MEASURING THE EFFICIENCY OF THE TURKISH ELECTRIC DISTRIBUTION SECTOR USING STOCHASTIC FRONTIER ANALYSIS

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ABSTRACT

MEASURING THE EFFICIENCY OF THE TURKISH ELECTRIC DISTRIBUTION SECTOR USING STOCHASTIC FRONTIER ANALYSIS

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This study analyzes the technical efficiencies of Turkish electricity distribution companies (21 in total) throughout 2002 and 2009. For this aim, we used six different model specifications, all of which are generated from two different Stochastic Frontier Analysis (SFA) models (Battese ve Coelli (1992&1995)).

At the end of the estimations of the models, it has been seen that the signs and significance levels of the coefficient estimations are very consistent and satisfactory in all models. We also observed consistency between the coefficient estimations of the different models despite the differences in the magnitudes of the coefficient estimations. For example, all model specifications confirm the presence of increasing returns to scale and of a mild technological progress over time in the market. In addition, among the inputs, all inputs except the quality of the electricity delivered are important in enhancing technical efficiency of the electricity distribution companies, according to the all alternative specifications. Again, all models showed that inefficiency effects rather than random error effects are of crucial importance in Turkish electricity distribution market.

As for the efficiency estimations of the alternative models, the main conclusion revealed by our study is that efficiency estimations of the Battese ve Coelli (1995) models are remarkably higher than those of the Battese ve Coelli (1992) models. The efficiency estimation differences between Battese and Coelli (1992&1995) models can be attributed to the environmental variables included into the Battese ve Coelli (1995) models, which are not generally controlled by electricity distribution companies.

Keywords: Technical Efficiency, Turkish Electricity Distribution Market, Stochastic Frontier Analysis (SFA).

ÖZ

TÜRKİYE ELEKTRİK DAĞITIM SEKTÖRÜNÜN ETKİNLİĞİNİN STOKASTİK SINIR ANALİZİ KULLANILARAK ÖLÇÜLMESİ

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Bu çalışma, 2002 ve 2009 yılları arasında Türkiye elektrik dağıtım şirketlerinin (toplam 21) teknik etkinliklerini analiz etmektedir. Bu amaçla, tamamı iki farklı Stokastik Sınır Analizi (SFA) modelinden (Battese ve Coelli (1992&1995)) türetilmiş altı farklı model tanımlaması kullandık.

Modellerin tahmini neticesinde, katsayı tahminlerinin işaret ve anlamlılık düzeylerinin çok tutarlı ve tatmin edici olduğu görülmüştür. Katsayı tahminlerinin büyüklüklerinde farklılıklar olmasına rağmen, farklı modellerin katsayı tahminleri arasında da tutarlılıklar gözlemledik. Örneğin, tüm modeller, pazarda ölçeğe göre artan getiri ve zamanla yavaş bir teknolojik ilerlemenin varlığını onaylamaktadır. Ayrıca, tüm alternatif modellere göre, girdiler içerisinde, dağıtılan elektriğin kalitesi hariç tüm girdiler elektrik dağıtım şirketlerinin teknik etkinliklerinin iyileştirilmesinde önemlidir. Yine tüm modeller, Türkiye elektrik dağıtım pazarında rassal hata etkisinden ziyade etkinsizlik etkisinin kritik öneme sahip olduğunu göstermiştir.

Alternatif modellerin etkinlik tahminlerine gelince, bu çalışmadan çıkan ana sonuç, Battese ve Coelli (1995) modellerinin etkinlik tahminlerinin Battese ve Coelli (1992) modellerinin etkinlik tahminlerinden önemli ölçüde yüksek olduğudur. Battese ve Coelli (1992&1995) modellerinin etkinlik tahminleri arasındaki farklılıklar, Battese ve Coelli (1995) modellerine dahil edilmiş olan, genellikle elektrik dağıtım şirketleri tarafından kontrol edilemeyen çevresel değişkenlere bağlanabilir.

Anahtar Kelimeler: Teknik Etkinlik, Turkiye Elektrik Dağıtım Pazarı, Stokastik Sınır Analizi (SFA).

To my wife Alev and my son Murat Kaan

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LIST OF ABBREVIATIONS

BOO : Build-Own-Operate

BOT : Build-Operate-Transfer

COLS : Corrected Ordinary Least Squares

CRS : Constant Returns to Scale

DEA : Data Envelopment Analysis

DSİ : State Hydraulic Works

EİEİ: Electrical Works Survey Administration

EPDK : Energy Market Regulation Authority

EÜAŞ : Electricity Generation Co.

GWh : Gigawatthour (1 GWh=10^{-3} TWh $= 10^{3}$ MWh $= 10^{6}$ kWh)

IPP : Independent Power Producer

MLE : Maximum Likelihood Estimation

MVA : Megavolt Amperes

MW : Megawatt

RTS : Returns to Scale

SFA : Stochastic Frontier Analysis

TC : Technological Change

TE : Technical Efficiency

TEK : Turkish Electricity Authority

TOR : Transfer of Operating Rights

TEAŞ : Turkish Electricity Generation and Transmission Co.

TEDAŞ: Turkish Electricity Distribution Co.

TEİAŞ : Turkish Electricity Transmission Co.

TETAŞ:Turkish Electricity Trading and Contracting Co.

TÜBİTAK: Scientific and Technical Research Council of Turkey

OLS : Ordinary Least Squares

ÖİB : Privatization Administration

VRS : Variable Returns to Scale

CHAPTER 1

INTRODUCTION

Turkish electricity sector has exhibited a substantial growth since the 1970s due to the rapid industrialization and urbanization: The installed electricity generation capacity increased at an average annual rate of 7.78%, from 2,235 MW in 1970 to 44,761 MW in 2009. During the same time period, the quantity of electricity generated has been climbed from 8,623 GWh to 194,813 GWh, indicating an average annual growth of 8.11%. Thanks to these enormous growth rates, per capita electricity consumption has been increased to 2,162 kWh in 2009, still remaining lower than the OECD average of 8,550 kWh, though.

Similar to those of the most of the countries all over the world, Turkish electricity sector was traditionally controlled by a large state-owned enterprise, named Turkish Electricity Authority (TEK)[1], which was a vertically integrated organization dominant in electricity generation, transmission and distribution. TEK was divided into two companies, Turkish Electricity Generation and Transmission Co. (TEAŞ)[2] and the Turkish Electricity Distribution Co. (TEDAŞ)[3], in 1994. Then in 2001, Turkish government kicked off a comprehensive reform program to liberate the electricity market by passing the Electricity Market Law no. 4628. According to the reform program, firstly generation, transmission and distribution activities in the electricity market would be unbundled, and then the generation and distribution assets would be privatized. Following this program, in 2002, TEAŞ was separated into three companies, the Electricity Generation Co. (EÜAŞ)[4], the Turkish Electricity Trading and

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[1] "Türkiye Elektrik Kurumu" in Turkish.
[2] "Türkiye Elektrik A.Ş." in Turkish.
[3] "Türkiye Elektrik Dağıtım A.Ş." in Turkish.
[4] "Elektrik Üretim A.Ş." in Turkish.

Contracting Co. (TETAŞ)[5] and the Turkish Electricity Transmission Co. (TEİAŞ)[6], which are responsible from the activities of electricity generation, wholesale trade and transmission, respectively.

In 2004, the government accepted the Electricity Sector Strategy Paper (Strategy Paper) and determined the necessary steps to be taken in the way of liberalization in the electricity market. Accordingly, privatization would start in the distribution sector (TEDAŞ), and then it would continue with the generation assets (EÜAŞ). In line with this, following several mergers between electricity distribution organizations of TEDAŞ, the Turkish electricity distribution network was divided into 21 regions, as announced in the Strategy Paper. A separate distribution company was established in each one of the 20 distribution regions owned by TEDAŞ. Although, it has been planned in the Strategy Paper that the privatizations of these companies would start in 2005 and finish in 2006; this plan could not be achieved. As a result of the considerable recent effort of the Privatization Administration (ÖİB)[7], the privatization tenders of all distribution companies have been finished in 2010. Also, most of the distribution companies have been handed over to the private sector, while handover procedures of the remaining are going on nowadays. In addition, approaching the end of the privatizations of the distribution companies, the privatizations of electricity generation assets have been started very recently, as planned in the Strategy Paper.

The Strategy Paper officially declared the benefits expected from electricity sector reform and privatization, one of which is decreasing of costs through effective and efficient operation of electricity generation and distribution assets. The Strategy Paper also clearly suggested that the main aim of the electricity sector reform is to obtain lower tariffs as a result of increases in the efficiency of the sector. For this

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[5] "Türkiye Elektrik Ticaret ve Taahhüt A.Ş." in Turkish.

[6] "Türkiye Elektrik İletim A.Ş." in Turkish.

[7] "Özelleştirme İdaresi Başkanlığı" in Turkish.

aim, it has been planned that the tariffs will be determined according to the "cost-reflective tariff structure" based on pre-determined efficiency and loss/theft targets. As stated by ÖİB (2010) the new tariff structure includes "price cap" for retail sales tariff and "revenue cap" for distribution and retail services, both of which are classified as incentive-based regulation schemes. According to this new tariff structure, the electricity generation companies can achieve substantial savings by generating the electricity at a lower wholesale cost than the regulated reference price, which probably triggers the construction of more efficient generation facilities. Electricity distribution companies also have a similar incentive to operate more efficiently. They can make extra money by outperforming the predetermined operational improvement targets (Erdoğdu, 2009).

In the traditional cost-of-service regulation schemes, the regulated companies recover their costs with a risk-free fixed rate of return and therefore have little incentive to minimize costs. In contrast, as stated above, incentive-based regulation schemes such as price or revenue cap provide incentive to operate more efficiently. In order to apply incentive-based regulation schemes, the regulated companies should be somehow benchmarked in the sense that their efficiency performances should be measured and compared with each other's. In the benchmarking applications, various methods have been used for estimating efficiency performances of companies. These methods can be broadly classified as parametric and non-parametric methods. In the parametric methods such as Corrected Ordinary Least Squares (COLS) and Stochastic Frontier Analysis (SFA) a cost or production function is estimated statistically, while in the non-parametric methods such as Data Envelopment Analysis (DEA) mathematical programming techniques are used. Each model has its own weaknesses and strengths and it is generally difficult to identify the "right" model among the legitimate ones.

In this study, we analyzed the efficiency performances of 21 electricity distribution companies between 2002 and 2009. For this aim, we used SFA method, which is based on an input distance function. In order to see whether the efficiency scores of the companies are sensitive to the model specifications, we preferred to utilize two different SFA models (Battese and Coelli (1992&1995)), and also generate three different versions for each model by adding a new input or environmental variable into previous version of a given model.[8] In doing this, we aimed to search the robustness of the findings.

The structure of the thesis is as follows:

In Chapter 2, the necessary explanations regarding the Turkish electricity market will be presented. In doing this, some chronological and intercountry comparisons will me made when necessary.

Chapter 3 starts with presenting the definitions of some important concepts. Then, two most popular efficiency measurement techniques, DEA and SFA, will be discussed and compared.

In Chapter 4, the models used in this study will be firstly explained in the distance function framework. Then, the specification of alternative models set up to measure efficiency scores of electricity distribution firms is presented. Lastly, the input, output and environmental variables used in these models are analyzed.

Chapter 5 presents the efficiency estimation results of alternative models. Also, the results will be discussed in this chapter by making some comparisons.

In Chapter 6, we conclude the study and discuss the further research areas.

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[8] In order to provide convenience, from now on, Battese and Coelli (1992) and Battese and Coelli (1995) will be denoted by BC92 and BC95, respectively.

CHAPTER 2

TURKISH ELECTRICITY MARKET

In this chapter, before explaining the Turkish electricity market, we make some necessary explanations regarding the distinguishing features of electricity as a commodity and features of electricity markets in general. Following this, historical evaluation of Turkish electricity market will be presented, and subsequently current structure of the market will be explained by making some chronological and intercountry comparisons.

2.1. GENERAL CHARACTERISTICS OF ELECTRICITY AND ELECTRICITY MARKETS

Electricity differs from all other goods and commodities. Firstly, in the physical sense, in contrast to all other goods, including other type of energies, electricity has neither volume nor weight. In addition, unlike virtually all products, it is not economically possible to store electricity. As a result of this feature, at any moment the amount of electricity produced must just equal the amount consumed. In other words, electricity must be consumed immediately when produced and delivered. Imbalances between production and consumption may raise severe problems. Failure at one point in the network (for example, failure of a generation plant) may have serious repercussions on the whole network, meaning that strong externalities in terms of network security (Atiyas and Dutz, 2004). Thus, supply and demand should be balanced in this sector by taking into account existing capacity constraints of generation plants, lines and transformers.

Another distinguishing feature of an electricity market is that it requires a large fixed network, which is usually realized by considerable amount of sunk costs. In other words, since it is not economically profitable for each firm to construct their own network, there exist strong economies of scale in the electricity market.

Electricity markets are vertically segmented into three phases: (i) generation, (ii) transmission, and (iii) distribution. In the generation phase, electricity is produced in power plants through a variety of technologies such as hydroelectric (using the flow of water), thermal (burning natural gas or coal), solar, nuclear and wind. Transmission is the phase where electricity generated is transferred over long distances. For this, by help of the alternating current (AC) system, the voltage of the electricity which leaves the power plant is increased in transformers, enabling electricity to travel over long-distance wires. At the destination, the voltage of the electricity is decreased in another transformer, and lower voltage wires carry it to residences and offices, which forms the distribution phase. Between these three phases there exist firms doing wholesale and retail trade of electricity. The operational principles of both type of trades are similar such that both involve metering, computing and billing. However, an important difference is that wholesale trade is performed mostly at the transmission segment with a large scale, while retail trade is at distribution level with smaller customers such as residences and offices (Atiyas and Dutz, 2004).

As a result of the need to balance supply and demand in electricity market and requiring huge capital investments, electricity has been considered historically as a "public good". Especially transmission and distribution segments of the electricity markets have been thought to be a typical example of natural monopolies. Until very recently, electricity has been supplied through vertically integrated enterprises. These enterprises have been state-owned monopolies in almost all countries over the world.[9] However, in the beginning of 1990s, the view that competition can be introduced in electricity markets has started to be

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[9] One important exception is USA where electricity enterprises have been private, although they have also monopoly rights over specific regions.

expressed. After successful liberalization examples in several countries such as United Kingdom, Australia and Norway, the liberalization process spread to all over the world. As stated in the following section, Turkey took several actions to attract the private firms in the energy sector in the 1980s. Though, the lack of legal and regulatory framework kept the private sector away energy markets including electricity.

2.2. HISTORICAL EVALUATION OF TURKISH ELECTRICITY MARKET

Turkish electricity market may be divided into three periods according to the establishment and splitting dates of the nationally-owned enterprise, TEK. These periods are as follows: (i) Pre-TEK period (1913-1970), (ii) TEK period (1970-1993), and (iii) Post-TEK period (1994-ongoing).

2.2.1. Pre-TEK period (1913-1970)

Electricity was started to be used in daily life in 1878. The first electricity generation plant commenced operations in London in 1882. As for Turkey, the first attempt to produce electricity was during the Ottoman Empire era at the beginning of the 20th century. The first electric generator was a 2 kW dynamo connected to the water mill installed in Tarsus, Mersin in 1902. Ottoman Empire introduced “Privileges for Public Wealth Law” in 1910 to attract foreign investors’ attention. Following this law, some privileges were given to electricity generation firms such as the Hungarian Ganz Partnership which established the “Ottoman Electricity Stock Company” with Hungarian and Belgium Banks. Then, in 1913 the first large scale electricity generation plant (with capacity of 13.4 MW) was built in Silahtarağa, İstanbul.

The installed electricity generation capacity and production of Turkey was respectively 33 MW and 50 million kWh when the Turkish Republic was founded in 1923. The privileged contracts for foreign electricity generation companies were approved by the new Turkish Republic Administration only for a temporary period, given the lack of technological knowledge in Turkey then. The electricity prices indexed to gold prices were high in the first years of the Turkish Republic. For this reason, some factories using electricity extensively preferred to build their own electric generation facilities. Besides, since the foreign private firms involved in the Turkish electricity industry were reluctant to invest in rural areas, both electricity generation and electrification had increased rather slowly. Therefore, starting from 1930s, the government increased its role in the electricity sector (Dilaver and Hunt, 2010). Firstly, in 1935, the Etibank (a governmental entrepreneurship) was established to operate in the electricity generation and mining sectors.[10] In the same year the Electrical Works Survey Administration (EİEİ)[11] was founded in order to examine electricity generation opportunities of Turkey. The Bank of Provinces[12] and State Hydraulic Works (DSİ)[13] were other institutions established by government in order to accelerate the investments in the electricity sector. Meanwhile, the installed capacity reached to 126 MW, while the generation was 213 million kWh and the number of the electrified provinces was 43.

Reached to 1950s, the first private-public partnerships were established in the form of concession companies (Çukurova Electric Co. and Kepez Electric Co.) to provide electricity to Adana-İçel and Antalya provinces respectively. At the beginning of 1950, installed capacity of Turkey had reached 407.8 MW while generation to 789.5 million kWh.

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[10] One of the private firms dominating Turkish electricity market until the establishment of Etibank in 1935 was Kayseri and Its Surroundings Electricity Distribution Co.(Kayseri ve Civarı Elektrik Dağıtım A.Ş. - KCETAŞ), which has been still operating in Kayseri.

[11] “Elektrik İşleri Etüd İdaresi” in Turkish.

[12] “İller Bankası” in Turkish.

[13] “Devlet Su İşleri” in Turkish.

2.2.2. TEK period (1970-1993)

In 1970 the sector was restructured extensively by establishment of Turkish Electricity Authority (TEK) to coordinate the electric sector totally. TEK was constructed as vertically integrated, thus controlling the country's electricity excluding municipally-owned distribution facilities[14] and three regional concession companies[15]. The installed capacity was 2,234.9 MW while the generation 8.6 billion kWh levels in 1970. By 1982, the installed capacity and energy generation reached 6,638.6 MW and 26.6 billion kWh respectively. In addition, during 1970-1982 period village electricification increased from 7% to 61%.

Turkish constitution used to define the provision of electricity as public service that could be supplied only by state-owned enterprises. Thus, the governments tried to achieve private participation in the industry only through concession arrangements such as Build-Operate-Transfer (BOT) and Transfer of Operating Rights (TOR).[16] Accordingly, the state should retain the ownership of investments at the end of the concession term and be the sole buyer of those services produced by private firm. These methods led to the initiation of some high cost projects in which most of the commercial risk was assumed by the state in the form of Treasury-backed purchase guarantees. In this regard, Law no. 3096 was enacted in 1984 to encourage private sector participation in the electricity industry. This law in effect abolished TEK's monopoly in the generation, transmission and

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[14] Following the introduction of Law no. 2705 in 1982, the distribution function of the municipal administrations was also transferred to TEK.

[15] These three regional concession companies were KCETAŞ, Çukurova and Kepez. Subsequently, Çukurova and Kepez, previously controlled by Uzan family, were seized by the State in June 2003. Meanwhile, in the Anotolian side of İstanbul the electricity was started to be distributed by another private firm, Aktaş, in 1990. However, since State Council (Danıştay) overruled the concession agreement of Aktaş in 2002, this company was nationalized by the State.

[16] In BOT model for generation a private firm builds and operates the plant for 15-20 years and then transfer it to State at no cost to the State), while in TOR model for generation and distribution a private firm only operates plant formally owned by the State.

distribution. In addition to BOT and TOR, this law also introduced the concept of autoproduction for private participation in the electricity generation[17] (PWC, 2008). Between 1988-1992, 10 private firms were authorized to operate in generation, transmission, distribution and trade of electricity within their legal district regions. In 1993, Decree with Power of Law no. 513 was introduced and TEK was incorporated in scope of the privatization.

2.2.3. Post-TEK period (1994-ongoing)

In the path of privatization, in 1994 TEK was unbundled into two state-owned enterprises, TEAŞ and TEDAŞ. In 2001, the Electricity Market Law no. 4628 was passed, with the aim of establishment of financially strong, stable and transparent electricity market under competitive and special law provisions for a sufficient, high-quality, continuous, low-cost and environment friendly supply of electricity to the disposal of consumers as well as the maintaining an independent regulatory and supervisory framework.[18] To achieve this, the Energy Market Regulation Authority (EPDK)[19] was established. In addition, as another important step toward privatization, TEAŞ was restructured and divided into three state-owned public enterprises, TEİAŞ, EÜAŞ and TETAŞ. Following this reorganization, EÜAŞ took over and operated the public power generation plants. TEİAŞ became the holder of all pervious Build-Own-Operate (BOO), Build-Operate-Transfer (BOT) and Transfer of Operating Rights (TOR) agreements and long term power purchase agreement with Treasury guaranties. It has also been responsible for

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[17] Autoproducers principally generate electricity for their own needs. However, they may sell out their excess energy provided that excess energy sold shall not exceed 20% of the energy generated at such autoproduction facility, according to the Electricity Market Law no. 4628, enacted in 2001.

[18] As the electricity sector had been prepared for privatization with several restructuring activities, at the same time the government was trying to make electricity sector more attractive for private firms. For example, in 1999, the Turkish constitution was amended in such a way that electricity investments became subject to private law, State Council's role was limited and international arbitration became possible.

[19] "Enerji Piyasası Düzenleme Kurulu" in Turkish. Indeed, the name of the Authority had been " The Electricity Market Regulatory Authority" in the Electricity Market Law no. 4628. It was later renamed as "Energy Market Regulatory Authority" in the Natural Gas Market Law no. 4646.

balancing of power operations between parties, covering both the physical and financial aspects.[20] TETAŞ was obliged to wholesale trading and contracting activities in the electrical market. Its main function has been to purchase electricity from EÜAŞ and other generators and to sell it to TEDAŞ.

In 2004, the government drew its road map for a reform in the electricity market by issuing the Strategy Paper. Strategy Paper aimed to restructure and liberalize the electricity sector in order to attract private investment, enhance the competition and increase the efficiency. For this, the following restructuring in core activities ranging from generation to distribution would be achieved in Turkish electricity market (PWC, 2008):

- EÜAŞ will be divided into portfolio companies with hydroelectric, lignite and gas fired plants. Whilst the major hydro plants, which will be transferred from DSİ, are planned to remain under EÜAŞ ownership, the thermal power plants and the smaller hydro plants are planned to be privatized.

- The transmission network operated by TEİAŞ will remain state-owned to guarantee independency and security of the system.

- TETAŞ will remain state-owned but with diminishing presence over time and will be substituted by private wholesalers and bilateral agreements between generators and distribution companies.

- Distribution activities will be fulfilled by privately-owned companies after the privatization. However, TEDAŞ will continue to own the distribution assets that will be operated by the private sector in privatized regions.

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[20] National Load Dispatch Center (Milli Yük Tevzi Merkezi – MYTM) and Market Financial Settlement Center (Piyasa Mali Uzlaştırma Merkezi – PMUM) were created within TEİAŞ's organisation in 2004 and 2006 respectively.

Strategy Paper states that the main purpose of the market liberalization is to achieve lower tariffs by increasing overall system efficiency. Accordingly, the tariffs will be calculated as "cost-reflective" based on pre-determined operating and loss/theft improvement targets.[21] In Strategy Paper, the years between 2006 and 2010 are accepted as a transition period to this "cost-reflective tariff structure".[22]

Strategy Paper suggests that the privatization of Turkish electricity sector is to be started from distribution (namely TEDAŞ) and upon its completion the process will be continued with generation assets (namely EÜAŞ).[23] In line with this, in April 2004 ÖİB started the necessary procedures to privatize TEDAŞ. With several mergers between electricity distribution organizations of TEDAŞ, Turkish electricity distribution network was divided into 21 regions, as announced in the Strategy Paper, based on geographical proximity, managerial structure, energy demand and other technical and financial factors. Out of 21 regions, 20 regions were owned by TEDAŞ.[24] A separate distribution company was established by the ÖİB in each one of the 20 distribution regions owned by TEDAŞ. 21 electricity distribution companies and their regions are shown in Table 2.1 and in Figure 2.1.

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[21] The electricity tariff increased in January 2008 for the first time since 2003.

[22] This transitory period has been extended to 2012 by the Law no. 5784 and dated 09.07.2008.

[23] According to Starodubtsew (2007), this sequence is not arbitrary: Before, Turkey's priority was to increase generation capacity to meet growing demand. This fact has encouraged investment in the generation sub-sector to the detriment of distribution networks, which may be considered as one of the reasons for the high level of network losses in Turkey.

[24] The only distribution region operated by a private company is Kayseri, whose operating rights were transferred to KCETAŞ in 1990.

Table 2.1. Electricity Distribution Companies and Regions

Distribution Company	Provinces
Akdeniz	Antalya, Burdur, Isparta
Aras	Erzurum, Ağrı, Ardahan, Bayburt, Erzincan, Iğdır, Kars
AYEDAŞ	İstanbul Anatolian Side
Başkent	Ankara, Kırıkkale, Zonguldak, Bartın, Karabük, Çankırı, Kastamonu
Boğaziçi	İstanbul European Side
Çamlıbel	Sivas, Tokat, Yozgat
Çoruh	Trabzon, Artvin, Giresun, Gümüşhane, Rize
Dicle	Diyarbakır, Şanlıurfa, Mardin, Batman, Siirt, Şırnak
Fırat	Elazığ, Bingöl, Malatya, Tunceli
Gediz	İzmir, Manisa
Göksu	Kahramanmaraş, Adıyaman
KCETAŞ	Kayseri
Menderes	Aydın, Denizli, Muğla
Meram	Kırşehir, Nevşehir, Niğde, Aksaray, Konya, Karaman
Osmangazi	Eskişehir, Afyon, Bilecik, Kütahya, Uşak
Sakarya	Sakarya, Bolu, Düzce, Kocaeli
Toroslar	Adana, Gaziantep, Hatay, Mersin, Osmaniye, Kilis
Trakya	Edirne, Kırklareli, Tekirdağ
Uludağ	Balıkesir, Bursa, Çanakkale, Yalova
Vangölü	Bitlis, Hakkari, Muş, Van
Yeşilırmak	Samsun, Amasya, Çorum, Ordu, Sinop

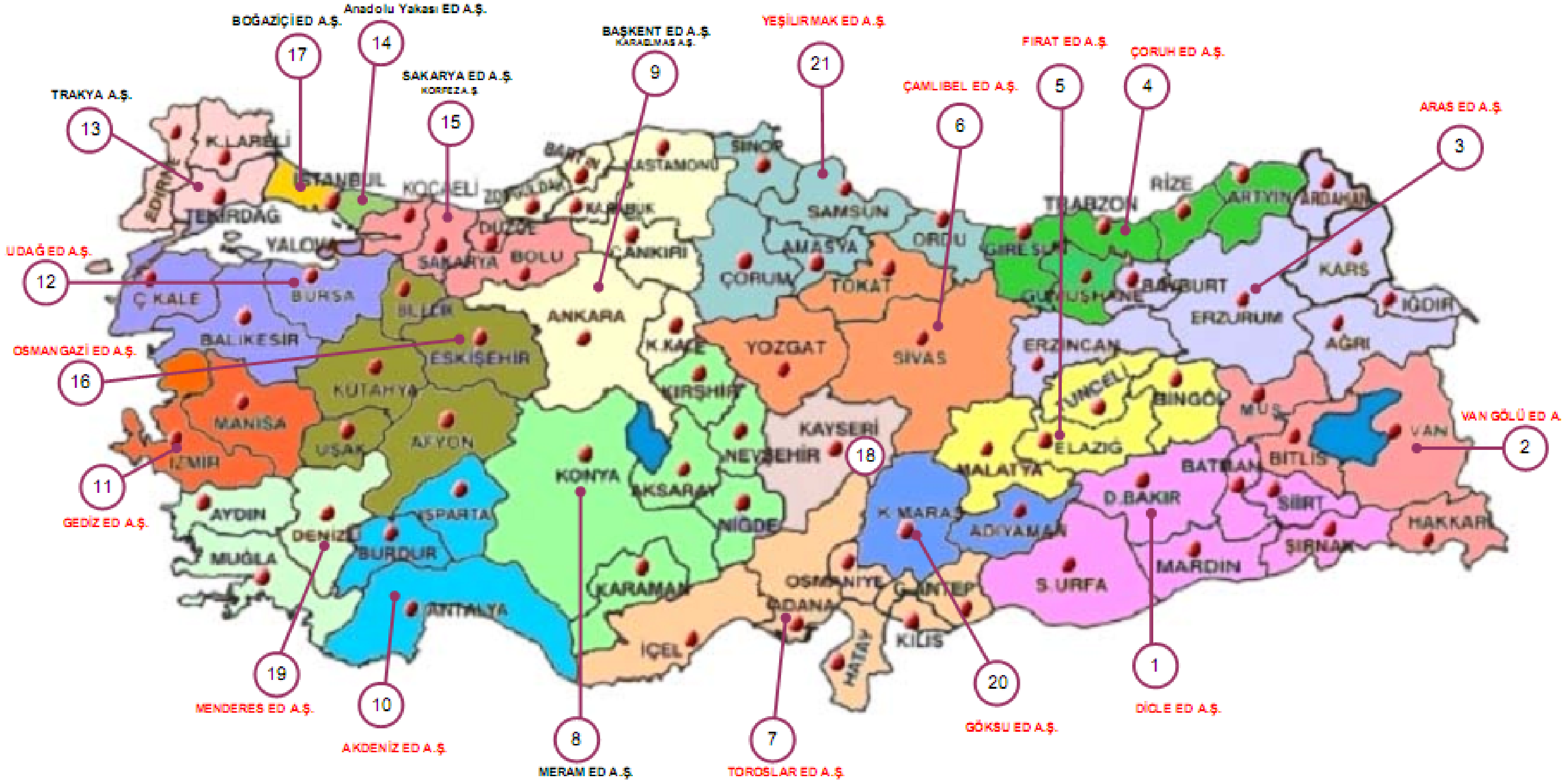

Figure 2.1. Electricity Distribution Regions

Source: (Strategy Paper)

Distribution companies will have the sole right for electricity sales to non-eligible[25] customers in their regions during the transition period. Eligible customers in a given region, on the other hand, can purchase electricity either from the distribution company operating in their region and/or from autoproducers and/or private generation companies via bilateral agreements. Once the transition period is over, private retail sales companies to be established will be allowed to sell electricity to all customers across the country. Meanwhile, distribution companies can determine their own end-user tariffs for the period after transition period in accordance with Electricity Market Tariffs Communique of EPDK. Meanwhile, the distribution firms have to buy 85% of electricity from TETAŞ during the transition period, then they can buy electricity from any supplier.

The Strategy Paper determined very strict deadlines for privatization of both electricity distribution and generation. It was planned that privatization in the distribution and generation would be finished by the end of 2006 and 2009 respectively. However, in practice, the privatization proceeded slowly than planned in the Strategy Paper. The privatization model to be applied for the electricity distribution firms was announced in January 2006. Privatization of distribution companies is to be executed using a Transfer of Operating Rights (TOR) model backed Share Sale model. According to this model, the investor will be the sole owner of the shares of the distribution company, which will be the unique licensee for the distribution of electricity in the designated region but will not have the ownership of distribution network assets and other items that are essential for the operation of distribution assets. The ownership of these distribution assets will remain with TEDAŞ. The investor, through its shares in

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[25] The concept of "eligible consumer" has been used to define large consumers with a minimum level of consumption. The rest of the consumers are named as "non-eligible" or "captive" consumers. Eligible consumers are free to choose their suppliers. At the beginning, the minimum consumption level to be accepted as eligible consumer was 9 GWh in 2003. Later, in 2005-2009 period, the eligible consumer limit was gradually reduced to 0.48 GWh. Following the transition period, all consumers will be accepted as eligible consumer.

the distribution company, however, will be granted the right to operate the distribution assets pursuant to TOR agreement with TEDAŞ (ÖİB, 2006).

After determining the privatization model for the electricity distribution, ÖİB firstly launched the privatization process for 3 distribution firms, namely Başkent, Sakarya and AYEDAŞ, in the middle of 2006. However, in January 2007 ÖİB postponed these privatizations just before the tender date.[26]

ÖİB kicked off the privatization of electricity distribution firms in 2008 again. For each distribution company, the date of tender, the date of handover, awarded firm and tender price are provided in Table 2.2. The current situation in the privatization of distribution firms are illustrated in Figure 2.2.

ÖİB, this time, started privatization of distribution firms with Başkent, Sakarya and Meram. These three firms were privatized and handed over to private sector successfully in 2009. Later, privatization tenders were held for Aras, Çamlıbel, Çoruh, Fırat, Osmangazi, Uludağ, Vangölü and Yeşilırmak; among them, the handover process for Çamlıbel, Çoruh, Osmangazi, Uludağ and Yeşilırmak were completed in 2010, while the process of Fırat has been finished in 2011. The handover processes of remaining (Aras and Vangölü) have been ongoing[27]. Privatization tenders were continued with Boğaziçi, Gediz and Trakya in August 2010, and finally tenders of Akdeniz, AYEDAŞ and Toroslar were hold in December 2010, and thus tender process of all distribution companies was completed. The handover process for these tenders has been continued as of the first days of year 2011. Meanwhile, in 2008, Menderes was handed over to the

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[26] One of the official reasons put forward by ÖİB was the completion of the infrastructure works to take above-ground middle voltage (MV) lines to underground (PWC, 2008). Indeed, trying to avoid any future legal disputes, the government seemed to postpone these privatizations until the parliamentary elections held in July 2007.

[27] Although the tender of Aras has been already hold in September 2008, its handover has not completed yet due to State Council's (Danıştay) decision of a stay of execution for this privatization.

private sector in accordance with law number 3096. [28] Tender for Göksu was hold in 1998, and following a long judicial process, its handover has been finished in 2011.

Table 2.2. Current Situation in Privatization of Electricity Distributions

Distribution Company	Tender Date	Handover Date	Awarded Firm	Tender Price ($)
Akdeniz	December 2010	-	Park Holding	1,165,000,000
Aras	September 2008	-	Kiler	128,500,000
AYEDAŞ	December 2010	-	İş Kaya-MMEKA	1,813,000,000
Başkent	July 2008	January 2009	Sabancı-Verbund	1,225,000,000
Boğaziçi	August 2010	-	İş Kaya-MMEKA	2,990,000,000
Çamlıbel	February 2010	September 2010	Kolin İnşaat	258,500,000
Çoruh	November 2009	October 2010	Aksa Elektrik	227,000,000
Dicle	August 2010	-	Karavil-Ceylan	228,000,000
Fırat	February 2010	January 2011	Aksa Elektrik	230,250,000
Gediz	August 2010	-	İş Kaya-MMEKA	1,920,000,000
Göksu	1998	January 2011	Akedaş	60,000,000
KCETAŞ	1990	1990	-	-
Menderes	January 2008	August 2008	Aydem	110,000,000
Meram	September 2008	October 2009	Alarko-Cengiz	440,000,000
Osmangazi	November 2009	June 2010	Eti Gümüş	485,000,000
Sakarya	July 2008	February 2009	Akenerji-CEZ	600,000,000
Toroslar	December 2010	-	Yıldızlar Holding	2,075,000,000
Trakya	August 2010	-	Aksa Elektrik	622,000,000
Uludağ	February 2010	September 2010	Limak	940,000,000
Vangölü	February 2010	-	Aksa Elektrik	100,100,000
Yeşilırmak	November 2009	December 2010	Çalık Holding	441,500,000

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[28] As stated in Section 2.2, Law no. 3096, enacted in 1984, is the first law forming a legal framework for private participation in electricity. For this aim, BOT contracts for new generation facilities, TOR contracts for existing generation and distribution assets, and the autoproducer system for companies wishing to produce their own electricity was first introduced in this Law.

Figure 2.2. Current Situation in the Privatization of Electricity Distribution Regions

As planned in the Strategy Paper, while the privatization process of distribution companies reached to the end, the preparation measures were started for the privatization of generation assets. Firstly, 52 river generation plants were divided into 19 different groups, and then the tenders for these groups were hold. In addition, the generation portfolio companies, combining hydro and thermal power plants, owned by EÜAŞ, were determined.

2.3. CURRENT STRUCTURE OF TURKISH ELECTRICITY MARKET

Despite the economic crises in 1994, 1998, 2001 and finally in 2008, the installed electricity generation capacity of Turkey has increased continuously since 1970. The installed capacity of 2,235 MW in 1970 reached to 44,761 MW in 2009, indicating a 7.78% annual growth. Similarly, throughout the same period, electricity generation of Turkey showed an increase in each year with an exception of 2009. Electricity generation of Turkey has been increased by 8.11% annually, from 8,623 GWh in 1970 to 194,813 GWh in 2009. As shown in Table 2.3 both installed electricity capacity and generation of Turkey have been heavily relied on thermal and hydro resources.

Annual development of Turkey's electricity generation by primary energy resources is detailed in Table 2.4. After Turkey started to use natural gas in generating electricity in 1985, the dependency on natural gas has been increased extensively in each year. For year 2009, out of 194,813 GWh total generation, 96,095 GWh is produced by natural gas, accounting for 49.33% of total electricity generation. Turkey’s increasing dependency on imported resources has been also monitored with respect to imported coal. In 2009, Turkey generated 16,596 GWh by imported coal, 8.52% of the total electricity generation. Locally produced lignite has been the second widely used energy resource in electricity generation. In 2009, 39,090 GWh was produced by lignite, 20.07% of total electricity generation. Although Fuel-Oil, Diesel oil, LPG, Naphtha and Wastes are other thermal resources, their usage in electricity generation in Turkey has been traditionally remained rather limited.[29]

Table 2.3. Installed Capacity and Generation in Turkey

Years	Installed Capacity				Generation			
	Thermal	*Hydro*	*Geother. Wind*	*Total*	*Thermal*	*Hydro*	*Geother. Wind*	*Total*
1970	1,510	725	-	2,235	5,590	3,033	-	8,623
1975	2,407	1,780	-	4,187	9,719	5,904	-	15,623
1980	2,988	2,131	-	5,119	11,927	11,348	-	23,275
1985	5,229	3,875	18	9,122	22,168	12,045	6	34,219
1990	9,536	6,764	18	16,318	34,315	23,148	80	57,543
1995	11,074	9,863	18	20,954	50,621	35,541	86	86,247
2000	16,053	11,175	36	27,264	93,934	30,879	109	124,922
2005	25,902	12,906	35	38,844	122,242	39,561	153	161,956
2006	27,420	13,063	82	40,565	131,835	44,244	221	176,300
2007	27,272	13,395	169	40,836	155,196	35,851	511	191,558
2008	27,595	13,829	393	41,817	164,139	33,270	1,009	198,418
2009	29,339	14,553	869	44,761	156,923	35,958	1,931	194,813

Notes: (1) Installed capacity values are in MW, while generation values are in GWh.
(2) Hard&Imported Coal also includes Asphaltite.
(3) Other Thermal includes Fuel-Oil, Diesel oil, LPG and Naphtha.
(4) Source: TEİAŞ, Electricity Generation & Transmission Statistics of Turkey, 2009

The contribution of hydro resources to electricity generation has shown some fluctuations depending on the weather conditions. In year 2009, the amount of electricity generated via hydro resources was 35,958 GWh, accounting for 18.46% of total electricity generation.

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[29] The Turkish government has prioritized the local and renewable resources in meeting the electricity demand for the coming years. The resource utilization targets are set as follows (Hakman 2009): (i) Decreasing the share of natural gas below 30% by 2020. (ii) Utilization of all known lignite and hard coal resources by 2023. (iii) Minimum share of 5% for nuclear plants by 2020. (iv) Minimum share of 30% for renewable resources by 2023. (v) Utilization of all economically and technically feasible hydro resources by 2023. (vi) 20,000 MW installed wind power capacity by 2023. (vii) Utilization of all geothermal electric production potential (600 MW) by 2023.

Table 2.4. Annual Development of Turkey's Electricity Generation By Primary Energy Resources

Years	Natural Gas	Hard & Imported Coal	Lignite	Renew. &Wastes	Other Thermal	Total Thermal	Hydro	Geother. &Wind	General Total
1975	-	1,427	2,686	220	5,386	9,719	5,904	-	15,623
1980	-	912	5,049	136	5,831	11,927	11,348	-	23,275
1985	58	710	14,318	-	7,082	22,168	12,045	6	34,219
1990	10,192	621	19,561	-	3,942	34,315	23,148	80	57,543
1995	16,579	2,232	25,815	222	5,772	50,621	35,541	86	86,247
2000	46,217	3,819	34,367	220	9,311	93,934	30,879	109	124,922
2005	73,445	13,246	29,946	122	5,483	122,242	39,561	153	161,956
2006	80,691	14,217	32,433	154	4,340	131,835	44,244	221	176,300
2007	95,025	15,136	38,295	214	6,527	155,196	35,851	511	191,558
2008	98,685	15,858	41,858	220	7,519	164,139	33,270	1,009	198,418
2009	96,095	16,596	39,090	340	4,804	156,923	35,958	1,931	194,813

Notes: (1) All values are in GWh.
(2) Hard&Imported Coal also includes Asphaltite.
(3) Other Thermal includes Fuel-Oil, Diesel oil, LPG and Naphtha.
(4) Source: TEİAŞ, Electricity Generation & Transmission Statistics of Turkey, 2009

Although in recent years we witnessed some efforts to use Turkey's geothermal and wind potential in electricity generation, their contribution to electricity generation is currently very limited, as seen in Table 2.4.

At this point, it may be intuitive to make a comparison between Turkey's electricity market and those of other countries. For this, we firstly examine the electricity generation, import, export and supply quantities of OECD countries by help of Table 2.5. As shown in this table, although produced more electricity than some of the OECD countries, Turkey's electricity generation is rather smaller than OECD average. In addition, it is evident from this table that the countries which are not surrounded with water have somewhat dealt with international trade of electricity. Among these countries, Turkey is one of the countries with low level of electricity import and export.[30]

One may also compare Turkey's electricity market with those of other countries with respect to primary energy resources used in electricity generation. Table 2.6 shows the installed electricity generation capacity of OECD countries. The most striking result obtained from Table 2.6 is that the countries with adequate hydro potential prefer to install their capacity in a way to exploit this potential. Austria, Canada, Iceland, New Zealand, Norway, Sweden and Switzerland belong to this group. The OECD countries may be also categorized according to whether they use nuclear energy in generating electricity or not. For some of the countries such as USA, France, Japan, Germany, Korea, Canada and United Kingdom, nuclear energy is an important energy resource in electricity generation. In the rest of the countries including Turkey, nuclear resources have never used or used rather limitedly.[31]

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[30] One possible reason for this may be that until very recently Turkey's electric system was not compatible with those of European countries. In September 2010, synchronization was achieved and connection between Turkey and Europe was provided.

[31] Turkey has been trying to build its first nuclear power plant for a long time. At the end of these efforts, Turkey signed a deal with Russia in May 2010 for building it in Akkuyu, Mersin. In December 2010, Turkey also signed a Memorandum of Understanding (MoU) with Japan to establish a nuclear power plant in Sinop after a failure of negotiations with the South Korea.

Table 2.5. Electricity Generation, Imports, Exports and Gross Supply of OECD Countries in 2009 (Estimate)

Countries	*Gross Generation*	*Imports*	*Exports*	*Gross Supply*
Australia	246,300	-	-	246,300
Austria	68,900	19,500	18,800	69,600
Belgium	91,000	9,500	11,300	89,200
Canada	622,600	18,200	53,700	587,100
Czech Republic	82,300	8,600	22,200	68,600
Denmark	36,200	11,200	10,900	36,500
Finland	71,600	15,500	3,400	83,700
France	541,700	19,200	44,900	516,000
Germany	596,800	41,900	54,100	584,500
Greece	55,800	7,600	3,200	60,200
Hungary	35,900	10,700	5,200	41,400
Iceland	16,800	-	-	16,800
Ireland	27,700	900	200	28,400
Italy	289,900	46,600	2,100	334,400
Japan	1,046,400	-	-	1,046,400
Korea	446,000	-	-	446,000
Luxembourg	3,900	6,000	2,600	7,300
Mexico	252,800	300	1,200	251,900
Netherlands	112,200	15,500	10,600	117,100
New Zealand	43,400	-	-	43,400
Norway	132,800	5,700	14,600	123,800
Poland	151,600	7,400	9,600	149,400
Portugal	49,900	7,600	2,800	54,700
Slovak Republic	26,200	9,000	7,700	27,500
Spain	294,300	6,800	14,900	286,200
Sweden	133,700	13,800	9,100	138,400
Switzerland	68,600	31,400	33,500	66,400
Turkey	194,100	800	1,600	193,300
U.Kingdom	371,800	6,600	3,700	374,600
USA	4,184,400	52,200	18,100	4,218,500
OECD Total	10,295,300	372,300	360,100	10,307,500
OECD Mean	343,177	12,410	12,003	343,583

Notes: (1) All values are in GWh.
(2) Source: IEA Statistics, Electricity Information, 2010

Table 2.6. Installed Capacity of OECD Countries in 2008

Countries	*Natural Gas*	*Coal*	*Liquid*	*Renew. &Wastes*	Total Thermal	Hydro	Nuclear	Other	Total
Australia	12,750	30,170	970	320	44,210	9,300	-	1,990	55,500
Austria	3,340	3,070	250	590	7,250	12,500	-	1,050	20,800
Belgium	-	-	-	-	9,120	1,420	5,830	390	16,760
Canada	2,180	-	70	3,090	37,260	74,610	13,350	2,420	127,640
Czech Republic	-	11,580	-	-	11,580	2,190	3,760	200	17,730
Denmark	2,140	5,920	1,080	180	9,320	10	-	3,170	12,500
Finland	1,960	7,800	970	-	10,730	3,100	2,670	150	16,650
France	-	-	-	-	25,650	25,180	63,260	3,740	117,830
Germany	-	-	-	-	79,550	10,000	20,490	29,240	139,280
Greece	2,830	4,810	2,380	30	10,050	3,180	-	1,030	14,260
Hungary	4,510	1,290	400	310	6,510	50	1,940	140	8,640
Iceland	-	-	120	-	120	1,880	-	580	2,580
Ireland	3,390	1,210	1,030	10	5,640	530	-	1,230	7,400
Italy	49,020	10,320	11,870	1,200	72,410	21,280	-	4,940	98,630
Japan	40,680	60,020	39,320	-	180,820	47,340	47,940	4,430	280,530
Korea	21,270	27,400	7,130	170	55,970	5,510	17,720	660	79,860
Luxembourg	450	-	-	10	460	1,130	-	70	1,660
Mexico	-	-	-	-	43,410	11,390	1,370	1,080	57,250
Netherlands	-	-	-	-	22,050	40	510	2,280	24,880
New Zealand	1,680	1,120	160	110	3,070	5,370	-	930	9,370
Norway	440	70	20	130	660	29,730	-	400	30,790

Table 2.6. (cont'd) Installed Capacity of OECD Countries in 2008

Countries	*Natural Gas*	*Coal*	*Liquid*	*Renew. &Wastes*	Total Thermal	Hydro	Nuclear	Other	Total
Poland	860	28,370	490	100	29,820	2,340	-	530	32,690
Portugal	2,630	2,130	2,970	40	7,770	5,060	-	2,940	15,770
Slovak Republic	-	-	-	-	2,590	2,550	2,200	20	7,360
Spain	-	-	-	-	47,830	18,450	7,370	19,880	93,530
Sweden	-	-	-	-	7,750	16,440	8,940	820	33,950
Switzerland	210	290	110	260	870	15,250	3,220	60	19,400
Turkey	15,050	10,660	1,820	60	27,590	13,830	-	390	41,810
U.Kingdom	29,180	29,990	5,870	1,780	66,820	4,370	10,980	3,430	85,600
USA	397,430	315,320	57,440	11,570	781,760	99,790	100,760	29,290	1,011,600
OECD Total	592,000	551,540	134,470	19,960	1,608,640	443,820	312,280	117,480	2,482,220

Notes: (1) All values are in GWh.
(2) Other includes Geothermal, Solar, Wind and Wave.
(3) Source: IEA Statistics, Electricity Information, 2010

As stated in Section 2.2, since nationally-owned TEK was constructed in 1970, the generation segment of the electricity market has been always dominated by State. Although in the following years several measures have been taken to encourage the private firms' interest for electricity, State has remained to be the main player and the controller of the electricity generation segment, as illustrated in Table 2.7. EÜAŞ (former TEK), affiliated partnerships of EÜAŞ and municipalities[32] are the government enterprises which have produced electricity in Turkey. In 2009, EÜAŞ and affiliated partnerships of EÜAŞ generated 70,785 MWh and 18,669 MWh electricity respectively; together, accounting for 45.92% of Turkey's total electricity generation. On the private side, electricity has been generated by concessionary companies, production companies, autoproducers, mobile power plants and TOR companies.[33] Among them, in 2009, production companies, autoproducers and mobile power plants and TOR companies obtained 44.91%, 6.93% and 2.24% share from Turkey's electricity generation, with 87,488 MWh, 13,498 MWh and 4,373 MWh of production, respectively.

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[32] The municipalities generated electricity by 1984 with very limited scope. In that year, according to the Law no. 2705, Municipality's power plants were transferred to EÜAŞ (former TEK).

[33] Concessionary companies and mobile power plants stopped generating electricity in 2003 and 2008 respectively.

Table 2.7. Annual Development of Turkey's Electricity Generation By the Electric Utilities

Years	EÜAŞ	Affiliated Partnerships of EÜAŞ	Concessionary Companies	Production Companies	Municipality	Autoproducers	Mobile Power Plants	TOR	Total
1970	6,273	-	876	-	785	689	-	-	8,623
1975	12,845	-	1,730	-	135	913	-	-	15,623
1980	19,415	-	1,610	-	62	2,189	-	-	23,275
1985	30,249	-	1,592	-	-	2,378	-	-	34,219
1990	52,854	-	1,305	23	-	3,361	-	-	57,543
1995	71,544	6,651	2,301	126	-	5,625	-	-	86,247
2000	73,942	19,292	1,903	12,039	-	15,962	644	1,141	124,922
2005	61,630	18,363	-	66,409	-	17,087	878	4,121	168,487
2006	71,082	13,634	-	72,669	-	14,437	418	4,061	176,300
2007	73,839	18,488	-	78,841	-	15,325	797	4,268	191,558
2008	74,919	22,798	-	80,333	-	15,723	331	4,315	198,418
2009	70,785	18,669	-	87,488	-	13,498	0	4,373	194,813

Notes: (1) All values are in GWh.

(2) Source: TEİAŞ, Electricity Generation & Transmission Statistics of Turkey, 2009

Table 2.8 shows the distribution of electricity generation by primary energy resources and electricity utilities for year 2009. Accordingly, the government enterprises (EÜAŞ and affiliated partnerships of EÜAŞ) have preferred to use local resources such as lignite and hydro, while private firms (Autoproducers, Production Companies, TOR Companies) have mostly generated electricity from imported resources such as natural gas and imported coal.

Table 2.9 illustrates the flow of electricity from generation to consumption through transmission and distribution segments, including the imports and exports as well. The most remarkable result obtained from this table is that throughout 1985-2009 period network losses in the distribution segment have increased extensively, while network losses of transmission decreased and continued to stay within the world standards.[34] As stated before, imports and exports levels of Turkey has been always remained in low levels; however, Turkey is generally a net electricity exporter.[35] Meanwhile, Figure 2.3 details the electricity flow for year 2008.[36]

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[34] In 1985, 4.7% and 8.0% of the electricity supplied to the network was lost in the transmission and distribution segments, respectively. The relevant figures were 2.1% and 13.3% in 2009.

[35] In 2009, Turkey imported electricity to Iraq and Syria, while Turkmenistan, Georgia and Azerbaijan are countries which sold electricity to Turkey.

[36] In Figure 2.3, electricity generation values of BO, BOT, TOR, Autoproducers and IPPs (Independent Power Producers) are net of internal consumption and transmission losses of 11 TWh. Similarly, electiricity distribution values of Distribution Companies are net of distribution losses of 24 TWh.

Table 2.8. The Distribution of Gross Electricity Generation by Primary Energy Resources and the Electricity Utilities in 2009

Utilities	*Natural Gas*	*Hard & Imported Coal*	*Lignite*	*Renew. &Wastes*	*Other Thermal*	Total Thermal	Hydro	Geother. &Wind	General Total	Share (%)
EÜAŞ	17,226	1,851	22,395	-	975	42,447	28,338	-	70,785	36
Affiliated Partnerships of EÜAŞ	6,694	-	11,975	-	-	18,669	-	-	18,669	10
Autoproducers, Production Companies, TOR	72,175	14,744	4,720	340	3,829	95,808	7,620	1,931	105,359	54
Total	96,095	16,596	39,090	340	4,804	156,923	35,958	1,931	194,813	100
Share (%)	49	9	20	0	2	81	18	1	100	

Notes: (1) All values are in GWh.

(2) Hard&Imported Coal also includes Asphaltite.

(3) Other Thermal includes Fuel-Oil, Diesel oil, LPG and Naphtha.

(4) Source: TEİAŞ, Electricity Generation & Transmission Statistics of Turkey, 2009

Table 2.9. Annual Development of Electricity Generation, Consumption, Imports, Exports and Consumption

Years	Gross Generation	Internal Consumption	Net Generation	Imports	Supplied to Network	Network Losses			Exports	Net Consumption
						Transmission	*Distribution*	*Total*		
1985	34,219	2,307	31,912	2,142	34,055	1,611	2,735	4,346	-	29,709
1990	57,543	3,311	54,232	176	54,407	1,787	4,893	6,680	907	46,820
1995	86,247	4,389	81,859	0	81,859	2,035	11,734	13,769	696	67,394
2000	124,922	6,224	118,698	3,791	122,489	3,182	20,574	23,756	437	98,296
2005	161,956	6,487	155,469	636	156,105	3,695	20,349	24,044	1,798	130,263
2006	176,300	6,757	169,543	573	170,116	4,544	19,245	23,789	2,236	144,091
2007	191,558	8,218	183,340	864	184,204	4,523	22,124	26,647	2,422	155,135
2008	198,418	8,656	189,762	789	190,551	4,388	23,093	27,482	1,122	161,948
2009	194,813	8,194	186,619	812	187,431	3,973	25,018	28,991	1,546	156,894

Notes: (1) All values are in GWh.
(2) Supplied to Network = Net Generation+Import.
(3) As the export is made on delivery at border basis, its losses are included in the section for transmission network losses.
(4) Source: TEİAŞ, Electricity Generation & Transmission Statistics of Turkey, 2009

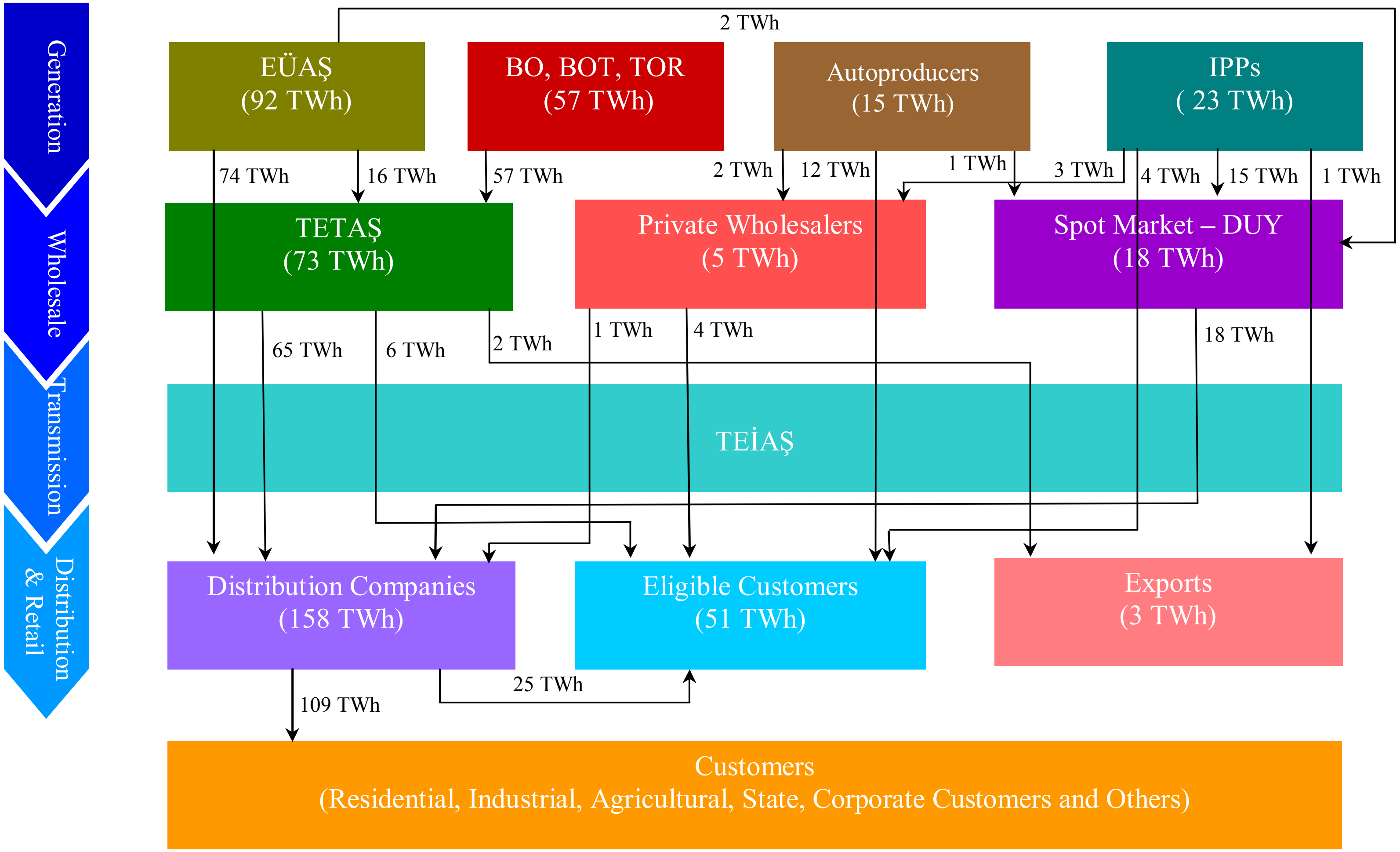

Figure 2.3. Electricity Flow for year 2008

Source: (Mert, 2010)

Per capita energy and electricity production and consumption of a country has been generally accepted as an indicator of the overall economic development of that country. Per capita installed electricity capacity of Turkey increased 5.22% annually from 1975 to 2009. In the same time period, per capita electricity consumption showed an annual increase of 5.48%, as shown in Table 2.10. However, when compared with other OECD countries, per capita installed capacity and generation of Turkey is extremely low. As seen in Table 2.11, out of 30 OECD countries, in 2008, Turkey performed better than only Mexico with respect to both indicators.

Table 2.10. Per Capita Electricity Capacity, Generation and Consumption in Turkey

Years	Per Capita				
	Installed Capacity	*Gross Generation*	*Supply*	*Gross Demand*	*Net Consumption*
1975	104	387	375	390	334
1980	114	520	519	550	456
1985	180	675	672	718	586
1990	289	1,019	947	1,006	829
1995	346	1,423	1,339	1,411	1,112
2000	402	1,841	1,799	1,891	1,449
2005	539	2,247	2,141	2,231	1,808
2006	549	2,385	2,272	2,363	1,936
2007	579	2,714	2,575	2,692	2,198
2008	585	2,774	2,649	2,770	2,264
2009	617	2,685	2,562	2,675	2,162

Notes: (1) Installed capacity values are in watt per capita, while others are in kWh per capita.
(2) Supply=Gross Consumption+Import-Export.
(3) Gross Demand=Gross Generation+Import-Export.
(4) Net Consumption=Supply-Network Losses
(5) Source: TEİAŞ, Electricity Generation & Transmission Statistics of Turkey, 2009

Table 2.11. Per Capita Electricity Capacity, Generation and Supply of OECD Countries in 2008

Countries	Per Capita		
	Installed Capacity	*Gross Generation*	*Gross Supply*
Australia	2,580	11,957	11,148
Austria	2,494	8,046	7,722
Belgium	1,565	7,927	8,422
Canada	3,830	19,541	17,954
Czech Republic	1,699	8,006	6,242
Denmark	2,277	6,630	6,685
Finland	3,135	14,576	16,403
France	1,838	8,966	7,721
Germany	1,696	7,759	6,952
Greece	1,269	5,667	5,676
Hungary	861	3,984	4,114
Iceland	8,063	51,563	50,000
Ireland	1,667	6,689	6,374
Italy	1,647	5,328	5,669
Japan	2,197	8,474	8,068
Korea	1,643	9,183	8,751
Luxembourg	3,388	7,347	13,673
Mexico	537	2,429	2,351
Netherlands	1,513	6,545	7,251
New Zealand	2,174	10,162	9,791
Norway	6,455	29,916	26,331
Poland	858	4,098	3,683
Portugal	1,485	4,331	5,028
Slovak Republic	1,360	5,360	4,972
Spain	2,052	6,881	6,293
Sweden	3,666	16,199	15,389
Switzerland	2,516	8,949	8,171
Turkey	588	2,791	2,665
U.Kingdom	1,395	6,347	6,173
USA	3,322	14,347	13,641
OECD Mean	2,086	9,031	8,549

Notes: (1) Installed capacity values are in watt per capita, while others are in kWh per capita.
(2) Source: IEA Statistics, Electricity Information, 2010

As stated in Section 2.2.3, in Turkey the electricity prices did not increase between 2003 and 2008. Following the unwelcome increases in January 2008, the electricity prices reached to 0.139 \$/kWh for industry, and to 0.165 \$/kWh for residence customers. With these new tariffs, Turkey started to price the industrial customers slightly more than OECD average, while the residence customers continue to pay less than OECD average, according to Table 2.12. Looking at the structure of electricity price in Turkey, we observe from Table 2.13 that generation cost makes up 64% of electricity price paid by a household in Turkey in 2008. Generation cost is followed by distribution cost, which is 11% of the electricity bill (Erdoğdu, 2009).

Table 2.12. Electricity Prices of Some OECD Countries According to OECD Mean in 2008

Countries	For Industry	Countries	For Residence
Korea	0.060	Korea	0.089
Norway	0.064	Mexico	0.096
New Zealand	0.071	Switzerland	0.154
Switzerland	0.094	Greece	0.157
Sweden	0.095	France	0.164
Finland	0.097	New Zealand	0.164
France	0.105	Norway	0.164
Greece	0.112	Turkey	0.165
Poland	0.119	Finland	0.172
Luxembourg	0.123	Czech Republic	0.191
Spain	0.125	Poland	0.193
Mexico	0.126	OECD Mean	0.199
Denmark	0.130	Japan	0.206
Portugal	0.131	Luxembourg	0.215
OECD Mean	0.133	Spain	0.218
Japan	0.139	Sweden	0.218
Turkey	0.139	Portugal	0.220
Belgium	0.140	Slovak Republic	0.220
Netherlands	0.140	Hungary	0.224
U.Kingdom	0.146	U.Kingdom	0.231
Czech Republic	0.151	Netherlands	0.243
Austria	0.154	Austria	0.257
Hungary	0.170	Belgium	0.266
Slovak Republic	0.174	Ireland	0.267
Ireland	0.186	Italy	0.305
Italy	0.290	Denmark	0.396

Notes: (1) All values are in \$/kWh.
(2) Source: IEA Statistics, Electricity Information, 2010

Table 2.13. Cost Structure of Electricity Price Paid by a Household in Turkey in 2008

Cost Type	Amount	Share (%)
Generation (a)	0.121069	64.07
Transmission (b)	0.004152	2.20
Distribution (c)	0.021417	11.33
Retail Sale (d)	0.001639	0.87
Total (A=a+b+c+d)	0.148277	78.47
Energy Fund (1%) (e)	0.001483	0.78
TRT Share (2%) (f)	0.002966	1.57
Municipality Consumption Tax (5%) (g)	0.007414	3.92
Total (B=e+f+g)	0.011862	6.28
VAT (18%) (C=(A+B)*0.18)	0.028825	15.25
Total (A+B+C)	0.188964	100.00

Notes: (1) All values are in TL/kWh.
(2) Source: Erdoğdu (2009)

CHAPTER 3

METHODOLOGY AND LITERATURE SURVEY

This chapter is devoted to methodologies used in estimating efficiency of firms. For this aim, firstly the definitions of some important concepts will be presented. Then, two most popular efficiency measurement techniques, Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA), will be discussed and compared with each other.

3.1. DEFINITIONS

3.1.1. Efficiency

“Efficiency” and “productivity” are two concepts which are used to characterize firms’ resource utilization performance. These two concepts are often treated as equivalent in the sense that if firm A is more productive than firm B, then it is generally believed that firm A is also more efficient. Indeed, they are related, but fundamentally different concepts. Following Ray (2004), the difference between them can be shown using an example of two firms producing single-output with single-input.

Assuming that firm A uses x_{A} units of the input x to produce y_{A} units of output y, and firm B produces y_{B} units using x_{B} units, then the average productiveness (AP) of these firms are

$$AP(\mathrm{A}) = \frac{y_{\mathrm{A}}}{x_{\mathrm{A}}} \tag{3.1}$$

$$AP(\mathrm{B}) = \frac{y_{\mathrm{B}}}{x_{\mathrm{B}}} \tag{3.2}$$

The firm with higher average productiveness is called as more productive. It should be noted that in the simple case with one-input and one-output, one does not need to know the technology to measure the average productiveness of the firms. It is enough to have the information about the input and output quantities. On the other hand, efficiency provides a comparison between a firm's actual output and the maximum producible quantity from its observed input.[37] For this, the technology described by a production function should be known to get the efficiencies of the firms. Suppose that the production function is given by

$$y = f(x) \tag{3.3}$$

and the maximum output producible from input x_{A}, and from input x_{B} are

$$y^*_{\mathrm{A}} = f(x_{\mathrm{A}}) \tag{3.4}$$

$$y^*_{\mathrm{B}} = f(x_{\mathrm{B}}) \tag{3.5}$$

For firm A, the output-oriented measure of efficiency is

$$TE^{\mathrm{A}}_o = \frac{y_{\mathrm{A}}}{y^*_{\mathrm{A}}} \leq 1 \tag{3.6}$$

If firm A produced the maximum producible output y^*_{A} from input x_{A}, its average productivity will be

$$AP^*(\mathrm{A}) = \frac{y^*_{\mathrm{A}}}{x_{\mathrm{A}}} \tag{3.7}$$

whereas at the observed input-output level, its productivity is

$$AP(\mathrm{A}) = \frac{y_{\mathrm{A}}}{x_{\mathrm{A}}} \tag{3.8}$$

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[37] This is just the definition of the "output-oriented technical efficiency", a type of technical efficiency definitions. More explanations regarding the type of technical efficiencies will be provided in Section 3.1.8.

Thus, the output-oriented technical efficiency of firm A can be written alternatively as

$$TE_o^{\mathrm{A}} = \frac{y_{\mathrm{A}}}{y_{\mathrm{A}}^*} = \frac{y_{\mathrm{A}}/x_{\mathrm{A}}}{y_{\mathrm{A}}^*/x_{\mathrm{A}}} = \frac{AP(\mathrm{A})}{AP^*(\mathrm{A})} \tag{3.9}$$

This relationship suggests that the technical efficiency of a firm is equal to its productivity divided by the productivity of a hypothetical firm producing the maximum output possible from the same input quantity. Figure 3.1 illustrates clearly the difference between productivity and efficiency for our simple case in which one-output is produced from one-input under decreasing returns to scale.

In figure 3.1, the observed input-output bundles of firms A and B are marked with $\times$. The slopes of the line *OA* and *OB* are equal to the average productivity of firm A and firm B, respectively. To determine the efficiency of the firms, we need to have the information regarding maximum output, y_{A}^* and y_{B}^*, producible from observed input quantities x_{A} and x_{B}. The maximum output producible from an input level depends on production function defined by underlying technology. The technical efficiency of firm A producing output y_{A} with input x_{A} is

$$TE_o^{\mathrm{A}} = \frac{y_{\mathrm{A}}}{y_{\mathrm{A}}^*} = \frac{y_{\mathrm{A}}/x_{\mathrm{A}}}{y_{\mathrm{A}}^*/x_{\mathrm{A}}} = \frac{\text{slope of } \mathit{0A}}{\text{slope of } \mathit{0A}^*} \tag{3.10}$$

Similarly, the technical efficiency of firm B

$$TE_o^{\mathrm{B}} = \frac{y_{\mathrm{B}}}{y_{\mathrm{B}}^*} = \frac{y_{\mathrm{B}}/x_{\mathrm{B}}}{y_{\mathrm{B}}^*/x_{\mathrm{B}}} = \frac{\text{slope of } \mathit{0B}}{\text{slope of } \mathit{0B}^*} \tag{3.11}$$

As can be seen from Figure 3.1, the firm A is more productive than firm B while firm B is more efficient than firm A. Thus, higher productivity does not always imply greater efficiency. This relationship holds only under constant returns to scale (CRS).

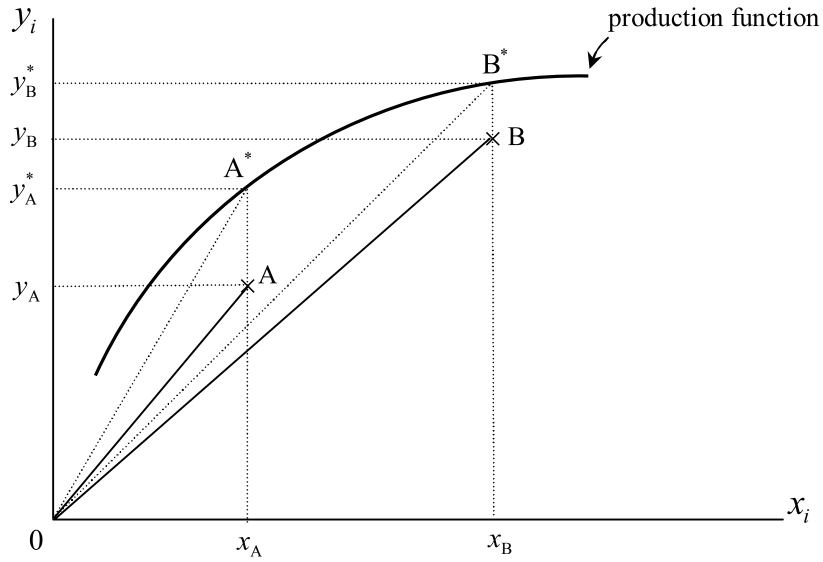

Figure 3.1. Productivity and Output-Oriented Technical Efficiency

Source: (Ray, 2004)

Leaving the simplified "one-input, one-output case" and starting to study on a more realistic multi-input, multi-output production technologies, one needs to represent production technologies by help of a set-theoretic framework. For this reason, before going into details of the technical efficiencies, we provide necessary definitions of some important concepts such as technology set, output set, input set and distance functions.

3.1.2. Technology Set

We use the notation of **x** and **y** to denote a $N\times 1$ input vector of non-negative real numbers and a non-negative $M\times 1$ output vector, respectively. The technology set consists of all input-output vectors (**x**, **y**) such that **x** can produce **y**. Notationally,

$$\mathrm{S} = \{(\mathbf{x},\mathbf{y}) : \mathbf{x} \text{ can produce } \mathbf{y}\} \tag{3.12}$$

3.1.3. Output Set

The output set, denoted as P(**x**), is the set of all output vectors, **y**, that can be produced using the input vector, **x**:

$$\mathrm{P}(\mathbf{x}) = \{\mathbf{y} : \mathbf{x} \text{ can produce } \mathbf{y}\} = \{\mathbf{y} : (\mathbf{x},\mathbf{y}) \in \mathrm{S}\} \tag{3.13}$$

The output set satisfies the following (Coelli et.al., 2005):

- $\mathbf{0} \in \mathrm{P}(\mathbf{x})$. Nothing can be produced from a given set of inputs, **x**.
- Non-zero output levels cannot be produced from zero levels of inputs.
- P(**x**) satisfies strong disposability of outputs. If $\mathbf{y} \in \mathrm{P}(\mathbf{x})$ and $\mathbf{y}' \leq \mathbf{y}$ then $\mathbf{y}' \in \mathrm{P}(\mathbf{x})$.
- P(**x**) satisfies strong disposability of inputs. If **y** can be produced from **x**, then **y** can be produced from any $\mathbf{x}' \geq \mathbf{x}$.
- P(**x**) is closed.
- P(**x**) is bounded. One cannot produce unlimited levels of outputs with a given set of inputs.
- P(**x**) is convex. If two combinations of output levels can be produced with a given input vector **x**, then any weighted average of these outputs can also be produced.

In Figure 3.1, the output set is illustrated for the simple case where two outputs, y_1 and y_2, are produced using the input vector, **x**.

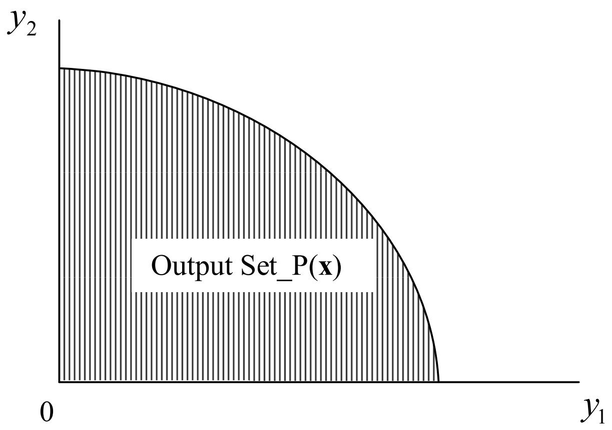

Figure 3.2. Output Set

3.1.4. Production Possibility Curve (Output Isoquant)

The boundary of output set is called as production possibility curve or output isoquant, shown in Figure 3.3. Production possibility curve represents the output combinations that could be produced using a given input level. One can draw a production possibility curve for each input level.

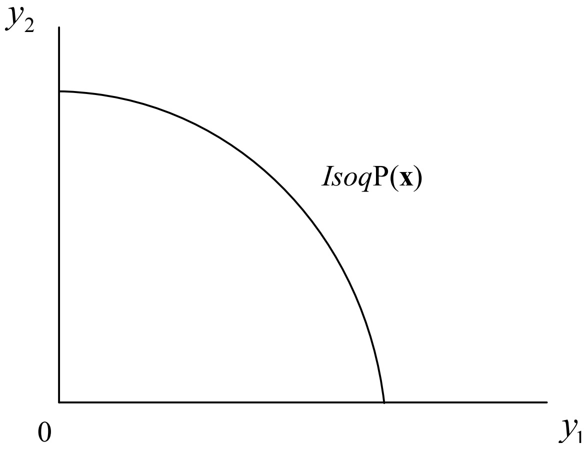

Figure 3.3. Production Possibility Curve

3.1.5. Input Set

The input set, L(**y**), consists of all input vectors, **x**, that can produce a given output vector, **y:**

$$\mathrm{L}(\mathbf{y}) = \{\mathbf{x} : \mathbf{x} \text{ can produce } \mathbf{y}\} = \{\mathbf{x} : (\mathbf{x}, \mathbf{y}) \in \mathrm{S}\} \qquad (3.14)$$

The properties of the input set are as follows:

- L(**y**) is closed for all **y**.
- L(**y**) is convex for all **y.**
- Inputs are said to be strongly disposable if $\mathbf{x} \in \mathrm{L}(\mathbf{y})$ and if $\mathbf{x}' \geq \mathbf{x}$ then $\mathbf{x}' \in \mathrm{L}(\mathbf{y})$.

Figure 3.4 shows the input set when two inputs, x_1 and x_2, are used in production of output vector **y**.

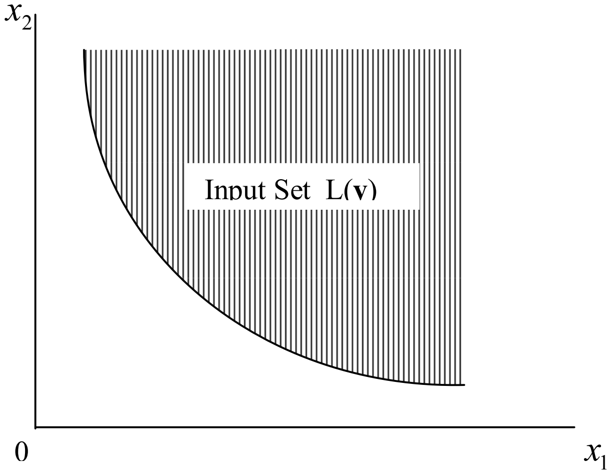

Figure 3.4. Input Set

It should be noted that the output and input set descriptions are the same because they contain the same information (Coelli, 2005): If **y** belongs to P(**x**), i.e. **y** can be produced using input vector **x**, then **x** belongs to the input set of **y**, L(**y**).

3.1.6. Input Isoquant

The boundary of the input set is called as input isoquant, shown in Figure 3.5. The input isoquant shows the combinations of inputs that could be used to produce a given output level. Similar to its output counterpart, an input isoquant could be drawn for each output level.

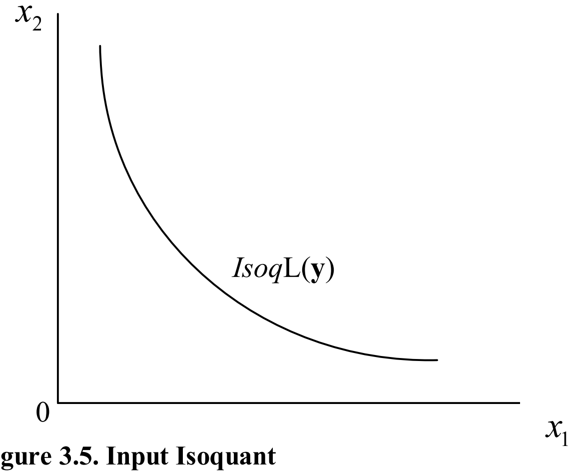

Figure 3.5. Input Isoquant

Taking into account the time, technical changes may be possible through time. If the technical advances occur, the production possibilities curve shifts upward, while input isoquant moves downward. It means that with technical advances, more output could now be produced using the same input level; or alternatively, less input is now needed to produce the same output level. A neutral[38] technical change (advance) is illustrated in Figure 3.6.

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[38] In the case of non-neutral technical change, the technical change favours production of one output (or usage of one input), and thus the shift in the production possibilities curve (or in the input isoquant) will not be parallel.

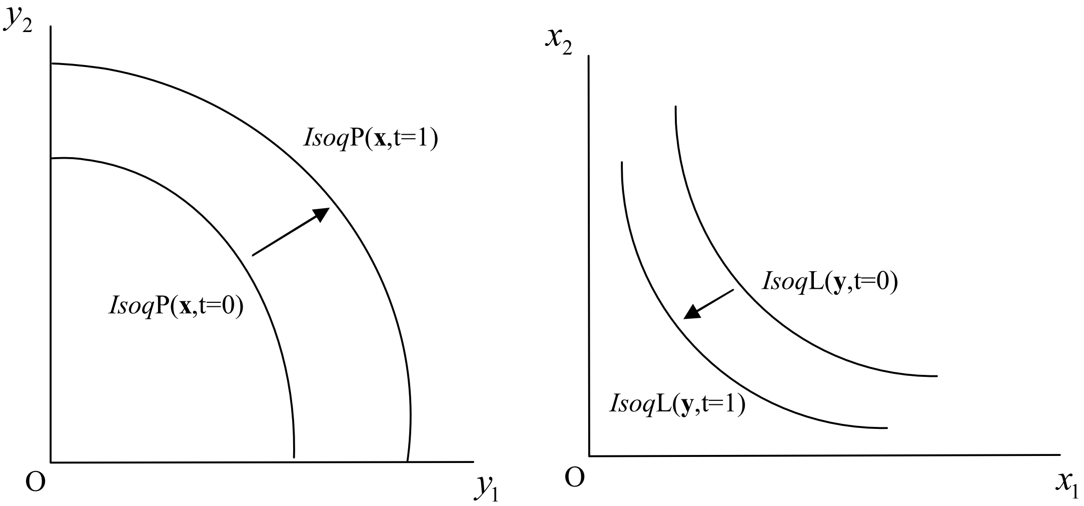

Figure 3.6. Technical Change (Advance)

3.1.7. Distance Functions

Distance functions, first introduced by Shephard (1953), are used in measuring efficiency and productivity. The basic idea behind this analytic tool is to determine the position of each firm relative to a frontier against which the efficiency is measured. More clearly, the distance of firms' input-output bundle to the frontier is measured in this technique. The most important advantage of the distance functions is that it allows describing a multi-input, multi-output production technology without specifying a behavioural objective such as cost-minimization or profit-maximization (Coelli, 2005).

Distance functions can be defined for both output vector and input vector.

3.1.7.1. Output Distance Functions

An output distance function represents the maximum proportional (radial) expansion of the output vector, given an input vector. Formally, the output distance function is defined on the output set, P(**x**), as:

$$d_O(\mathbf{x},\mathbf{y}) = \min\{\delta : (\mathbf{y}/\delta) \in \mathrm{P}(\mathbf{x})\} \tag{3.15}$$

The properties of the output distance function $d_O(\mathbf{x},\mathbf{y})$ are as follows (Coelli, 2005):

(i) $d_O(\mathbf{x},\mathbf{0}) = 0$ for all non-negative **x.**

(ii) $d_O(\mathbf{x},\mathbf{y})$ is non-decreasing in **y** and non-increasing in **x**.

(iii) $d_O(\mathbf{x},\mathbf{y})$ is linearly homogeneous in **y**.

(iv) $d_O(\mathbf{x},\mathbf{y})$ is quasi-convex in **x** and convex in **y**.

(v) If **y** belongs to the output set of **x** (i.e. $\mathbf{y} \in \mathrm{P}(\mathbf{x})$), then $d_O(\mathbf{x},\mathbf{y}) \le 1$.

(vi) $d_O(\mathbf{x},\mathbf{y}) = 1$ if **y** is on the production possibilities curve (namely, on the frontier of the output set).

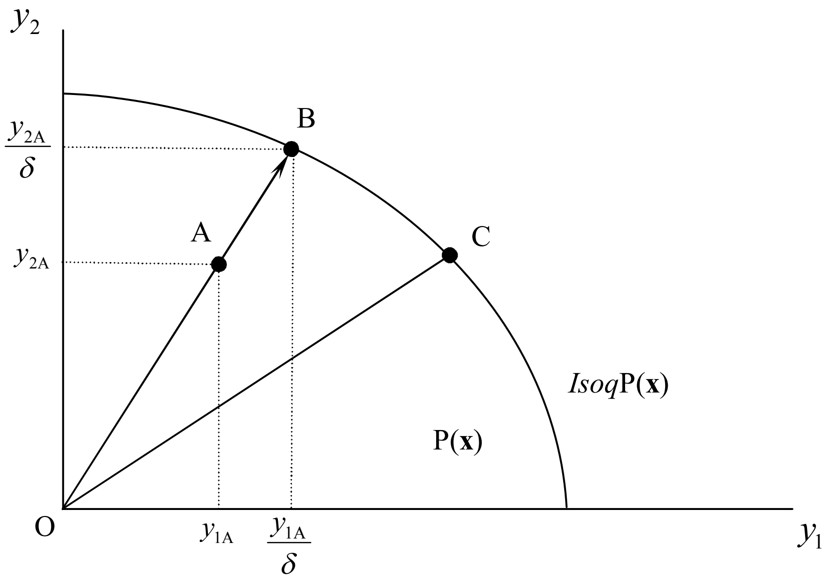

Figure 3.7. Output Distance Function and Production Possibility Curve

The notion of the output distance function is demonstrated in Figure 3.7 for the simple case where two outputs, y_1 and y_2, are produced using the input vector **x**.

The output distance measure is the reciprocal the factor by which the production of all output quantities could be increased while still remaining within the feasible output set P(**x**) for the given input level **x**. Thus, the value of the distance function for the firm A using input level **x** to produce outputs y_1 and y_2 is equal to the ratio $\delta = \mathrm{OA/OB}$, which is less than 1. On the other hand, the firms B and C are on the production possibilities curve, thus their output distance function values equal to 1.

3.1.7.2. Input Distance Functions

An input distance function demonstrates the minimal proportional (radial) contraction of the input vector, given an output vector. It is defined on the input set, L(**y**), as:

$$d_\mathrm{I}(\mathbf{x},\mathbf{y}) = \max\{\rho : (\mathbf{x}/\rho) \in \mathrm{L}(\mathbf{y})\} \tag{3.16}$$

The properties of the input distance function $d_\mathrm{I}(\mathbf{x},\mathbf{y})$ are as follows (Coelli, 2005):

(i) $d_\mathrm{I}(\mathbf{x},\mathbf{y})$ is non-increasing in **y** and non-decreasing in **x**.

(ii) $d_\mathrm{I}(\mathbf{x},\mathbf{y})$ is linearly homogeneous in **x**.

(iii) $d_\mathrm{I}(\mathbf{x},\mathbf{y})$ is concave **x** and quasi-concave in **y**.

(iv) If **x** belongs to the input set of **y** (i.e. $\mathbf{x} \in \mathrm{L}(\mathbf{y})$), then $d_\mathrm{I}(\mathbf{x},\mathbf{y}) \geq 1$.

(v) $d_\mathrm{I}(\mathbf{x},\mathbf{y}) = 1$ if **x** is on the input isoquant (namely, on the frontier of the input set).

Figure 3.8 illustrates the input distance function for the simple case where two inputs, x_1 and x_2, are used in production of output vector, **y**. The value of the input distance function for the firm A using $x_{1\mathrm{A}}$ of input x_1 and $x_{2\mathrm{A}}$ of input x_2 to produce output vector **y** is equal to the ratio $\rho = OA/OB$, which is larger than 1. On the other hand, since the firms B and C are on the input isoquant, their input distance functions take the value of 1.

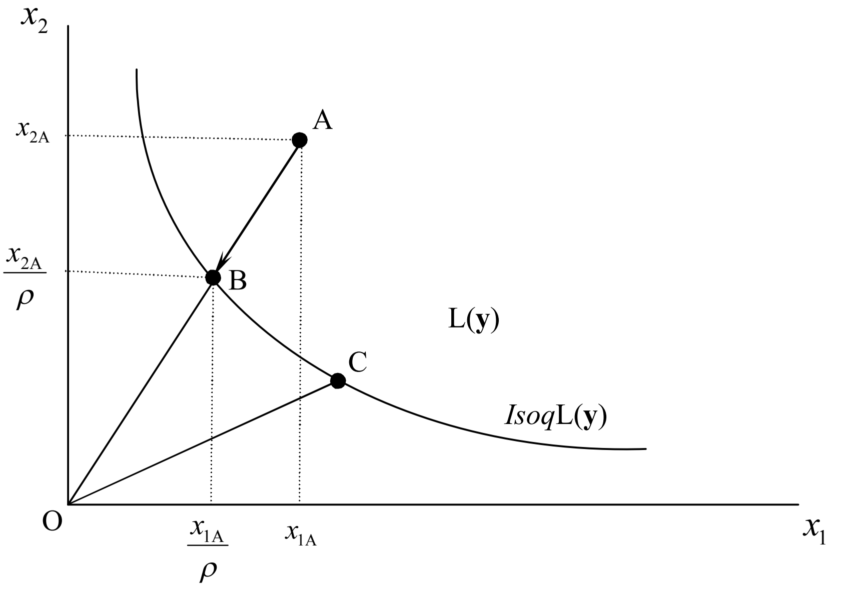

Figure 3.8. Input Distance Function and Input Isoquant

3.1.8. Technical Efficiency

Koopmans (1951) provides the formal definition of technical efficiency as: "*a producer is technically efficient if an increase in any output requires a reduction in at least one other output, or an increase in at least one input, and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output*". However, Farrell's (1957) seminal work is considered to be the first to provide a theoretical framework for determination of technical efficiencies.

The technical efficiency is one of two components of a firm's efficiency, according to Farrel (1957).[39] The level of technical efficiency of a particular firm

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[39] The other component of the efficiency is allocative efficiency which reflects the ability of the firm to use the inputs in optimal proportions, given their respective prices and the production technology. Technical and allocative efficiency together provide the economic efficiency. Since

is characterized by the relationship between observed production and some ideal or potential production (Greene, 1993). The measurement of firm specific technical efficiency is based upon deviations of observed output from the best production or efficient production frontier. If a firm's actual production point lies on the frontier it is perfectly efficient. If it is located inside the frontier then it is technically inefficient.

The technical efficiency may be expressed in terms of output-oriented or input-oriented.

3.1.8.1. Output-Oriented Technical Efficiency

In the output-oriented technical efficiency, an answer to the question of "By how much can output quantities be proportionally expanded without altering the input quantities?" is searched (Coelli, 2005). In other words, output-oriented technical efficiency measures the ability of the firm to obtain maximum output for a given input vector. The output-oriented technical efficiency can be shown by help of output distance function which is drawn in Figure 3.7. In that figure, the distance AB is the amount by which all outputs could be proportionally increased without extra input. In other words, the distance AB is the technical inefficiency of firm A. Thus, the output-oriented technical efficiency of this firm in terms of ratio is equal to one minus AB/OB; namely,

$$TE = OA/OB \tag{3.17}$$

As explained in Section 3.1.7.1, the output distance function $d_O(\mathbf{x},\mathbf{y})$ is also equal to the ratio OA/OB. In other words, the output distance function and

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this study aims to measure the technical efficiencies of the electricity distribution firms, we give the explanations regarding only technical efficiency.

output-oriented technical efficiency take the same value, which is between zero and one:

$$TE = d_{\mathrm{O}}(\mathbf{x}, \mathbf{y}) = OA / OB \tag{3.18}$$

If the firm under consideration (like firm C in Figure 3.7) is on the production possibility curve, it means that the firm is technically efficient.

3.1.8.2. Input-Oriented Technical Efficiency

In the input-oriented technical efficiency, the question of “By how much can input quantities be proportionally reduced without altering the output quantities?” is examined. Figure 3.8 illustrating the input distance function can be used to explain the input-oriented technical efficiency. The distance *AB* in Figure 3.8 is the amount by which inputs could be proportionally decreased without a reduction in input. Hence, the distance *AB* provides the technical inefficiency of firm A. Thus, the input-oriented technical efficiency of this firm in terms of ratio is equal to one minus *AB/OA*; namely

$$TE = OB / OA \tag{3.19}$$

As explained in Section 3.1.7.2, the input distance function $d_{\mathrm{I}}(\mathbf{x}, \mathbf{y})$ for firm A is equal to the ratio OA / OB. In other words, input-oriented technical efficiency is reciprocal of the input distance function:

$$TE = \frac{1}{d_{\mathrm{I}}(\mathbf{x}, \mathbf{y})} = OB / OA \tag{3.20}$$

The points which are on the input isoquant (like C in figure 3.8) correspond to the technically efficient cases, with a value of one for the technical efficiency score.

3.2. EFFICIENCY MEASUREMENT

As explained in Section 3.1, technical efficiency is defined as the distance of a firm from an efficient frontier which is accepted as a benchmark. The problem here is that while one can observe input-output combinations of the firms, the efficient frontier is not known. For this reason, the efficient frontier should be firstly determined.

There are several methods of constructing the efficient frontier. These methods can be categorized according to the assumptions and techniques which are used. First, the frontier may be determined *parametrically* or *non-parametrically*. In parametric approach, the functional form for the frontier and distribution of the deviations from it are assumed, and then the frontier is estimated using econometric techniques. Non-parametric approaches, on the other hand, neither impose any *a priori* assumptions about functional form of the frontier nor make any distributional assumptions for the deviations from the frontier. Instead, nonparametric approaches rely on linear programming to calculate piecewise linear segments of the efficient frontier.

Another categorization of the efficiency measurement methods is based on the structure of the deviations from the frontier. In this respect, the technical efficiency can be calculated *deterministically* or *stochastically*. In the deterministic approach, the distance between an observed inefficient firm and the efficient frontier is entirely attributed to the inefficiency. On the contrary, in stochastic approaches, one can attribute some part of the deviations from the frontier to random noises.

In the literature, one of the most popular methods in measuring the efficiency of firms is Stochastic Frontier Analysis (SFA), which is astochastic and parametric method. Among the nonparametric methods, Data Envelopment Analysis (DEA) has been used widely.

3.2.1. Data Envelopment Analysis (DEA)

Following the proposition in Farrel (1957), Boles (1966) and Shephard (1970) suggested a linear programming method to determine the efficient frontier as a piecewise-linear convex hull. However, this mathematical programming method has gained popularity with Charnes et al. (1978), in which this method was first named as data envelopment analysis (DEA).

Charnes et al. (1978) suggested an input-oriented approach to measuring efficiency assuming constant returns to scale (CRS). In the following years, Fare et al. (1983) and Banker et al. (1984) relaxed the CRS assumption and introduced the variable returns to scale (VRS) into DEA model.

Now we set out the linear programming problem corresponding to the basic input-oriented DEA specification of Charnes et al. (1978) under CRS assumption.[40] For this, as a starting point assume that there exist only one output which is produced from only one input. In this simple case, the efficiency is simply measured as a ratio between output and input of the relevant *i*-th firm:[41]

$$TE_i = \frac{output_i}{input_i} \tag{3.21}$$

However, firms usually produce more than one output using many inputs. Thus, in such multi-input $\mathbf{x}_i$ and multi-output $\mathbf{y}_i$ cases, the inputs and outputs may be

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[40] Since this study aims to use SFA rather than DEA in measuring technical efficiencies of electricity distribution companies, in this section we find it enough to explain DEA under only Charnes et al. (1978) specification.

[41] Although the equation 3.21 is just definition of productivity rather than efficiency, we can use them interchangeably under CRS assumption, as stated in Section 3.1.1.

aggregated into an average input and an average output by using input and output weights (**u** and **v** vectors, respectively). In this formulation the efficiency of the *i*-th firm takes the form:

$$TE_i = \frac{\mathbf{u}'\mathbf{y}_i}{\mathbf{v}'\mathbf{x}_i} \tag{3.22}$$

Here, it is supposed that a common set of weights (**u** and **v**) is valid for each firm, meaning that the importance given to the inputs and outputs are the same for all the firms under study. This restriction is relaxed by Charnes et al. (1978) letting each firm adopt its own set of weights. Now we turn back to explanations regarding Charnes et al. (1978) model.

We assume that there are *N* inputs and *M* outputs for each of *I* firms. The column vectors $\mathbf{x}_i$ and $\mathbf{y}_i$ represent the input and output vector for *i*-th firm. **X** is a *NxI* input matrix and **Y** is a *MxI* output matrix for all *I* firms. For each firm, we continue measuring the ratio of all outputs over all inputs, $\mathbf{u}'\mathbf{y}_i/\mathbf{v}'\mathbf{x}_i$, where **u** is an *Mx1* vector of output weights and **v** is a *Nx1* vector of input weights. The optimal weights of *i*-th firm are found by solving the following mathematical programming problem:

$$\begin{aligned} &\max_{\mathbf{u},\mathbf{v}} (\mathbf{u}'\mathbf{y}_i/\mathbf{v}'\mathbf{x}_i) \\ \text{st} \quad &(\mathbf{u}'\mathbf{y}_j/\mathbf{v}'\mathbf{x}_j) \le 1, \quad j = 1,2,\ldots,I \\ &\mathbf{u},\mathbf{v} \ge \mathbf{0} \end{aligned} \tag{3.23}$$

Here, we are searching the optimal values of **u** and **v** for the *i*-th firm, such that the efficiency measure of this firm is maximized, subject to the constraints that efficiency measures of all firms must be less than or equal to one. Solving this mathematical programming for each of the I firms, one may determine the most favourable set of weights for each firm.

It should be noticed that if $(\mathbf{u}^*, \mathbf{v}^*)$ is a solution to the mathematical programming given above, then $(\alpha\mathbf{u}^*, \alpha\mathbf{v}^*)$ is another solution, meaning that we face infinite number of solutions (Coelli et.al., 2005). To avoid this problem, Charnes et al. (1978) imposed the constraint $\mathbf{v}'\mathbf{x}_i = 1$. With this new constraint, the linear programming takes the form:

$$\begin{aligned} &\max_{\boldsymbol{\mu},\mathbf{v}}(\boldsymbol{\mu}'\mathbf{y}_i) \\ \text{st} \quad &\mathbf{v}'\mathbf{x}_i = 1, \\ &\boldsymbol{\mu}'\mathbf{y}_j - \mathbf{v}'\mathbf{x}_j \leq 0, \quad j = 1,2,\ldots,I \\ &\boldsymbol{\mu}, \mathbf{v} \geq \mathbf{0} \end{aligned} \tag{3.24}$$

Since this mathematical programming is different from the previous one, we changed the notation from $\mathbf{u}$ and $\mathbf{v}$ to $\boldsymbol{\mu}$ and $\mathbf{v}$, as used in Coelli et.al. (2005). This form of DEA model is known as the *multiplier form*. Taking its dual, we can obtain the *envelopment form* of the DEA model:

$$\begin{aligned} &\min_{\theta,\boldsymbol{\lambda}} \theta \\ \text{st} \quad &-\mathbf{q}_i + \mathbf{Y}\boldsymbol{\lambda} \geq 0, \\ &\theta\mathbf{x}_i - \mathbf{X}\boldsymbol{\lambda} \geq 0, \\ &\boldsymbol{\lambda} \geq \mathbf{0} \end{aligned} \tag{3.25}$$

The envelopment form takes the i-th firm and then seeks to radially contract the input vector $\mathbf{x}_i$, as much as possible, while still remaining in the feasible input set. Thus, similar to the multiplier form, the envelopment form is also solved for each of the I firms. In the envelopment form, θ is the amount of radial reduction in the use of each input without any change in outputs. Thus, scalar θ represent technical efficiency of the relevant *i*-th firm. In this specification, $\boldsymbol{\lambda}$ is a Ix1 vector of constants.

The inner-boundary of the input set constitutes the piece-wise efficient frontier. The radial contraction of the input vector $\mathbf{x}_i$ produces a projected point ($\mathbf{X\lambda}, \mathbf{Y\lambda}$) on this frontier. This projected point is a linear combination of observed data points. The constraints of the envelopment form ensure that this projected point cannot lie outside the feasible set (Coelli et.al. 2005).

As an illustration of the DEA technique, we consider five firms using two inputs, x_1 and x_2, to produce one output, y. The linear programming solution produces piece-wise linear frontier SS′, shown in Figure 3.9. Firms which are situated on this frontier (C, D and E) are fully efficient while firms which lie above-right of the frontier (A and B) are inefficient.

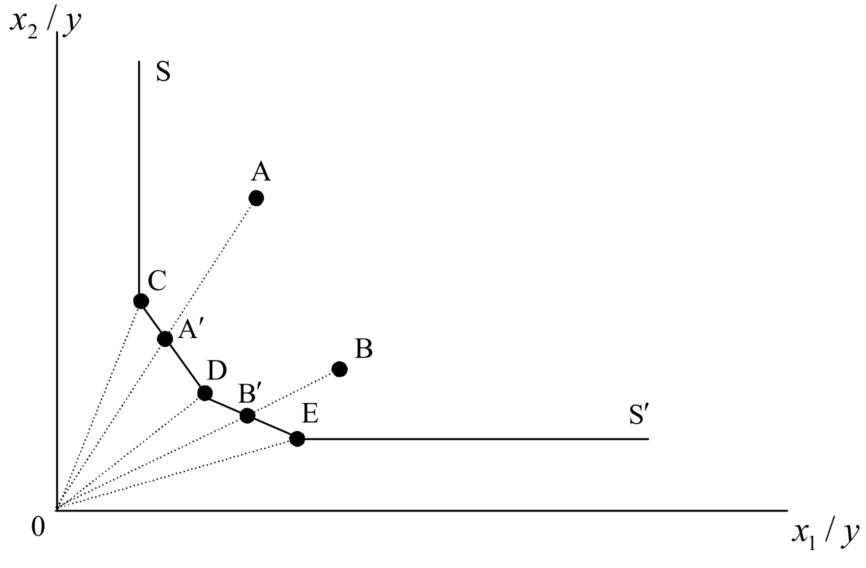

Figure 3.9. Input-Oriented Efficiency Measurement with DEA

The technical efficiency of firm A is captured by the ratio $0A'/0A$. One should note that the point A′ in Figure 3.9 does not represent a firm. Point A′ illustrates the position where firm A would occupy if it could be made fully efficient by radially reducing its use of both inputs.

As illustrated, the input-oriented DEA method calculates efficiency scores by reducing radially input usage, and in this way moving the firm towards the best practice frontier suggested by the all other observations.

3.2.2. Stochastic Frontier Analysis (SFA)

It is possible to estimate a production frontier using cross-sectional data on *I* firms. For this aim, all data points are enveloped by an arbitrarily-chosen function. Aigner and Chu (1968) used this approach using a Cobb-Douglass production frontier of the form:

$$\ln y_i = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni} - u_i \qquad (3.26)$$

where y_i is the output of the *i*-th firm, x_{ni} is the *n*-th input used by *i*-th firm, β 's are unknown parameters and u_i is a non-negative random variable associated with technical inefficiency.

Production frontier given in equation 3.26 is deterministic in the sense that all observed output points y_i 's are bounded from above by a deterministic frontier of $\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni})$. Accordingly, these kind of deterministic specifications exclude the possibility of the measurement error and other sources of statistical noises, and attribute all deviations from the frontier, $(\exp(-u_i))$ to the technical inefficiency. This assumption may be problematic especially when statistical noises are possible due to measurement errors in inputs, x_{ni}, specification errors in production function and any shocks outside the control of the firms. Thus, as an alternative to the deterministic specification, stochastic production frontier is defined by introducing another random variable representing statistical noise.

Stochastic frontier analysis (SFA) was proposed simultaneously by Aigner et al. (1977) and Meeusen and van den Broeck (1977). They added a symmetric random error (v_i) to the deterministic production frontier in order to account for the statistical noises:

$$\ln y_i = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni} + v_i - u_i \tag{3.27}$$

It is assumed that random error v_i independently distributed from technical inefficiency term u_i, and both errors are uncorrelated with the explanatory input variables x_{ni}. In SFA, the frontier, $\left(\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni} + v_i) \right)$, bounding above the outputs has now a stochastic nature. Since the error term (v_i) is a random variable with positive or negative value, the stochastic frontier varies about the deterministic part of the model, $\left(\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni}) \right)$.

Following Coelli et.al. (2005), we can examine the stochastic frontier model graphically by help of a Cobb-Douglas frontier function. For the simple case in which only one input, x_i, is used in the production of output y_i, Cobb-Douglas stochastic frontier can be alternatively written as:

$$\ln y_i = \beta_0 + \beta_1 \ln x_i + v_i - u_i \tag{3.28}$$

$$y_i = \exp(\beta_0 + \beta_1 \ln x_i + v_i - u_i) \tag{3.29}$$

$$y_i = \underbrace{\exp(\beta_0 + \beta_1 \ln x_i)}_{\substack{\text{deterministic} \\ \text{component}}} \underbrace{\exp(v_i)}_{\text{noise}} \underbrace{\exp(-u_i)}_{\text{inefficiency}} \tag{3.30}$$

In equation 3.30, $\exp(-u_i)$ takes a value between zero and one and provides us the technical efficiency of the *i*-th firm. It measures the output of the relevant firm relative to the output of a fully-efficient firm using the same amount of inputs:

$$TE_i = \frac{y_i}{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni} + v_i)} \tag{3.31}$$

$$TE_i = \frac{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni} + v_i - u_i)}{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_{ni} + v_i)} \tag{3.32}$$

$$TE_i = \exp(-u_i) \tag{3.33}$$

Figure 3.10 shows such a stochastic production frontier with decreasing returns to scale.

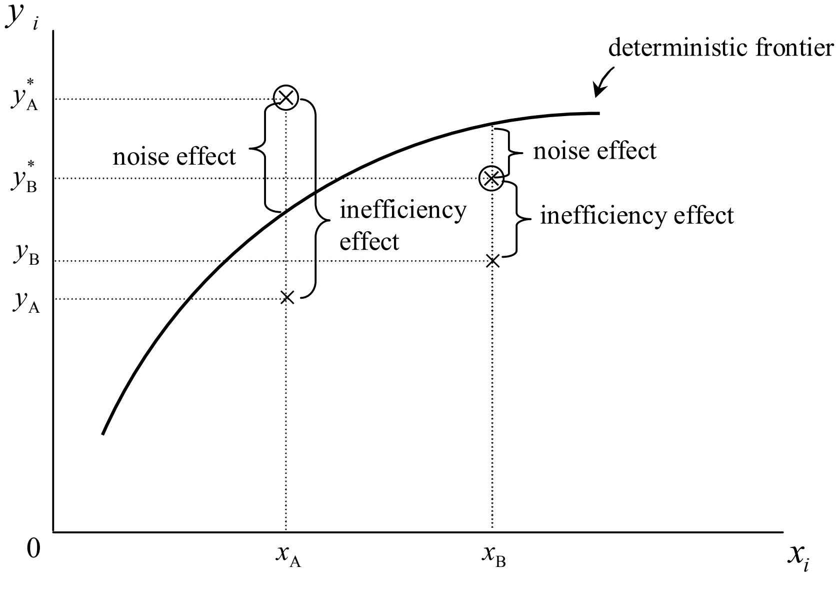

Figure 3.10. The Stochastic Production Frontier

Source: (Coelli et al., 2005).

In Figure 3.10, the observed output and input combinations of two firms, A and B, are depicted with $\times$. In the absence of inefficiency effects ($u_A = u_B = 0$), the frontier outputs, which are stochastic, would be

$$y_i^* = \exp(\beta_0 + \beta_1 \ln x_i + v_i) \qquad i{=}A,\ B. \tag{3.34}$$

These frontier values are shown with $\otimes$. The stochastic frontier can be above or below the deterministic frontier when the error term v_i is positive and negative, respectively. The observed outputs are below the deterministic frontier when the sum of the noise and inefficiency effect is negative ($v_i - u_i < 0$).

In order to determine technical efficiencies using a stochastic production frontier, one should estimate firstly the parameters of the production frontier in equation (3.27). However, the stochastic production frontier has a "composed error ε_i" including an noise component v_i and inefficiency component u_i. Thus, it is necessary to make some assumptions about these error terms. They are as follows (Coelli et al., 2005):

- $E(v_i) = 0,$ (zero mean) (3.35)
- $E(v_i^2) = \sigma_v^2,$ (homoskedastic) (3.36)
- $E(v_i v_j) = 0 \quad \forall i \neq j$ (uncorrelated) (3.37)
- $E(u_i^2) = \text{constant},$ (homoskedastic) (3.38)
- $E(u_i u_j) = 0 \ \forall i \neq j$ (uncorrelated) (3.39)

As can be seen, the properties of the noise term v_i are suitable to apply Ordinary Least Squares (OLS) technique. However, inefficiency term u_i has feature of $u_i \geq 0$, making the composed error term ε_i asymmetric:

$$E(\varepsilon_i) = E(v_i) - E(u_i) = 0 - E(u_i) = -E(u_i) \leq 0 \qquad (3.40)$$

Since $E(\varepsilon_i) = -E(u_i) \leq 0$, estimation of equation 3.27 by OLS can provide consistent estimate of β_n's (*n=1.2.,,,N*), but not of the β_0. The OLS estimator of the β_0 is biased downwards. Also, OLS does not provide estimates of firm-specific technical efficiency. One solution to this problem is to make additional assumptions regarding the inefficiency term (u_i), and to use maximum likelihood estimation (MLE) technique. The distributions used in the literature for the inefficiency term (u_i) are half-normal[42], truncated-normal[43], exponential[44] and gamma[45]. Kumbhakar and Lovell (2000) provides the log-likelihood functions for these different models. Ritter and Simar (1997) suggests that different assumptions about distributions generally give rise to similar rankings among firms although technical efficiency scores vary depending on the assumptions made.

Before maximizing the log-likelihood functions of different models, it is convenient to reparameterise them. For example, the models we utilize in this study are based on the Battese and Corra (1977) in which the log-likelihood function for truncated-normal distribution is reparameterized using $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$. The parameter γ must lie between 0 and 1. If it equals to zero it means that all deviations from the frontier are due to noise v_i; on the other hand, the value of one for the parameter γ means all deviations are because of the technical inefficiency.[46]

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[42] Aigner et al. (1977).

[43] Stevensen (1980).

[44] Meeusen and van den Broeck (1977).

[45] Greene (1993).

[46] An alternative reparametresation is due to Aigner et al. (1977) which replaces σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda^2 = \sigma_u^2 / \sigma_v^2$ for half-normal model. In this case, a value of zero for

Maximizing the the log-likelihood functions, one should set first order derivatives with respect to unknown parameters to zero. However, first-order conditions are highly nonlinear and cannot be solved analytically (Coelli et al., 2005). Thus, an iterative optimization procedure is utilized to estimate the values of the parameters (β's, σ, and γ - or λ). Judge et al. (1985) provides information on the iterative optimization procedures.

Obtaining the estimated values of the parameters, the predictor of the inefficiency component ($\hat{u}_i = E\{u_i | y_i\}$) should be found. For this aim, conditional pdf, $p(u_i | y_i)$, is determined in order to see likely and unlikely values of u_i after firm *i* has been selected and after we have observed its output, y_i (Coelli et al., 2005). Then, the technical efficiency of the *i*-th firm is found using the predictor value of $\hat{u}_i$ in the equation $TE_i = \exp(-\hat{u}_i)$.

The explanations made above are regarding the technical efficiency predictions for a simple production model in which only one type of output is produced. In the case of multiple outputs, this simple model does not permit the prediction of the efficiency scores, and one may aggregate the multiple outputs into a single index of output such as aggregate revenue, or Tornqvist and Fisher index. For such an aggregation, the prices of the output should be available, and revenue maximization assumption is required. However, in most of the sectors, the pricing of the outputs cannot be meaningful; or if so, it is not possible to reach their prices, or most importantly revenue maximization assumption may not be met. For such multi-output production technologies, the method of distance functions, introduced in Section 3.1.7, has been used extensively in the literature. In this study, we follow this suit and measure the efficiency of electricity distribution

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parameter λ means that there are no technical inefficiency effect and all deviations from the frontier is due to noise.

companies by help of distance functions. The explanations regarding SFA models we utilized in this study will be presented in Section 4.1.

3.2.3. Comparison of DEA and SFA

SFA and DEA are the most common methods used for estimating frontier functions and thereby measuring technical efficiencies of firms. DEA is based on linear programming whereas SFA employ econometric techniques. Since these two techniques are radically different, SFA and DFA methods have their own strengths and weaknesses. The pros and cons of these methods have been extensively discussed in the literature.

The main advantage of DEA is that it does not need any restriction on the functional form of the production relationship between inputs and outputs. In other words, this method allows the data to “speak for themselves” (Mortimer, 2002). SFA, in contrast, requires strong assumptions regarding the form of the frontier. Similarly, DEA does not require any assumption for the underlying distribution of the inefficiency term while SFA imposes distributional assumption on inefficiency term.

As a result of having no assumptions regarding the form of the frontier and inefficiency term, DEA is a deterministic method in nature. In other words, all deviations from the efficiency frontier are assumed to be under control of the firm, so attributed as inefficiency.[47] Another drawback of DEA is that it does not allow any statistical significance tests. On the contrary, SFA can model the stochastic shocks by help of the random error introduced into the specification of the frontier. With SFA one may also carry out statistical tests on different models with alternative specifications.

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[47] Several studies have aimed to provide a statistical foundation to DEA. One of these studies is Simar and Wilson (2002) which employ a bootstrapping technique.

As emphasized by Jacobs (2000), there exists a sharp trade-off in making a selection between these two methods. Thus, the literature comparing empirically and experimentally these two methods is growing extensively.[48] The literature comparing these two methods has no conclusion on which method is more advanced and correct. In this literature, one can find some suggestions as to selecting the correct method, although they should be considered just as rule of thumb in nature. For example, Banker et al. (1993) favoured DEA method where measurement error is unlikely and the assumptions of the neoclassical production theory are in question. In contrast, they claimed that econometric methods performs well when severe measurement errors exist and the underlying production technology can be illustrated by help of a simple functional form.

We may mention additional strengths and weaknesses of these methods. For instance, with DEA it is possible to identify "peers" for the inefficient firms, in this way inefficient firms can compare directly themselves with their efficient counterparts. However, the efficiency estimations of DEA method is extremely sensitive to variable selection, size of the sample and data errors. For example, as more variables are included in DEA models, the number of firms on the frontier increases. In addition, in DEA at least one of the firms should obtain full efficiency score, namely 1. This is so because of the fact that DEA only measures efficiency relative to best practice in the sample studied. For this reason, it is not meaningful to compare efficiency scores calculated from two different DEA studies. On the other hand, SFA method usually necessitates estimating a considerable amount of parameters, some of which may be frequently found insignificant or even with wrong signs.

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[48] Mortimer (2002) reviewed systematically the studies comparing these competing methods.

CHAPTER 4

MODELS AND DATA

In this chapter we first explain the models used in this study in the distance function framework. In addition, the specification of alternative models set up to measure efficiency scores of electricity distribution firms is presented. Lastly, the input, output and environmental variables used in these models are analyzed in this chapter.

4.1. MODELS

In this study, the models we utilize are based on the concept of distance function. As explained in Section 3.1.7, distance functions allow describing a multi-input, multi-output production technology without the need to specify a behavioural objective such as cost-minimisation or profit-maximisation.

In Turkish electricity market, distribution companies have been responsible from serving all customers in predetermined regions. In other words, similar to those of other countries, outputs in Turkish electricity market are accepted as exogenous. Thus, we measure the input-oriented technical efficiency of electricity distribution companies by help of input distance function. To be clear, we search an answer to the question of “By how much can input quantities be proportionally reduced without altering the output quantities?”. Meanwhile, as explained in Section 3.1.7.2, input-oriented technical efficiency is reciprocal of the input distance function:

$$TE = \frac{1}{d_{\mathrm{I}}(\mathbf{x},\mathbf{y})} \tag{4.1}$$

To empirically estimate technical efficiencies with this relationship, one should first specify a functional form for the input distance. The functional forms with the following features should be preferred (Coelli and Perlman, 2000): (i) flexible, (ii) easy to calculate, (iii) suitable for the imposition of homogeneity. The translog form has these features, and thus extensively used in the literature.[49] For this reason, we also selected the translog form to specify the input-distance function.

The translog input distance function[50] for M outputs and N inputs may be specified as:

$$\ln d_{it}(\mathbf{x},\mathbf{y}) = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{l=1}^{M} \alpha_{ml} \ln y_{mit} \ln y_{lit} + \sum_{n=1}^{N} \beta_n \ln x_{nit}$$

$$+\frac{1}{2}\sum_{n=1}^{N}\sum_{k=1}^{N} \beta_{nk} \ln x_{nit} \ln x_{kit} + \sum_{m=1}^{M}\sum_{n=1}^{N} \rho_{mn} \ln y_{mit} \ln x_{nit} + \alpha_t t \qquad (4.2)$$

where i (i=1,2,…,I) denotes the i-th firm in the sample and t (t=1,2,…,T) is time trend to cover the technical change.

As input-distance function is linear homogeneous in inputs, the parameters in equation 4.2 must fulfill the following regularity conditions:

$$\sum_{n=1}^{N} \beta_n = 1 \qquad (4.3)$$

$$\sum_{k=1}^{N} \beta_{nk} = 0 \qquad (4.4)$$

$$\sum_{n=1}^{N} \rho_{mn} = 0 \quad (m=1,2,\ldots,M) \qquad (4.5)$$

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[49] Coubb-Douglas functional form is another candidate for distance functions. However, Coubb-Douglas form, which is a special case of translog form, is not flexible in the sense that it restricts the elasticity of substitutions.

[50] In order to provide clarity in notations, from now on, we will not use the subscription I indicating that the distance function is input-oriented unless it is necessary. Meanwhile, one should note that the notation of *I* (italic) denotes the number of the firms in the sample.

Symmetry is also imposed by the following conditions:

$$\alpha_{ml} = \alpha_{lm} \quad (m,\ l=1,2,\ldots,M) \tag{4.6}$$

$$\beta_{nk} = \beta_{kn} \quad (n,\ k=1,2,\ldots,N) \tag{4.7}$$

Homogeneity in inputs implies that

$$d_{\mathrm{I}}(w\mathbf{x},\mathbf{y}) = wd_{\mathrm{I}}(\mathbf{x},\mathbf{y}) \ , \quad w>0 \tag{4.8}$$

As suggested by Lovell et al. (1994), selecting one of the inputs arbitrarily (say N-th input) and setting $w = 1/x_N$, we obtain

$$d_{\mathrm{I}}(\mathbf{x}/x_M,\mathbf{y}) = d_{\mathrm{I}}(\mathbf{x},\mathbf{y})/x_M \tag{4.9}$$

With the normalization[51], the translog distance function given in equation 4.2 can be written as follows:

$$\ln\bigl(d_{it}(\mathbf{x},\mathbf{y})/x_{Ni}\bigr) = \alpha_0 + \sum_{m=1}^{M}\alpha_m \ln y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{l=1}^{M}\alpha_{ml}\ln y_{mit}\ln y_{lit} + \sum_{n=1}^{N-1}\beta_n \ln x^*_{nit}$$
$$+\frac{1}{2}\sum_{n=1}^{N-1}\sum_{k=1}^{N-1}\beta_{nk}\ln x^*_{nit}\ln x^*_{kit} + \sum_{m=1}^{M}\sum_{n=1}^{N-1}\rho_{mn}\ln y_{mit}\ln x^*_{nit} + \alpha_t t \tag{4.10}$$

where $x^*_{nit} = x_{nit}/x_{Nit}$.

This expression can be rearranged as follows:

$$-\ln(x_{Nit}) = \alpha_0 + \sum_{m=1}^{M}\alpha_m \ln y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{l=1}^{M}\alpha_{ml}\ln y_{mit}\ln y_{lit} + \sum_{n=1}^{N-1}\beta_n \ln x^*_{nit}$$
$$+\frac{1}{2}\sum_{n=1}^{N-1}\sum_{k=1}^{N-1}\beta_{nk}\ln x^*_{nit}\ln x^*_{kit} + \sum_{m=1}^{M}\sum_{n=1}^{N-1}\rho_{mn}\ln y_{mit}\ln x^*_{nit} + \alpha_t t + v_{it} - u_{it} \tag{4.11}$$

where v_{it} is a random statistical noise and u_{it} is equal to $\ln d_{it}(\mathbf{x}_i,\mathbf{y}_i) \geq 0$ measuring the technical inefficiency of i-th firm at time t.

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[51] The operation of deflating N-1 inputs by the N-th input is called normalization.

In practice, it has been assumed that the random statistical noise v_{it} has the standard features, it is an independently and identically distributed (iid) random error term ($v_{it} \sim$ *iid N*(0, σ_v^2)). As for inefficiency term u_{it}, however, different assumptions have been used in literature, and based on these assumptions, different models have been produced. Among them, we utilized BC92&BC95, both of which are classified as time-varying inefficiency models. In other words, these models let the technical efficiency scores change over time.

The elasticities of the input distance function $\ln d_{it}(\mathbf{x},\mathbf{y})$ with respect to inputs and outputs provide valuable information[52]: Firstly, for cost-minimising levels of inputs, the elasticity of input distance function with respect to an input x_{nit}, ε_{nit}, equals to cost share of the *n*-th input for *i*-th firm at time period *t*, s_{nit};

$$\varepsilon_{nit} = \frac{\partial \ln d_{it}(\mathbf{x},\mathbf{y})}{\partial \ln x_{nit}} \tag{4.12}$$

$$= \beta_n + \sum_{k=1}^{N} \beta_{nk} \ln x_{kit} + \sum_{m=1}^{M} \rho_{mn} \ln y_{mit} = s_{nit} \tag{4.13}$$

Therefore, elasticity ε_{nit} provides information about the relative importance of the *n*-th input (Rasmussen 2010).

Similarly, for cost-minimising levels of inputs, the elasticity of input distance function with respect to an output y_{mit} ,τ_{mit}, equals to the negative of the elasticity of cost with respect to the *m*-th output;

$$\tau_{mit} = \frac{\partial \ln d_{it}(\mathbf{x},\mathbf{y})}{\partial \ln y_{mit}} \tag{4.14}$$

$$= \alpha_m + \sum_{l=1}^{M} \alpha_{ml} \ln y_{lit} + \sum_{n=1}^{N} \delta_{mn} \ln x_{nit} \tag{4.15}$$

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[52] For the derivation of the following elasticities, see Fare and Primont (1995).

In this study, we divide all output and input variables by their respective overall sample means, which does not change the efficiency scores obtained, but allow one to interpret the estimated first-order parameters ,β_n and α_m, directly as elasticities, ε_{nit} and τ_{mit} respectively, evaluated at the sample means (Rungsuriyawiboon and Coelli 2004).

Meanwhile, the sum of the elasticities of input distance function with respect to outputs provides the the degree of returns to scale (*RTS*);

$$RTS = \sum_{m=1}^{M} \tau_{mit} \tag{4.16}$$

If the *RTS* is less than unity in absolute value, it means that the production technology has increasing returns. In contrast, if the *RTS* is larger than unity, then the production technology has decreasing returns to scale. The *RTS* with the value of unity indicates the constant returns (Goto and Tsutsui 2008).

It is also possible to calculate the technological change (*TC*) or shift in the production frontier over time;[53]

$$TC = \frac{\partial \ln d_{it}(\mathbf{x},\mathbf{y})}{\partial t} = \alpha_t \tag{4.17}$$

If TC is found to be positive, it means that there exists a technological progress in production. A negative *TC,* in contrast, indicates technological backwardness.

4.1.1. Battese and Coelli (1992)

BC92 assumes that inefficiency term u_{it} is an exponential function of time. In other words,

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[53] For a graphical representation of technological change in the production frontier, see Figure 3.6.

$$u_{it} = u_i(\exp(-\eta(t-T))) \quad , \quad i=1,2,\ldots,N;\ t=1,2,\ldots,T \tag{4.18}$$

where u_i is firm specific inefficiency terms assumed to be a *iid* nonnegative truncated normal distribution, namely $u_i \sim iid\ N^+(\mu, \sigma_u^2)$, and η is an unknown parameter to be estimated. Since this model has just one unknown parameter, it is rather inflexible in comparison to similar models.[54] Another limitation of this model is that it does not allow for a change in the rank ordering of firms over time although the efficiency scores of the firms change. In other words, the firm that is ranked *n*-th at the first time period is always ranked *n*-th (Coelli et. al. 2005).[55]

BC92 suggests that the minimum-mean-squared-error predictor of the technical efficiency (TE_{it}) of the *i*-th firm in the time period *t* is equal to the expectation of $\exp(-u_{it})$ conditional on the composed error term $v_{it} - u_{it}$:

$$TE_{it} = E\left[\exp(-u_{it}) \middle| v_{it} - u_{it}\right] \tag{4.19}$$

In this study, we produced three alternative BC92 model specifications using different input variables and a time trend. The detailed explanations regarding these alternative specifications can be found in Section 4.2.

4.1.2. Battese and Coelli (1995)

BC92's restriction that the rank ordering of firms over time does not change may turn out to be an important drawback especially when there exist several factors (sometimes called "environmental variables") which may affect efficiencies of the firms differently. For example, if some of the firms were privatized during the time period examined, then it would be logical to expect that the efficiencies of these firms would increase more than those of other non-privatized companies. To

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[54] For example, Kumbhakar (1990) assumes a similar but a little more flexible structure for inefficiency term u_{it}. Accordingly, $u_{it} = u_i\left(1 + \exp(at + bt^2)\right)^{-1}$ in which *a* and *b* are unknown parameters to be estimated.

[55] The same limitation is valid for other similar studies such as Kumbhakar (1990).

overcome this potential problem, the authors of BC92 introduced another model (BC95) which let not only inefficiency term u_{it} but also the ranking of the firms change over time.

BC95 assumes that inefficiency term u_{it} is a *iid* nonnegative truncated normal distribution, $u_{it} \sim iid\ N^{+}(\mu_{it}, \sigma_u^2)$, where

$$\mu_{it} = \delta_0 + \sum_{h=1}^{H} \delta_h z_{hit} \qquad (4.20)$$

In this specification, z_{hit} is the *h*-th exogenous environmental variable which is expected to determine the firm-specific efficiency u_{it} by affecting the mean of its distribution μ_{it}. In addition, δ_h (*h*=1, 2, …, *H*) are slope parameters to be estimated. Negative parameters indicate that the variables of these parameters improve efficiency; in contrast, if one finds the sign of the some of these exogenous variables positive, it implies that these variables decrease the efficiency.

Similarly to BC92, we generated three different models based on BC95. These alternative model specifications are also explained in Section 4.2 in detail.

Meanwhile, in this study, all model estimates were obtained by maximum likelihood estimation techniques. We used the software program FRONTIER 4.1., which was written by Tim Coelli.

4.2. MODEL SPECIFICATIONS AND DATA

The first job in efficiency measurement studies is to determine the inputs, outputs and other (environmental) factors of the relevant sector. Although electricity distribution technologies are similar all over the world, a wide variety of factor combinations are employed in the efficiency studies of this sector.[56] In other words, a variable has been used as input, output or environmental variable in different studies.[57] The absence of consensus on which variables should be used as input, output or environmental variable may be explained, to some extent, by lack of data (Hattori et al., 2005).

Before introducing our models and variables, we should underline several important points: First, it is certainly desirable to take many factors and variables into account in the efficiency studies. However, in practice there are several reasons for limiting the number of variables used. First of all, degrees of freedom problem prevent taking all variables into account, especially when flexible models such as translog are used in the estimation. Second, when too many factors are included into model, some of them are probably found to be highly correlated, leading the problem of multicollinearity. Last, the difficulties of data collection may cause to limit the number of variables.[58]

Other important point to be addressed is that in this study we aimed to measure technical efficiency by using only physical measures of the variables. If the price data is available and it is reasonable to assume a behavioral objective such as cost minimization, it is possible (even preferable) to predict cost efficiency using a cost frontier. Although we have price data for the variables used in this study, we

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[56] Jamasb and Pollitt (2001) reviewed 20 efficiency studies regarding electricity distribution sector, and showed that there is no firm consensus in the literature on which variables best describe the performance of electricity distribution units.

[57] As can be seen from Table 3.1, the efficiency studies of Turkish electricity distribution sector also exhibit a wide variety in the input-output selection.

[58] Since we have a rather extensive data set, the last reason is not so valid for our study.

prefer not to predict cost efficiency because of the fact that cost minimization assumption is very questionable in regulated markets such as electricity distribution sectors mainly due to political and regulatory interventions (Rungsuriyawiboon and Coelli 2004).

Now we may begin to introduce our models and variables used. Utilizing BC92 we firstly built a base model called BC92-1 with two outputs and three inputs. Then we extended it twice by adding one input at a time to analyze the effects of the added variable on overall efficiency. We called the extended BC92 models as BC92-2 and BC92-3.

In addition to input and output variables, there are obviously other environmental factors, which can affect the efficiency of the electricity distribution firms. We took into account environmental factors which are not under the control of the relevant firms by generating three alternative BC95 models. Our BC95 models are based on the most extended version of the BC92 models, namely BC92-3. To be more precise, we created three BC95 models (BC95-1, BC95-2 and BC95-3) by adding to BC92-3 model one environmental variable at a time. The alternative model specifications are shown in Table 4.1.

Our base model BC92-1 and its five extensions have two outputs, electricity delivered in MWh, y_1 and number of customers , y_2. The reason for using number of customer in addition to electricity delivered is that a large part of distribution activities (metering services, customer connections, billing etc.) are directly correlated to the number of customers. Thus, when electricity delivered is used as the only output variable, there exist the risk of unfairly discriminating against those firms which sell smaller amounts of electricity per customer. Meanwhile, according to the extensive review by Jamasb and Pollitt (2001), these two variables are the most frequently used outputs in 20 benchmarking studies reviewed.[59]

Table 4.1. Specification of Models

Variable		Models					
		BC92-1	*BC92-2*	*BC92-3*	*BC95-1*	*BC95-2*	*BC95-3*
y_1	Electricity delivered	√	√	√	√	√	√
y_2	Number of customers	√	√	√	√	√	√
x_1	Number of employees	√	√	√	√	√	√
x_2	Length of distribution line	√	√	√	√	√	√
x_3	Transformer capacity	√	√	√	√	√	√
x_4	Outage hours per customer		√	√	√	√	√
t	Time			√	√	√	√
z_1	Customer density				√	√	√
z_2	Customer structure					√	√
t	Time						√

In the base BC92-1 model, the number of employees, x_1, the length of the distribution line in km , x_2 and transformer capacity in MVA , x_3 are used as input variables. With number of employees we aimed to approximate the labor input. Capital input was taken into account by other two variables, the length of the distribution line and transformer capacity. These three variables have been similarly found to be the most widely used input variables in Jamasb and Pollitt (2001).

The first extended model BC92-2 includes the quality of electricity distribution, x_4 as an input variable in addition to those of base model BC92-1. The quality of electricity distribution is generally used as input in efficiency studies.[60] Appa et al. (2010) examined the quality of electricity distribution in detail. Accordingly, the

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[59] Neuberg (1977) suggested “separate marketability of components” property in defining outputs. Since electricity delivered and number of customers have this property, in literature they are routinely chosen as output variables, if the necessary data is available.

[60] Coelli et.al. (2008), Growitsch et.al. (2009) and Bağdadioğlu and Senyücel (2010) are the studies which used quality of electricity distribution as input. This variable is, in contrast, used as an output by Appa et al. (2010).

quality of electricity distribution may be separated into two broad categories: technical quality and quality of customer service (ability to meet customers' needs such as new connections or repairs). Technical quality may be measured in terms of interruption of service or regularity in the voltage level supplied. Frequency of outages and duration of outages provide the technical quality in terms of interruption of service. For Turkish electricity distribution market, information regarding both the number of outages and their total duration is available. Following Growitsch et al. (2009), we prefer to use the average duration of blackouts per customer as a proxy for service reliability.[61]

The third model BC92-3 is created by adding a time trend ,t as an input variable into BC92-2 model. In so doing, we aimed to capture the technological changes or frontier shifts, if any.

As stated above, we created alternative BC95 models by adding environmental variables into the most extended BC92 model, namely BC92-3. Although these added environmental variables affect efficiencies of the firms, they are beyond managerial control of the relevant firms. These environmental variables are directly used for explaining the mean inefficiency term μ_{it}.

The first BC95 model (BC95-1) includes an environmental variable z_1 to account for the differences in the customer densities of regions (measured in number of customers per km of distribution line). One may expect that increasing customer density leads to higher technical efficiency, holding other things equal.

In BC95-2 model, another environmental variable regarding the customer structure z_2 is taken into account (proportion of sales in MWh to residential

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[61] Similarly, Bağdadioğlu and Senyücel (2010) also used the average outage duration per consumer for the quality variable. Coelli et al. (2008), on the other hand, prefer to use total number of outages for this input variable.

customers to total sales). In contrast to the customer density, we do not pose *a priori* expectations on the effect of the customer structure on the efficiency estimation. However, several studies such as Hirschhausen et al. (2006) reported that an increase of the share of industrial customers represents a disadvantage for the electricity distribution companies in terms of efficiency.

In addition to these environmental variables, we used in Model 95-3 a time trend t to explain the changes in the mean inefficiency term μ_{it}.

Meanwhile, our data set explained above involves annual data on 21 electricity distribution firms over the eight-year period from 2002 to 2009. This data is obtained from the web page of TEDAŞ. Descriptive statistics over the variables are shown in Table 4.2. The mean values of the variables for each distribution firm over the period examined are given in Table 4.3. As can be seen from this table, Boğaziçi is the largest electricity distribution firm with respect to both output variables, electricity delivered and number of customers. This firm is followed by Toroslar with regard to electricity delivered, and by Başkent with regard to number of customers.

Table 4.2. Descriptive Statistics

Variable	Descriptive Statistics						
	Description	*Unit*	*Mean*	*Minimum*	*Maximum*	*Median*	*Std.Dev.*
y_1	Electricity delivered	MWh	6,105,994.0	1,382,135.0	21,300,000.0	4441497	4,609,341.0
y_2	Number of customers	person	1,348,031.0	320,639.0	3,886,951.0	1197765	828,941.3
x_1	Number of employees	person	1,391.5	493.0	4,042.0	1223.5	652.6
x_2	Length of distribution line	km	39,348.8	12,801.0	95,271.0	37083.5	18,708.44
x_3	Transformer capacity	MVA	4,437.4	868.0	13,244.0	4050	2,922.1
x_4	Outage duration per customer	hour/customer	0.042	0.002	0.202	.0319	.0354
z_1	Customer density	customer/km	38.3	14.9	130.8	27.4	28.5
z_2	Customer structure	%	28.0	10.8	46.0	27.5	9.0

Table 4.3. Descriptive Statistics_Mean values over the period 1992-1999

	Outputs		Inputs				Enviro.Variables	
	y_1	y_2	x_1	x_2	x_3	x_4	z_1	z_2
Akdeniz	4,880,183.9	1,272,226.4	1,091.3	48,412.5	4,200.9	0.015	26.2	0.263
Aras	2,014,846.6	661,074.6	1,494.8	39,069.3	1,518.8	0.083	16.9	0.413
AYEDAŞ	7,596,034.6	1,919,549.9	1,976.6	15,892.6	5,106.9	0.011	120.6	0.423
Başkent	9,749,431.1	2,753,702.0	3,044.3	81,451.5	8,546.1	0.055	33.8	0.326
Boğaziçi	18,443,143.0	3,459,975.5	1,899.1	29,297.1	11,802.8	0.014	118.0	0.334
Çamlıbel	1,842,603.8	681,132.1	919.5	30,398.1	1,571.4	0.017	22.4	0.320
Çoruh	2,090,649.9	916,081.1	1,125.5	42,181.1	1,700.9	0.052	21.7	0.426
Dicle	11,754,074.0	921,164.6	1,768.9	37,580.3	4,773.8	0.122	24.6	0.263
Fırat	2,052,389.3	603,790.9	1,206.9	32,971.9	1,648.6	0.037	18.3	0.277
Gediz	11,883,492.0	2,190,529.0	1,554.5	37,418.3	8,089.6	0.034	58.7	0.247
Göksu	2,969,988.4	438,268.3	652.3	16,507.8	1,577.0	0.095	26.6	0.161
KCETAŞ	2,058,853.8	469,141.1	625.3	14,644.5	1,693.5	0.013	32.0	0.215
Menderes	4,873,664.3	1,331,714.8	921.1	55,792.5	4,889.6	0.034	23.8	0.273
Meram	4,974,487.1	1,384,797.4	1,924.1	55,462.6	5,719.6	0.040	25.0	0.226
Osmangazi	4,137,207.5	1,157,794.4	1,043.5	30,506.8	3,790.8	0.022	37.9	0.208
Sakarya	6,331,141.0	1,232,741.5	1,006.5	36,818.9	5,653.5	0.028	34.0	0.154
Toroslar	12,118,692.0	2,436,088.4	2,423.1	69,691.3	7,956.3	0.029	34.9	0.238
Trakya	4,265,767.4	701,327.0	569.3	13,971.5	2,967.1	0.042	50.2	0.163
Uludağ	8,306,224.3	2,063,678.6	1,555.1	46,591.8	6,040.3	0.019	44.2	0.222
Vangölü	2,176,295.9	361,626.9	946.9	23,334.5	1,123.3	0.050	15.5	0.380
Yeşilırmak	3,706,695.4	1,352,253.6	1,473.3	68,330.8	2,814.6	0.073	19.8	0.359

The graphs showing the development of the variables over time are presented in Appendix A. For all firms, a continuous increasing trend is observed in both output variables (electricity delivered and number of customers) over this period. As for the input variables, the number of employees shows a decreasing trend in all firms while length of distribution line and transformer capacity usually increase over the entire period. On the other hand, the data of other input variable, outage duration per customer, does not reveal any clear structural tendency. Examining the graphs of the environmental variables of the firms, Boğaziçi and AYEDAŞ attract our attention especially with respect to customer density. The number of customers per km of distribution line is extensively greater in both side of İstanbul than those of other regions.

CHAPTER 5

ESTIMATION RESULTS

In this chapter, efficiency estimation results of alternative models studied are presented. In addition, comparing the results of these models, we attempt to draw some robust conclusions in the light of these results.

5.1. ESTIMATION RESULTS FOR ALTERNATIVE BC92 MODELS

The parameter estimates of the input distance function for alternative BC92 models (BC92-1, BC92-2 and BC92-3) are presented in Table 5.1. Given that we normalized each variable by its sample mean and then used their natural logarithm, the first-order coefficients (α_m, β_n; m=1,..,M; n=1,…,N) can be directly interpreted as elasticities at the sample mean. As explained in Section 4.1, input elasticities provide information regarding input contribution shares.

First of all, the estimated parameters of the input distance function should satisfy regularity condition in the sense that the distance function is decreasing in outputs and increasing in inputs. In other words, the first-order coefficients of the outputs α_m and inputs β_n should take negative and positive values, respectively.[62]

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[62] A negative coefficient implies a decrease in input distance function, meaning that an expansion in the input set. In contrast, a positive coefficient implying an increase in the distance function corresponds to a contraction of the feasible input set.

Table 5.1. Estimation Results of Alternative BC92 Models

Variable	Param.	Model BC92-1		Model BC92-2		Model BC92-3	
		Coefficient	*t-ratio*	*Coefficient*	*t-ratio*	*Coefficient*	*t-ratio*
Constant	α_0	0.422***	7.33	0.414***	7.26	0.395***	6.82
$\ln y_1$	α_1	-0.118***	-3.60	-0.145***	-3.66	-0.154***	-4.15
$\ln y_2$	α_2	-0.397***	-9.39	-0.361***	-7.94	-0.390***	-8.78
$(\ln y_1)^2$	α_{11}	-0.169	-1.30	-0.226	-1.63	-0.126	-0.92
$(\ln y_2)^2$	α_{22}	0.477***	3.20	0.536***	3.22	0.521***	3.11
$(\ln y_1)(\ln y_2)$	α_{12}	0.102	0.85	0.071	0.53	0.025	0.19
$\ln x_1$	β_1	0.213	-	0.189	-	0.202	-
$\ln x_2$	β_2	0.531***	13.64	0.546***	12.70	0.546***	13.16
$\ln x_3$	β_3	0.256***	6.63	0.253***	5.95	0.238***	5.87
$\ln x_4$	β_4	-	-	0.012	1.28	0.014	1.52
$(\ln x_2 / x_1)^2$	β_{22}	0.297***	2.85	0.389***	3.70	0.347***	3.12
$(\ln x_3 / x_1)^2$	β_{33}	0.003	0.03	-0.002	-0.02	-0.016	-0.15
$(\ln x_4 / x_1)^2$	β_{44}	-	-	0.015	1.48	0.015	1.39
$(\ln x_2 / x_1)(\ln x_3 / x_1)$	β_{23}	-0.065	-0.67	-0.113	-1.17	-0.073	-0.72
$(\ln x_2 / x_1)(\ln x_4 / x_1)$	β_{24}	-	-	-0.029*	-1.76	-0.023	-1.44
$(\ln x_3 / x_1)(\ln x_4 / x_1)$	β_{34}	-	-	0.030*	1.80	0.026	1.55
$(\ln y_1)(\ln x_2 / x_1)$	ρ_{12}	-0.197***	-3.32	-0.185**	-2.60	-0.162**	-2.36
$(\ln y_1)(\ln x_3 / x_1)$	ρ_{13}	0.188**	2.16	0.229**	2.37	0.168*	1.83
$(\ln y_1)(\ln x_4 / x_1)$	ρ_{14}	-	-	-0.021	-1.00	-0.020	-0.95
$(\ln y_2)(\ln x_2 / x_1)$	ρ_{22}	0.241***	3.49	0.192**	2.50	0.163**	2.13
$(\ln y_2)(\ln x_3 / x_1)$	ρ_{23}	-0.256***	-3.03	-0.228**	-2.56	-0.170*	-1.95
$(\ln y_2)(\ln x_4 / x_1)$	ρ_{24}	-	-	0.010	0.43	0.016	0.66
t	α_t	-	-	-	-	0.008***	2.74
Variance	σ^2	0.035***	11.30	0.033***	10.77	0.037***	11.42
Variance ratio	γ	0.975***	188.3	0.975***	157.3	0.979***	232.7
	μ	0.367***	7.09	0.356***	6.51	0.382***	7.42
	η	0.003	0.54	0.004	0.67	-0.004	-0.52
Log-likelihood		281.295		282.799		285.511	

Notes: (1) ***, ** and * denote significance at the 1%, 5% and 10% level using a two-tailed test.
(2) β_1 is calculated by homogeneity conditions.

Looking at estimated parameters of two first-order output coefficients, α_1 and α_2, it can be seen that they have the negative sign as expected, and are statistically significant at 1% significance level, in all three alternative models. We also observe that alternative models provided rather similar estimated values for each α_1 and α_2 output parameters. In addition, the sum of first-order output coefficients is less than 1 in absolute value in all alternative models (0.52, 0.51, 0.54, respectively), indicating the presence of increasing returns to scale at the mean of the data. To be more precise, for increasing both outputs by 1%, we need to increase the input requirements only about by 0.5%.

As for the estimated first-order input coefficients, the results show that they have positive signs as expected across all models. Among them, those of length of distribution line (β_2) and transformer capacity (β_3) are statistically significant at the 1% significance level.[63] In addition, the magnitudes of these coefficients differ slightly across the alternative models. Accordingly, when these first-order input coefficients are interpreted as cost share, we can conclude that expenses for distribution line account for slightly more than half of the total costs at the sample mean. Expenses for the transformers and employees approximately account for 25% and 20% of total costs, respectively.

As explained in Section 4.2, the quality variable defined as outage duration per customer has been taken into account in Model BC92-2 and Model BC92-3. Although in both models, the sign of the quality variable is positive as expected; its value is not statistically significant. It means that introducing the quality variable into the analysis has no statistically significant effect on the estimated efficiency scores.

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[63] Since the coefficient for number of employees (β_1) is calculated by homogeneity conditions, its significance test has not be done. Nevertheless, its estimated value is rather high, which lead us to conclude that this input is also important.

In searching technical change (*TC*) in the production frontier over time, a time trend is included into Model BC92-3. As shown in equation 4.17, the coefficient of this time trend α_t provides the shift in the production frontier if any. This coefficient has been found positive (0.008) and statistically significant at 1% significance level. This indicates that the production frontier exhibits a technological progress of 0.8% per year over the period studied.

In all three alternative specifications of BC92, the variance parameters, σ^2 and γ, are statistically significant at 1% significance level.[64] The estimated value of parameter γ is approximately found 0.98 in all alternative models, indicating that the variance of the composed error term σ^2 is attributed to almost entirely the variance of the technical inefficiency term σ_u^2. In other words, the technical inefficiency component (σ_u^2) dominates the random noise component σ_v^2, which makes the usage of deterministic distance functions instead of stochastic ones plausible.

As for parameter η in the exponential model of BC92, defined by equation 4.18, Model BC92-1 and Model BC92-2 provide positive estimates while Model BC92-3 calculates a negative estimate.[65] However, these estimated values of the parameter η are statistically insignificant, meaning that there is no significant change in the technical efficiency scores through time, according to alternative BC92 models.

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[64] σ^2 and γ are reparameterized coefficients equivalent to $\sigma_v^2 + \sigma_u^2$ and σ_u^2 / σ^2, respectively. As explained in Section 3.2.2, these reparameterizations are necessary for maximizing the likelihood function.

[65] As explained in Section 4.1.1, positive/negative η estimates correspond to increases/decreases in the technical efficiency scores over time.

Table 5.2. Technical Efficiency Scores for Model BC92-1

Company	Rank	Efficiency Scores							
		2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Akdeniz	12	0.609	0.610	0.611	0.612	0.614	0.615	0.616	0.617
Aras	17	0.517	0.519	0.520	0.521	0.523	0.524	0.525	0.527
AYEDAŞ	2	0.928	0.928	0.929	0.929	0.929	0.929	0.930	0.930
Başkent	21	0.404	0.405	0.406	0.408	0.409	0.411	0.412	0.414
Boğaziçi	6	0.720	0.721	0.722	0.723	0.724	0.725	0.726	0.726
Çamlıbel	10	0.663	0.664	0.665	0.666	0.668	0.669	0.670	0.671
Çoruh	13	0.588	0.589	0.590	0.591	0.593	0.594	0.595	0.596
Dicle	11	0.627	0.628	0.630	0.631	0.632	0.633	0.634	0.635
Fırat	14	0.556	0.558	0.559	0.560	0.562	0.563	0.564	0.566
Gediz	5	0.734	0.735	0.736	0.737	0.737	0.738	0.739	0.740
Göksu	7	0.711	0.712	0.713	0.714	0.715	0.716	0.717	0.717
KCETAŞ	3	0.815	0.816	0.817	0.817	0.818	0.819	0.819	0.820
Menderes	15	0.550	0.552	0.553	0.554	0.556	0.557	0.558	0.560
Meram	18	0.496	0.497	0.499	0.500	0.501	0.503	0.504	0.506
Osmangazi	4	0.807	0.808	0.808	0.809	0.810	0.810	0.811	0.812
Sakarya	8	0.706	0.707	0.708	0.709	0.710	0.711	0.712	0.713
Toroslar	19	0.491	0.493	0.494	0.495	0.497	0.498	0.500	0.501
Trakya	1	0.992	0.992	0.992	0.992	0.992	0.992	0.992	0.992
Uludağ	9	0.671	0.672	0.673	0.674	0.675	0.676	0.677	0.678
Vangölü	16	0.520	0.521	0.522	0.524	0.525	0.526	0.528	0.529
Yeşilırmak	20	0.462	0.463	0.465	0.466	0.468	0.469	0.470	0.472
Mean		0.646	0.647	0.648	0.649	0.650	0.651	0.652	0.653

The year-by-year technical efficiency predictions of alternative BC92 models (BC92-1, BC92-2 and BC92-3) are presented in Table 5.2, Table 5.3 and Table 5.4, respectively. As a result of BC92 specification, the rankings of the companies do not change although their efficiency scores change over the periods. Since Model BC92-1 and Model BC92-2 estimate positive but insignificant values for parameter η, the efficiency scores of all companies show a slight increase during 1992-1999 period in these models. In contrast, with a negative and insignificant estimate for parameter η, Model BC92-3 indicates minor efficiency decreases during the same time period.

Table 5.3. Technical Efficiency Scores for Model BC92-2

Company	Rank	Efficiency Scores							
		2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Akdeniz	11	0.610	0.610	0.611	0.612	0.613	0.614	0.615	0.616
Aras	16	0.527	0.528	0.529	0.530	0.531	0.532	0.533	0.534
AYEDAŞ	2	0.939	0.939	0.939	0.939	0.939	0.939	0.940	0.940
Başkent	21	0.405	0.406	0.407	0.408	0.409	0.410	0.411	0.412
Boğaziçi	5	0.731	0.732	0.733	0.733	0.734	0.735	0.735	0.736
Çamlıbel	10	0.662	0.663	0.664	0.665	0.665	0.666	0.667	0.668
Çoruh	12	0.603	0.604	0.605	0.606	0.607	0.608	0.609	0.610
Dicle	13	0.597	0.598	0.599	0.599	0.600	0.601	0.602	0.603
Fırat	14	0.558	0.559	0.560	0.561	0.562	0.563	0.564	0.565
Gediz	6	0.728	0.729	0.730	0.730	0.731	0.732	0.732	0.733
Göksu	7	0.716	0.717	0.717	0.718	0.719	0.719	0.720	0.721
KCETAŞ	4	0.767	0.767	0.768	0.769	0.769	0.770	0.770	0.771
Menderes	15	0.555	0.556	0.557	0.558	0.559	0.560	0.561	0.562
Meram	18	0.494	0.495	0.496	0.497	0.498	0.499	0.500	0.501
Osmangazi	3	0.790	0.791	0.791	0.792	0.793	0.793	0.794	0.794
Sakarya	8	0.694	0.694	0.695	0.696	0.697	0.697	0.698	0.699
Toroslar	19	0.488	0.489	0.490	0.491	0.492	0.493	0.494	0.495
Trakya	1	0.984	0.984	0.984	0.984	0.984	0.984	0.984	0.984
Uludağ	9	0.670	0.671	0.672	0.673	0.673	0.674	0.675	0.676
Vangölü	17	0.527	0.528	0.529	0.530	0.531	0.532	0.533	0.534
Yeşilırmak	20	0.479	0.480	0.481	0.482	0.483	0.484	0.485	0.486
Mean		0.644	0.645	0.646	0.646	0.647	0.648	0.649	0.649

Table 5.4. Technical Efficiency Scores for Model BC92-3

Company	Rank	Efficiency Scores							
		2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Akdeniz	11	0.606	0.605	0.604	0.603	0.602	0.601	0.599	0.598
Aras	17	0.499	0.498	0.497	0.496	0.494	0.493	0.492	0.490
AYEDAŞ	2	0.937	0.937	0.937	0.937	0.936	0.936	0.936	0.936
Başkent	21	0.421	0.419	0.418	0.417	0.415	0.414	0.413	0.411
Boğaziçi	4	0.774	0.774	0.773	0.772	0.771	0.771	0.770	0.769
Çamlıbel	10	0.631	0.630	0.629	0.628	0.627	0.626	0.625	0.624
Çoruh	13	0.573	0.572	0.571	0.569	0.568	0.567	0.566	0.565
Dicle	12	0.599	0.598	0.597	0.596	0.595	0.594	0.593	0.591
Fırat	15	0.534	0.532	0.531	0.530	0.529	0.527	0.526	0.525
Gediz	6	0.754	0.753	0.752	0.751	0.750	0.750	0.749	0.748
Göksu	8	0.691	0.690	0.689	0.688	0.687	0.686	0.685	0.684
KCETAŞ	5	0.773	0.773	0.772	0.771	0.770	0.770	0.769	0.768
Menderes	14	0.549	0.547	0.546	0.545	0.544	0.542	0.541	0.540
Meram	18	0.495	0.494	0.492	0.491	0.490	0.488	0.487	0.486
Osmangazi	3	0.788	0.787	0.786	0.786	0.785	0.784	0.784	0.783
Sakarya	7	0.704	0.703	0.702	0.701	0.700	0.699	0.698	0.697
Toroslar	16	0.507	0.506	0.504	0.503	0.502	0.500	0.499	0.498
Trakya	1	0.988	0.988	0.988	0.988	0.988	0.988	0.988	0.988
Uludağ	9	0.683	0.682	0.681	0.680	0.679	0.678	0.677	0.676
Vangölü	19	0.495	0.493	0.492	0.491	0.489	0.488	0.487	0.485
Yeşilırmak	20	0.468	0.466	0.465	0.464	0.462	0.461	0.460	0.458
Mean		0.641	0.640	0.639	0.638	0.637	0.636	0.635	0.634

Table 5.5 presents the average efficiency scores for each company over the eight-year period for alternative BC92 models. In all three alternative models, Trakya is the most efficient electricity distribution company with an efficiency score of 0.99 approximately. The second most efficient company is AYEDAŞ, according to all alternative models. Model BC92-1 determines KCETAŞ as the third most efficient company, while Osmangazi is the third most efficient company according to Model BC92-2 and Model BC92-3. As for the most inefficient company, all three models point Başkent with an approximate efficiency score of 0.41, which is somewhat unexpected result. It implies that the same output quantities could have been produced by Başkent even when the input usage was reduced by 59% approximately. Yeşilırmak appears as the second most inefficient

electricity distribution company, according to all alternative model specifications. The third most inefficient company is Toroslar according to Model BC92-1 and Model BC92-2, while Model BC92-3 concludes that the third most inefficient company is Vangölü.

Table 5.5. Average Efficiency Scores for Alternative BC92 Models

Company	Average Efficiency Scores		
	BC92-1	*BC92-2*	*BC92-3*
Akdeniz	0.613	0.613	0.602
Aras	0.522	0.531	0.495
AYEDAŞ	0.929	0.939	0.937
Başkent	0.409	0.409	0.416
Boğaziçi	0.723	0.734	0.772
Çamlıbel	0.667	0.665	0.628
Çoruh	0.592	0.607	0.569
Dicle	0.631	0.600	0.595
Fırat	0.561	0.562	0.529
Gediz	0.737	0.731	0.751
Göksu	0.714	0.718	0.688
KCETAŞ	0.818	0.769	0.771
Menderes	0.555	0.559	0.544
Meram	0.501	0.498	0.490
Osmangazi	0.809	0.792	0.785
Sakarya	0.710	0.696	0.701
Toroslar	0.496	0.492	0.502
Trakya	0.992	0.984	0.988
Uludağ	0.675	0.673	0.680
Vangölü	0.524	0.531	0.490
Yeşilırmak	0.467	0.483	0.463

Table 5.6 tabulates the summary statistics of technical efficiency scores obtained by alternative BC92 models. As shown in this table, all three models provide similar statistics for the efficiency scores: In all models, the efficiency scores vary from 0.41 to 0.99 approximately while their average is equal to about 0.64. An obvious reason for the similarity between estimated efficiency scores is that one

of the input variables (the quality variable) included into the model specifications has been found to be lack of power to affect efficiency scores.[66]

Table 5.6. Summary Statistics of Technical Efficiency Scores for Alternative BC92 Models

Model	Summary Statistics				
	Mean	*Minimum*	*Maximum*	*Median*	*Std. Dev.*
BC92-1	0.650	0.404	0.992	0.632	0.149
BC92-2	0.647	0.405	0.984	0.613	0.144
BC92-3	0.638	0.411	0.988	0.603	0.152

5.2. ESTIMATION RESULTS FOR ALTERNATIVE BC95 MODELS

Table 5.7 tabulates parameter estimates of the input distance function for alternative BC95 models (BC95-1, BC95-2 and BC95-3). Similar to the BC92 applications given in the previous section, since each variable is normalized by its sample mean and their natural logarithm is used, one may directly interpret the first-order coefficients (α_m, β_n; m=1,..,M; n=1,…,N) as elasticities at the sample mean.

As stated before, the input distance function should be decreasing in outputs and increasing in inputs. The results confirmed that the input distance functions estimated using alternative BC95 models has fulfilled this condition at the sample mean: All the parameter estimates have the appropriate sign ($\alpha_m < 0$ for all m outputs and $\beta_n > 0$ for all n inputs). In addition, they are found to be statistically significant at the 1% significance level in all models.

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[66] Taking alternative BC95 models into account as well, a more systematic comparison between all alternative models will be made in Section 5.3.

Table 5.7. Estimation Results of Alternative BC95 Models

Variable	Param.	Model BC95-1		Model BC95-2		Model BC95-3	
		Coefficient	*t-ratio*	*Coefficient*	*t-ratio*	*Coefficient*	*t-ratio*
Constant	α_0	0.128***	4.36	0.126**	2.56	0.160***	4.89
$\ln y_1$	α_1	-0.241***	-2.96	-0.332***	-3.39	-0.266***	-4.49
$\ln y_2$	α_2	-0.64***	-7.05	-0.581***	-4.49	-0.669***	-9.63
$(\ln y_1)^2$	α_{11}	-0.398***	-2.9	-0.410**	-2.31	-0.474***	-3.48
$(\ln y_2)^2$	α_{22}	0.159	0.65	0.218	1.14	0.179	1.02
$(\ln y_1)(\ln y_2)$	α_{12}	0.063	0.36	0.011	0.07	0.058	0.43
$\ln x_1$	β_1	0.19	-	0.19	-	0.158	-
$\ln x_2$	β_2	0.237***	2.75	0.1	0.83	0.19**	2.52
$\ln x_3$	β_3	0.573***	7.56	0.698***	8.93	0.645***	13.44
$\ln x_4$	β_4	0.000	0.01	0.012	0.50	0.007	0.35
$(\ln x_2 / x_1)^2$	β_{22}	0.643***	6.2	0.419***	4.02	0.480***	5.33
$(\ln x_3 / x_1)^2$	β_{33}	-0.239**	-2.0	-0.424***	-3.41	-0.434***	-3.80
$(\ln x_4 / x_1)^2$	β_{44}	0.05**	2.0	0.062**	2.33	0.056**	2.59
$(\ln x_2 / x_1)(\ln x_3 / x_1)$	β_{23}	-0.353***	-3.81	-0.119	-1.30	-0.183*	-1.97
$(\ln x_2 / x_1)(\ln x_4 / x_1)$	β_{24}	-0.104***	-3.04	-0.121***	-3.15	-0.107***	-3.66
$(\ln x_3 / x_1)(\ln x_4 / x_1)$	β_{34}	0.067**	2.04	0.073**	2.18	0.069**	2.58
$(\ln y_1)(\ln x_2 / x_1)$	ρ_{12}	-0.097	-0.97	-0.181*	-1.77	-0.143	-1.33
$(\ln y_1)(\ln x_3 / x_1)$	ρ_{13}	0.404***	3.81	0.469***	4.34	0.436***	3.83
$(\ln y_1)(\ln x_4 / x_1)$	ρ_{14}	-0.071	-1.39	-0.079	-1.58	-0.072*	-1.79
$(\ln y_2)(\ln x_2 / x_1)$	ρ_{22}	0.186	1.53	0.185	1.53	0.103	0.80
$(\ln y_2)(\ln x_3 / x_1)$	ρ_{23}	-0.163**	-2.04	-0.155*	-1.87	-0.111	-1.30
$(\ln y_2)(\ln x_4 / x_1)$	ρ_{24}	0.062	1.06	0.059	1.06	0.057	1.23
t	α_t	0.006	1.65	0.004	0.79	0.006	1.45
Variance	σ^2	0.01***	3.77	0.013***	2.92	0.012***	5.28
Variance ratio	γ	0.911***	12.97	0.955***	22.78	0.978***	47.89
Constant	δ_0	0.45***	4.88	0.581**	2.49	0.583***	10.52
z_1	δ_1	-0.009***	-3.94	-0.009	-1.53	-0.01***	-13.32
z_2	δ_2	-	-	-0.797***	-3.68	-0.736***	-3.64
z_3	δ_3	-	-	-	-	0.015	1.50
Log-likelihood		196.32		196.94		198.81	

Notes: (1) ***, ** and * denote significance at the 1%, 5% and 10% level using a two-tailed test.
(2) β_1 is calculated by homogeneity conditions.

In examining two first-order output coefficients, α_1 and α_2, we observe that their magnitudes vary mildly between alternative models. As for their sum, the alternative models provide somewhat similar figures, which are less than 1 in absolute value: The sum of the first-order output conditions amount to 0.88, 0.91 and 0.93 respectively in absolute value in alternative BC95 models. It means that we need to increase the input requirements by 0.9% approximately in order to increase both outputs by 1%. Thus, this finding shows that there exists increasing returns to scale at the mean of the data.

An examination of the estimated first-order input coefficients reveals that transformer capacity, β_3 is statistically significant at the 1% significance level across alternative models. The coefficient of length of distribution line, β_2 is found to be significant at the 1% and 5% significance levels in Model BC95-1 and Model BC95-3, respectively.[67] All alternative BC95 models incorporate the quality variable defined as outage duration per customer. These models produced statistically insignificant coefficients for quality variable. It implies that the quality variable has no statistically significant effect on the estimated efficiency scores. Looking the magnitudes of the input coefficients, we observe that they may differ across the alternative models. From these models, however, it is safe to conclude that expenses for transformers account for more than half of the total costs at the sample mean.

Technical change (*TC*) in the production frontier over time has been examined in all alternative models. The coefficient of the time trend α_t included to catch a possible *TC* is found to be positive in all models. Although this coefficient is not statistically significant at even 10% significance level, its t-ratio is found to be rather high, especially in Model BC95-1 and Model BC95-3. Thus, in the light of the findings of these models, we may conclude that the production technology has

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[67] As stated before, the coefficient for number of employees (β_1) calculated by homogeneity conditions, ant thus its significance test has not be done.

been improving at a rate of 0.6% per year, although this figure is not statistically significant.

The variance parameters, σ^2 and γ, are statistically significant at 1% significance level. The estimated value of the parameter γ ranges between 0.91 and 0.98 depending on the alternative model. This supports the conclusion that most of deviations from the frontier are due to technical inefficiency, σ_u^2 rather than statistical noise, σ_v^2.

As explained in Section 4.1.2, in BC95 framework, several environmental factors which have the potential to affect the efficiencies of the companies are included into model specification. The mean inefficiency, μ_{it}, is directly defined in terms of these environmental variables. The first environmental factor included into all alternative BC95 is the customer density of the regions in which the distribution companies operate. This environmental factor is measured in terms of number of customers per km of distribution line. The estimated parameter of the customer density, δ_1 is negative in all models; and statistically significant in Model BC95-1 and Model BC95-3, but slightly insignificant in Model BC95-2. Accordingly, it may be possible to derive the conclusion that companies operating in a region with higher customer density are more efficient than other firms.

Another environmental variable expected to affect efficiency of companies is the customer structure defined as proportion of sales in MWh to residential customers to total sales. This environmental variable is included into Model BC95-2 and Model BC95-3. Both models estimate negative and statistically significant parameters ,δ_2 for this environmental variable, meaning that efficiencies of the companies serving to mostly the residential customers are higher than those of other companies.

The third environmental variable which may explain the mean inefficiency is a time trend, which is included only into Model BC95-3. The estimated parameter of the time trend, δ_3 is positive, but statistically insignificant. If it was significant, we would conclude that the efficiencies of the firms decrease over time.

Table 5.8, Table 5.9 and Table 5.10 present the technical efficiency predictions of alternative BC95 models (BC95-1, BC95-2 and BC95-3), respectively. In contrast to BC92 specification, both the efficiency scores and the rankings of the companies change over the periods. Meanwhile the rankings of the companies in the relevant year are shown in parentheses in tables. As can be seen from the bottom line of the tables, the average efficiency level in the electricity distribution fluctuates mildly year by year.

As can be seen from Table 5.8, Table 5.9 and Table 5.10, the individual efficiency scores and rankings of the distribution companies may show substantial change over the period examined. Thus, it may be unreasonable to derive strict conclusions which are valid for every year. However, all the alternative BC95 models determine the same companies as the most efficient ones. These companies are AYEDAŞ, Boğaziçi and Gediz, all of which have an efficiency score larger than 0.95. On the other hand, as for the most inefficient companies, Meram shows the worst performance according to all alternative models. The second and third most inefficient companies vary depending on the model used. According to Table 5.11 in which the eight-year average efficiency scores are tabulated, it is safe to suggest that Yeşilırmak, Fırat and Vangölü are other companies with low efficiency levels. It should be stressed, however, that since the efficiency levels of some companies are generally rather close to each other, one should treat the rankings of the companies with some caution.

Table 5.8. Technical Efficiency Scores for Model BC95-1

Company	Efficiency Scores and Rankings							
	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Akdeniz	0.815 (17)	0.808 (15)	0.804 (14)	0.793 (15)	0.813 (15)	0.787 (14)	0.794 (15)	0.800 (14)
Aras	0.865 (10)	0.838 (13)	0.827 (12)	0.787 (16)	0.757 (20)	0.730 (20)	0.734 (19)	0.716 (20)
AYEDAŞ	0.987 (3)	0.992 (1)	0.989 (2)	0.982 (2)	0.985 (2)	0.989 (1)	0.991 (1)	0.992 (1)
Başkent	0.833 (13)	0.774 (17)	0.779 (16)	0.779 (17)	0.818 (14)	0.810 (11)	0.805 (14)	0.795 (15)
Boğaziçi	0.988 (2)	0.992 (2)	0.989 (1)	0.990 (1)	0.974 (3)	0.986 (2)	0.989 (2)	0.991 (2)
Çamlıbel	0.896 (6)	0.885 (10)	0.893 (7)	0.878 (9)	0.836 (12)	0.826 (10)	0.848 (11)	0.844 (12)
Çoruh	0.863 (11)	0.857 (11)	0.861 (11)	0.869 (10)	0.877 (7)	0.840 (9)	0.819 (13)	0.835 (13)
Dicle	0.844 (12)	0.893 (9)	0.889 (8)	0.890 (8)	0.839 (11)	0.791 (12)	0.860 (9)	0.786 (16)
Fırat	0.765 (19)	0.757 (19)	0.754 (19)	0.741 (19)	0.757 (19)	0.747 (18)	0.758 (17)	0.740 (18)
Gediz	0.988 (1)	0.973 (4)	0.983 (3)	0.949 (5)	0.967 (4)	0.966 (4)	0.968 (3)	0.924 (9)
Göksu	0.816 (16)	0.838 (14)	0.823 (13)	0.827 (12)	0.839 (10)	0.857 (8)	0.859 (10)	0.871 (11)
KCETAŞ	0.879 (9)	0.916 (6)	0.866 (10)	0.862 (11)	0.856 (9)	0.888 (7)	0.912 (8)	0.949 (7)
Menderes	0.757 (20)	0.773 (18)	0.740 (20)	0.798 (14)	0.796 (16)	0.784 (16)	0.940 (6)	0.955 (5)
Meram	0.671 (21)	0.675 (21)	0.577 (21)	0.654 (21)	0.665 (21)	0.675 (21)	0.679 (21)	0.886 (10)
Osmangazi	0.928 (5)	0.966 (5)	0.937 (5)	0.947 (6)	0.950 (6)	0.934 (5)	0.940 (5)	0.948 (8)
Sakarya	0.886 (8)	0.912 (8)	0.804 (15)	0.815 (13)	0.825 (13)	0.789 (13)	0.837 (12)	0.952 (6)
Toroslar	0.889 (7)	0.914 (7)	0.937 (6)	0.901 (7)	0.866 (8)	0.785 (15)	0.758 (16)	0.778 (17)
Trakya	0.980 (4)	0.986 (3)	0.878 (9)	0.953 (4)	0.954 (5)	0.919 (6)	0.938 (7)	0.976 (3)
Uludağ	0.818 (15)	0.844 (12)	0.982 (4)	0.976 (3)	0.986 (1)	0.979 (3)	0.968 (4)	0.971 (4)
Vangölü	0.825 (14)	0.793 (16)	0.776 (17)	0.737 (20)	0.762 (18)	0.755 (17)	0.751 (18)	0.711 (21)
Yeşilırmak	0.790 (18)	0.753 (20)	0.759 (18)	0.744 (18)	0.771 (17)	0.743 (19)	0.733 (20)	0.720 (19)
Mean	0.861	0.864	0.850	0.851	0.852	0.837	0.851	0.864

Note: The rankings of the companies in the relevant year are given in parentheses.

Table 5.9. Technical Efficiency Scores for Model BC95-2

Company	Efficiency Scores and Rankings							
	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Akdeniz	0.841 (15)	0.826 (15)	0.828 (14)	0.818 (15)	0.840 (16)	0.821 (16)	0.826 (19)	0.812 (19)
Aras	0.967 (5)	0.940 (10)	0.930 (8)	0.886 (11)	0.859 (13)	0.835 (14)	0.842 (16)	0.818 (16)
AYEDAŞ	0.986 (1)	0.991 (2)	0.986 (2)	0.976 (3)	0.981 (2)	0.989 (1)	0.992 (1)	0.993 (1)
Başkent	0.824 (16)	0.767 (20)	0.771 (19)	0.777 (20)	0.845 (15)	0.844 (13)	0.844 (15)	0.833 (15)
Boğaziçi	0.985 (3)	0.992 (1)	0.987 (1)	0.989 (1)	0.970 (4)	0.979 (3)	0.987 (2)	0.989 (2)
Çamlıbel	0.951 (6)	0.940 (9)	0.965 (6)	0.961 (5)	0.910 (8)	0.900 (9)	0.929 (10)	0.917 (10)
Çoruh	0.947 (7)	0.948 (7)	0.948 (7)	0.970 (4)	0.975 (3)	0.960 (5)	0.946 (6)	0.937 (9)
Dicle	0.889 (13)	0.946 (8)	0.925 (9)	0.919 (10)	0.874 (11)	0.810 (19)	0.896 (11)	0.816 (18)
Fırat	0.823 (17)	0.812 (17)	0.808 (16)	0.804 (18)	0.832 (17)	0.825 (15)	0.838 (17)	0.817 (17)
Gediz	0.986 (2)	0.953 (4)	0.977 (4)	0.924 (9)	0.963 (5)	0.967 (4)	0.969 (4)	0.902 (11)
Göksu	0.802 (18)	0.815 (16)	0.797 (17)	0.809 (17)	0.826 (18)	0.846 (12)	0.863 (13)	0.892 (13)
KCETAŞ	0.917 (8)	0.938 (11)	0.870 (12)	0.879 (12)	0.871 (12)	0.906 (8)	0.935 (8)	0.970 (5)
Menderes	0.759 (20)	0.778 (19)	0.746 (20)	0.815 (16)	0.820 (19)	0.811 (18)	0.959 (5)	0.969 (6)
Meram	0.659 (21)	0.665 (21)	0.550 (21)	0.654 (21)	0.667 (21)	0.682 (21)	0.687 (21)	0.894 (12)
Osmangazi	0.905 (12)	0.949 (6)	0.916 (10)	0.934 (7)	0.943 (6)	0.933 (6)	0.939 (7)	0.946 (8)
Sakarya	0.863 (14)	0.881 (13)	0.779 (18)	0.793 (19)	0.805 (20)	0.789 (20)	0.831 (18)	0.947 (7)
Toroslar	0.909 (10)	0.949 (5)	0.968 (5)	0.941 (6)	0.908 (9)	0.813 (17)	0.778 (20)	0.790 (20)
Trakya	0.970 (4)	0.981 (3)	0.822 (15)	0.933 (8)	0.941 (7)	0.911 (7)	0.933 (9)	0.977 (4)
Uludağ	0.780 (19)	0.804 (18)	0.980 (3)	0.980 (2)	0.990 (1)	0.988 (2)	0.979 (3)	0.981 (3)
Vangölü	0.914 (9)	0.884 (12)	0.885 (11)	0.835 (14)	0.852 (14)	0.848 (11)	0.849 (14)	0.770 (21)
Yeşilırmak	0.907 (11)	0.855 (14)	0.863 (13)	0.860 (13)	0.894 (10)	0.894 (10)	0.879 (12)	0.867 (14)
Mean	0.885	0.887	0.871	0.879	0.884	0.874	0.891	0.897

Note: The rankings of the companies in the relevant year are given in parentheses.

Table 5.10. Technical Efficiency Scores for Model BC95-3

Company	Efficiency Scores and Rankings							
	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Akdeniz	0.814 (16)	0.785 (17)	0.790 (15)	0.777 (14)	0.796 (15)	0.770 (16)	0.777 (17)	0.776 (18)
Aras	0.980 (4)	0.936 (9)	0.923 (8)	0.866 (11)	0.823 (14)	0.788 (13)	0.781 (16)	0.748 (20)
AYEDAŞ	0.990 (1)	0.993 (2)	0.985 (3)	0.972 (3)	0.977 (2)	0.989 (1)	0.993 (1)	0.994 (1)
Başkent	0.835 (15)	0.767 (18)	0.770 (18)	0.773 (18)	0.833 (12)	0.827 (10)	0.826 (12)	0.826 (13)
Boğaziçi	0.985 (3)	0.995 (1)	0.988 (1)	0.991 (1)	0.958 (3)	0.979 (3)	0.989 (2)	0.991 (2)
Çamlıbel	0.958 (7)	0.939 (7)	0.957 (5)	0.928 (6)	0.864 (9)	0.844 (9)	0.853 (11)	0.840 (12)
Çoruh	0.958 (6)	0.948 (6)	0.947 (7)	0.956 (4)	0.951 (5)	0.907 (5)	0.880 (9)	0.875 (10)
Dicle	0.837 (14)	0.888 (11)	0.880 (10)	0.883 (10)	0.830 (13)	0.777 (15)	0.858 (10)	0.781 (16)
Fırat	0.811 (17)	0.789 (15)	0.784 (16)	0.768 (19)	0.780 (17)	0.764 (17)	0.770 (18)	0.750 (19)
Gediz	0.990 (2)	0.953 (4)	0.979 (4)	0.918 (8)	0.957 (4)	0.965 (4)	0.971 (4)	0.908 (9)
Göksu	0.772 (19)	0.787 (16)	0.771 (17)	0.774 (17)	0.776 (18)	0.788 (14)	0.794 (15)	0.801 (14)
KCETAŞ	0.897 (10)	0.920 (10)	0.852 (11)	0.850 (12)	0.834 (11)	0.861 (8)	0.895 (8)	0.928 (7)
Menderes	0.733 (20)	0.745 (19)	0.717 (20)	0.776 (16)	0.773 (19)	0.763 (18)	0.925 (5)	0.939 (5)
Meram	0.664 (21)	0.660 (20)	0.546 (21)	0.635 (21)	0.642 (21)	0.653 (21)	0.653 (21)	0.862 (11)
Osmangazi	0.910 (8)	0.952 (5)	0.912 (9)	0.921 (7)	0.921 (7)	0.900 (6)	0.906 (7)	0.915 (8)
Sakarya	0.851 (13)	0.873 (12)	0.765 (19)	0.777 (15)	0.787 (16)	0.758 (19)	0.804 (13)	0.935 (6)
Toroslar	0.903 (9)	0.936 (8)	0.955 (6)	0.917 (9)	0.881 (8)	0.792 (12)	0.760 (19)	0.777 (17)
Trakya	0.977 (5)	0.986 (3)	0.835 (12)	0.930 (5)	0.931 (6)	0.893 (7)	0.917 (6)	0.967 (4)
Uludağ	0.778 (18)	0.804 (14)	0.987 (2)	0.980 (2)	0.993 (1)	0.987 (2)	0.972 (3)	0.978 (3)
Vangölü	0.865 (12)	0.818 (13)	0.805 (14)	0.755 (20)	0.764 (20)	0.749 (20)	0.738 (20)	0.665 (21)
Yeşilırmak	0.880 (11)	0.821 (21)	0.827 (13)	0.813 (13)	0.840 (10)	0.818 (11)	0.800 (14)	0.785 (15)
Mean	0.876	0.871	0.856	0.855	0.853	0.837	0.851	0.859

Note: The rankings of the companies in the relevant year are given in parentheses.

Table 5.11. Average Efficiency Scores for Alternative BC95 Models

Company	Average Efficiency Scores		
	BC95-1	*BC95-2*	*BC95-3*
Akdeniz	0.802	0.826	0.786
Aras	0.782	0.885	0.856
AYEDAŞ	0.988	0.987	0.987
Başkent	0.799	0.813	0.807
Boğaziçi	0.987	0.985	0.984
Çamlıbel	0.863	0.934	0.898
Çoruh	0.853	0.954	0.928
Dicle	0.849	0.884	0.842
Fırat	0.752	0.820	0.777
Gediz	0.965	0.955	0.955
Göksu	0.841	0.831	0.783
KCETAŞ	0.891	0.911	0.880
Menderes	0.818	0.832	0.796
Meram	0.685	0.682	0.664
Osmangazi	0.944	0.933	0.917
Sakarya	0.852	0.836	0.819
Toroslar	0.853	0.882	0.865
Trakya	0.948	0.934	0.930
Uludağ	0.940	0.935	0.935
Vangölü	0.764	0.855	0.770
Yeşilırmak	0.752	0.878	0.823

Table 5.12 presents summary statistics of efficiency scores obtained using alternative BC95 models. Looking into these statistics, one may claim that these models produced rather similar efficiency levels. The average of the efficiency scores is about 0.86, and the scores range between 0.55 and 0.99. As stated before, a more comprehensive comparison between all alternative models applied in this study will be made in the following section.

Table 5.12. Summary Statistics of Technical Efficiency Scores for Alternative BC95 Models

Model	Summary Statistics				
	Mean	*Minimum*	*Maximum*	*Median*	*Std. Dev.*
BC95-1	0.854	0.577	0.992	0.778	0.092
BC95-2	0.883	0.55	0.993	0.85	0.083
BC95-3	0.857	0.546	0.995	0.804	0.094

5.3. COMPARISON BETWEEN ALTERNATIVE BC92&BC95 MODELS

Before comparing the efficiency and rank estimations of the alternative models, we firstly looked at the parameter estimates of different distance functions given in Table 5.1 and Table 5.7.

First of all, it has been noticed that BC92&BC95 models produced rather different estimated values for first-order output coefficients. However, there exists a consistency between all alternative models in terms of scale of return in the market. To be more precise, in all alternative models sum of the first-order output coefficients has been found less than 1 in absolute value, indicating that the presence of increasing returns to scale is witnessed by all models.

The magnitude of the first-order input parameters obtained using BC92&BC95 models are not similar to each other. Among the inputs considered, distribution line has been determined as the most important input by BC92 models, while BC95 models indicates transformers as the most crucial input. However, all BC95 models reached a consistent result with regard to the quality variable: The coefficient of the quality variable is found to be statistically insignificant, meaning that taking the quality into account does not alter the efficiency score estimations drastically.

All alternative BC92&BC95 models estimate a positive coefficient for the time trend which is included into distance functions to explain the shift in the production function. The finding of a positive coefficient for the time trend means that the input isoquant curve has been shifting to left-down over time. In other words, the market has been advancing technologically. However, this coefficient has been found to be slightly insignificant in BC95 models, while it is significant in BC92-3 model.

Alternative BC92&BC95 models exhibit a consistency regarding the structure of error variance. Accordingly, it has been shown that the coefficient of variance ratio γ is statistically significant and rather close to 1, indicating the importance of inefficiency effects rather than random error effects in this study.

When comparing the technical efficiency scores obtained in BC92&BC95 models, we firstly realize that the estimated efficiency scores are substantially higher in BC95 models than those in BC92 models. This difference may be seen clearly from Table 5.6 and Table 5.12: The average efficiency score in BC95 models is about 0.86 while it is approximately 0.64 in BC92 models. The minimum levels of efficiency estimations are especially lower in BC92 models compared to those of BC95 models.

In addition to comparison of average efficiency estimations resulted from different models, it is also possible to compare efficiency estimations of these models for each company at each time period. This is achieved by calculating the correlations between efficiency estimations of different models, which is presented in Table 5.13. Making firstly a comparison between the same kinds of models, we observe rather strong correlations between them: The correlations between efficiency estimations of BC92 models range from 0.989 to 0.995. As for the efficiency estimations of BC95 models, their correlations with each other reduce slightly, but still taking rather high values between 0.870 and 0.962. When making comparisons between efficiency estimations of BC92&BC95 models, we continue to observe rather high correlations between BC92 models and Model BC95-1, ranging between 0.709 and 0.751. However, the same conclusion cannot be drawn with respect to the remaining BC95 models. Their correlations with BC92 models drop substantially to the levels between 0.494 and 0.574. Indeed, the reasons for the finding of relatively low correlations between efficiency estimations of BC92&BC95 models are indeed apparent to us. Firstly, these two models are rather different structurally in the sense that in contrast to BC92, BC95 includes environmental variables which may affect the efficiency estimations. Secondly and most importantly, these environmental variables we included into BC95 models are generally found to be statistically significant, meaning that they change the efficiency estimations drastically.

Table 5.13. Correlations of Technical Efficiency Scores Using Alternative Models

	Correlations					
	BC92-1	*BC9-22*	*BC92-3*	*BC95-1*	*BC95-2*	*BC95-3*
BC92-1	1.000	0.995	0.989	0.709	0.494	0.533
BC92-2		1.000	0.991	0.714	0.510	0.549
BC92-3			1.000	0.751	0.514	0.574
BC95-1				1.000	0.870	0.920
BC95-2					1.000	0.962
BC95-3						1.000

We also compared the ranking estimations of alternative models via correlations which are tabulated in Table 5.14. We observe that the pattern of the correlations between ranking estimations is very similar to that of correlations between efficiency estimations.

Table 5.14. Correlations of Rankings Using Alternative Models

	Correlations					
	BC92-1	*BC9-22*	*BC92-3*	*BC95-1*	*BC95-2*	*BC95-3*
BC92-1	1.000	0.992	0.978	0.729	0.510	0.550
BC92-2		1.000	0.986	0.732	0.522	0.567
BC92-3			1.000	0.773	0.529	0.593
BC95-1				1.000	0.849	0.899
BC95-2					1.000	0.949
BC95-3						1.000

CHAPTER 6

CONCLUSION & FURTHER STUDIES

In this study, technical efficiencies of Turkish electricity distribution companies have been analyzed for the period between 2002 and 2009. For this aim, we used SFA method, which is based on an input distance function. In order to see whether the efficiency scores of the companies are sensitive to the model specifications, we preferred to utilize two different SFA models (BC92&BC95), and also generate three different versions for each model by adding a new input or environmental variable into previous version of a given model.

First of all, it has been shown that all alternative specifications of both models (BC92&BC95) satisfy the regularity conditions. In other words, the first-order coefficients of the outputs and inputs are found to be negative and positive, respectively. Examining the first-order coefficients of the outputs, we see that these coefficients are statistically significant in all alternative model specifications, although their magnitude may change depending on the model which we utilized. All model specifications, however, tell the same story regarding the returns to scale in Turkish electricity distribution market: The sum of the first-order coefficients of outputs are found to be less than one in all model specifications, indicating the presence of increasing returns to scale at the mean of the data. This finding is line with that of Bağdadioğlu and Weyman-Jones (2008), but contrary to that of Bağdadioğlu and Senyücel (2010).

Looking into the estimated first-order input coefficients, we saw that these coefficients take the positive values as expected in all alternative model specifications. In addition, all first-order input coefficients – except that of “quality of electricity delivered” are found to be statistically significant in all model specifications. This finding suggests that the three inputs considered in this study (number of employees, lengthy of the distribution line and transformer capacity) are of importance in enhancing the technical efficiency of the electricity distribution companies. Among them, the most crucial input varies depending on the model specifications: According to the models based on BC92, the distribution lines is critical for electricity distribution companies to enhance their efficiencies. The models based on BC92, on the other hand, indicates the transformers as the most important input significantly affecting efficiency.

Our finding that the coefficient of quality of electricity delivered is not statistically significant deserves some further exploration because of the fact that it may seem to be interesting and somewhat unexpected at first glance. In adding the quality variable into model specifications, we aimed to observe whether the measured inefficiency of an individual distribution company is due to poor employment of the other inputs or due to higher input requirements as a result of a higher quality level. The insignificancy of this input variable means that the inclusion of the quality variable into models does not affect estimated efficiency scores of the electricity distribution companies. In other words, in our case, the reason for the inefficiency of a distribution company with a higher quality level is not higher input requirements needed to achieve this high quality level. Instead, the reason is the poor employment of the other inputs, namely just itself of the technical inefficiency. Meanwhile, in the literature, there exist studies reaching conflicting conclusions regarding the importance of the quality variable in the efficiency analysis. For example, Coelli et al. (2008) also showed that the incorporation of the quality does not affect significantly the technical efficiency scores. On the other hand, several studies such as Growitsch et al. (2009), Giannakis et al. (2005) and Bağdadioğlu and Senyücel (2010) revealed the importance and significance of the quality variable in the efficiency analysis. However, it should be noticed that Growitsch et al. (2009) and Bağdadioğlu and Senyücel (2010) found that the inclusion of the quality variable reduces estimated efficiency scores, which is completely in contrast to the finding of Giannakis et al. (2005).

We included a time trend into all input distance functions to catch the changes in the efficiencies due to any shift in the production function. All alternative BC92&BC95 models estimated a positive coefficient for the time trend, indicating the presence of a technological progress in the electricity distribution market over time. However, this coefficient has been found to be slightly insignificant in BC95 models, while it is significant in BC92 models. Despite, given that both magnitudes of this coefficient and its t-ratios are generally rather high in BC95 models, it can be concluded that our models witnessed a mild technological progress (approximately 0.6%-0.8% per year) in the electricity distribution market over time.

With regard to the underlying error variance, our study reached to a rather consistent conclusion: In all alternative BC92&BC95 models, the coefficient of variance ratio (γ) is found to be statistically significant and rather close to one, indicating the importance of inefficiency effects rather than random error effects in this study. This conclusion is in line with those of previous studies such as Bağdadioğlu and Weyman-Jones (2008) and Bağdadioğlu and Senyücel (2010). According to this finding, the random error effects are of little importance in Turkish electricity distribution market, thus one may claim that instead of SFA the deterministic methods such as DEA and COLS can be safely used in the efficiency analysis of this market.

BC95 models include three environmental variables which have potential to affect the inefficiency of electricity distribution companies. The first environmental factor is the customer density of the regions, measured in terms of number of customers per km of distribution line. This study revealed that the customer density of a region positively affects the technical efficiency of the relevant distribution company, which is not a surprising result given that companies operating in crowded regions have a natural efficiency advantage over those with a weak customer density.

Another environmental factor considered is the customer structure defined as proportion of sales in MWh to residential customers to total sales. We find that efficiencies of the companies serving to mostly the residential customers are higher than those of other companies. This conclusion is line with that of Hirschhausen et al. (2006). However, the reason behind this finding is not apparent to us at the moment, thus it deserves some further analysis.

As another environmental variable, we also take into account a time trend. The results revealed that the efficiencies of the distribution companies decline over time, but in a statistically insignificant extent.

As for the efficiency estimations of the alternative models, the main conclusion revealed by our study is that efficiency estimations of the BC95 models are notably higher than those of the BC92 models: The average efficiency score in BC95 models is about 0.86 while it is approximately 0.64 in BC92 models. Given that the most important difference between BC92&BC95 models is the environmental variables included into the the BC95 models, we may argue that the efficiency estimation differences between BC92&BC95 models can be attributed to these environmental variables. In other words, an important part of the technical inefficiency of the electricity distribution companies may be due to the environmental variables such as customer density and structure of the regions in which the distribution companies operate. One should notice that the distribution companies have very limited capability to control these environmental variables. Overall, we may conclude that this study witnessed the importance of the environmental variables in the efficiency studies regarding Turkish electricity distribution market.

In searching the consistency between alternative models, we also compared the technical efficiency estimations of these models by calculating correlations. The results show that regarding both efficiency scores and ranking there exist strong correlations between estimations of the models based on the same model type (BC92 or BC95). On the other hand, comparing estimations of the models based on the different model type, the correlations dropped to the level of 0.494. Looking at the most efficient and inefficient companies estimated by alternative models, we observe that Trakya, AYEDAŞ, KCETAŞ and Osmangazi appear as the most efficient companies, and on the side of inefficient companies, Başkent, Yeşilırmak and Toroslar line up, according to BC92 models. As for the BC95 models, the efficiency scores and rankings of the companies change over time. However, generally speaking, one may conclude that AYEDAŞ, Boğaziçi and Gediz are the companies operating most efficiently, while Meram, Fırat and Vangölü are the worst performers. The main conclusion obtained from these comparisons is that the efficiency and ranking estimations have been rather sensitive to the models used. Thus, it appears to be of crucial importance to work on different model specifications in the efficiency studies.

Another important conclusion drawn from this study is that in spite of efficiency differences between estimations of the alternative models, at the very beginning of the liberalization of electricity distribution market there appear considerable opportunities of improvement in the efficiencies. For example, the most inefficient companies such as Yeşilırmak, Meram, Fırat and Toroslar could achieve almost the same output levels even by reducing the inputs by half. However, decreasing the inputs does not seem to be an appropriate strategy in enhancing the efficiency of the Turkish electricity distribution market. For example, although, as seen from the graphs presented in Appendix A, Başkent and Meram reduced the number of employees substantially following their privatizations, these reorganizations have not enhanced their efficiency performances. In addition, given that the electricity usage in Turkey have been in an increasing trend and this trend will continue in the coming years, we may expect that the efficiency of the distribution companies may increase without any need to cut in input usage.

It may be possible to extend this study in several directions: First of all, the loss/theft ratios, which are very high especially in the eastern part of Turkey, may be taken into account. We preferred not to do it for two reasons: Firstly, we measured the technical efficiencies by using physical quantities of inputs, not their costs. Secondly, the electricity distribution companies achieve to reach the electricity to end-users, but mostly fail in metering the electricity usage and collecting the bills in the eastern part of Turkey. Thus, taking directly into consideration the loss/theft differences would lead to substantial and unfair drops in the efficiency estimations of the companies operated in the eastern part of Turkey. This is exactly what Bağdadioğlu and Senyücel (2010) reported. They estimated 0.50 and 0.47 as efficiencies of Dicle and Vangölü, respectively when ignoring the loss/theft differences. Taking into account the loss/theft differences, the efficiencies of these two companies dropped to 0.10 and 0.12 respectively, which seem to be incredibly low.

Since the electricity distribution companies have been started to be handed over to private sector very recently, in this study we could not examine effects of the change in the ownerships on the efficiency of the companies. For the coming years, it would be of great interest to work on this issue.

In literature there are plenty of studies comparing the efficiency estimations obtained from parametric and non-parametric methods. To the best of our knowledge, there is no such a study estimating simultaneously the efficiency levels of Turkish electricity distribution companies with both parametric and non-parametric methods. This may be another topic for a future work. However, one should not expect a strong consistency between estimations of these parametric and non-parametric methods, given that the results of the previous studies in the literature have been mostly in this direction.

The cost related with the distribution of electricity is 11% of the total electricity tariff. The most important cost item in the electricity tariffs is the generation cost with a share of 64%. Thus, efficiency enhancements in the electricity generation are as important as those relevant in the electricity distribution. In literature, to the best of our knowledge, only Sarıca and Or (2007) analyzed the efficiency performances of 65 thermal, hydro and wind electricity power plants using DEA. Thus, one area of future work may be studying on efficiencies of electricity generation plants, especially via SFA.

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APPENDIX A

GRAPHS OF VARIABLES

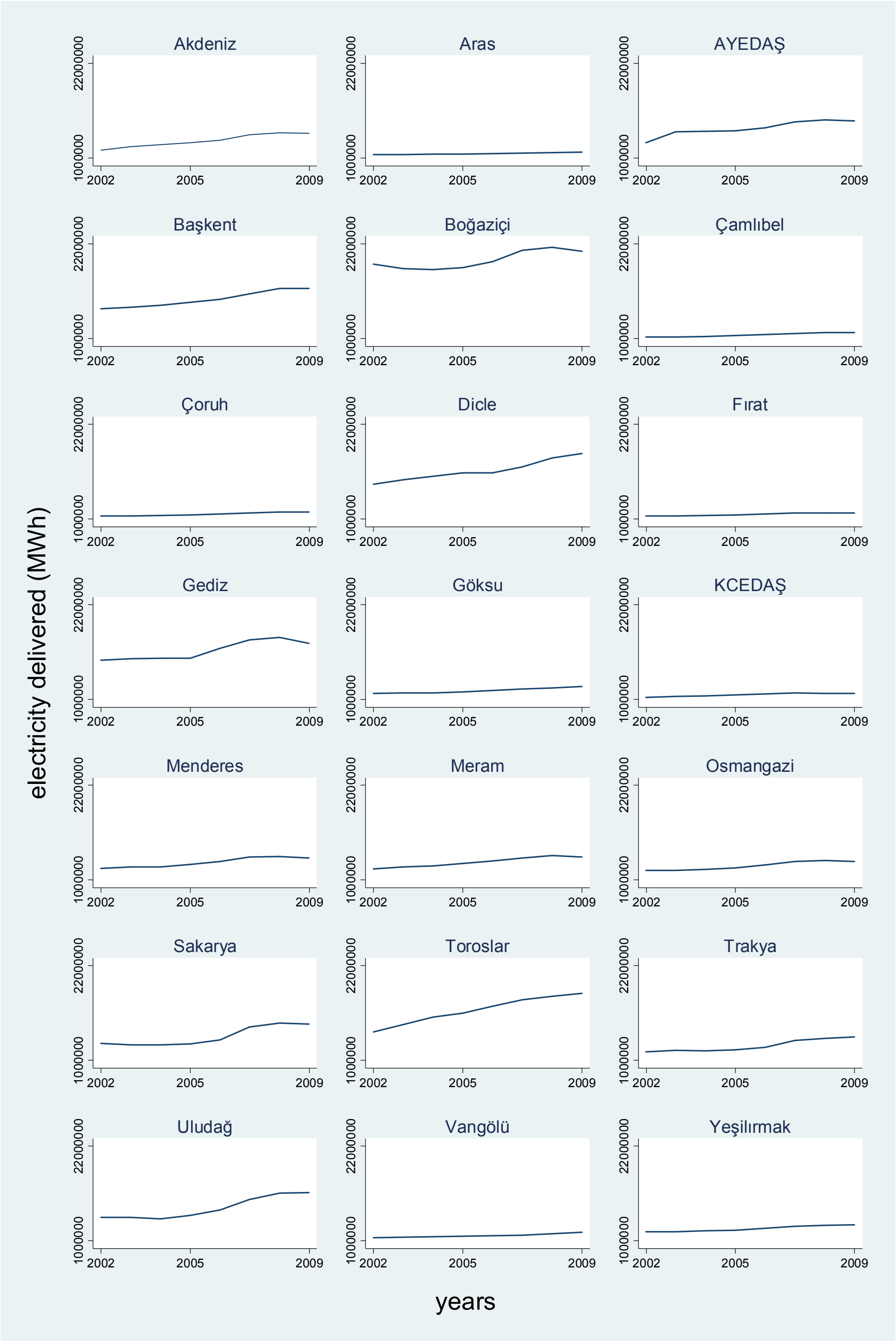

Figure A.1. Electricity Delivered

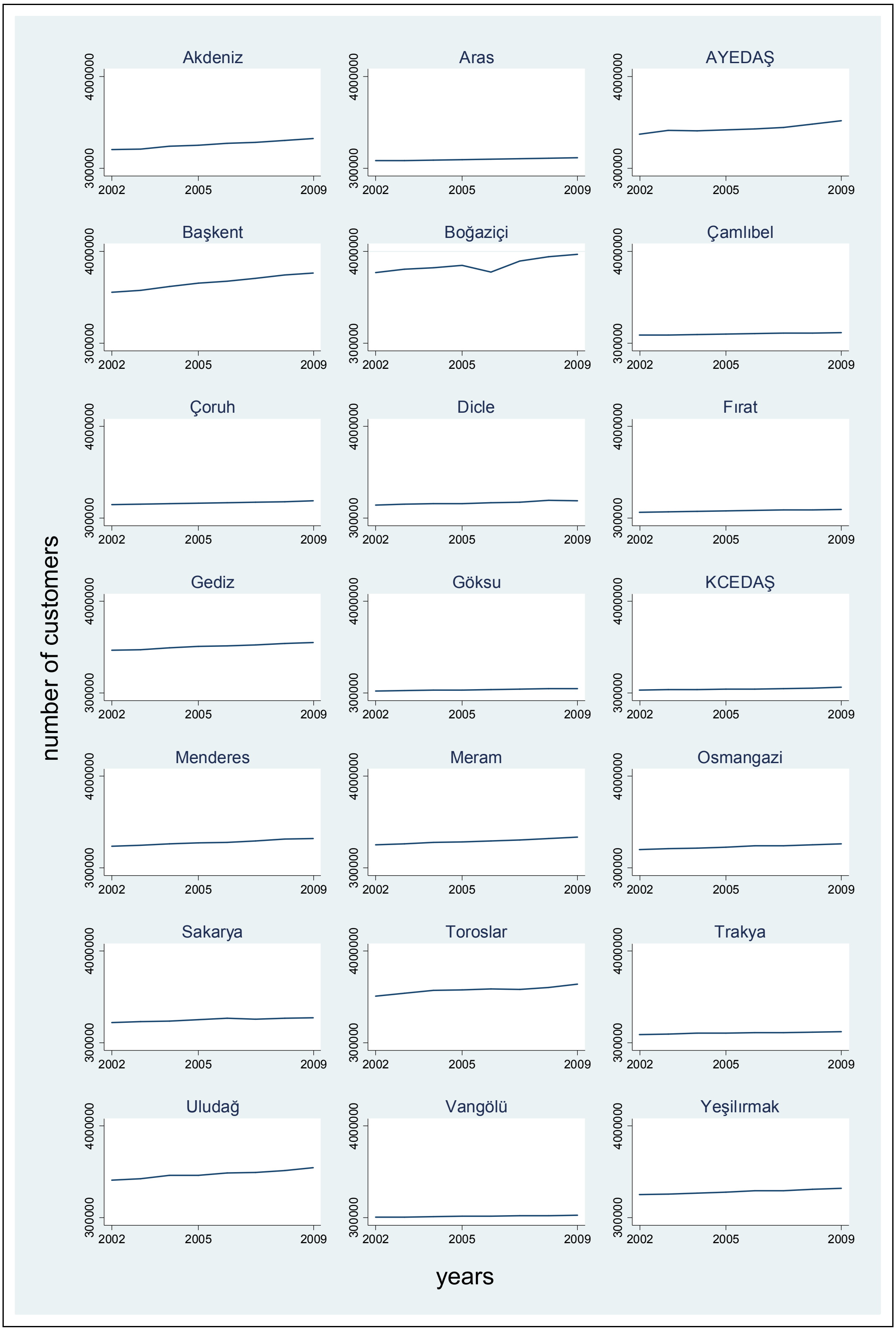

Figure A.2. Number of Customers

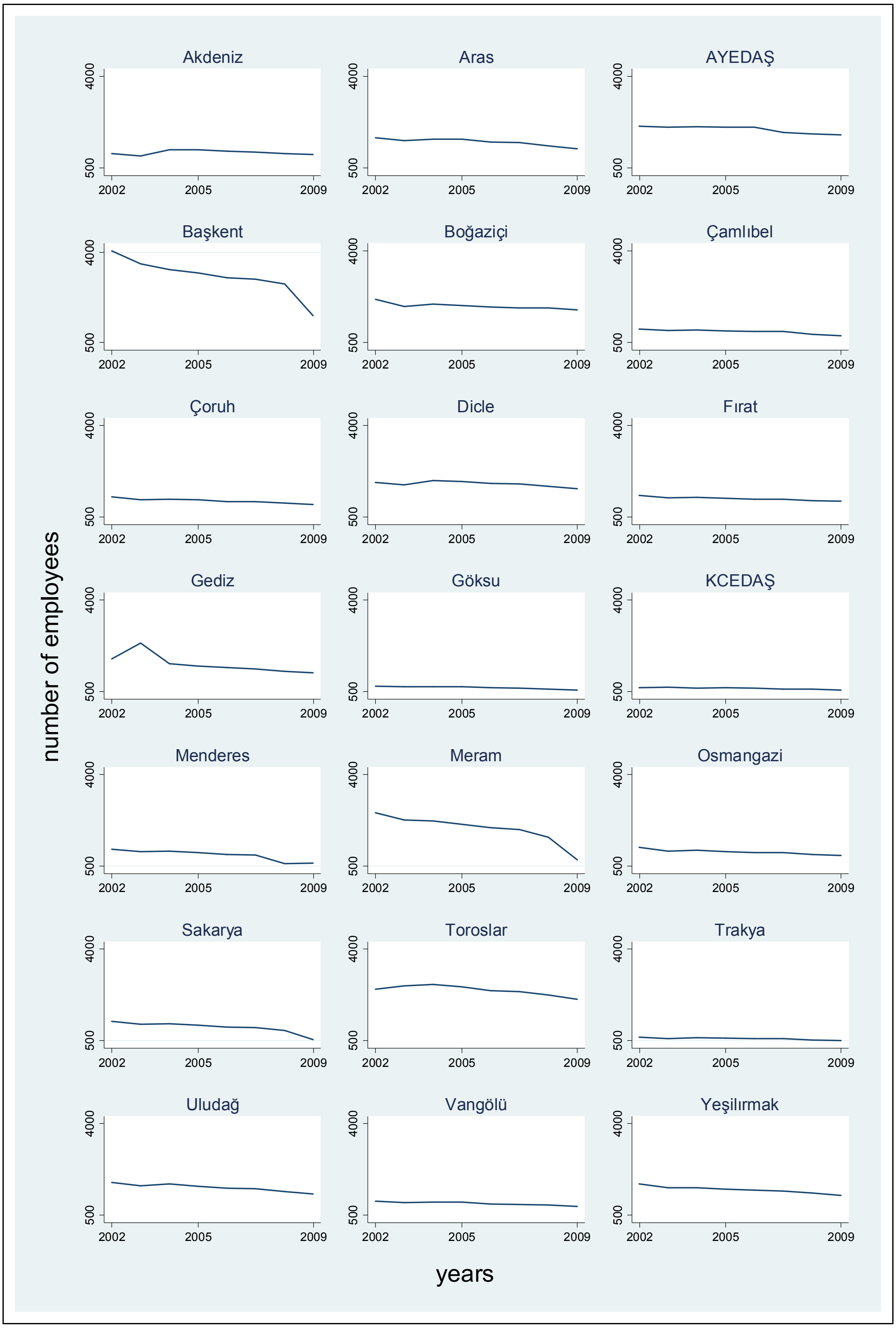

Figure A.3. Number of Employees

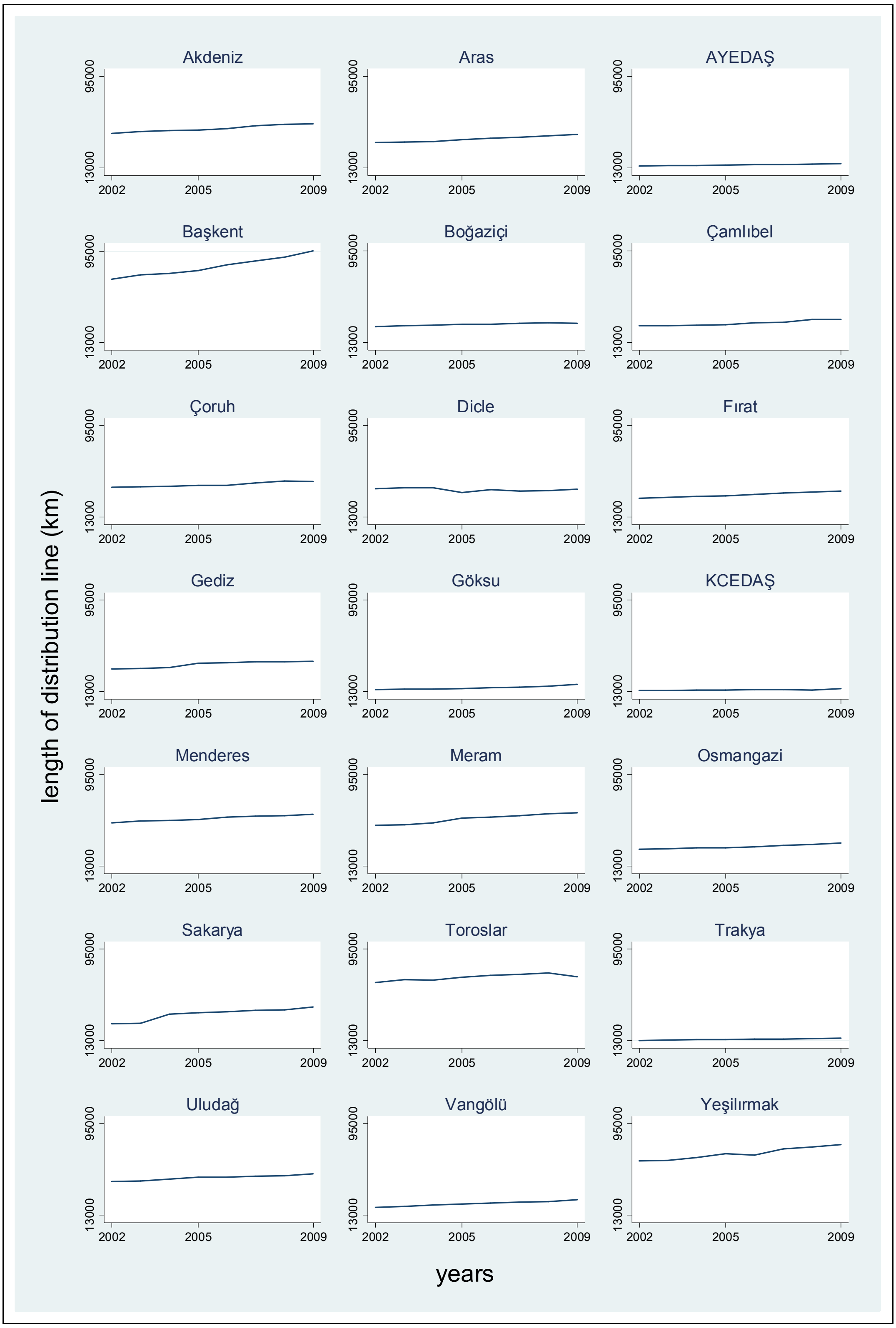

Figure A.4. Length of Distribution Line

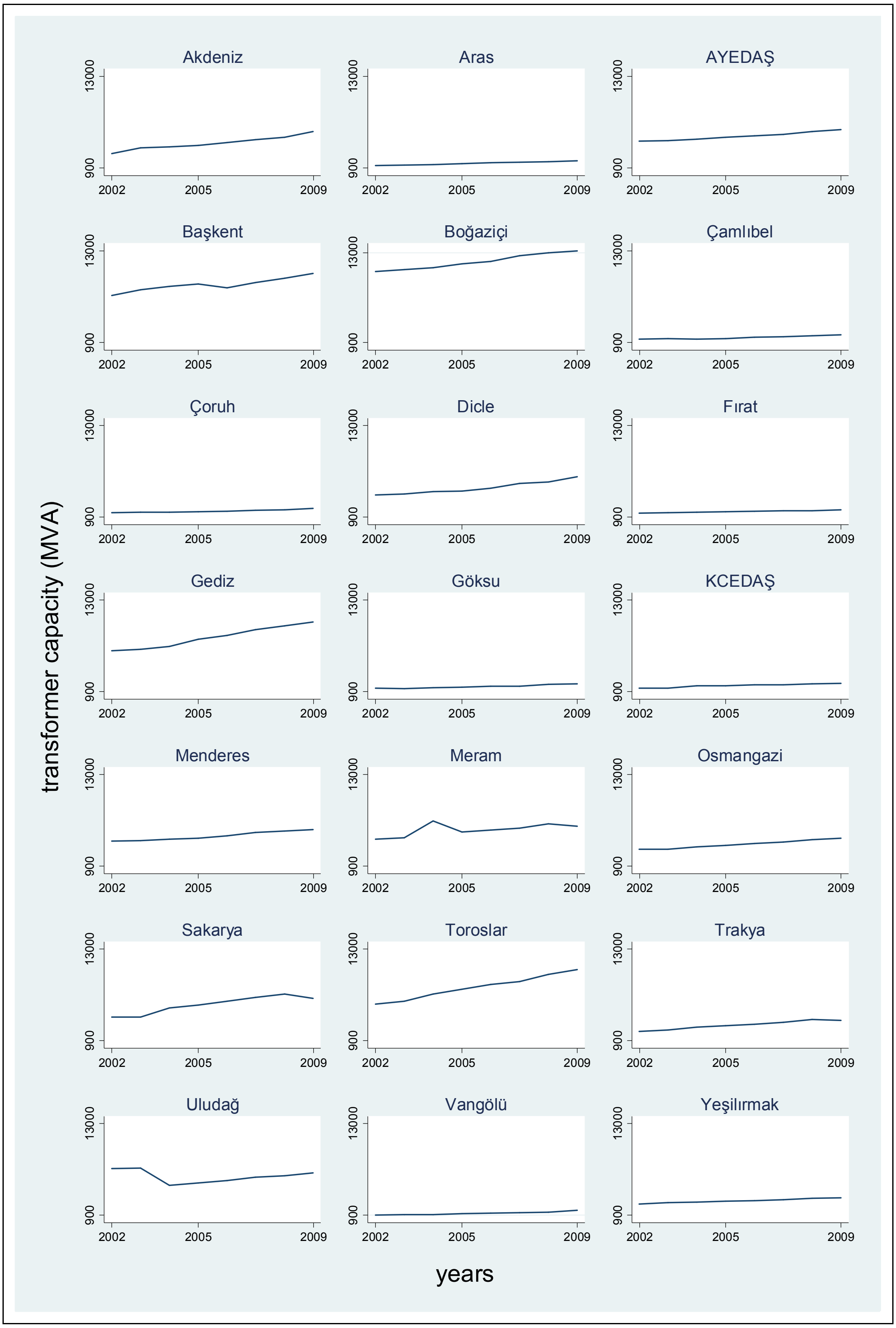

Figure A.5. Transformer Capacity

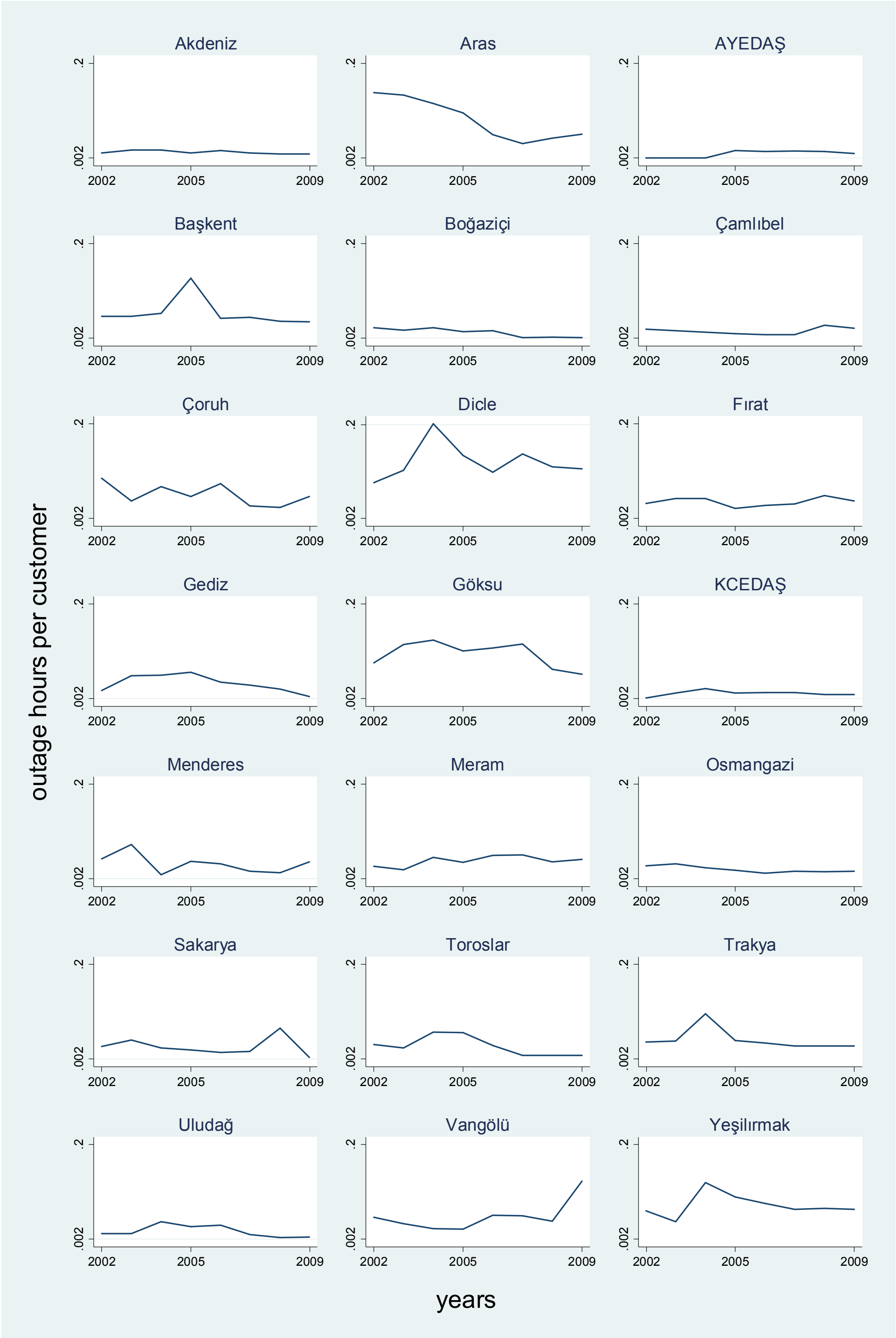

Figure A.6. Outage Hours per Customer

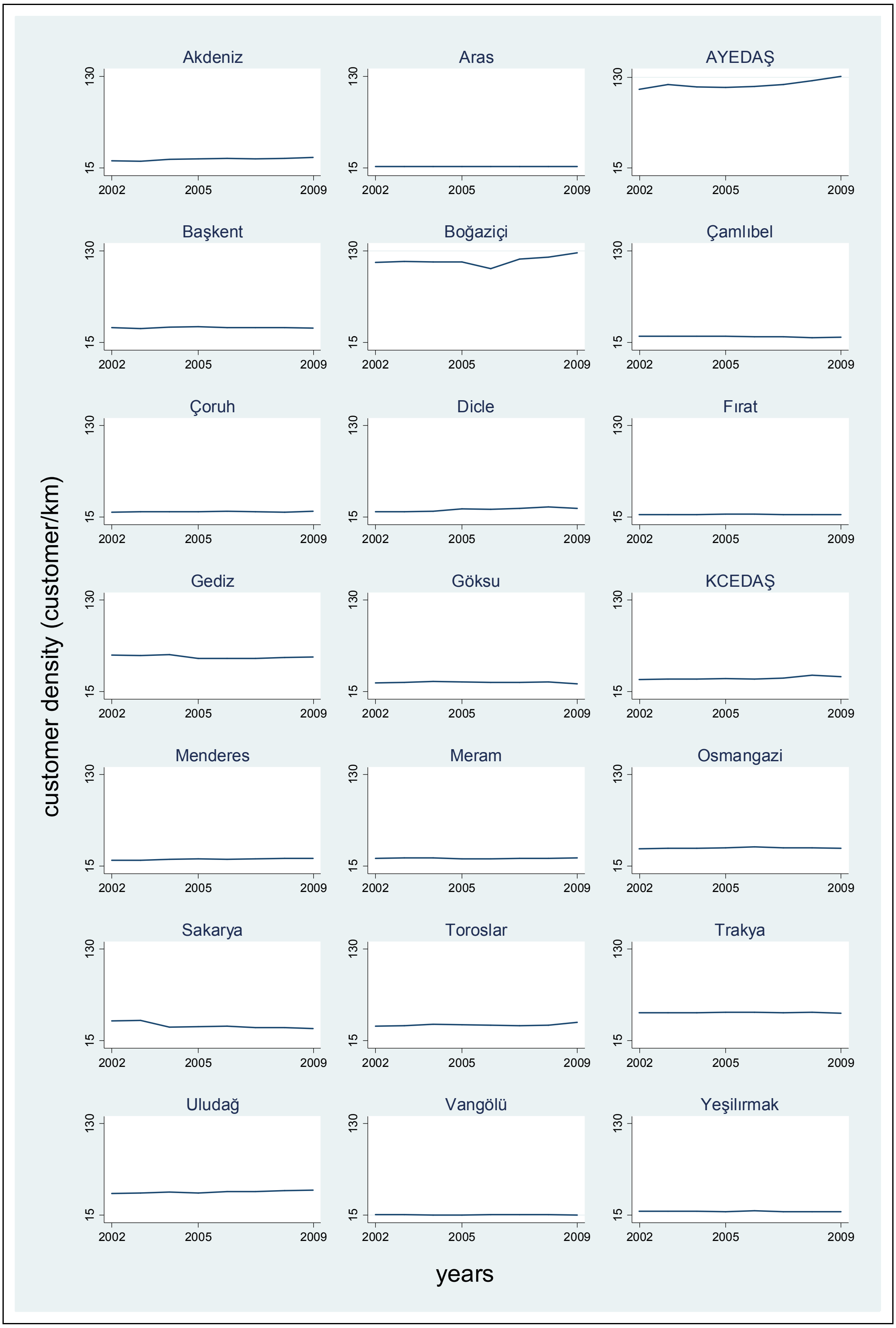

Figure A.7. Customer Density

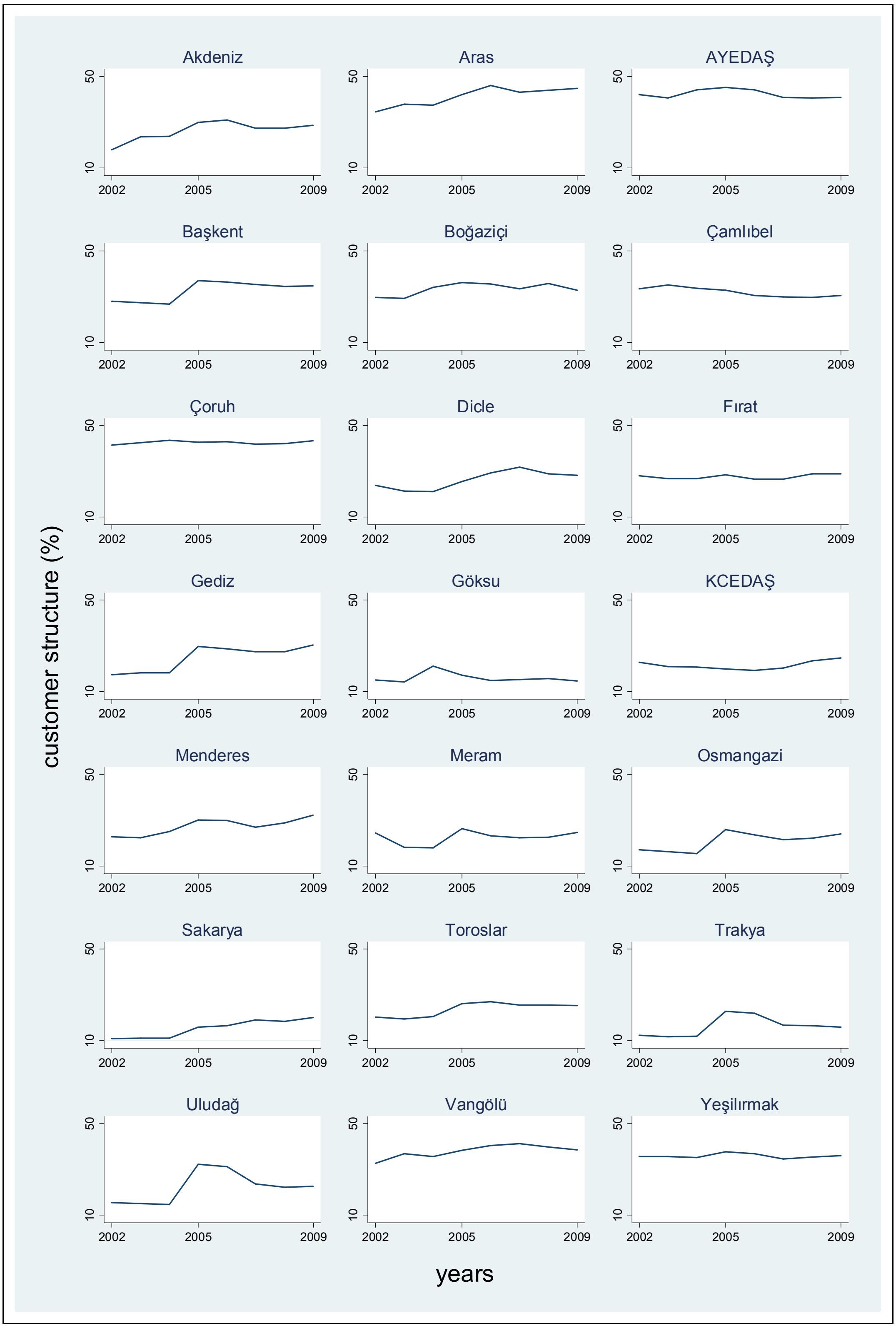

Figure A.8. Customer Structure