	13225	12613	0
9	TR21	0.88	0	0	21168	64200	0	28925
10	TR22	1.00	0	0	0	0	0	0
11	TR31	1.00	0	0	0	0	0	0
12	TR32	0.83	127563	0	5025	0	0	0
13	TR33	0.73	296888	0	21937	0	0	0
14	TR41	1.00	355950	0	43721	0	0	0
15	TR42	1.00	0	0	0	0	0	0
16	TR51	1.00	0	0	0	0	0	0
17	TR52	1.00	0	0	0	0	0	0
18	TR61	1.00	0	0	0	0	0	0
19	TR62	1.00	0	0	0	0	0	0
20	TR63	0.98	55562	0	0	94058	0	3299
21	TR71	0.97	638040	0	24969	4246	0	0
22	TR72	0.67	486040	0	0	0	0	6150
23	TR81	0.98	23792	93	15014	0	0	15689
24	TR82	0.66	68315	5	7854	0	0	4955
25	TR83	0.82	468209	0	42532	0	0	0
26	TR90	1.00	0	0	0	0	0	0
	Avg.		0.92					

Bibliography

[1] T. J. Coelli, D. S. P. Rao, C. J. O'Donnell, and G. E. Battese. *An introduction to efficiency and productivity analysis.* Springer Science & Business Media, 2005.

[2] W. W. Cooper, L. M. Seiford, and K. Tone. *Introduction to data envelopment analysis and its uses: with DEA-solver software and references.* Springer Science & Business Media, 2006.

[3] R. Färe, S. Grosskopf, M. Norris, and Z. Zhang. Productivity growth, technical progress, and efficiency change in industrialized countries. *The American economic review*, pages 66–83, 1994.

[4] Temel Ekonomik Göstergeler. http://www2.kalkinma.gov.tr/kamuyat/ilozet.html.

[5] Tarım İstatistikleri, Sorularla Resmi İstatistikler Dizisi-5. `https://biruni.tuik.gov.tr/yayin/views/visitorPages/index.zul`, 2008.

[6] *Bitkisel Üretim Özel İhtisas Komisyonu Raporu, 10. Kalkınma Planı.* T.C. Kalkınma Bakanlığı, 2014.

[7] T. J. Coelli and D. S. Rao. Total factor productivity growth in agriculture: a malmquist index analysis of 93 countries, 1980–2000. *Agricultural Economics*, 32 (s1):115–134, 2005.

[8] M. J. Farrell. The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 120(3):253–290, 1957.

[9] A. Charnes, W. W. Cooper, and E. Rhodes. Measuring the efficiency of decision making units. *European journal of operational research*, 2(6):429–444, 1978.

[10] D. Hellriegel, J. W. Slocum, and R. W. Woodman. *Organizational Behavior*. GI - Organizational Behavior Series. South-Western College Pub., 1998. ISBN 9780538880244. URL `https://books.google.com.tr/books?id=f5kXAQAAMAAJ`.

[11] A. Tarım. Veri zarflama analizi: Matematiksel programlama tabanlı göreli etkinlik ölçüm yaklaşımı. *Sayıştay Yayınları, Ankara*, 15:5–40, 2001.

[12] R. Färe, S. Grosskopf, and C. A. K. Lovell. The structure of technical efficiency. *The Scandinavian Journal of Economics*, pages 181–190, 1983.

[13] T. C. Koopmans et al. *Activity analysis of production and allocation*. Number 13. Wiley New York, 1951.

[14] G. Debreu. The coefficient of resource utilization. *Econometrica: Journal of the Econometric Society*, pages 273–292, 1951.

[15] R. Färe, S. Grosskopf, and C. A. K. Lovell. *The Measurement of Efficiency of Production*. Studies in Productivity Analysis. Springer Netherlands, 2013. ISBN 9789401577212. URL `https://books.google.com.tr/books?id=T7LnCAAAQBAJ`.

[16] F. R. Førsund and N. Sarafoglou. On the origins of data envelopment analysis. *Journal of Productivity Analysis*, 17(1):23–40, 2002.

[17] A. Gülcü, H. Tutar, and C. Yeşilyurt. Sağlık sektöründe veri zarflama analizi yöntemi ile göreceli verimlilik analizi. *Seçkin Yayıncılık, Ankara*, 2004.

[18] R. D. Banker, A. Charnes, and W. W. Cooper. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, 30(9): 1078–1092, 1984.

[19] M. K. C. Vincent and V. Charles. *Data Envelopment Analysis and Its Applications to Management*. Cambridge Scholars Publishing, 2012.

[20] L. R. Murillo and J. Vega. The use of parametric and nonparametric frontier methods to measure the productive efficiency in the industrial sector. *A Comparative Study. University of York, York, UK*, 2000.

[21] H. D. Sherman. Hospital efficiency measurement and evaluation: Empirical test of a new technique. *Medical care*, 22(10):922–938, 1984.

[22] K. Vincová. Using dea models to measure efficiency. *Biatec*, 13(8):24–28, 2005.

[23] H. D. Sherman and J. Zhu. *Service productivity management: Improving service performance using data envelopment analysis (DEA).* Springer Science & Business Media, 2006.

[24] A. Charnes and W. W. Cooper. Programming with linear fractional functionals. *Naval Research Logistics (NRL)*, 9(3-4):181–186, 1962.

[25] J. Zhu. *Quantitative models for performance evaluation and benchmarking: data envelopment analysis with spreadsheets*, volume 213. Springer, 2014.

[26] P. Byrnes, R. Färe, and S. Grosskopf. Measuring productive efficiency: an application to illinois strip mines. *Management Science*, 30(6):671–681, 1984.

[27] R. D. Banker and R. M. Thrall. Estimation of returns to scale using data envelopment analysis. *European Journal of Operational Research*, 62(1):74–84, 1992.

[28] T. Coelli. A guide to deap version 2.1: a data envelopment analysis (computer) program. *Centre for Efficiency and Productivity Analysis, University of New England, Australia*, 1996.

[29] D. W. Caves, L. R. Christensen, and W. E. Diewert. The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica: Journal of the Econometric Society*, pages 1393–1414, 1982.

[30] S. Malmquist. Index numbers and indifference surfaces. *Trabajos de estadística*, 4 (2):209–242, 1953.

[31] R. Mahadevan. A dea approach to understanding the productivity growth of malaysia's manufacturing industries. *Asia Pacific Journal of Management*, 19(4): 587–600, 2002.

[32] E. Thanassoulis. *Introduction to the theory and application of data envelopment analysis*. Springer, 2001.

[33] T. S. Ahn. *Efficiency and related issues in higher education: a data envelopment analysis approach*. University Microfilms, 1987.

[34] N. K. Avkiran. Investigating technical and scale efficiencies of australian universities through data envelopment analysis. *Socio-Economic Planning Sciences*, 35(1):57–80, 2001.

[35] Z. Sinuany-Stern, A. Mehrez, and A. Barboy. Academic departments efficiency via dea. *Computers & Operations Research*, 21(5):543–556, 1994.

[36] P. Nayar and Y. A. Ozcan. Data envelopment analysis comparison of hospital efficiency and quality. *Journal of medical systems*, 32(3):193–199, 2008.

[37] D. Gillen and A. Lall. Developing measures of airport productivity and performance: an application of data envelopment analysis. *Transportation Research Part E: Logistics and Transportation Review*, 33(4):261–273, 1997.

[38] H. D. Sherman and G. Ladino. Managing bank productivity using data envelopment analysis (dea). *Interfaces*, 25(2):60–73, 1995.

[39] R. B. Staub, G. S. e Souza, and B. M. Tabak. Evolution of bank efficiency in brazil: A dea approach. *European journal of operational research*, 202(1):204–213, 2010.

[40] K. Sarıca and I. Or. Efficiency assessment of turkish power plants using data envelopment analysis. *Energy*, 32(8):1484–1499, 2007.

[41] D. Ballayan, G. DeSantis, et al. Compendium of agricultural-environmental indicators 1989-91 to 2000. 2003.

[42] N. Aldaz and J. A. MillÁN. Regional productivity of spanish agriculture in a panel dea framework. *Applied Economics Letters*, 10(2):87–90, 2003.

[43] J. A. Millan and N. Aldaz. Agricultural productivity of the spanish regions: a non-parametric malmquist analysis. *Applied economics*, 30(7):875–884, 1998.

[44] E. Deliktaş and M. Candemir. Production efficiency and total factor productivity growth in turkish state agricultural enterprises. Technical report, 2007.

[45] T. Tipi and E. Rehber. Measuring technical efficiency and total factor productivity in agriculture: the case of the south marmara region of turkey. *New Zealand Journal of Agricultural Research*, 49(2):137–145, 2006.

[46] G. Armagan, A. Ozden, and S. Bekcioglu. Efficiency and total factor productivity of crop production at nuts1 level in turkey: Malmquist index approach. *Quality & Quantity*, 44(3):573–581, 2010.

[47] T. Alemdar and M. N. Oren. Determinants of technical efficiency of wheat farming in southeastern anatolia, turkey: a nonparametric technical efficiency analysis. *Journal of Applied Sciences*, 6(4):827–830, 2006.

[48] T. Tipi, N. Yildiz, M. Nargeleçekenler, and B. Çetin. Measuring the technical efficiency and determinants of efficiency of rice (oryza sativa) farms in marmara region, turkey. *New Zealand Journal of Crop and Horticultural Science*, 37(2):121–129, 2009.

[49] B. Iraizoz, M. Rapun, and I. Zabaleta. Assessing the technical efficiency of horticultural production in navarra, spain. *Agricultural Systems*, 78(3):387–403, 2003.

[50] B. Ozkan, H. Akcaoz, and F. Karadeniz. Energy requirement and economic analysis of citrus production in turkey. *Energy Conversion and Management*, 45(11):1821–1830, 2004.

[51] G. Unakitan, H. Hurma, and F. Yilmaz. An analysis of energy use efficiency of canola production in turkey. *Energy*, 35(9):3623–3627, 2010.

[52] B. Khoshnevisan, S. Rafiee, M. Omid, and H. Mousazadeh. Applying data envelopment analysis approach to improve energy efficiency and reduce ghg (greenhouse gas) emission of wheat production. *Energy*, 58:588–593, 2013.

[53] A. Syp, A. Faber, M. Borzęcka-Walker, and D. Osuch. Assessment of greenhouse gas emissions in winter wheat farms using data envelopment analysis approach. *Pol. J. Environ. Stud*, 24:2197, 2015.

[54] A. Nabavi-Pelesaraei, R. Abdi, S. Rafiee, and H. G. Mobtaker. Optimization of energy required and greenhouse gas emissions analysis for orange producers using data envelopment analysis approach. *Journal of Cleaner Production*, 65:311–317, 2014.

[55] V. Hoang and M. Alauddin. Input-orientated data envelopment analysis framework for measuring and decomposing economic, environmental and ecological efficiency: an application to oecd agriculture. *Environmental and Resource Economics*, 51(3):431–452, 2012.

[56] A. Lilienfeld and M. Asmild. Estimation of excess water use in irrigated agriculture: a data envelopment analysis approach. *Agricultural water management*, 94(1):73–82, 2007.

[57] H. E. Bradley. *Operational Research'90: Selected Papers from the Twelfth IFORS International Conference on Operational Research*, volume 12. Pergamon, 1991.

[58] S. El-Mahgary and R. Lahdelma. Data envelopment analysis: visualizing the results. *European Journal of Operational Research*, 83(3):700–710, 1995.

[59] T. Binici, C. R. Zulauf, O. O. Kacira, and B. Karli. Assessing the efficiency of cotton production on the harran plain, turkey. *Outlook on AGRICULTURE*, 35(3): 227–232, 2006.

[60] M. Candemir, M. Özcan, M. Güneş, and E. Deliktaş. Technical efficiency and total factor productivity growth in the hazelnut agricultural sales cooperatives unions in turkey. *Mathematical and Computational Applications*, 16(1):66–76, 2011.

[61] K. L. Poudel, T. G. Johnson, N. Yamamoto, S. Gautam, and B. Mishra. Comparing technical efficiency of organic and conventional coffee farms in rural hill region of nepal using data envelopment analysis (dea) approach. *Organic agriculture*, 5(4): 263–275, 2015.

[62] I. Guzmán and N. Arcas. The usefulness of accounting information in the measurement of technical efficiency in agricultural cooperatives. *Annals of Public and Cooperative Economics*, 79(1):107–131, 2008.

[63] H. E. Aktan and P. K. Samut. Analysis of the efficiency determinants of turkey's agriculture sector by two-stage data envelopment analysis (dea)/türk tariminin etkinlik bilesenlerinin iki asamali veri zarflama analizi (vza) ile incelenmesi. *Ege Akademik Bakis*, 13(1):21, 2013.

[64] H. Tunca and E. Deliktaş. Oecd ülkelerinde tarımsal etkinlik ölçümü: Dinamik veri zarflama analizi/measurement of agriculture efficiency in oecd countries: Dynamic data envelopment analysis. *Ege Akademik Bakis*, 15(2):217, 2015.

[65] K. Galanopoulos, E. Lindberg, Y. Surry, K. Mattas, et al. Agricultural productivity growth in the mediterranean and tests of convergence among countries. In *98 Seminar of the European th Association of Agricultural Economists, Chania*, volume 29, 2006.

[66] A. Nin, C. Arndt, and P. V. Preckel. Is agricultural productivity in developing countries really shrinking? new evidence using a modified nonparametric approach. *Journal of Development Economics*, 71(2):395–415, 2003.

[67] M. A. Trueblood and J. Coggins. Intercountry agricultural efficiency and productivity: a malmquist index approach. *Manuscrito http://www. apec. umn. edu/faculty/jcoggins*, 2003.

[68] C. Arnade. Using a programming approach to measure international agricultural efficiency and productivity. *Journal of Agricultural Economics*, 49(1):67–84, 1998.

[69] C. Thirtle, D. Hadley, and R. Townsend. Policy-induced innovation in sub-saharan african agriculture: A multilateral malmquist productivity index approach. *Development Policy Review*, 13(4):323–348, 1995.

[70] A. Nin-Pratt, B. Yu, and S. Fan. Comparisons of agricultural productivity growth in china and india. *Journal of Productivity Analysis*, 33(3):209–223, 2010.

[71] M. Karacuka, E. Deliktaş, and H. Tunca. Ab ülkeleri karşisinda türk tariminin rekabet gücü: Dinamik veri zarflama analizi. *Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi*, 28(3), 2014.

[72] M. Ş. Mollavelioğlu and R. Ceylan. Türkiye ve ab ülkelerinde tarımsal toplam faktör verimliliği ve yakınsama analizi. *Akdeniz İİBF Dergisi*, 20:86–103, 2010.

[73] H. Yılmaz and A. Gül. Ab ve türkiye'nin tarımsal üretim etkinlik ve verimliliği üzerine küresel krizlerin etkileri. *Türkiye IX. Tarım Ekonomisi Kongresi*, 1:221–228, 2010.

[74] N. A. Eroğlu and M. Bozoğlu. Destekleme politikalarının türkiye'deki tarımsal etkinlik ve toplam faktör verimliliğine etkileri. 2017.

[75] A. K. Kiani. An empirical analysis of tfp gains in the agricultural crop-sub-sector of nwfp using malmquist index approach. Georgia Institute of Technology, 2009.

[76] C. Thirtle, J. Piesse, A. Lusigi, and K. Suhariyanto. Multi-factor agricultural productivity, efficiency and convergence in botswana, 1981–1996. *Journal of Development Economics*, 71(2):605–624, 2003.

[77] H. Son Nghiem and T. Coelli. The effect of incentive reforms upon productivity: evidence from the vietnamese rice industry. *Journal of Development Studies*, 39(1): 74–93, 2002.

[78] N. Aldaz and J. A. Millán. A comparison of agricultural productivity in the european union regions. 2003.

[79] P. Chaitip, C. Chaiboonsri, and F. Inluang. The production of thailand's sugarcane: Using panel data envelopment analysis (panel dea) based decision on bootstrapping method. *Procedia Economics and Finance*, 14:120–127, 2014.

[80] P. Kaya and H. E. Aktan. Türk tarim sektörü verimliliğinin parametrik olmayan bir yöntemle analizi. *Journal of Alanya Faculty of Business/Alanya Isletme Fakültesi Dergisi*, 3(1), 2011.

[81] U. Özok. Veri zarflama analizi ve malmquist-toplam faktör verimliliği endeksi ile türkiyeâdeki illerin tarım etkinliklerinin incelenmesi. Master's thesis, Yüksek Lisans Tezi, Ankara, Gazi Üniversitesi Fen Bilimleri Enstitüsü, 2006.

[82] E. Ball, R. Färe, S. Grosskopf, and O. Zaim. Accounting for externalities in the measurement of productivity growth: the malmquist cost productivity measure. *Structural change and economic dynamics*, 16(3):374–394, 2005.

[83] K. B. Atici and V. V. Podinovski. Using data envelopment analysis for the assessment of technical efficiency of units with different specialisations: An application to agriculture. *Omega*, 54:72–83, 2015.

[84] Nomenclature Of Territorial Units For Statistics (NUTS) . `https://biruni.tuik.gov.tr/DIESS/SiniflamaTurListeAction.do`, .

[85] Agriculture PPI . http://www.turkstat.gov.tr/PreTablo.do?alt$_i d = 1101$, .

[86] TUIK, Regional Statistics. https://biruni.tuik.gov.tr/bolgeselistatistik/, .

[87] Government Investments by Sectors. http://www2.kalkinma.gov.tr/kamuyat/ilozet.html.

[88] *TR71 Düzey 2 Bölgesi Tarım ve Hayvancılık Sektöründe Mevcut Durum ve 2014-2023 Yılları Stratejileri ve Hedefleri Raporu.* T.C. Ahiler Kalkınma Ajansı, 2013.