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TECHNOLOGY ORIENTED EFFICIENCY ANALYSES OF R&D COMPANIES: LONGITUDINAL APPROACH

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A B S T R A C T

This study evaluates the efficiency and productivity of technology companies included in the BIST 100 Index and Fortune 500 list using the DEA-Malmquist model. Firstly, technology-oriented efficiency analyses were conducted. In the second stage, we aim to analyze the efficiency trend of longitudinal (panel) data using the Malmquist approach to understand the frontier shift and efficiency changes from 2005 to 2019. R&D expenditure, R&D personnel cost, total personal number, and marketing expenditure were considered as inputs, while total income, export income, and the patent number were considered as outputs. According to the findings, fifteen of twenty-seven firms were on the frontier once, but only three were on the frontier more than three times. Eighteen firms improved in the Malmquist Index (TFPCH) from 2015 to 2019, with the most improvement in 2015-2016. Besides that, in 2019, a performance improvement of seven percent compared to 2015. Furthermore, it is determined that Scale Efficiency scores increase by 0.163 for extra Net Sales of firms.

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1. INTRODUCTION

Our age is the age of technology and information. The change in this age is happening at a rate that has not happened before. Especially after the second half of the 20th century, globalization increased rapidly, economic boundaries disappeared, and the world became a single market. As a result of the emergence of global competition worldwide, change has occurred rapidly. The wind of change has caused a rapid change in products and services (Turulja and Bajgoric, 2018).

The market demands have become more complex, and the lifespan of products and services has been shortened regarding on the developments in information and communication technologies, changes in customer requests and expectations, increased competition, and mobility in the qualified and competent workforce with technology transfer (Altschuller et al., 2010; Hosseini and Sheikhi, 2012; Bhatt et al., 2010; Vecchiato, 2015). Companies must be innovation-oriented and respond quickly to the changes to survive under this wind of change and innovation occurring in their external environment (Chen et al., 2010; Nashiruddin, 2018; Atalay et al., 2013).

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Companies should focus on Research and Development (R&D) activities to be sustainable and present their differences against their competitors in the face of the winds of change occurring in the sector and customer dynamics. Due to the innovative products that emerge as a result of R&D studies, businesses can closely follow new technologies, improve their learning capabilities and produce fast solutions for the expectations of their customers, increasing the firms' performance (Ho et al., 2005). Due to R&D investments, expenditures, and studies, businesses increase the profitability of new product/service production, provide a competitive advantage and maintain their presence (Light et al., 2016; Wang et al., 2013; Vivero, 2002; Chen et al., 2019). In this context, R&D is the driving force of technological progress and economic growth in the long term (Liu et al., 2020; Aristovnik, 2014). Therefore, the R&D activities of countries have been extensively studied in the literature (Cullmann et al., 2009; Cincera et al., 2009).

Technological innovations lead to increased productivity and growth (Aktop, 2021). The basis of R&D activities is innovation. R&D can be defined as transforming the ideas put forward into successful innovations and renewing, developing, and updating the product/service (Haapanen et al., 2016). Research has shown that R&D can increase the innovation success of the business by increasing its innovation capabilities (Lin et al., 2020). Furthermore, research has found that innovation activities are critical to sectoral and sustainable success, especially in information-oriented companies (Wu et al., 2019), increase business profitability (Wang et al., 2010), increased sectoral competitiveness due to improved operating performance (Verdu et al., 2012) and play an essential role in improving the living standards of societies (Liv d., 2019; Marshall and Parra, 2019).

In the past decade, it has been clear that R&D is the force behind the rapid rise and competitive successes of giants such as Apple, Facebook, Amazon, Samsung, Huawei, and Microsoft. In recent years, many studies have been conducted on the impact of R&D on firm performance. In developed countries such as the US, Italy, Germany, and the UK over the past 20 years, there have been many studies measuring the impact of R&D expenditures on firm output (Koutroumpis et al., 2020; Filatotchev and Piesse, 2009; Griffith et al., 2006; Ehie and Olibe, 2010).

The purpose of the study is twofold. The first is to evaluate the relative efficiency of the observed firms. The second is to conduct longitudinal (panel) data analysis using the Malmquist index.

Within the scope of the study, we attempted to determine the relationship between the relative efficiency level of the companies and their business performance by using the Data Envelopment Analysis (DEA) method. DEA is an important method used to simultaneously evaluate the relationship between input and output capacity utilization (Gok and Sezen, 2011). DEA is a parameterless efficiency measurement model developed to measure the efficiency of the goods and services produced by the economic decision-making units with similar characteristics and working based on linear programming (Sahin and Ozdemir, 2020). DEA is a "data-driven" approach that allows relative comparison to evaluate the performance of a set of states or units that transform multiple inputs into multiple outputs (Cooper et al., 2004). Therefore, it was thought to be the appropriate research method within the scope of the study.

Sten Malmquist developed Malmquist Total Factor Productivity (MTFP). David Caves entered the literature as an index with his contributions and is the most used method to examine productivity analysis changes (Caves et al., 1982). The primary purpose of this index is to measure and examine productivity within a specific time limit (Keskin Benli, 2012). This index, in which more than one input and output is used, explains the progress and decline in productivity and technological change over time (Sahin and Ozdemir, 2020).

This work offers a variety of contributions to the existing literature. First, companies that were not previously listed in the stock market and Fortune 500 were selected in a sample together. The impact of R&D expenditures on firm performance was not studied from a broad perspective. Many past studies selected companies traded on the country's stock exchanges as examples. However, no previous study has identified two variables with international validity and reliability, such as both the stock market and the Fortune 500, as a set of samples simultaneously. Although companies traded on the stock exchange receive a certain large amount in trading volume and stock value, they may not have the same proportion of reserves in front of consumers. However, the Fortune 500 list is ranked by data such as turnover, cash flow, and export values most during the year. In this sense, fortune 500 listed companies have an impact on consumers and are preferred by consumers with confidence. The companies listed in the BIST 100 and Fortune Turkey 500 list between 2015 and 2019 were determined as samples. Second, the variables in the study were used together for the first time. The study evaluates the effects of R&D expenditure on business performance from a broad perspective. Thirdly, there is no common opinion in the literature regarding the impact of R&D expenditures on firm performance. Our study contributes to the existing literature by conducting a comprehensive analysis on this topic. In addition, whether R&D is the only requirement for company sustainability will be examined. Fourth and final, the literature is examined, and it is seen that similar studies are mainly carried out in developed countries. For this reason, the study sample was selected as Turkey, one of the developing countries. In this way, it is aimed to be a role model for developing countries.

The research paper is organized as follows. The following section describes the methodology of the analysis. Section 3 presents the results. Section 4 discusses the findings and portrays the conclusion and opportunities for future work.

2. RELATED WORKS

Research in the literature has found that R&D investments and expenditures have a positive impact on (i) Firm Performance (Ehie and Olibe, 2010; Tung and Binh, 2021; Eberhart et al., 2004; Li, 2012; Kumbhakar et al., 2012; Tubbs, 2007; Krishnan et al., 2009; Morbey and Reithner, 1990), (ii) Financial Performance (Eberhart et al., 2004, Chiao, 2013; Jaisinghani, 2015; Armstrong et al., 2006; Vanderpal, 2015), (iii) Market Value (Ehie and Olibe, 2010; Sougiannis, 1994; Armstrong et al., 2006) and (Iv) Information Creation and Innovation Promotion (Guellec and Pottelsbeghe, 2004). However, there are many studies in the literature that R&D processes have a negative effect on firm performance. For example, Vithessonthi and Racela (2016) and Hsu and Boggs (2003) found a negative relationship between R&D and firm performance; Brown and Svenson (1988) found that the increase in R&D investments had no significant impact on sales revenue, and Guo et al. (2004) found that R&D had no positive impact on business profitability.

The objective of Firsova et al. (2022)'s study was the application of the data envelopment analysis (DEA) and Malmquist productivity index and its components to assess the dynamics of the development of the knowledge-intensive services sector.

The main purpose of Dai and Liu (2009)'s paper is to evaluate the R&D efficiency and productivity growth of 16 High-Tech industries in China for a period of 2002 to 2007.

Han et al. (2014)'s study examines the R&D efficiency patterns of 15 Korean regions for 2005–09. It employs data envelopment analysis to identify the regions' R&D performances relative to the best practices from the static perspective, and the Malmquist productivity index to evaluate their changes in performance within a given timeframe, providing a dynamic perspective.

The aim of Firsova and Chernyshova (2020)'s work was to evaluate the dynamics of regional innovation development and compare the Russian regions according to their innovation efficiency, used resources, and achieved results.

Liao et al. (2016)'s study aimed to analyze the dynamic changes in the scientific research innovation efficiency of Guangzhou Institute of Respiratory Diseases (GIRD) from the year 2009–2013.

Song and Zang (2013)'s paper analyzes R&D efficiency changes in the pharmaceutical industry by DEA-Malmquist on the basis of the selected panel data from 2002 to 2011.

Consequently, it is seen that R&D expenditures affect financial performance with sectoral diversity. (Griffith et al., 2006; Guo et al. 2004; Ehie and Olibe, 2010; Jaisinghani, 2015; Zhaohui and Xiaokang, 2011; Goto and Sueyoshi, 2008) Furthermore, R&D expenditures in some sectors do not affect financial performance (Sueyoshi and Goto, 2013). Accordingly, the relationship between R&D and firm performance still needs to study.

3. METHODOLOGY

This study investigated the relative efficiency of 27 Turkish firms based on 2019 data through a four-stage process. Descriptive analysis was conducted in the first stage. The second stage was concerned with evaluating the relative efficiency of the observed firms. Longitudinal (panel) data (2015-2019) analysis was conducted using the Malmquist index in the third stage. Simple Regression Analysis was conducted to examine how the Net Sales of DMUs determine their Scale Efficiency in the last stage.

3.1 The Applicability of Data Envelepment Analysis

DEA was chosen as the analysis method to be carried out within the scope of this study. International studies were examined to determine the input and output variables used in DEA. Many studies in the literature used the DEA method to analyze the effect of R&D expenditures on firm performance. For example, Sueyoshi and Goto (2013) analyzed the relationship between R&D expenditure and the corporate value of companies operating in the Japanese IT sector. Zhong et al. (2011) analyzed the relationship between R&D investments and the productivity of companies operating in the Chinese IT industry. Sueyoshi and Goto (2009) analyzed the relationship between R&D investments and the financial performance of enterprises operating in the Japanese machinery industry. DEA analysis realizes the effect of R&D expenditures on firm performance in these studies. The closest study to our study is Balteiro et al. (2006) 's work. Balteiro et al. (2006) analyzed the impact of R&D and innovation activities on Product Effectiveness as a variable were selected Personal Number, Shareholder Shares, Loans, R&D expenditures, R&D Partnerships, Sales Revenue, Patents, Product Innovations, and Process Innovations. Other studies using DEA can be summarized as follows: Kula and Özdemir (2007); Yalama and Sayım (2008); Sadjadi et al. (2011); Sueyoshi and Goto (2009); Sueyoshi and Goto (2013); Zhong et al. (2011); Balteiro et al. (2006).

3.2 DEA Models

Using only financial data to evaluate business performance may not give accurate results in evaluating business performance. For this reason, it is crucial to analyze the firm performance by using different criteria instead of using a single criterion. Data Envelopment Analysis (DEA) is an analysis method that allows many input and output variables to be used independently (Bayaraa et al., 2020).

Data Enveloping analysis (DEA) was first introduced by Farrell (1957) and developed by Charnes et al. (1978). The DEA measures efficiency within the Decision-Making Unit (DMU) using various inputs (Dobos and Vorosmarty, 2019; Khodakarami et al., 2014; Hilmola et al., 2015). Although DEA has only been used to measure the productivity of non-profit businesses in the past, it also analyzes the productivity of many sectors (Yenilmez and Girginer, 2012; Avkiran, 2001). DEA is a data-driven approach that allows multiple input variables to be transformed into output variables and is used in performance evaluation (Bayaraa et al., 2020). Thus, DEA succeeds in successfully measuring the performance of DMUs, despite the problems encountered in analyzes using multiple inputs and outputs variables. With this aspect, DEA can determine the strengths and weaknesses according to the dynamics of each sector (Celik and Ayan, 2017).

3.3 Mathematical Structure of DEA

The basic efficiency measure is the ratio of total outputs to total inputs (Ramanathan, 2003; Emrouznejad and Cabanda, 2014).

$$Efficiency = \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{rj}} \qquad (1)$$

where
y_{rj}= the amount of r^{th} output from DMU j,
u_r= the weight given to the r^{th} output,
x_{ij}= the amount of i^{th} input used by DMU j,
v_i= the weight given to the i^{th} input.

The basic DEA models based on returns to scale and model orientation are; CCR (CRS) Input-Orientation, CCR (CRS) Output-Orientation, BCC (VRS) Input-Orientation, and BCC (VRS) Output-Orientation (Ozcan, 2014).

As follows, the calculation of DEA scores is briefly explained using mathematical notations; the efficiency scores for a group of peer DMUs ($j = 1 \dots . n$) are computed for selected outputs ($y_{rj}, r = 1, \dots, s$) and inputs ($x_{ij}, i = 1, \dots\dots, m$) (Cooper et al., 2006, Ozcan, 2014 and, Emrouznejad and Cabanda, 2014).

CCR (CRS)-Input Orientation
(CCR-I);

$$Min_{\lambda,h,S_i^-,S_r^+} \Phi$$

s.t.

$$\sum_j \lambda_j x_{ij} + S_i^- = \Phi x_{ij_0} \quad \forall i$$

$$\sum_j \lambda_j y_{rj} - S_r^+ = y_{rj_0} \quad \forall r$$

$$s_i^-, s_i^+ \geq 0 \quad \forall i, \forall r$$

$$\lambda_j \geq 0 \qquad (2)$$

CCR (CRS)-Output Orientation
(CCR-O);

$$Min_{\lambda,h,S_i^-,S_r^+} h$$

s.t.

$$\sum \lambda_j x_{ij} + S_i^- = x_{ij_0} \quad \forall i$$

$$\sum \lambda_j y_{rj} - S_r^+ = h y_{rj_0} \quad \forall r$$

$$s_i^-, s_i^+ \geq 0 \quad \forall i, \forall r$$

$$\lambda_j \geq 0 \qquad (3)$$

BCC (VRS)-Input Orientation
(BCC-I);

$$\Phi$$

s.t.

$$\sum_j \lambda_j x_{ij} + S_i^- = \Phi x_{ij_0} \quad \forall i$$

$$\sum_j \lambda_j y_{rj} - S_r^+ = y_{rj_0} \quad \forall r$$

$$\sum_j \lambda_j = 1$$

$$s_i^-, s_i^+ \geq 0 \quad \forall i, \forall r$$

$$\lambda_j \geq 0 \quad \forall_j. \qquad (4)$$

BCC (VRS)-Output Orientation
(BCC-O);

$$\theta$$

s.t.

$$\sum_j \lambda_j x_{ij} + S_i^- = x_{ij_0} \; \forall i$$

$$\sum_j \lambda_j y_{rj} - S_r^+ = \theta y_{rj_0} \quad \forall r$$

$$\sum_j \lambda_j = 1$$

$$s_i^-, s_i^+ \geq 0 \quad \forall i, \forall r$$

$$\lambda_j \geq 0 \quad \forall_j. \qquad (5)$$

3.4 Malmquist Total Factor Productivity Index

Productivity can be represented as the ratio between outputs and inputs (Medarevi´c and Vukovi´c, 2021). Malmquist (1953) promoted a quantity index, defined as the amount by which one consumption bundle must be radially scaled to constitute the same utility level provided by some base consumption bundle (Malmquist, 1953 and, Grifell-Tatjé and Lovell, 1995).

Following Malmquist's concept, Färe et al. developed the DEA-based Malmquist total factor productivity (TFP) to contain all factors of production (Malmquist, 1953, Färe et al., 1992, Färe et al., 1994).

The Malmquist index (MI) has gained popularity for measuring productivity change.

The DEA-based Malmquist TFP index is expressed using the following formula (Ozcan, 2008)

$$M_I^{t+1}\,(y^{t+1}, x^{t+1}, y^t, x^t) =$$

$$\left[\frac{D_I^t(y^{t+1},x^{t+1})}{D_I^t(y^t,x^t)}\; x\; \frac{D_I^{t+1}(y^{t+1},x^{t+1})}{D_I^t\,(y^t,x^t}\right]^{1/2} \quad (6)$$

Where
M_I = Malmquist Index
D_I = Input Distance Functions
X= Input Vector
Y= Output Vector

The Malmquist productivity index is divided into two elements; the first element is the technical change in efficiency (ECH) (the catch-up effect) the second element is technological change (TECH) (the frontier shift effect) (Färe et al., 2011).

$$ECH = \frac{D_I^{t+1}\,(y^{t+1}, x^{t+1})}{D_I^t(y^t, x^t)}$$

$$TECH = \left[\frac{D_I^t(y^{t+1}, x^{t+1})}{D_I^{t+1}(y^{t+1}, x^{t+1})}\; x\; \frac{D_I^t(y^t, x^t)}{D_I^{t+1}\,(y^t, x^t}\right]^{1/2}$$

The change in the Malmquist productivity index (TFPCH) is the result of the multiplication of the change in technical efficiency (ECH) and technological change (TECH). If this index is greater than 1, the productivity increases between points of time t and t + 1. Otherwise, productivity decreases if TFP is less than one and is stagnant if it equals one. At the same time, the Malmquist index determines the contribution of diffusion and learning (efficiency change or the catching up effect) and innovation (technical change of shifts in the frontier of technology) to productivity changes (Medarevi´c and Vukovi´c, 2021).

3.5 Sample

The study is based on data from 27 companies included in Borsa İstanbul Inc. (BIST 100) index and Fortune Turkey 500 list between 2015 and 2019. The BIST 100 index shows the top 100 companies with the highest trading volume and market value traded in Borsa İstanbul Inc. The Fortune 500 list is a crucial indicator of international studies and lists the top 500 companies with the highest turnover in the local area.

Companies listed in the BIST 100 Index and the Fortune Turkey 500 list between 2015 and 2019 were selected. The reasons for choosing this sample are: (1) Companies included in the BIST 100 Index are the most valuable and most traded in Turkey, (2) Fortune 500 businesses generally operate in the high-tech and service industry, and (3) The businesses in the Fortune 500 list are listed according to their "Net Sales", "Net Sales Change", "Total Assets", "Equity" "Exports" (Ozutku, 2019) and (4) It is accepted in international studies in the Fortune 500 list (Sarıkaya and Akarca, 2011; Kılıc et al., 2021; Razi et al., 2019; Powers et al., 2020; Liozu, 2019; Gunay et al., 2018).

The correct selection of DMUs to be compared is vital and DMUs should be homogeneous. In other words, DMUs should be performing the same tasks with similar objectives using the same inputs and outputs under the same set of market conditions (Golany, 1989). The sample size is expected to be at least 2 or 3 times larger than the sum of the number of inputs and outputs (Ramanathan, 2003). Since there are 27 DMUs, 4 inputs, and 3 outputs, this requirement was met. Descriptive statistics of the sample are presented in Appendix 1.

3.6 Inputs, Outputs, and Data

When the studies in the literature are examined, it is seen that the country's stock exchanges are selected as examples in many studies to analyze the effect of R&D expenditures on firm performance. For example, in Wang et al. (2013), high-tech companies traded on the Taiwan Stock Exchange; Ghaffar and Khan (2014) found pharmaceutical companies traded on the Pakistan Stock Exchange; Vithessonthi and Racela (2016) are listed on the U.S. stock exchange; Sueyoshi and Goto (2013) operate IT businesses traded on the Japan Stock Exchange; Sueyoshi and Goto (2008) cited the machinery industry traded on the Japanese stock exchanges as examples. Other studies that choose country exchanges as a sample in their studies can be listed as follows: Kula and Ozdemir (2007); Yalama ve Sayım (2008); Cassia et al. (2009).

In this study, the data of companies included in the BIST 100 and Fortune Turkey 500 lists between 2015 and 2019 were used to examine the impact of R&D expenditures on firm performance. In the literature, New Product Sales (Kafouros et al., 2015), Patents (Lin et al., 2012), New

Product Turnover (Visser et al., 2010), etc. variable was used to measure the effect of R&D expenditures on firm performance. input and output variables were selected based on previous theoretical and experimental studies. Considering previous studies and available data, we decided to use four inputs and three outputs for this study. The definition of the relevant variables is presented as follows.

During the analysis, while R&D Expenditure (i1), R&D Personnel Cost (i2), Personal Number (i3), and Marketing Expenditure (i4) were selected as the input variable; Total Income (o1), Export Income (o2), and Patent Number (o3) were selected as the output variable.

R&D Expenditure (i1) represents the total budget spent on all Research and Development (R&D) activities carried out to develop new products, processes, or technologies in different parts of the business. R&D Expenditure is a primary index that reflects the effort spent on R&D competence in different departments (Dong and Wu, 2012). Therefore, R&D Expenditure is included in the study as an input variable. In addition, R&D expenditure has found its place in many studies in the literature as input value (Ouenniche and Carrales, 2018; Zhang et al., 2007; Guan and Chen, 2010; Hagedoorn and Cloodt, 2003; Rousseau and Rousseau, 1997).

R&D Personnel Cost (i2) represents the total budget paid to all personnel involved in R&D activities carried out within the enterprise. There are two primary inputs in R&D processes; R&D investments and R&D personnel (Wang, 2007). R&D personnel is the most critical factor in reflecting the enterprise's R&D capabilities (Dong and Wu, 2012). However, instead of the R&D Personnel Number, the R&D Personnel Cost variable was used in the study. Because all personnel (software developers, designers, researchers, technicians, etc.) involved in any stage of R&D activities are defined as R&D personnel. However, since the dynamics of each enterprise are different, the number of software developers, designers, researchers, or technicians employed is different. For example, while companies operating in the telecommunications sector mostly have software developers, more research personnel in businesses operating in the food sector. However, the wages of personnel working in a similar business line are almost equal. Therefore, if the number of R&D personnel were used as a variable, the analysis might not be accurate. As a result, we think using the R and D personnel cost variable in the study is more accurate. R&D Personnel Cost has been included in some studies in the literature as an input variable (Hu et al., 2014; Ouenniche and Carrales, 2018).

The total personal number (i3) represents the full-time employees of the enterprise. We explained why the number of R&D personnel was not included in the analysis. However, the activities of the enterprises are possible thanks to the personnel. Therefore, we used this variable to examine the impact of the total number of employees of the enterprise on R&D activities and operating income. Personal Number has found a place in studies in the literature as an input variable (Wang, 2007; Dobrzanski, 2018; Cazares et al., 2013; Ouenniche and Carrales, 2018; Kayalıdere and Kargin, 2004).

Marketing Expenditure (i4) shows the firm's total marketing expenditure. Firms spend their marketing expenses to be successful in the market, and therefore they invest a significant amount in marketing activities (Fine et al., 2017). Companies' advertising expenditure, promotion activities, sponsorships, and social responsibility activities are related to customer value. These activities have significant effects on firms' long-term market and market value (Conchar et al., 2005; Pruitt et al., 2004). In addition, the literature has found that marketing expenditures have significant effects on firm performance (Sing et al., 2005; Krasnikov and Jayachandran, 2008; Luo, 2008; Feng et al., 2016). So, in this study, marketing expenditure is included as another input variable.

Total income (o1) represents the total amount of income of the business in one year. Businesses must constantly develop innovation activities to compete, acquire new customers, retain existing customers and maintain their assets. Therefore, it is thought that there is a clear link between R&D expenditures and the financial performance of enterprises. For example, businesses developing products for customer demands have higher sales levels (Srinivasan et al., 2009), or businesses obtain new incomes by selling or renting patent rights (Teirlinck, 2017). Many studies determine a relationship between R&D activities and company income in the literature (XU and Tang, 2010; Eberhart et al., 2015, 2013; Jaisinghani, 2015; Vanderpal, 2015). However, as stated in the introduction of the study, it is known that there is no linear and positive relationship between R&D and financial performance in many studies in the literature (Lantz and Sahut, 2005; Sundaram et al., 1996; Liv d., 2008). Therefore, Total Income is used as an output variable in the study to clarify the relationship between R&D expenditures and firm performance.

Export Income (o2) represents all the revenues businesses have obtained from their overseas sales. We assume that due to R&D studies of enterprises, productivity will increase, and export income will increase with their increased productivity (Cieslik et al., 2018). When the studies in the literature are examined, it has been determined that businesses with R&D expenditures export more than enterprises without R&D expenditures (Golovko, and Valentini, 2011; Love and Roper, 2013). Therefore, Export Income is one of the most used variables in the literature to measure the impact of R&D expenditures on firm performance (Sinimole and Saini, 2020; Halaskova et al., 2020; Bojnec and Ferto, 2015; Guan and Ma, 2003; Imran et al., 2018; Cieslik et al., 2014; Braunerhjelm, 1996; Hirsch and Bijaoui, 1985).

The patent number (o3) represents the number of all intellectual and industrial property rights (applications and registrations) filed due to the R&D studies implemented within the enterprise. New ideas, methods, designs, and products that emerge from R&D personnel and R&D expenditures are protected by patents. Therefore, the patent is accepted as an output of R&D activities (Aktop, 2021)

The data are taken from Espacenet, which is under the right ownership of the European Patent Institute (Espacenet, 2021). The patent is the right to protection obtained from scientific or technical research. Businesses constantly develop new R&D activities in terms of competitive advantage and customer satisfaction. We assume that R&D activities increase the innovation performance of enterprises and R and D outputs, increasing the number of patents (Binh, Tung, 2020; Dong and Wu, 2012; Sinimole and Saini, 2020). Patents have been used as an output variable in many studies in the literature (Dong and Wu, 2012; Chen and Chen, 2011; Lin et al., 2012; Rousseau and Rousseau, 1998; Wang, 2007; Karadayi and Ekinci, 2019; Sharma and Thomas, 2008; Hu et al., 2014; Fu and Yang, 2009).

The data of the input and output variables used in the study were taken from the official website of the Public Disclosure Platform (KAP). The Public Disclosure Platform is a platform where everyone should see the data of all businesses traded in the Turkish Capital Market and Exchange. The status and data of the companies in the Fortune Turkey 500 list are taken from the Fortune Turkey website.

Between 2015 and 2019, 89 companies were found that were both listed in the BIST 100 Index and included in the Fortune Turkey 500 list. All variables must be complete for DEA to be performed correctly and without errors. For this reason, 50 companies were excluded from the study because their data was incomplete or because the data in the annual reports and the Fortune Turkey 500 list did not match. The study was conducted with data from the remaining 27 firms from 2015 to 2019 (Table 1). Input and output values are enclosed on the basis of years in the annex.

Table 1. Descriptive statistics of input and output variables, 2015–2019.

PERIOD	INPUT/ OUTPUT	MINIMUM	MEDIAN	MEAN	MAXIMUM
2015	I1	0.573	7.042	29.637	265.723
	I2	0.465	3.655	40.415	734.725
	I3	440	2105	5998	34147
	I4	11.87	86.84	373.29	2722.01
	O1	225.9	1052.8	5226.9	36893.3
	O2	12.62	290.30	1627.04	10723.04
	O3	0.000	0.000	7.741	81.000
2016	I1	0.5366	7.7665	39.1258	383.8441
	I2	0.4592	4.1890	50.1630	859.1430
	I3	453	2297	6085	33224
	I4	5.798	98.273	416.804	3227.324
	O1	253.9	1307.9	5516.5	34854.8
	O2	12.55	394.39	1735.15	12286.68
	O3	0.00	0.00	27.44	251.00
2017	I1	0.7876	13.1130	41.2171	317.1920
	I2	0.115	7.383	56.601	1046.544
	I3	470	2425	6418	34502
	I4	9.231	125.076	499.989	4027.699
	O1	346.0	1785.3	7635.5	53948.1
	O2	18.14	407.02	2491.52	17830.09
	O3	0.00	1.00	60.37	906.00
2018	I1	0.5045	12.5510	50.5227	368.5680
	I2	0.4162	5.5907	64.4875	1202.4850
	I3	479	2224	6376	33417
	I4	18.35	126.84	554.76	5094.43
	O1	586.6	2352.8	10582.8	88552.2
	O2	28.23	807.12	3478.83	27303.44
	O3	0.00	0.00	20.44	341.00
2019	I1	1.345	14.390	52.908	419.583
	I2	0.2167	12.0340	85.0302	1501.6170
	I3	510	2232	6443	32180
	I4	22.70	201.35	608.57	5094.43
	O1	584.5	2492.9	11528.5	89600.8
	O2	45.43	1054.32	4218.08	33375.43
	O3	0.000	0.000	3.889	81.000

4. RESULT

4.1 Descriptive Analysis

Table 1 reports descriptive statistics for input and output variables for the period 2015–2019. These variables were used to evaluate the total factor productivity of the Turkish firms in the study.

According to Table 1;

- The mean number of R&D Expenditures has increased between 2015 and 2019, with a
- the five-year average of 42.682.
- The mean number of R&D Personnel Cost has increased between 2015 and 2019, with a five-year average of 59.339.
- The mean number of Total personal numbers has increased between 2015 and 2019, excluding 2018, with a five-year average of 6,264,000.
- The mean number of Marketing Expenditures has increased between 2015 and 2019, with a five-year average of 490.683.
- The mean Total Income increased between 2015 and 2019, with a five-year average of 8,098.040.
- The mean number of Export Income has increased between 2015 and 2019, with a five-year average of 2,710.124.
- The mean number of Total personal numbers has increased between 2015 and 2019, excluding 2018 and 2019, with a five-year average of 23.796

4.2 Results of DEA

Table 2 presents the DEA calculations of the CRS, VRS, and SE scores for 2019.

Table 2. Efficiency scores of CRS, VRS, and SE in 2019.

DMU	Efficiency Scores			Σλ	Return to Scale	Reference Set (Benchmarks)
	CRS	VRS	SE			
DMU1	1.00000	1.00000	1.00000	1.00000	Constant	
DMU2	0.98320	1.00000	0.98320	4.60180	Decreasing	DMU1- DMU11
DMU3	0.43227	0.48091	0.89886	5.77610	Decreasing	DMU5- DMU11
DMU4	0.59123	0.62081	0.95235	2.33870	Decreasing	DMU1- DMU11
DMU5	1.00000	1.00000	1.00000	1.00000	Constant	
DMU6	0.68591	1.00000	0.68591	15.34090	Decreasing	DMU1- DMU5-DMU21
DMU7	0.31855	0.38774	0.82156	1.70150	Decreasing	DMU1- DMU19-DMU21
DMU8	0.30351	0.32150	0.94404	1.71520	Decreasing	DMU1- DMU11
DMU9	0.65701	0.72785	0.90267	1.21500	Decreasing	DMU1- DMU11
DMU10	0.10505	0.19083	0.55049	0.08710	Increasing	DMU1
DMU11	1.00000	1.00000	1.00000	1.00000	Constant	
DMU12	0.39423	0.63103	0.62474	0.10820	Increasing	DMU1- DMU11
DMU13	0.04768	0.15858	0.30067	0.03200	Increasing	DMU1
DMU14	0.23209	0.86065	0.26967	0.02780	Increasing	DMU1
DMU15	0.49120	0.67097	0.73207	0.09720	Increasing	DMU1
DMU16	0.31233	0.75739	0.41238	0.15160	Increasing	DMU1- DMU11
DMU17	0.30469	1.00000	0.30469	0.02550	Increasing	DMU1
DMU18	1.00000	1.00000	1.00000	1.00000	Constant	
DMU19	1.00000	1.00000	1.00000	1.00000	Constant	
DMU20	0.08240	0.54429	0.15139	0.01270	Increasing	DMU1
DMU21	1.00000	1.00000	1.00000	1.00000	Constant	
DMU22	0.10113	0.64619	0.15650	0.03520	Increasing	DMU1- DMU11
DMU23	0.50431	1.00000	0.50431	0.20880	Increasing	DMU1- DMU11
DMU24	0.11820	0.72503	0.16303	0.14070	Increasing	DMU11
DMU25	0.52259	1.00000	0.52259	0.00800	Increasing	DMU1
DMU26	0.03508	0.64354	0.05451	0.00670	Increasing	DMU1
DMU27	1.00000	1.00000	1.00000	1.00000	Constant	
Mean	0.52677	0.75434	0.66428			
Median	0.49120	0.75739	0.73207			
Maximum	1.00000	1.00000	1.00000			
Minimum	0.03508	0.15858	0.05451			
St. Dev.	0.35738	0.27133	0.33273			

According to Table 2;

- 7 out of the 27 firms were technically efficient in the CRS model.
- These were firms: DMU1, DMU5, DMU11, DMU18, DMU19, DMU21, and DMU27. The findings indicated that they were efficient at the technical and scale levels. The remaining 20 firms were found technically inefficient. Technical efficiency scores ranged from 0.03508 to 1. The average technical efficiency score was 0.52677.
- The CRS efficient firms were also efficient in pure technical and scale efficiency measures.
- The variable return to scale (VRS) represents pure technical efficiency. It measures inefficiencies due to managerial underperformance only.
- The firms DMU2, DMU6, DMU17, DMU23, and DMU25 were VRS-efficient but not CRS-efficient. These firms were technically efficient, and their inefficiency in CRS was due to environmental factors rather than technical factors. The average VRS efficiency score was 0.75434, and the standard variation was 0.27133.
- The scale efficiency calculated by the DEA method revealed that seven firms were efficient and operating under constant returns to scale. Seven firms were operating under decreasing returns to scale, meaning that input increases cause less than proportional output increases. Their average scale efficiency was 0.8841.
- On the other hand, 13 firms were operating under increasing returns to scale. Their average scale efficiency was 0.3652. Increasing returns to scale results from positive feedback within the market to improve something already developed or to worsen an already bad situation.

Efficiency scores were presented for firms for each year in Table 3. 15 of 27 firms were on the frontier once, but only three firms were on the frontier more than three times.

Table 3. The efficiency of firms under constant return to scale, 2015–2019.

DMU	Efficiency Scores (CRS)					Number of Times on the Frontier
	2015	2016	2017	2018	2019	
DMU1	1.00000	1.00000	1.00000	1.00000	1.00000	5
DMU2	1.00000	1.00000	1.00000	0.84077[d]	0.98320[d]	3
DMU3	1.00000	1.00000	0.53788[d]	1.00000	0.43227[d]	3
DMU4	1.00000	1.00000	0.55296[d]	1.00000	0.59123[d]	3
DMU5	1.00000	1.00000	0.94286[d]	1.00000	1.00000	4
DMU6	0.13299[d]	0.33024[d]	0.07833[i]	1.00000	0.68591[d]	1
DMU7	0.30737[d]	0.39445[d]	1.00000	0.95012[d]	0.31855[d]	1
DMU8	0.37439[d]	0.57189[i]	0.75549[d]	1.00000	0.30351[d]	1
DMU9	0.63808[i]	0.60716[i]	0.56160[d]	0.52942[d]	0.65701[d]	
DMU10	0.18263[d]	0.16728[d]	0.12138[i]	0.12469[i]	0.10505[i]	
DMU11	1.00000	1.00000	1.00000	1.00000	1.00000	5
DMU12	0.46488[i]	0.44721[i]	0.37176[i]	0.45720[i]	0.39423[i]	
DMU13	0.05111[i]	0.06058[i]	0.05038[i]	0.04801[i]	0.04768[i]	
DMU14	0.17868[i]	0.13063[i]	0.34512[i]	0.27554[i]	0.23209[i]	
DMU15	1.00000	1.00000	1.00000	0.22297[i]	0.49120[i]	3
DMU16	0.50660[i]	0.47707[i]	0.26791[i]	0.25662[i]	0.31233[i]	
DMU17	0.45987[i]	0.43090[i]	0.33794[i]	0.26806[i]	0.30469[i]	
DMU18	0.10667[i]	0.11385[i]	0.13483[i]	0.10771[i]	1.00000	1
DMU19	0.14413[i]	0.06881[i]	0.05679[i]	0.14252[i]	1.00000	1
DMU20	0.09204[i]	0.11352[i]	0.08874[i]	0.07029[i]	0.08240[i]	
DMU21	0.25183[i]	0.19405i	0.51528[i]	0.83114[i]	1.00000	1
DMU22	0.17511[i]	0.16474[i]	0.12306[i]	0.13560[i]	0.10113[i]	
DMU23	1.00000	1.00000	1.00000	0.89373[i]	0.50431[i]	3
DMU24	0.05553[i]	0.09580[i]	0.08748[i]	0.06801[i]	0.11820[i]	
DMU25	0.20280[i]	0.29916[i]	0.26741[i]	0.60038[i]	0.52259[i]	
DMU26	0.07111[i]	0.07094[i]	0.04984[i]	0.04958[i]	0.03508[i]	
DMU27	0.09984[i]	0.22176[i]	0.15323[i]	0.39327[i]	1.00000	1
Mean	0.46280	0.48000	0.45927	0.52836	0.52677	
Median	0.30737	0.39445	0.34512	0.45720	0.49120	
Maximum	1.00000	1.00000	1.00000	1.00000	1.00000	
Minimum	0.05111	0.06058	0.04984	0.04801	0.03508	
St. Dev.	0.38343	0.37467	0.36987	0.38778	0.35738	

Note: *i = increasing return to scale, d = decreasing return to scale.*

On the other hand, Table 3 reports the efficiency reference set or peers (also called benchmarks) for each inefficient firm. Each reference set comprises several peers to which inefficient firms may be benchmarked. The most appeared firm in reference sets was DMU1, with 18 times.

4.3 Results of the Malmquist Index

The results of the Malmquist index are presented in Table 4.

According to Table 4;

- Eighteen firms improved in the Malmquist Index [TFPCH] from 2015 to 2019, with the most improvement in 2015-2016.
- Ten firms improved in the Efficiency Change [ECH] from 2015 to 2019, with the most improvement shown in 2017-2018.
- Sixteen firms improved in the Frontier Shift (TECH) from 2015 to 2019, with the most improvement in 2016-2017.
- Ten firms improved in the Pure Efficiency Change [PECH] from 2015 to 2019, with the most improvement in 2017-2018.
- Ten firms improved in the Scale Efficiency Change [SECH] from 2015 to 2019, with the most improvement in 2018-2019.

Table 4. The average Malmquist index, frontier shift, and efficiency changes from 2015 to 2019.

DMU	Malmquist Index [TFPCH]	Efficiency Change [ECH]	Frontier Shift [TECH]	Pure Efficiency Change [PECH]	Scale Efficiency Change [SECH]
DMU1	1.12802	1.00000	1.12802	1.00000	1.00000
DMU2	1.11189	0.99577	1.11661	1.00000	0.99577
DMU3	0.71666	0.81085	0.88384	0.83275	0.97369
DMU4	0.67848	0.87688	0.77374	0.88765	0.98787
DMU5	0.92653	1.00000	0.92653	1.00000	1.00000
DMU6	0.97189	1.50700	0.64492	1.54934	0.97267
DMU7	0.79282	1.00897	0.78577	0.87592	1.15190
DMU8	0.68080	0.94889	0.71747	0.96050	0.98790
DMU9	1.11271	1.00734	1.10461	1.03170	0.97639
DMU10	0.99019	0.87088	1.13700	0.97505	0.89317
DMU11	1.00765	1.00000	1.00765	1.00000	1.00000
DMU12	1.02958	0.95963	1.07290	1.01512	0.94533
DMU13	1.17044	0.98282	1.19090	0.99977	0.98305
DMU14	1.14879	1.06757	1.07609	0.96318	1.10838
DMU15	0.89718	0.83717	1.07168	0.90506	0.92499
DMU16	1.16696	0.88610	1.31695	1.07915	0.82111
DMU17	1.12191	0.90220	1.24353	1.00000	0.90220
DMU18	1.48503	1.74980	0.84869	1.06227	1.64723
DMU19	1.78755	1.62298	1.10140	1.28334	1.26465
DMU20	1.16299	0.97270	1.19562	1.06179	0.91610
DMU21	1.11089	1.41164	0.78695	1.00000	1.41164
DMU22	1.14576	0.87174	1.31434	0.94674	0.92078
DMU23	0.62308	0.84270	0.73939	1.00000	0.84270
DMU24	1.19945	1.20785	0.99305	1.01753	1.18705
DMU25	1.30047	1.26699	1.02643	1.00000	1.26699
DMU26	1.02690	0.83804	1.22536	1.06134	0.78961
DMU27	1.26647	1.77898	0.71191	1.08027	1.64679
2015–2016	1.44151	1.08014	1.33455	0.98030	1.10184
2016–2017	1.29350	0.90725	1.42573	0.99902	0.90815
2017–2018	0.84167	1.17785	0.71458	1.12699	1.04513
2018–2019	0.73650	1.06178	0.69365	0.96017	1.10582
2015–2019	1.07830	1.05676	1.04213	1.01662	1.04024

4.4 Results of Regression Analysis

Simple Regression Analysis was conducted to examine how the Net Sales of DMUs determine their Scale Efficiency. The results of the analysis are presented in Table 5.

According to Table 5; the results of simple regression are a significant relationship between Scale efficiency and Net Sales ($F(1,25)=6,068$, $p<.05$, Adjusted R2: 0.163). Scale Efficiency increases by 0.163 for extra Net Sales of firms.

Table 5. The Results of Simple Regression Analysis

Variables	**B**	**Std. Error**	**β**
Net Sales (TL)	7.6651E-12	.000	.442*
Constant	.574	.069	

Constant: Scale Efficiency (SE)
Note: R^2= 0.195; Adj. R^2=0.163 ; $F(1,25)$=6,068, * $p<.05$

5. DISCUSSION AND CONCLUSION

As stated in the introduction, the purpose of the study is twofold. The first is to evaluate the relative efficiency of the observed firms. The second is to conduct longitudinal (panel) data analysis using the Malmquist index.

7 out of the 27 firms were found technically efficient In the CRS model. These are as follows;

- Tüpraş Petrol Rafinerileri A.Ş. (Dmu1)
- Turkcell İletişim Hizmetleri A.Ş. (Dmu5)
- Sarkuysan Elektrolitik Bakir Sanayi Ve Ticaret A.Ş. (Dmu11)
- Yataş Yatak Ve Yorgan Sanayi Ticaret A.Ş (Dmu18)
- Kaleseramik Çanakkale Kalebodur Seramik Sanayi A.Ş. (Dmu19)
- Ege Profil Ticaret Ve Sanayi A.Ş. (Dmu21)
- Alarko Carrier Sanayi Ve Ticaret A.Ş. (Dmu27)

The finding indicated that they were efficient at the technical and scale levels. Mentioned 27 firms could achieve the same level of performance and the same output levels by using 47.323% fewer resources. Otherwise, firms needed to produce 1.8983 (=1/0.52677) times as many outputs from the same level of inputs. For this reason, an inefficient firm had to reduce its inputs and improve its internal practices.

Five firms were VRS-efficient but not CRS-efficient. These are as follows;

- Ford Otomotiv Sanayi A.Ş. (Dmu2)
- Türk Telekomünikasyon A.Ş. (Dmu6)
- Türk Prysmian Kablo Ve Sistemleri A.Ş. (Dmu17)
- Ege Endüstri Ve Ticaret A.Ş. (Dmu23)
- İhlas Holding A.Ş. (Dmu25)

These firms were technically efficient, and their inefficiency in CRS was due to environmental factors rather than technical factors.
Seven firms were operating under decreasing returns to scale. Namely input increases cause less than proportional output increases for these firms. These are as follows;

- Ford Otomotiv Sanayi A.Ş. (Dmu2)
- Arçelik A.Ş. (Dmu3)
- Ereğli Demir Ve Çelik Fabrikalari A.Ş.(Dmu4)
- Türk Telekomünikasyon A.Ş. (Dmu6)
- Vestel Eektronik Sanayi Ve Ticaret A.Ş. (Dmu7)
- Aselsan Elektronik Sanayi Ve Ticaret A.Ş. (Dmu8)
- Petkim Petrokimya Holding A.Ş. (Dmu9)

On the other hand, 13 firms were operating under increasing returns to scale. Namely input increases cause greater than proportional output increases These are as follows;

- Ülker Bisküvi Sanayi Ticaret A.Ş. (Dmu10)
- Aksa Akrilik Kimya Sanayi A.Ş.(Dmu12)
- Mavi Giyim San. Ve Tic. A.Ş. (Dmu13)
- Kerevitaş Gida Sanayi Ve Ticaret A.Ş. (Dmu14)
- Otokar Otomotiv Ve Savunma Sanayi A.Ş. (Dmu15)
- Karsan Otomotiv Sanayii Ve Ticaret A.Ş. (Dmu16)
- Türk Prysmian Kablo Ve Sistemleri A.Ş. (Dmu17)
- Dyo Boya Fabrikalari Sanayi Ve Ticaret A.Ş. (Dmu20)
- Bursa Çimento Fabrikasi A.Ş. (Dmu22)
- Ege Endüstri Ve Ticaret A.Ş. (Dmu23)
- Karel Elektronik Sanayi Ve Ticaret A.Ş. (Dmu24)
- İhlas Holding A.Ş. (Dmu25)
- Doğtaş Kelebek Mobilya San. Ve Tic. A.Ş. (Dmu26)

The reference sets comprise several peers to which inefficient firms may be benchmarked. The most appeared firm in reference sets was TÜPRAŞ PETROL RAFİNERİLERİ A.Ş. (DMU1), with 18 times. Namely, TÜPRAŞ PETROL RAFİNERİLERİ A.Ş. (DMU1) serves as a Best-Practice Model for 18 firms. According to the lambda values, all firms are classified into three groups: those who operated with decreasing returns to scale, those who operated with increasing returns to scale, and the most efficient that operated with constant returns to scale.

The results of Simple Regression Analysis demonstrate that Scale Efficiency increases by 0.163 for extra Net Sales of firms. Based on these results, it can be said that if a firm wants to increase its R&D efficiency score, it should increase its Net Sales.

According to Malmquist Analysis results; MFP scores of 18 firms are above 1 in the 2015-2019 period. KALESERAMİK ÇANAKKALE KALEBODUR SERAMİK SANAYİ A.Ş. (DMU19) is the first DMU in the Malmquist Index [TFPCH]. Also, it is efficient for all DEA models. ALARKO CARRIER SANAYİ VE TİCARET A.Ş. (DMU27) is the first DMU in Efficiency Change [ECH]. KARSAN OTOMOTİV SANAYİİ VE TİCARET A.Ş. (DMU16) is the first DMU in terms of Frontier Shift (TECH). TÜRK TELEKOMÜNİKASYON A.Ş. (DMU6) is the first DMU in Pure Efficiency Change [PECH].

Performance of the firms increased 44% (2016) and 29% (2017) compared to the previous years. Besides, 7% (2019) performance improvement is found compared to 2015.

However, in 2018 a performance decrease of 44% compared to 2017, and in 2019 a performance decrease of 27% compared to 2018 was detected. The performance decrease might be related to the 2018-2019 global financial tightening and depreciation of the Turkish Lira. Respectively, firstly 2018-2019 global financial tightening and depreciation of the Turkish Lira triggered the decrease of technological change (TECH) (the frontier shift effect). Then TECH caused to decrease in Malmquist Index (TFPCH).

The most improvement in the Malmquist Index [TFPCH] appeared in 2015-2016, the most improvement in the Efficiency Change [ECH] appeared in 2017-2018, the most improvement in the Frontier Shift (TECH) appeared in 2016-2017, the most improvement in the Pure Efficiency Change [PECH] appeared in 2017-2018 and, the most improvement in the Scale Efficiency Change [SECH] appeared in 2018-2019.

Using the DEA method and Malmquist total factor productivity index, our study has empirically shown a large margin for improvement in efficiency in Turkish firms.

In Firsova et al. (2022)'s study, it is said that it can be concluded that the change in aggregate costs explains most of the differences in efficiency. Our findings are in line with Firsova et al. (2022)'s study. According to our results, it can be said that if a firm wants to increase its R&D efficiency score, it should increase its Net Sales. The results of Dai and Liu (2009)'s paper shows that the R&D efficiency is at a relatively low level in Chinese High-Tech industries as well as productivity growth. However, efficiency firms have high technology in our study. This situation is thought to be due to the fact that Chinese companies generally make labor-intensive production.

In Han et al. (2014)'s study, the appearance of three efficient regions and 12 inefficient regions clearly indicates an interregional disparity in terms of static R&D efficiency. In line with Han et al. (2014)'s study, in our study, 7 out of the 27 firms were found technically efficient in the CRS model and there is a disparity across firms.

Firsova and Chernyshova (2020)'s paper shows that the impact of innovation policy on the innovative development in the Russian regions. In line with this, in our study, the DMUs with high R&D Expenditure and R&D Personnel Cost have more efficient and productivity score rather than the DMUs with relatively low R&D Expenditure and R&D Personnel Cost.

Liao et al. (2016)'s study shows that the scientific research innovation efficiency of the Guangzhou Institute of Respiratory Diseases (GIRD) was generally high and kept on growing. In our study, it is determined that most Turkish firms have high R&D efficiency.

Song and Zang (2013)'s paper indicates that TFP in the pharmaceutical industry and its affiliated three subsectors shows an upward trend and the growth in different industries are quite different. In line with this, in our study, the Turkish firms have been divided into three sub-group (High Net Sales Group, Medium Net Sales Group, and Low Net Sales Group) in terms of their Net Sales. Our results demonstrate that 2 firms are efficient in the High Net Sales Group; 2 firms are efficient in the Medium Net Sales Group and 3 firms are efficient in the Low Net Sales Group.

Several strategies for efficiency improvements and cost reduction were suggested in this paper. Managers of inefficient firms should follow the example of their top-performing peers to find the proper relationship between inputs and outputs in their specific contexts.

Further studies can be developed on new models applying different DEA approaches (Fuzzy DEA, Two-Stage DEA, Network DEA, etc.) to evaluate the efficiency and productivity of DMUs.

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Appendix:

Appendix 1. Descriptive statistics of DMUs

FIRM	DMU Code	Net Sales TL
Tüpraş Petrol Rafinerileri A.Ş.	DMU1	89,600,778,240.00
Ford Otomotiv Sanayi A.Ş.	DMU2	39,209,017,344.00
Arçelik A.Ş.	DMU3	31,941,773,312.00
Ereğli Demir Ve Çelik Fabrikalari A.Ş.	DMU4	27,465,185,280.00
Turkcell İletişim Hizmetleri A.Ş.	DMU5	25,137,135,616.00
Türk Telekomünikasyon A.Ş.	DMU6	23,657,107,456.00
Vestel Eektronik Sanayi Ve Ticaret A.Ş.	DMU7	17,174,122,496.00
Aselsan Elektronik Sanayi Ve Ticaret A.Ş.	DMU8	13,012,550,656.00
Petkim Petrokimya Holding A.Ş.	DMU9	11,672,219,648.00
Ülker Bisküvi Sanayi Ticaret A.Ş.	DMU10	7,803,120,128.00
Sarkuysan Elektrolitik Bakir Sanayi Ve Ticaret A.Ş.	DMU11	5,780,611,072.00
Aksa Akrilik Kimya Sanayi A.Ş.	DMU12	3,645,900,032.00
Mavi Giyim San. Ve Tic. A.Ş.	DMU13	2,862,882,048.00
Kerevitaş Gida Sanayi Ve Ticaret A.Ş.	DMU14	2,492,865,792.00
Otokar Otomotiv Ve Savunma Sanayi A.Ş.	DMU15	2,430,642,944.00
Karsan Otomotiv Sanayii Ve Ticaret A.Ş.	DMU16	1,704,291,456.00
Türk Prysmian Kablo Ve Sistemleri A.Ş.	DMU17	1,462,576,768.00
Yataş Yatak Ve Yorgan Sanayi Ticaret A.Ş	DMU18	1,166,946,176.00
Kaleseramik Çanakkale Kalebodur Seramik Sanayi A.Ş.	DMU19	1,159,076,864.00
Dyo Boya Fabrikalari Sanayi Ve Ticaret A.Ş.	DMU20	1,134,431,360.00
Ege Profil Ticaret Ve Sanayi A.Ş.	DMU21	1,047,210,176.00
Bursa Çimento Fabrikasi A.Ş.	DMU22	1,028,223,552.00
Ege Endüstri Ve Ticaret A.Ş.	DMU23	1,003,058,176.00
Karel Elektronik Sanayi Ve Ticaret A.Ş.	DMU24	813,299,200.00
İhlas Holding A.Ş.	DMU25	715,883,392.00
Doğtaş Kelebek Mobilya San. Ve Tic. A.Ş.	DMU26	602,401,728.00
Alarko Carrier Sanayi Ve Ticaret A.Ş.	DMU27	584,526,528.00