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ESTIMATING THE VALUE OF AN ENERGY EXCHANGE FOR TURKEY

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Abdurrahman Kurucak

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The thesis of Abdurrahman Kurucak was reviewed and approved* by the following:

Anastasia V. Shcherbakova
Assistant Professor of Energy Economics, Risk, and Policy
Thesis Advisor

Seth Blumsack
Assistant Professor of Energy Policy and Economics

Zhen Lei
Assistant Professor of Energy and Environmental Economics

Turgay Ertekin
Head, John and Willie Leone Family Department of Energy and Mineral Engineering
Professor of Petroleum and Natural Gas Engineering
George E. Trimble Chair in Earth and Mineral Sciences
Undergraduate Program Officer of Petroleum and Natural Gas Engineering

*Signatures are on file in the Graduate School.

Abstract

The new Electricity Market Law of Turkey was enacted very recently in March 2013. The law builds the legal framework for the establishment on an energy exchange, which has been a topic discussed in the Turkish electricity market for a long time. The aim of this study is to estimate the value of this prospective energy exchange for Turkey.

In order to estimate a value, two different scenarios were compared. In the first scenario, it was assumed that a hypothetical retailer procures its entire electricity requirement from the spot market. In the second scenario, an optimal procurement strategy that benefits from both the spot and forward markets was calculated. Since currently no forward electricity markets exist in Turkey, there is no price data for the derivatives. In order to overcome this challenge, a forward price model is developed by constructing a spot price model first and then defining a relationship between spot and forward prices using the spot price data from January 2010 to December 2012.

The developed spot price model revealed that electricity prices are highly seasonal, while the forward price model revealed unlike most commodity markets, the market price of risk is negative and hence the futures contract quotes are higher than the expected spot prices. Those results are in agreement with the literature.

Finally, my analysis points out that the prospective exchange is indeed valuable for a hypothetical company which is assumed to supply 5% of Turkey's electricity consumption, with an estimated the value of around TL27.3 million or $14.2 million for the first six months of 2013.

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Dedication

to Gulin, Yigit Ali and Elif Kurucak

Chapter 1

Introduction

1.1 Background

Power markets, by their nature, are known to bear extreme price volatility which is much higher than other assets. This is mainly due to non-storability of electric power. Consequently, it is important for the players in the electricity market to hedge their risks. Derivatives traded in organized markets such as exchanges are specifically created as tools to help companies to hedge the risks associated with highly volatile prices.

The Republic of Turkey started the deregulation of its electricity market in 2001, when the Electricity Market Law (EML) entered into force. During the years following the enactment of the EML, the level of private participation and hence the level of competition in the market increased steadily. In December 2009 a spot market started to operate. However, absent a financial forwards market, the participants of Turkish electricity market are subject to price risk.

Nevertheless, this situation is about to change. The new Electricity Market Law of Turkey was enacted on 03/30/2013, repealing the Electricity Market Law of 2001. With the new law comes a market activity named "market operation". It is defined as the "*operation of organized wholesale markets and financial settlement of activities taking place in such markets*". The law also dictates the establishment of the Energy Market Operation Company (Turkish: Enerji Piyasaları İşletme Anonim Şirketi - EPIAS). EPIAS is envisaged to establish an energy exchange along with the exchange operator Borsa İstanbul A.Ş. to provide market participants with new risk management tools.

The need for an energy exchange in Turkey is a topic that has been discussed for a long time, and with the enactment of the new EML, the legal framework for such an exchange was provided. According to the law, EPIAS will start its operations in six months following the enactment date of 3/30/2013.

1.2 Objective of the study

The objective of this study is to estimate the value of such an energy exchange for the companies that take part in the Turkish electricity market by finding out to what extent this new market will improve the procurement outcomes by these companies. As there are no developed power exchanges in Turkey, all trade is done through bilateral contracts and on the spot market. A power exchange is going to give the market participants another market to trade in. Therefore, after the establishment of the exchange, market participants will have the option to purchase their entire energy requirement either from the exchange or from the spot market, or to construct an optimal mix of purchases from the two. Hence the difference in the procurement cost for a hypothetical company for the current situation (i.e., purchase everything from the spot market), and the procurement cost for a mix of spot and futures contracts which is optimized to the company's risk preferences should give an estimate of the energy exchange for this company.

However to make such a comparison, price estimates for futures contracts are necessary. As there is no exchange yet, there is no forward price data either. This challenge can be overcome by simulating the values of futures contracts, i.e., by constructing a forward price model for Turkish electricity market.

There are two common approaches for the pricing of derivatives in an electricity market. If there is a large set of data for forward prices, it is more appropriate to calibrate a price model using forward price data and then use this model to valuate derivatives in the future [Deng and Oren, 2006]. A drawback of this approach, apart from the data requirement, is that not all contracts are written on forward prices. An important portion of derivatives are written on spot prices and a model developed by this approach is not sufficient to price these derivatives. The second approach is more preferred when there is not enough or no forward market data, like in the case for the Turkish electricity market. In this case, first a spot price model is developed and a link between spot and forward prices is defined. Although it is more difficult to implement this approach since it requires a definition of a link between prices, it is preferable to the first approach when

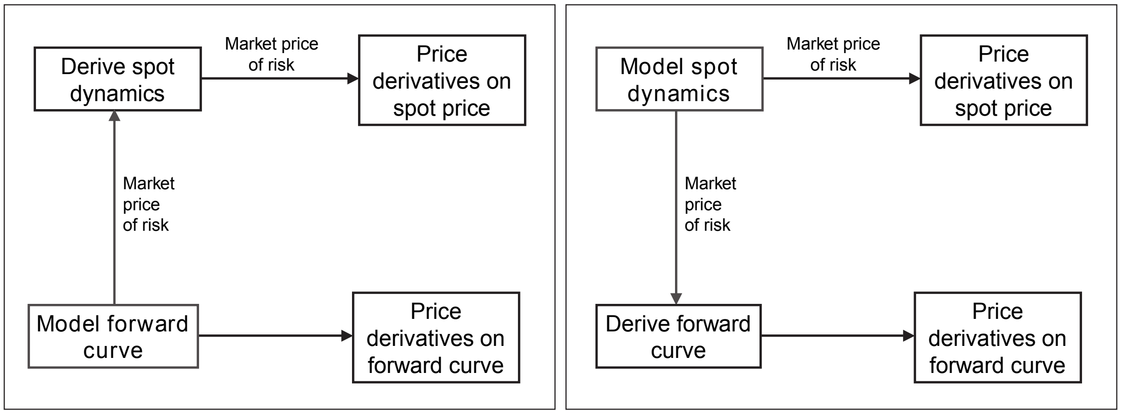


Figure 1.1: Two alternative approaches to pricing electricity derivatives [Weron, 2007, p.150]. The left panel shows the approach that uses forward prices. The model on the right panel uses spot prices.

there is a lack of forward price data or when it is needed to valuate derivatives written on spot prices [Weron, 2007]. Figure 1.1 shows a schematic of two common approaches used in derivative pricing in electricity market.

Therefore first a spot price model is needed in order to proceed with further calculations. The following methodology is proposed in order to fulfill the objective of this study:

1. Collect historical spot prices for the Turkish electricity market and calibrate the parameters of a spot price model to the data.

2. Using the spot price model, define a link between spot and futures prices and simulate a series of futures prices for contracts of varying lengths.

3. For a hypothetical market participant, develop an optimal electricity purchasing strategy using:

   (a) Only spot prices (which is the only current option)

   (b) A mix of spot and futures contract prices

4. The difference in costs of these two purchasing strategies will signal the potential value of the electricity futures exchange for the hypothetical company.

Figure 1.2 shows a flowchart of the methodology.

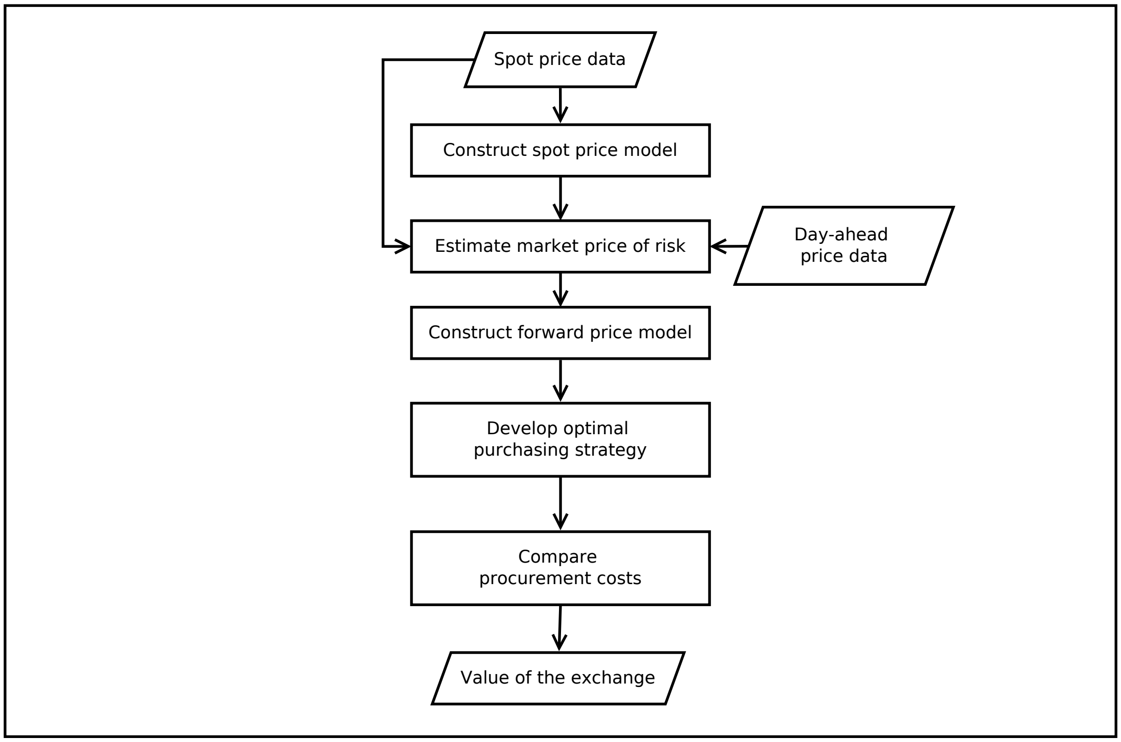


Figure 1.2: Flowchart of methodology.

This study contributes to the existing literature in at least three ways. First, I developed a spot price model for the Turkish electricity market; to the best of my knowledge there are no spot price models in the literature that specifically address the Turkish electricity market. Second, a forward price model is developed and again to the best of my knowledge, none exist in the literature. Lastly, the value of the upcoming energy exchange for Turkey was estimated. There are some studies regarding the structure Turkish electricity market after the new EML, thus mentioning the expectations from EPIAS (See e.g., Alaçam [2012], Sanlı [2012]). However, I hope this study to be a first attempt as a quantitative analysis for the prospective exchange for Turkey.

The structure of the paper will be as follows:

Chapter 2 summarizes the background and structure of Turkish electricity market. Chapter 3 describes the suggested spot price model. In Chapter 4, the methodology and results for futures price estimation are presented. Chapter 5 is about developing an optimal procurement strategy and estimating of the value of an energy exchange for Turkey. Finally, Chapter 6 is the conclusion.

Chapter 2

Turkish Electricity Market

2.1 A Brief History

Electricity power started to be used in everyday life in 1878 and the first power plant went into service in 1882 in London. In 1902, electric power was generated in Turkey for the first time in Tarsus – a town near Mediterranean coast – using a 2kW hydro turbine. The first sizeable power plant was a 15 MW thermal plant built in Silahtaraga, Istanbul in 1913 [Ozturk et al., 2007].

Following the foundation of Turkish Republic in 1923, electric power generation was almost exclusively carried out by foreign investors as a result of liberal economic policies until the 1930's. The only Turkish electricity company was Kayseri ve Civarı Elektrik Türk Anonim Şirketi, which was established in 1926 [Hepbaşlı, 2005]. Installed capacity was 33 MW which was mainly composed of thermal plants and the annual production was 45 GWh. An economic crisis started in 1926 and deepened with the global depression in 1929. Consequently, inflation rates and therefore energy prices increased significantly.

As a result of the trauma caused by the economic crisis, liberal economic policies of Turkey were replaced with Keynesian[1] economic policies like many other developing countries in the world. As a newly founded country that had experienced an economic crisis after a war, there was a lack of private capital accumulation. Therefore, Turkey adopted The First Industrialization Plan in 1933 and incorporated a public industrializa-

[1] In Keynesian economics, it is argued that government should intervene the economy especially in the times of recession.

tion policy [Devlet Planlama Teşkilatı]. This started an era of nationalization and almost all electricity companies were nationalized between 1938 and 1944. By 1950, installed capacity was 408 MW and annual electricity production was 790 GWh.

Figure 2.1 shows the historical development of installed capacity and electric power generation in Turkey.

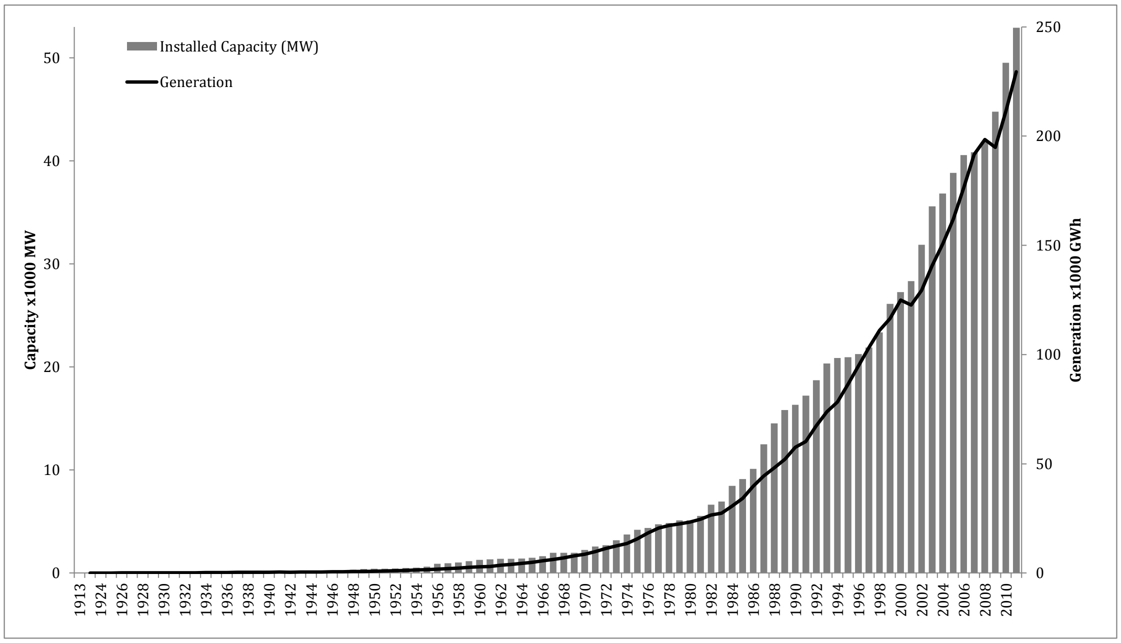


Figure 2.1: Historical development of installed capacity and power generation in Turkey. (Source: TEIAS)

Although the change of the government in 1950 promoted an economic system in which both the state and private sector direct the economy; government was still the dominant actor. In order to increase the share of hydraulic power generation, a public institution, the General Directory of State Hydraulic Works was established in 1953 to build large dams.

In the 1960s Turkey experienced a planned development period. In the first (1963 –1967) and second development plans (1968 – 1972), the main aim was the efficient use of power plants and increased use of hydraulic energy resources. The Ministry of Energy and Natural Resources (Turkish: Enerji ve Tabii Kaynaklar Bakanlığı - ETKB) was established in 1963 and became responsible for Turkish energy policy. In 1970, the Turkish Electricity Administration (Turkish: Türkiye Elektrik Kurumu - TEK) was founded to aggregate all market activities and have a state monopoly for the electricity market in Turkey. After the transfer of distribution activities from local administrations in 1982, TEK literally became a state owned vertically integrated monopoly.

Turkey was seriously affected by the oil crisis of 1973 when OPEC countries announced an increase for the price of crude oil. The increased prices of energy inputs yielded another economic crisis. As a result of deteriorated economic conditions, Turkey adopted liberal economic policies once more in the 1980s, and electricity investments were decreased like other public investments [Özkıvrak, 2005]. Furthermore, the government initiated some incentives such as "take or pay"[2] guaranties to draw the interests of private investors to the electricity market [Yılmaz and Uslu, 2007]. To this end, in 1984, the first law (Law No. 3096) that allows private companies to take part in the electricity industry was enacted. According to the law, private companies could sign Build Operate and Transfer (BOT) contracts for new generation facilities and Transfer of Operating Rights (TOOR) contracts for existing generation and distribution assets [Atiyas and Dutz, 2003]. These contracts allowed private companies to trade in the electricity market, which previously was a right that exclusively belonged to TEK, while providing the government with the necessary financial resources to build new generation facilities.

TEK was incorporated in a privatization program and split into two separate state-owned enterprises, Turkish Electricity Generation and Transmission Company (Turkish: Türkiye Elektrik Üretim İletim Anonim Şirketi - TEAS) and Turkish Electricity Distribution Corporation (Turkish: Türkiye Elektrik Dağıtım Anonim Şirketi - TEDAS) in 1993. Turkey's Constitutional Court, on the other hand, issued a series of rulings in 1994 and 1995; which made the implementation of the privatization in the electricity sector almost impossible. Therefore, in August 1999, the Turkish Grand National Assembly agreed to a constitutional amendment to allow the privatization of public services and to international arbitration to resolve disputes. However the reform process in the electricity market was interrupted for all of those years. As a consequence, in order to meet the increasing demand for electricity, guarantees were provided to enhance the attractiveness of BOT projects for adding new generation capacity. In order to enhance private sector participation, The Build Operate and Own (BOO) (Law No. 4283) was also enacted in 1997; again with "take or pay" guarantees [Erdogdu, 2005].

In 2001, the Electricity Market Law (EML) (Law No. 4628) was enacted with the

[2] In take or pay contracts customers agree to pay the suppliers a certain amount for a certain amount of the product. Customers either take the product or pay a penalty or the price of the product for not taking it.

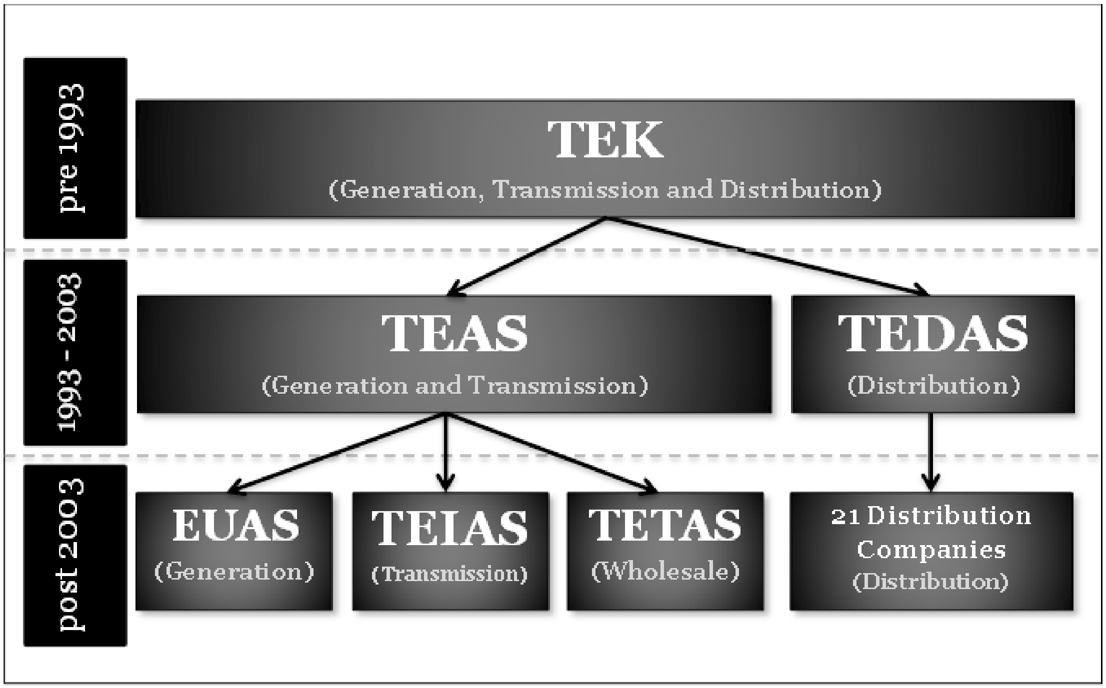


Figure 2.2: Changes in the structure of vertically integrated electricity company TEK over time.

purpose of ensuring the development of a financially strong and transparent electricity market operating in a competitive environment; delivery of sufficient, high quality, low cost and environmentally – friendly electric power to consumers; and autonomous regulation and supervision of this market. In accordance with the law, TEAS was restructured to form three new state-owned public enterprises in 2003: Turkish Electricity Transmission Company (Turkish: Türkiye Elektrik İletim Anonim Şirketi - TEIAS), Electricity Generation Company (Turkish: Elektrik Üretim Anonim Şirketi - EUAS) and Turkish Electricity Trading and Contracting Company (Turkish: Türkiye Elektrik Üretim İletim Anonim Şirketi - TETAS). Figure 2.2 shows how the state owned vertically integrated electricity company TEK was restructured over time.

According to the new law, the Electricity Market Regulatory Authority was established as an autonomous regulatory body. It was eventually renamed as Energy Market Regulatory Authority (Turkish: Enerji Piyasası Düzenleme Kurumu - EPDK) with the additional regulatory duties in natural gas, oil and liquefied petroleum gas markets. Deregulation of Turkish electricity market officially started with this law.

Finally, the ‘new’ Electricity Market Law (Law No. 6446) was enacted very recently

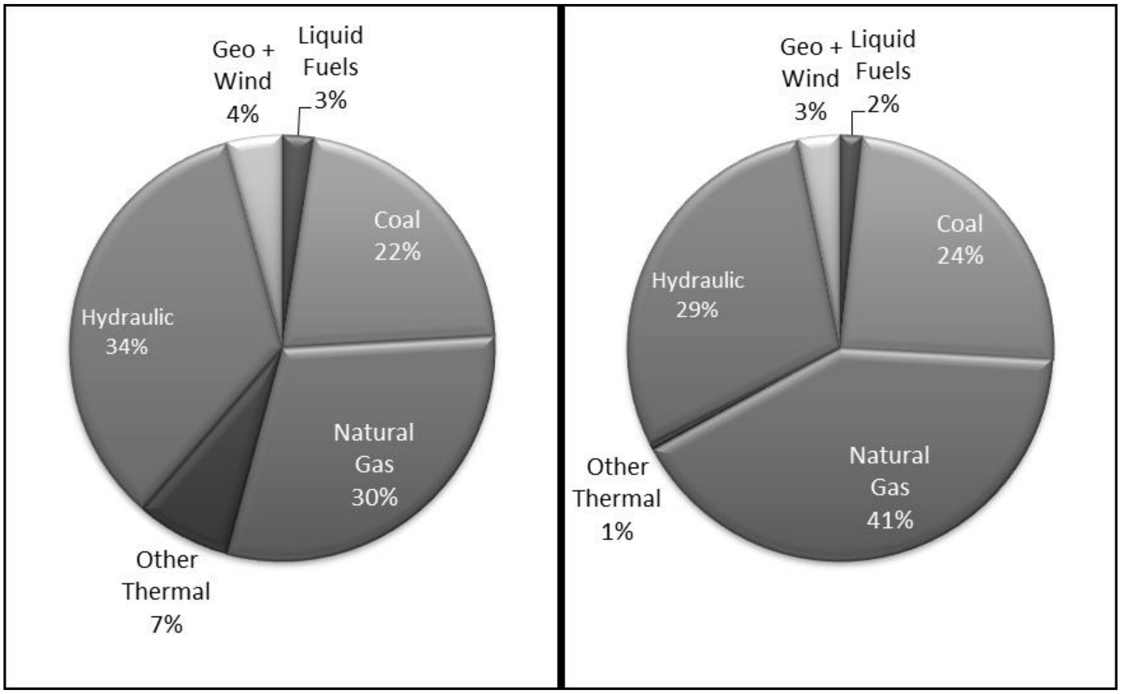


Figure 2.3: *Left Panel:* Installed capacity of Turkey by source at the end of 2012. *Right Panel:* Power generation of Turkey in 2012 by source. (Source: TEIAS)

in March 2013. The Law introduced some important changes, such as the addition and repeal of certain types of licenses. The market operation license was introduced while the auto-producer license was repealed. Wholesale and retail licenses have been combined into the supply license. A pre-licensing process is defined for generators in order for them to be able to generate during the time needed to complete the bureaucratic details. Probably the most significant change is the introduction of a new electricity market activity called "market operation", which was defined in the law as the "operation of organized wholesale markets and financial settlement of activities taking place in such markets". The market operator, Energy Markets Operation Company (Turkish: Enerji Piyasaları İşletme Anonim Şirketi - EPIAS) will be established and operate the day-ahead, intraday, balancing power, ancillary services, over-the-counter (OTC) and derivatives markets.

Installed power generation capacity of Turkey was at the end of 2012, $57,058$ MW while annual generation was $239,101$ GWh. Figure 2.3 shows the installed capacity and electricity power generation of Turkey by sources of generation at the end of 2012.

2.2 Market Structure

Electricity is a commodity that cannot be economically efficiently stored. This means that, in order to keep the system running properly, generation and consumption have to be balanced in real time.

According to the EML generation, transmission, distribution, supply, import and export of electricity power, and electricity market operation are market activities and a corresponding license is required in order to be engaged in these activities. Licenses are granted by the Energy Market Regulatory Authority (Turkish: Enerji Piyasası Düzenleme Kurumu - EPDK).

Electricity production can be done by EUAS, its partners, private producers, and BOT, BO and TOOR contract holders.

Generated electricity can be sold to suppliers and eligible consumers.

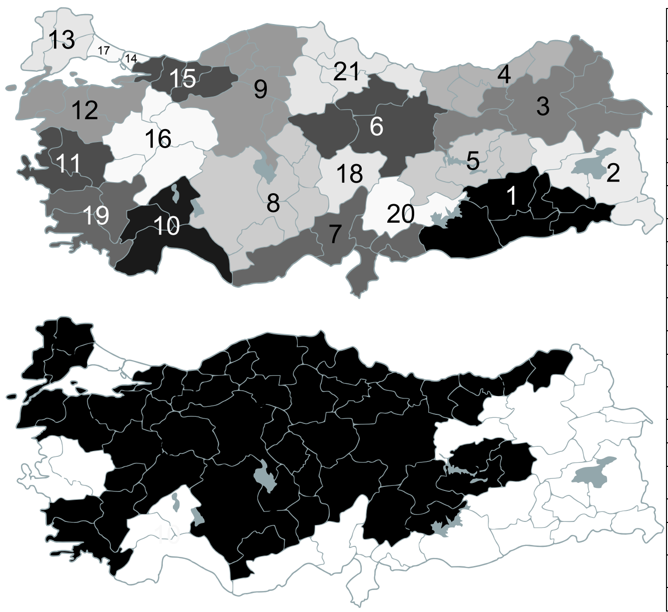
The Turkish Electricity Transmission Co. (TEIAS), a government owned company, is the transmission company. Other duties and responsibilities of TEIAS include load distribution, frequency control, capacity increase of the transmission system, and real-time system reliability monitoring.

Distribution activities in Turkish Electricity Market are carried out by the Turkish Electricity Distribution Company (TEDAS) and its partnerships and private distribution companies in their respective distribution regions. The Electricity Sector Reform and Privatization Strategy Paper of 2004 (Strategy Paper)[3] determines the 21 distribution regions of Turkey. According to the Strategy Paper, privatization of 20 distribution regions, except for the Kayseri region which was already privately operated, was to complete by July 31, 2006. The first privatization, on the other hand, was held in 2008 and privatization of 12 regions have been completed as of March 2013 [Özelleştirme İdaresi Başkanlığı]. Maps of the 21 distribution regions and privatized regions are given in the top and bottom panels of Figure 2.4, respectively.

Wholesale and retail activities are carried out by the Turkish Electricity Wholesale Corporation (Turkish: Türkiye Elektrik Ticaret ve Taahhüt A.Ş. - TETAS) and private wholesale companies. There are 182 supply licensees as of March 2013.

Electricity trade in Turkey is carried out either via bilateral contracts or in the bal-

[3] http://www.enerji.gov.tr/yayinlar_raporlar/Elektrik_Enerjisi_Sektoru_Reformu _ve_Ozellestirme_Strateji_Belgesi.pdf



1	Dicle Elektrik Dağıtım A.Ş.
2	Vangölü Elektrik Dağıtım A.Ş
3	Aras Elektrik A.Ş.
4	Çoruh Elektrik Dağıtım A.Ş.
5	Fırat Elektrik Dağıtım A.Ş.
6	Çamlıbel Elektrik Dağıtım A.Ş.
7	Toroslar Elektrik Dağıtım A.Ş.
8	Meram Elektrik Dağıtım A.Ş.
9	Başkent Elektrik Dağıtım A.Ş.
10	Akdeniz Elektrik A.Ş.
11	Gediz Elektrik Dağıtım A.Ş.
12	Uludağ Elektrik Dağıtım A.Ş.
13	Trakya Elektrik Dağıtım A.Ş.
14	İstanbul Anadolu Yak. El. Dağ. A.Ş.
15	Sakarya Elektrik Dağıtım A.Ş.
16	Osmangazi Elektrik Dağıtım A.Ş.
17	Boğaziçi Elektrik Dağıtım A.Ş
18	Kayseri ve Civarı Elektrik T.A.Ş
19	Menderes Elektrik Dağıtım A.Ş.
20	Göksu Elektrik Dağıtım A.Ş.
21	Yeşilırmak Elektrik Dağıtım A.Ş.

Figure 2.4: Electricity distribution regions of Turkey. The top panel shows the 21 distribution regions. Black colored regions on the bottom panel are the ones where privatization process was completed.

ancing and settlement market. Figure 2.5 shows the current structure of the electricity market in Turkey. As can be seen in this figure, EUAS sells all its generation to TETAS. Generation companies under BOT, BO and TOOR contracts also sell all of their generation to TETAS. On the other hand, subsidiaries and portfolio generation groups of EUAS sell electricity to distribution companies. TETAS supply electric power to eligible consumers that signed procurement contracts with TETAS in the pre-EML period. Once these contracts are expired or canceled for any reason, eligible consumers can no longer sign another contract with TETAS. Private generators can sell energy to eligible consumers or supply companies through bilateral agreements.

Generators and suppliers can also trade electric power in the balancing and settlement market. Distribution companies have supply licenses; hence they also take part in the balancing and settlement market. TETAS represents BOT, BO and TOOR companies in the balancing and settlement market [Camadan and Erten, 2010].

Currently, the balancing and settlement market is operated by two state-owned units which are under the body of TEIAS. The National Load Dispatch Center (Turkish: Milli

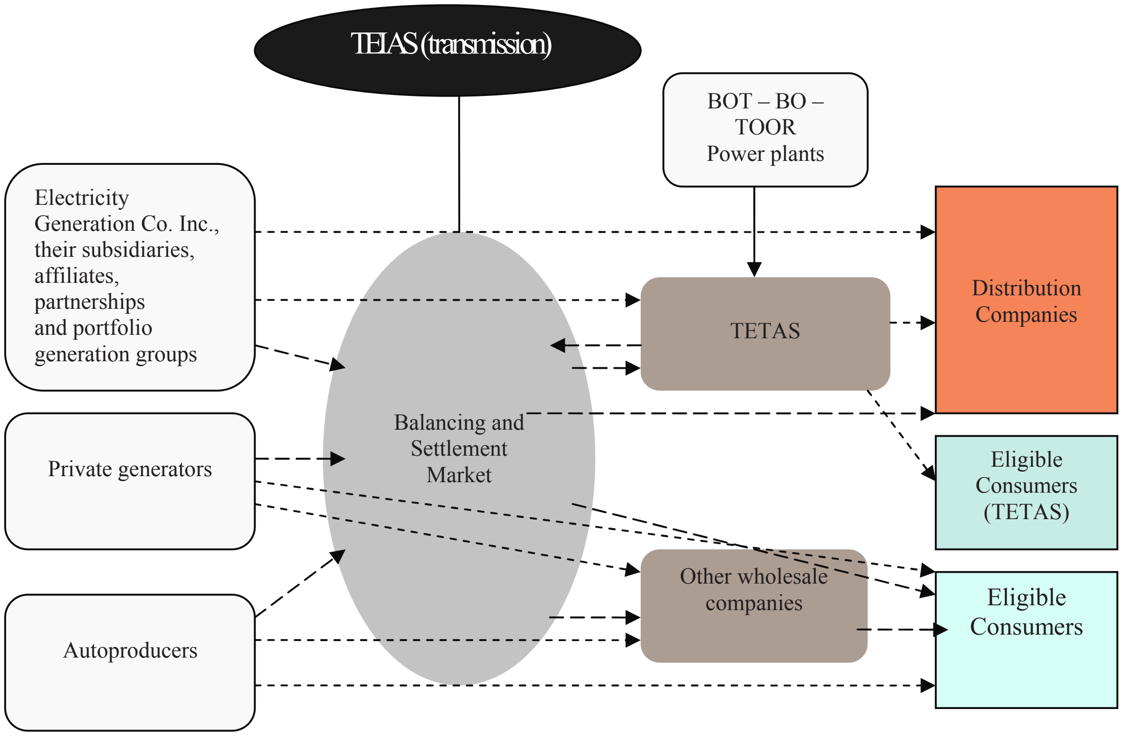


Figure 2.5: Structure of the Turkish electricity market[Camadan and Erten, 2011]

Yük Tevzi Merkezi - MYTM) is responsible for real time balancing of electricity supply and demand while the Market Financial Settlement Center (Turkish: Piyasa Mali Uzlaştırma Merkezi - PMUM), is responsible for the financial settlement of the system. Following the enactment of the new EML, market operation licensee EPIAS will take over the responsibilities of PMUM.

2.3 Electricity Contracts in Turkey

Establishment of an energy exchange in Turkey is an issue that has been discussed for a long time. The first step in establishing an exchange was taken by the Turkish Derivatives Exchange – TurkDEX (Turkish: Vadeli İşlem ve Opsiyon Borsası – VOB) in September 2011 with the introduction of the "TurkDEX – Base Load Electricity" futures contract. This is the only contract that had been introduced to date. Trading Procedures that apply to "TurkDEX-Base Load Electricity" futures contract are shown in Table A.1.

The TurkDEX's contract had not drawn much attention. Trading value of the futures contract was slightly over $12.5M in 2012. This is less than one day's trading value in the spot market. Although TurkDEX is established as a commodity exchange, it is not a very successful one. Almost 92% of its trade value is on the contracts was written on the stock exchange index. This is probably why electricity contracts did not work very well.

There are, however, important developments regarding the establishment of a more advanced energy exchange in Turkey. The new EML was enacted in March 2013 which established the EPIAS, hence creating the legal infrastructure for a derivatives market that is integrated with the balancing and settlement market.

Chapter 3

Spot Price Model

In order to reach the goal of estimating the value of the prospective energy exchange of Turkey, it is necessary to compare the current procurement cost of a hypothetical company with the cost when there exists an exchange. In other words, it is necessary to develop an optimal procurement strategy when there is a forwards market along with a spot market. The problem is, there are no forward price data for the Turkish electricity market. Therefore, in order to be able to do the desired cost comparison, I first need to simulate the prices of futures contracts. This simulation however, requires a prior spot price model.

In this Chapter a spot price model is developed using spot price data from the Turkish electricity market. The Chapter is divided into two sections. In Section 3.1, I describe the proposed spot price model. Results of the model are presented in Section 3.2.

3.1 Modeling Spot Electricity Price

Power markets are known to bear extreme price volatility by their nature. The reason behind this characteristic of the electricity markets is that electricity cannot be stored in an economically efficient way. In order to protect themselves against this high price risk, market participants should hedge their risks. Hence, price forecasts are crucial for an energy company's decision making and strategy development processes. This in turn has driven research in electricity price modeling and forecasting [Lemming, 2003].

3.1.1 Characteristics of Spot Electricity Prices

Since electricity is essentially a non-storable good, demand and supply have to be balanced in real time. As a consequence, small changes in load or generation can cause dramatic fluctuations in price in a matter of hours. Bierbrauer et al. [2007] summarized characteristics of electricity spot prices under the following four titles:

Seasonality Demand in electricity markets is of cyclical nature, which causes the resulting electricity prices to be cyclical as well. Daily, weekly and yearly seasonal patterns are common in electricity prices as a result of varying level of business activities and climate conditions. Hence, spot electricity prices show seasonal behavior.

Volatility Due to the lack of storage, electricity markets cannot benefit from the smoothing effect of inventories. This makes the changes in electricity prices more extreme than even oil and natural gas prices which are known to be very volatile. Figure 3.1 shows the daily percent change in spot electricity prices together with the daily percent change in the Borsa Istanbul Stock Exchange National 100 Index (BIST100) between January 2010 and December 2012. It can be seen in the figure that the spot electricity prices are extremely volatile, sometimes showing more than a 250% change in the daily basis, while changes in the stock exchange index is barely visible.

Mean reversion The mean reversion suggests that highs and lows in the price of a commodity are temporary and that the price will move to its average in the long run. Mean reversion is a common characteristic of commodity prices, and electricity prices are not an exception to that. What is different about electricity prices is that the speed of the mean reversion is faster than other commodities. This phenomenon can easily be explained by the way the market operates. Increase in demand cause generators with higher marginal costs to enter the market and push the prices higher. Once the demand returns to normal levels, these generators stop producing, so price returns towards the mean. See Figure 3.2 as an example. Figure 3.2 shows the supply and demand curves for the NordPool power exchange, which is one of the oldest electricity markets in the world. It can be clearly seen from the graph that when the demand for electricity increases, the demand curve shifts to the right, and as a result of the shape of the supply curve prices increase very sharply.

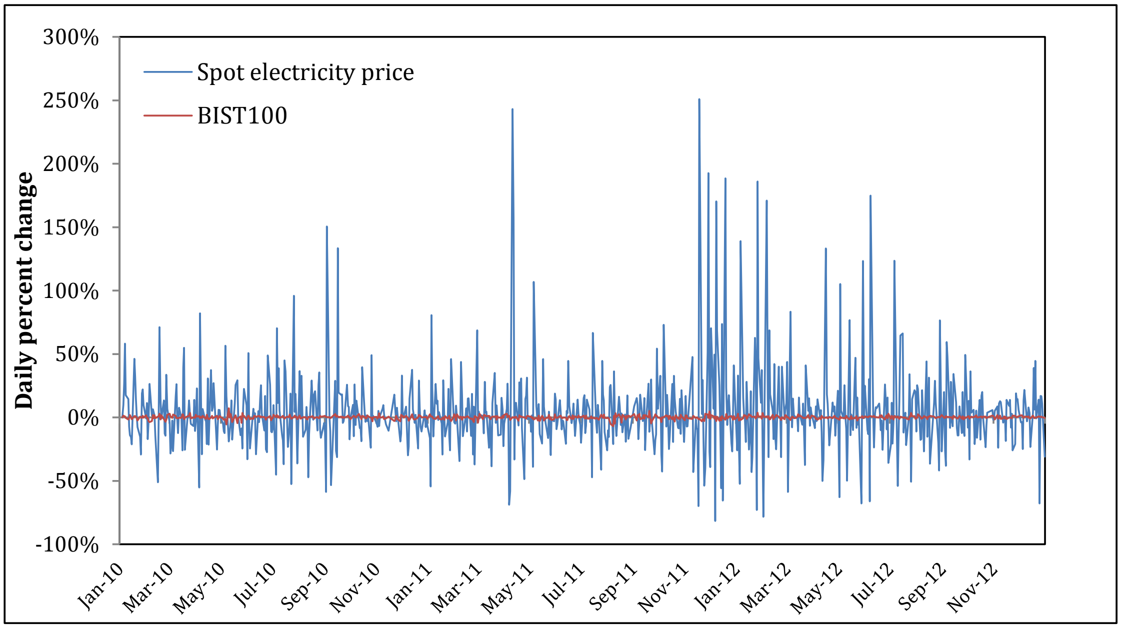


Figure 3.1: Daily percent change in spot electricity prices vs. Turkish stock exchange index.

Spikes Spikes are another characteristic property of electricity prices. Spikes are defined as very sharp increases or decreases of the price in a very short period time. The spikes are caused by unexpected events such as plant failures or generators inability to supply the demanded amount. Figure 3.3 shows the spot price data for the Turkish electricity market on February 13, 2012. Note that the price is around TL200 at 8:00 AM and suddenly rises to a historical high price of around TL2000 at 9:00 AM which is a 10 fold increase in one hour.

3.1.2 Spot Price Models

Weron [2007] classified the approaches that are used in modeling spot prices under six classes. These are: production cost models, equilibrium models, fundamental models, statistical models, non-parametric models and quantitative models. Production cost models use the marginal costs of generation units and the estimates of demand as an input to estimate spot prices. These type of models are capable of forecasting prices quite accurately; however they are more suitable for regulated markets rather than competitive markets because they generally neglect strategic bidding practices (See, for example, Ramos et al. [1999] and Kamat and Oren [2004] for the application of a production

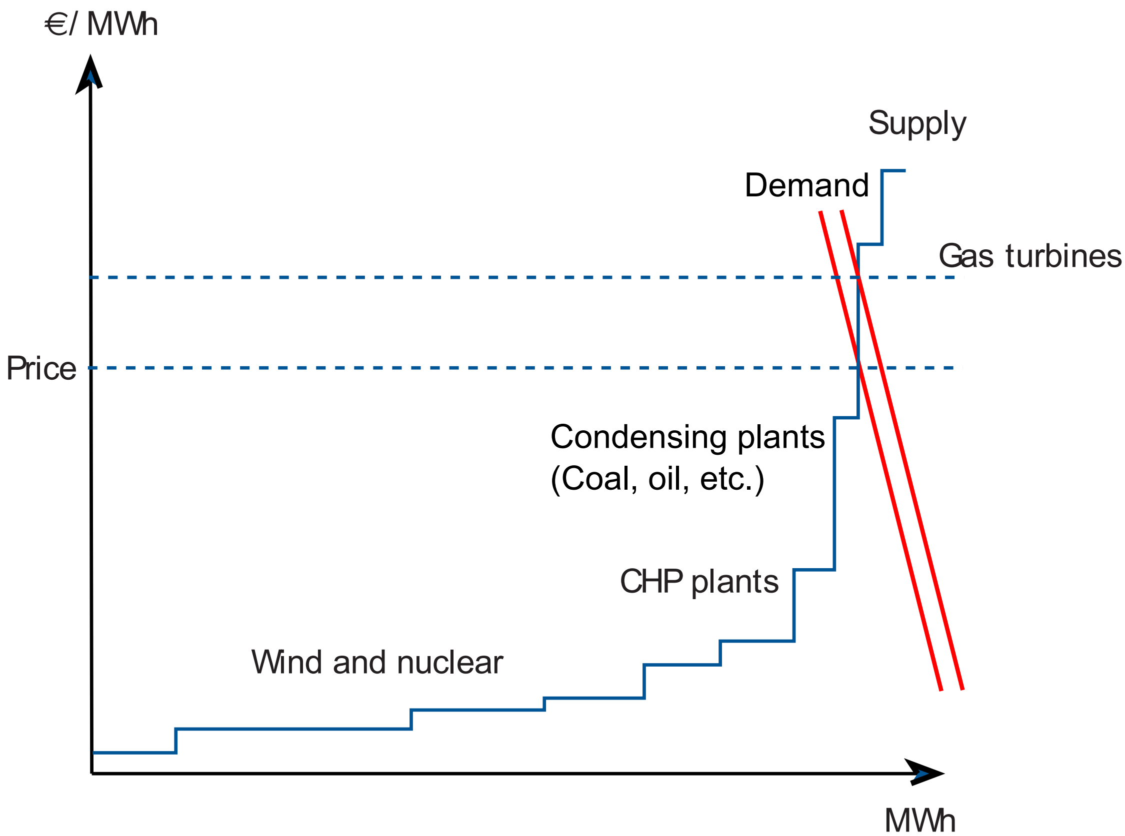


Figure 3.2: Supply and demand curves for the NordPool Power Exchange [Krohn et al., 2009, p.18]. The blue line represents supply curve. The red line represents demand curve.

cost model to the electricity market). Equilibrium (or game theory) models can be considered as extensions of production cost models in that they include strategic bidding practices. These type of models are particularly used for markets without a price history, but generally only qualitative results can be obtained [see e.g., Ventosa et al., 2005, Gao and Sheble, 2010]. Fundamental (or structural) methods are bottom up methods in which additional data other than historical price data (e.g., weather and fuel costs) are implemented as inputs in the model. These models demand large amounts of quality data in order to be accurate[see e.g., Skantze and Ilic, 2001, Wallace and Fleten, 2003]. Statistical (or technical analysis) models are pure statistical models that are appropriate for price forecasts However they are not very efficient and are often time consuming to solve. [see e.g., Davison et al., 2002, Ventosa et al., 2005]. Artificial intelligence-based models are non-parametric models that make use of techniques like neural networks or

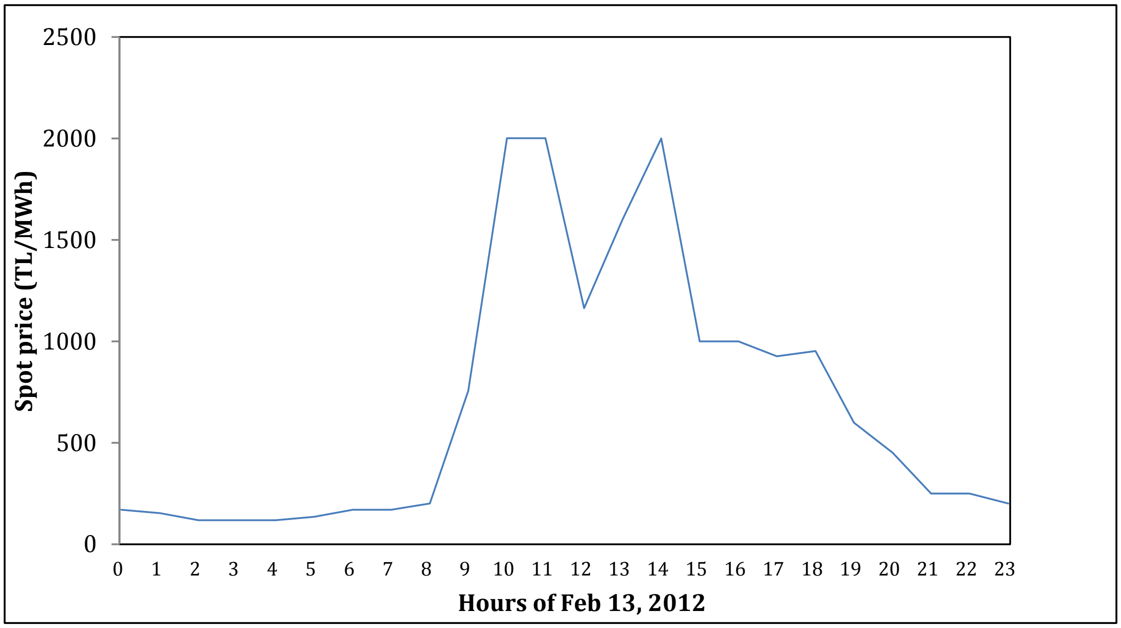


Figure 3.3: Hourly spot price for the Turkish electricity market on February 13, 2012.

fuzzy logic. However, they perform best for short-term forecasts and their reliability for long-term predictions are questionable [see e.g., Szkuta et al., 1999, Wang and Ramsay, 1998]. Finally, quantitative (or stochastic, econometric, reduced form) models use techniques that estimate the statistical properties of historical prices and uses these properties to price derivatives. Since I am going to use the spot price model for derivatives pricing purposes, quantitative models are the most appropriate for this analysis.

3.1.3 A Spot Price Model for Turkish Electricity Market

3.1.3.1 Type of price model

As stated in Section 3.1.2, quantitative models are the models that are commonly used for derivatives valuation and risk management. Another reason for choosing such a model is that only market data available to me in the course of this study which is sufficient for the selected model.

Bierbrauer et al. [2007] compared various quantitative models (simple mean-reverting models, mean-reverting models with jumps, and regime-switching models with two and three independent states) for electricity spot prices and found that the regime-switching models are superior to the other methods investigated. In regime-switching models, the stochastic behavior of time series data is modeled by two or more phases that have different characteristics. They stressed that the best results are obtained using a two-regime model with a Gaussian distribution in the spike regime. Hence, a two-regime regime switching model that is composed of a mean-reverting and a spike regime is incorporated in my model.

3.1.3.2 Data

I used hourly system marginal prices from 1/1/2010 to 12/31/2012. These are ex-post spot prices which are accessible online at PMUM's website[1]. Unit of the prices is Turkish Lira per megawatt hour of energy (TL/MWh)[2]. As electricity contracts are generally traded on daily average prices, these hourly prices were used to calculate daily average prices. Since spot prices were assumed to be log-normally distributed, natural logarithms of average daily prices were then used in the model. Figure 3.5 shows the quantile-quantile plot of natural logarithm of average daily prices vs. normal distribution. The figure shows the log-normality assumption holds pretty well. Figure 3.4 shows the average daily prices against their natural logarithms, while Table 3.1 gives summary statistics for the data.

Table 3.1: Summary statistics

Variable	Mean	Std. Dev.	Min	Max
Daily average price	126.51	44.73	11.92	687.35
Log of daily average price	4.78	0.38	2.48	6.53
Number of observations		1096		

3.1.3.3 Parametric structure

Prices in electricity markets follow seasonal patterns. Therefore many models in the literature suggest a structure composed of a totally predictable deterministic (or seasonal) and a stochastic (random) component [Pilipovic, 1998, Bierbrauer et al., 2007, Bunn and Karakatsani, 2003, Burger et al., 2004, De Jong and Huisman, 2002, Lemming, 2003, Lucia and Schwartz, 2002].

[1] https://rapor.pmum.gov.tr/analytics/saw.dll?PortalPages&path=/shared/Raporlar/_portal/SgofSmfListeleme
[2] Exchange rate is $\$1 = \text{TL}1.92$ at the time of writing.

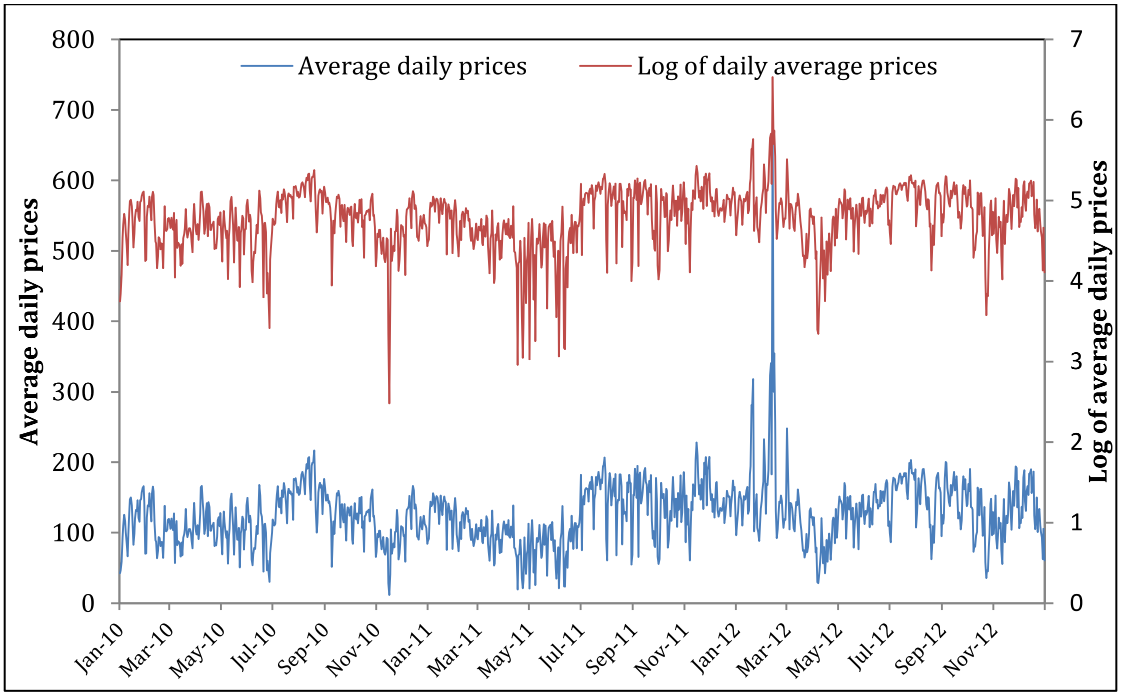


Figure 3.4: Average daily spot prices and the natural logarithm of daily average spot prices in the Turkish electricity market.

$$\ln P_t = f(t) + S_t \tag{3.1}$$

where, P_t = spot electricity price

$f(t)$ = deterministic component of spot electricity price

t = period

S_t = stochastic component of spot electricity price

An expression for stochastic component can be obtained by rearranging Eq. (3.1), i.e.,

$$S_t = \ln P_t - f(t) \tag{3.2}$$

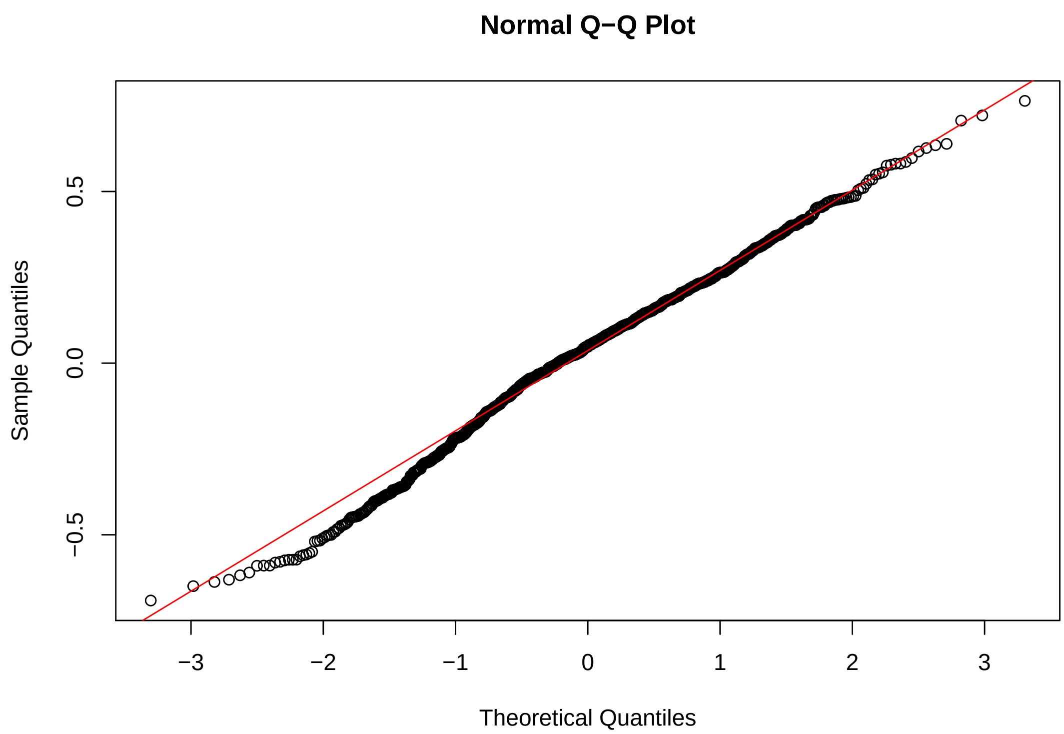


Figure 3.5: Q-Q plot of natural logarithm of daily average spot prices.

Deterministic Component

Auto-correlation plot of the data (Figure 3.6a) and a plot of monthly average prices (Figure 3.6b) suggest that there exists a weekly and a yearly cyclic behavior in the data. In order to account for these seasonal effects, I suggested a deterministic function of the form;

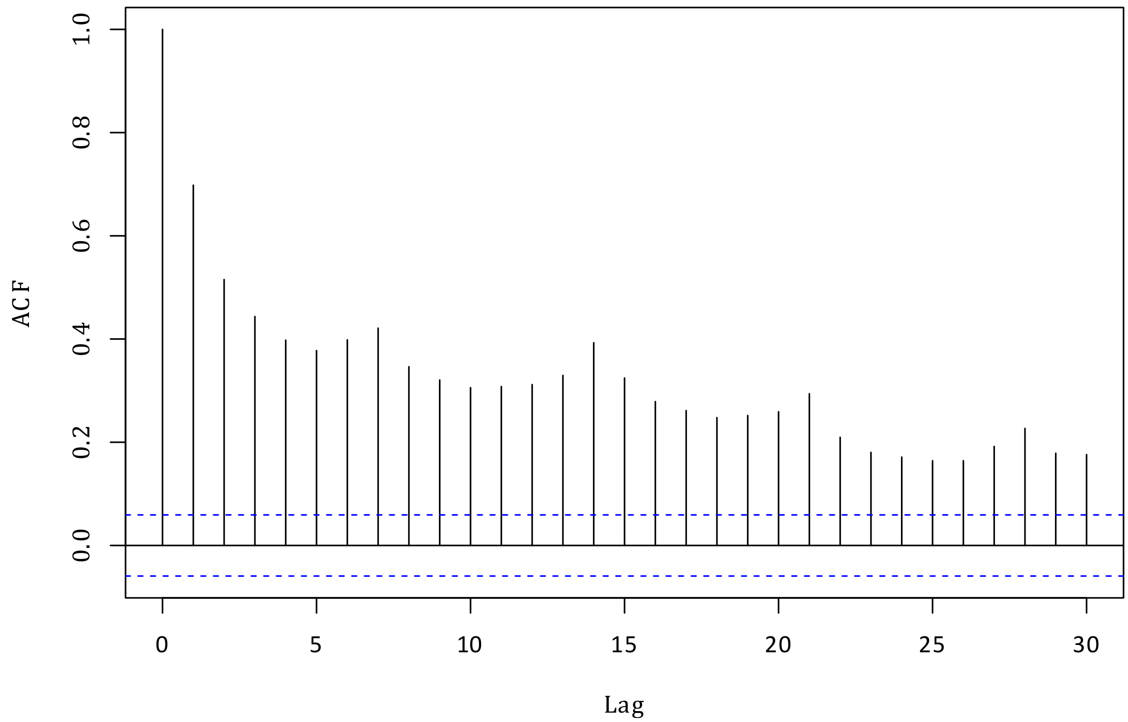
$$f(t) = \beta_0 + \sum_{i=2}^{7} \beta_{1i} D_{it} + \sum_{j=2}^{12} \beta_{2j} M_{jt} \tag{3.3}$$

where $f(t)$ is deterministic component of spot electricity price, t is the date, D_{it} and M_{jt} are dummy variables for i^{th} day of the week and j^{th} calendar month.

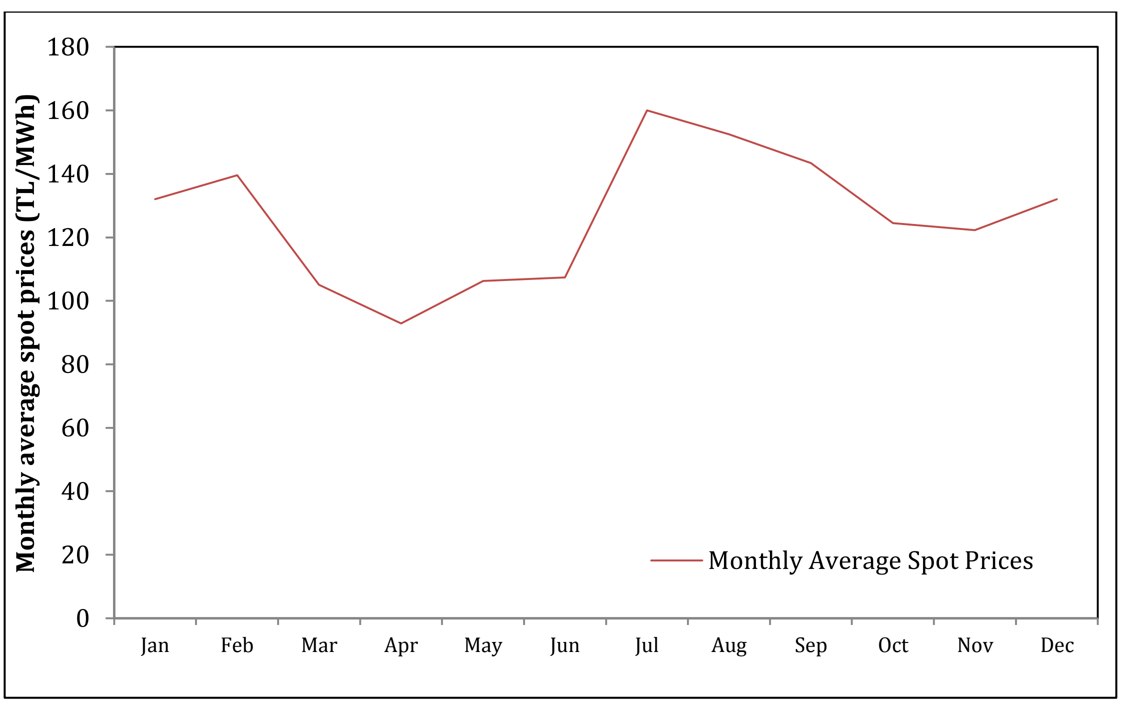
Subtracting the deterministic function from the original data gives the deseasonalized data which I use for stochastic modeling purposes.

Stochastic component

De Jong and Huisman [2002] suggested a two-regime regime-switching spot price model



(a) Auto-correlation plot of log spot price data. A 7 day cycle is obvious in the plot.



(b) Monthly average spot prices between January 2010 and December 2012.

Figure 3.6: Seasonality Analysis

that closely resembles the true characteristics of electricity prices, such as mean reversion and spikes. The model consists of a mean-reverting normal regime and a spike regime to account for jumps and spikes in the prices.

A Vasicek [1977] process, which is a very famous mean-reverting stochastic process especially in financial modeling, is suggested for mean-reverting part of the model. The reason why Vasicek's model is so popular is that the differential equation has a closed form solution. The spike part is modeled as a Gaussian distribution.

$$\text{Mean-reverting regime: } S_{M,t} = S_{M,t-1} + \alpha(\mu_M - S_{M,t-1}) + \varepsilon_{M,t} \quad \text{where } \varepsilon_{M,t} \overset{\text{i.i.d.}}{\sim} N(0, \sigma_M^2) \tag{3.4}$$

$$\text{Spike regime: } S_{S,t} = \mu_S + \varepsilon_{S,t} \quad \text{where } \varepsilon_{S,t} \overset{\text{i.i.d.}}{\sim} N(0, \sigma_S^2) \tag{3.5}$$

Here:
S =stochastic component of price
t =period
α =mean reversion rate
μ_i =long-time mean of regime i
σ_i^2 =variance of regime i

A Markov transition matrix was used to define regime switching characteristics of the model.

$$TM = \begin{bmatrix} p_{MM} & p_{MS} \\ p_{SM} & p_{SS} \end{bmatrix} \tag{3.6}$$

The transition matrix is composed of the switching probabilities from one regime to the other. Subscripts denote "from regime to regime", eg., p_{MS} is the probability of switching from mean-reverting regime to spike regime or in other words, the probability of period $t+1$ being in the spike regime while period t is in mean reverting regime and so on.

In order to calculate the switching probabilities, I need to decide what a spike is. As suggested in Clewlow and Strickland [2000], a recursive filter was applied. The procedure is as follows: the mean and standard deviation of the whole data set is calculated in the first iteration. Data points that are more than three sample standard deviations from the mean are removed from the data. The mean and standard deviation of the remaining data set is recalculated in the second iteration and data points that are more than three sample standard deviations from the mean are removed from the data again. This procedure is repeated until there are no data points that are three standard deviations away from the mean can be identified.

Parameters of each regime were calibrated by the method of maximum log-likelihood. Log-likelihood functions of mean reverting and spike regimes are respectively given by;

$$LL_M = -\frac{(S_{M,t} - S_{M,t-1} - \alpha(\mu_M - S_{M,t-1}))^2}{2\sigma_M^2} - \ln(\sigma_M^2) - \frac{1}{2}\ln(2\pi) \tag{3.7}$$

$$LL_S = -\frac{(S_{S,t} - \mu_S)^2}{2\sigma_S^2} - \ln(\sigma_S^2) - \frac{1}{2}\ln(2\pi) \tag{3.8}$$

where, LL_i = log-likelihood function of regime i

$S_{i,t}$ = stochastic component of spot electricity price in regime i at period t

α = mean reversion rate

μ_i = long-time mean of regime i

σ_i^2 = variance of regime i

$\pi = 3.14159$

The log-likelihood function of the model can be calculated by weighing log-likelihood function of each regime by its probability of occurrence, i.e.,

$$LL = \pi_M LL_M + \pi_S LL_S \tag{3.9}$$

The solution to the unconstrained maximization problem below calibrates model parameters α, μ_M, σ_M^2, μ_S, and σ_S^2 to the data;

$$\underset{\alpha,\mu_M,\sigma_M^2,\mu_S,\sigma_S^2}{\text{maximize}} LL(\alpha,\mu_M,\sigma_M^2,\mu_S,\sigma_S^2) \tag{3.10}$$

3.2 Results

3.2.1 Deterministic (Seasonal) Component

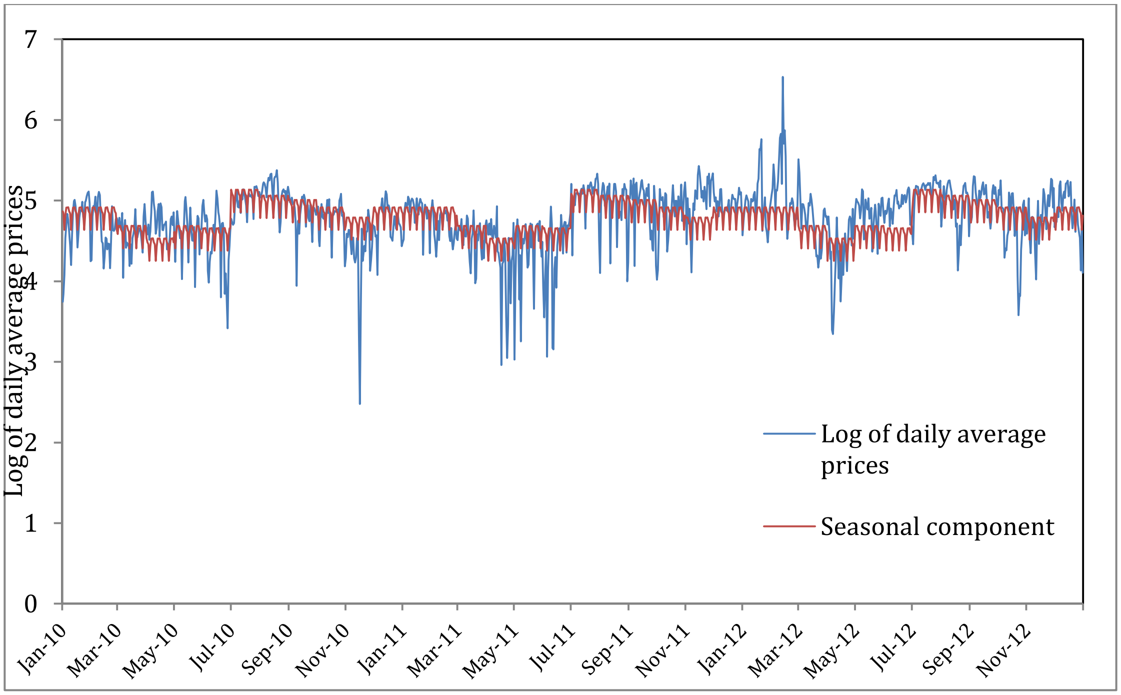
Coefficients of the deterministic component, $f(t) = \beta_0 + \sum_{i=2}^{7} \beta_{1i} D_{it} + \sum_{i=2}^{12} \beta_{2i} M_{it}$ were calculated by ordinary least squares regression. I generated dummy variables to represent each day of the week and for each calendar month. Natural logarithms of spot prices were then regressed over these dummy variables to calculate the respective coefficients. The constant β_0 gives the deterministic part of spot price for a Sunday in January. Coefficients of dummy variables give additional effect of varying the week of the day and the month. Table 3.2 shows the results of the regression. Only the coefficients that are significant at 95% confidence interval were used in further calculations. Figures 3.7b and 3.7a show actual prices vs. deseasonalized prices and seasonal component on actual prices, respectively. It can be interpreted from the figures that a large portion of the spot prices are described by deterministic component.

3.2.2 Spike Filtering

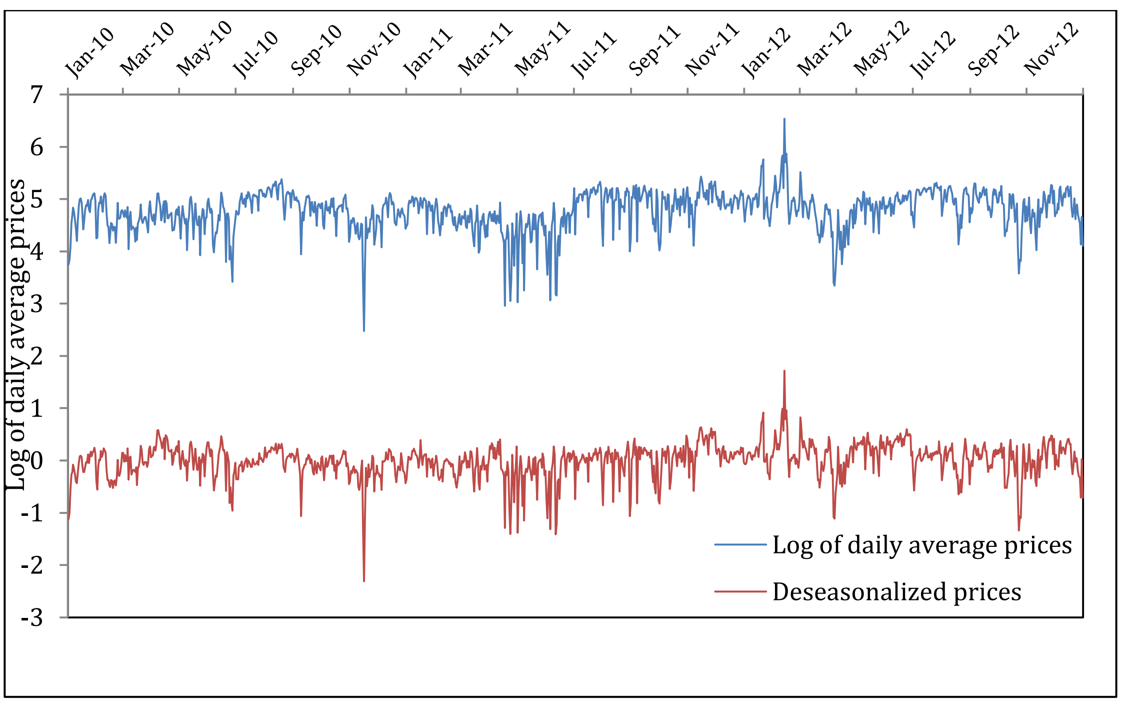
Spike filtering is of crucial importance in the model. Incorporating the filtering mechanism, details of which was given in Section 3.1.3.3, 46 data points out of 1096 were identified as spikes resulting in a spike frequency of $f_{spikes} = 0.04197$. Figure 3.8 shows data points that are identified as spikes out of the whole data set.

Once the spikes are identified, switching probabilities can be determined. Out of 46 spikes 16 were followed by another spike and 30 were followed by a data point in mean-reverting regime, while 1020 data points in mean-reverting regime were followed by another data point in mean-reverting regime and 30 data points in mean-reverting regime were followed by a data point in spike regime.

Hence, the Markov transition matrix becomes;



(a) Actual price data and estimated seasonal component



(b) Actual prices vs. deseasonalized prices. The difference between the two curves in Figure 3.7a gives the deseasonalized curve.

Figure 3.7: Seasonality effect

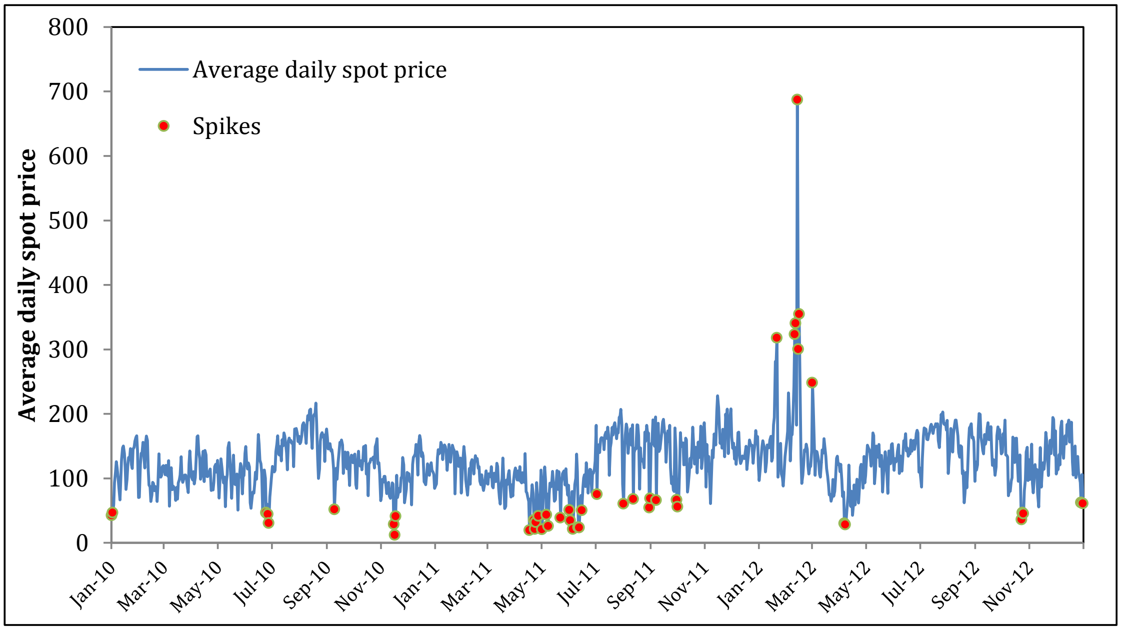


Figure 3.8: Spike analysis. Red dots represent the data points that are identified as spikes.

$$TM = \begin{bmatrix} p_{MM} & p_{MS} \\ p_{SM} & p_{SS} \end{bmatrix} = \begin{bmatrix} \frac{1020}{1050} & \frac{30}{1050} \\ \frac{30}{46} & \frac{16}{46} \end{bmatrix} = \begin{bmatrix} 0.9714 & 0.0286 \\ 0.6522 & 0.3478 \end{bmatrix} \tag{3.11}$$

3.2.3 Calibration of Model Parameters

After the removal of deterministic component and the calculation of the spike frequency, log-likelihood functions of both regimes were weighed with respect to their probabilities of occurrence. A Python code was written to maximize the resulting log-likelihood function to calibrate model parameters. Table 3.3 shows the results of the calibration process.

Calculated parameters show that the mean reversion rate is 0.35760 which suggests the time needed to return to the mean is roughly three days. As expected, variance of the mean reverting regime is less than spike regime. On the other hand, the differences between variances of the both regimes are not as dramatic as expected. This is probably due to the use of a weighed log-likelihood function. The high weight (or probability of occurrence) of the mean reverting regime, which is around 96%, seems to smoothen the

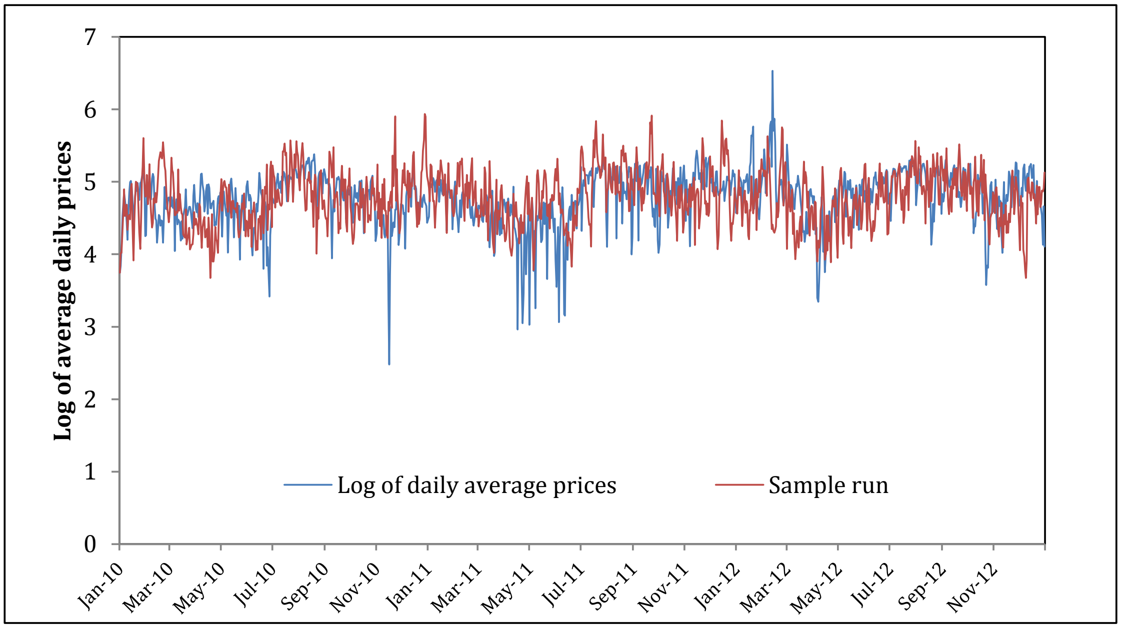


Figure 3.9: Estimated prices vs. actual prices.

spike regime. This effect can also be seen in Figure 3.9. Figure 3.9 shows a sample run of the model together with the actual price data. Although the model follows the trend of actual price data quite well, spikes in the model are not as severe as in the actual data, again due to the smoothing effect of high weight of mean reverting regime.

Table 3.2: Regression results for deterministic component

	Dependent variable:
	Log of average daily spot price
Mon	0.178***
	(0.037)
Tue	0.279***
	(0.037)
Wed	0.276***
	(0.037)
Thu	0.281***
	(0.037)
Fri	0.231***
	(0.037)
Sat	0.206***
	(0.037)
Feb	−0.004
	(0.050)
Mar	−0.229***
	(0.048)
Apr	−0.385***
	(0.049)
May	−0.230***
	(0.048)
Jun	−0.258***
	(0.049)
Jul	0.219***
	(0.048)
Aug	0.146***
	(0.048)
Sep	0.093*
	(0.049)
Oct	−0.061
	(0.048)
Nov	−0.124**
	(0.049)
Dec	0.014
	(0.048)
Constant	4.636***
	(0.042)
Observations	1,096
Adjusted R^2	0.252
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 3.3: Calibrated model parameters

Parameter	Value
α	0.35760
μ_M	0.00169
σ_M^2	0.24934
μ_S	0.00104
σ_S^2	0.32607
log-likelihood	45.184

α =mean reversion rate; μ_i =long-time mean of regime i; σ_i^2 =variance of regime i

Chapter 4

Pricing of Derivatives

Electricity prices are more volatile than the prices of any other commodity. Together with constant input or output prices, the financial risk of the companies participating in the market becomes even more significant. Spot prices can be both input and output prices for the companies that play different roles in the market, e.g., output price for generators and input price for utilities. Consider a utility which purchases electric power in the spot market and sells it to its customers at a regulated price. In the case that there is a spike in the spot price when the utility has to deliver electricity, the utility might lose a lot of money or even go bankrupt. For a generator which sells power in the competitive market, on the other hand, negative spikes or sudden decreases in the price are the main source of risk. Prices can drop to the levels below the costs for the generator and the generator will suffer from a reduction in profits or even face a loss [Weron, 2007]. Therefore, regardless of spot prices being input or output price, companies are open to price risk and should hedge against these risks associated with spot price.

Derivatives are the tools developed to hedge this risk and in order to develop an optimal hedging strategy, the pricing of derivatives is of crucial importance. A fair value of the hedge is required to choose the optimal strategy among possible hedging strategies. There are two modeling approaches for estimating the value of a derivative in an electricity market. The first approach is to calibrate the underlying price model using forward prices. This approach is particularly useful for pricing contracts written on forward prices and it also does not require any prior spot price modeling. However, not all contracts are written on forward prices. Besides, most electricity markets do not have well established forward markets - as in the case of Turkey - so it may be a problem to find proper forward price data. The second approach is modeling spot price first, then defining a relationship between spot and forward prices, and then valuate the derivatives accordingly. Although it is harder to implement, using this approach makes it possible to valuate contracts written both on spot and forward prices [Janczura, 2012]. Moreover, in our case it is the only viable option as there is no forward price data available.

4.1 The relationship between spot and futures prices

The standard approach for pricing derivatives is known as 'no-arbitrage condition' or 'cost-of-carry'; that is, a trader should be indifferent between purchasing the commodity now and keeping until the time of use and purchasing a forward contract to get the commodity at the time of use [Pilipovic, 1998]. This relationship that links spot and forward prices cannot be used for electricity because electricity is a commodity that cannot be stored [Shawky et al., 2003].

The non-storability of electricity leaves the bank account as the only tradable asset in the spot market [Benth et al., 2003]. Consider two scenarios. In the first scenario, I enter into a futures contract. When the time of contract expiration comes, I pay the price of the contract and receive the commodity and immediately sell it in the market. In the second scenario, I borrow money from the bank and purchase the commodity now. At the time of contract expiration, I sell the commodity and pay the bank the money I borrowed and some amount of principle. I should be indifferent between these two scenarios and I can use the no arbitrage condition. Therefore, the discounted value of the bank account is risk-neutral under any measure equivalent to the actual measure $\mathscr{P}$. The market is arbitrage-free but there is no unique martingale measure, i.e., the market is incomplete. Another criterion is necessary in order to choose a pricing measure [Janczura, 2012].

"Risk premium" is such a criterion that is commonly used in electricity derivatives valuation literature. The risk premium is a concept defined as a "reward for investing into a risky asset instead of a risk-free one" [see e.g. Benth et al., 2008a, Weron, 2007]. What is intended by 'risk premium' approach is to select a risk-neutral measure that is concordant with the prices of forward contracts [Janczura, 2012].

In the financial mathematics literature, the term market price of risk is used rather than the risk premium. Weron [2007] defines the market price of risk (λ) as "*the difference between the drift in the original 'risky' probability measure $\mathscr{P}$ and the drift in* *the risk-neutral measure $\mathscr{P}^{\lambda}$ in the stochastic differential equation governing the price dynamics*."

Once the market price of risk is defined, the relationship between the forward price and the expected spot price is given by;

$$F_{0,\tau} = \mathbb{E}^{\mathscr{P}^{\lambda}}(S_t) \tag{4.1}$$

where, $F_{0,\tau}$ = price of a forward contract at time 0 that matures at time τ

S_t = spot electricity price

$\mathbb{E}^{\mathscr{P}^{\lambda}}(S_t)$ = expected value of spot price with respect to the pricing probability measure $\mathscr{P}^{\lambda}$

4.2 Modeling Forward Price Curve

As stated in Section 3.1.3, the suggested spot price model is a regime-switching model that consists of a mean-reverting and a spike regime. Therefore, the resulting forward price curve ($F_{t,\tau}$) also has two parts that reflect the stable mean-reverting regime ($F^M_{t,\tau}$) and the spike regime ($F^S_{t,\tau}$). Suppose we are at time $t = 0$. Then, the forward curve for maturities $\tau = 1,\ldots,T$ is given by;

$$F_{0,\tau} = F^M_{0,\tau} + F^S_{0,\tau} \tag{4.2}$$

In the following subsections, I describe the steps that are necessary to go from the spot price model to the forward price model.

4.2.1 Mean Reverting Part

Recall from Chapter 3 that the mean reverting part of the spot price model was a Vasicek process. In continuous form, the Vasicek process is given by;

$$dS_{M,t} = \alpha(\mu_M - S_{M,t}) + \sigma_M dW_t \tag{4.3}$$

where, $S_{M,t}$ = stochastic component of spot price

α = mean reversion rate

μ_M = long-time mean of mean reverting regime

σ_M = standard deviation of mean-reverting regime

dW_t = increment to standard Brownian motion or drift term

Under a risk-neutral measure, assuming the market price of risk (λ) is constant, we can rewrite Eq. (4.3) as;

$$dS_{M,t} = \alpha(\mu_M + \lambda^* - S_{M,t}) + \sigma_M dW_t^\lambda \tag{4.4}$$

$$\text{where, } \lambda^* = \text{-}\lambda \frac{\sigma_M}{\alpha}$$

Recall that spot price is composed of a deterministic and a stochastic part, i.e., $\ln P_t = f(t) + S_t$. Rewriting this equation yields;

$$S_t = \ln P_t - f(t) \tag{4.5}$$

As stated before the differential equation defining Vasicek process has an explicit solution. The explicit solution to Eq.(4.4) for $\ln P_t$ after substituting Eq.(4.5) is;

$$\ln P_{M,t} = f(t) + (\ln(P_{M,0}) - f(0))\, e^{-\alpha t} + (\mu_M + \lambda^*)\left(1 - e^{-\alpha t}\right) + \sigma_M \int_0^t e^{\alpha(u-t)} dW_t^\lambda(u) \tag{4.6}$$

The expected value and variance of $\ln P_{M,t}$ are given by;

$$\mathbb{E}\left(\ln P_{M,t}\right) = f(t) + (\ln(P_{M,0}) - f(0))\, e^{-\alpha t} + (\mu_M + \lambda^*)\left(1 - e^{-\alpha t}\right) \tag{4.7}$$

$$\operatorname{Var}\left(\ln P_{M,t}\right) = \frac{\sigma_M^2}{2\alpha}\left(1 - e^{-2\alpha t}\right) \tag{4.8}$$

Since I used the natural logarithm of spot prices in the model, it is assumed the spot price has a lognormal distribution. Hence the expected value of spot price is given by;

$$\mathbb{E}\left(P_{M,t}\right) = \exp\left[\mathbb{E}\left(\ln P_{M,t}\right) + \frac{1}{2}\mathrm{Var}\left(\ln P_{M,t}\right)\right]$$

The mean-reverting part of the forward curve is then given by;

$$\begin{aligned} F_{0,\tau}^{M} &= \pi_{M,\tau}\mathbb{E}\left(P_{M,t}\right) \\ &= \pi_{M,\tau}\exp\left[f(t) + (\ln(P_0) - f(0))e^{-\alpha t} + (\mu_M + \lambda^*)\left(1 - e^{-\alpha t}\right) + \frac{\sigma_M^2}{4\alpha}\left(1 - e^{-2\alpha t}\right)\right] \end{aligned} \tag{4.9}$$

$$\begin{aligned} \text{where, } \pi_{M,\tau} &= \text{probability of } S_\tau \text{ being in mean reverting regime} \\ f(t) &= \text{deterministic function at time T} \\ P_0 &= \text{spot price at } t = 0 \\ \alpha &= \text{mean reversion rate} \\ \sigma_M^2 &= \text{variance of mean-reverting regime} \end{aligned}$$

The probability of price being in the mean-reverting regime $\pi_{M,\tau}$ can be calculated by raising the transition matrix TM, which was defined in Section 3.1.3.3, to the τ power, which is the number of periods until contract maturation.

The only variable remained unknown in Eq. (4.9) is $\lambda^* = \text{-}\lambda\frac{\sigma_M}{\alpha}$. In order to estimate the market price of risk, λ, the estimation method suggested by Kolos and Ronn [2008] is used. Taking day-ahead prices as the initial price of the contract, and spot (real-time) prices for the same day as the final price, and making use of method of moments, the market price of risk may be estimated by;

$$\hat{\sigma} = \frac{1}{\sqrt{\Delta t}}\sqrt{\frac{n}{n-1}\mathrm{Var}\left(\ln\frac{P}{P_{DA}}\right)} \tag{4.10}$$

$$\hat{\lambda} = \frac{\overline{\ln\frac{P}{P_{DA}}}}{\hat{\sigma}\Delta t} + \frac{\hat{\sigma}}{2} \tag{4.11}$$

where, $\widehat{\sigma}$ is daily volatility, P is real-time or spot price, P_{DA} is day-ahead price which is set at date $t-1$ for the electricity to be delivered at date t, n is number of observations, and Δt is the time difference between observations, which is one day in our case. Once the market price of risk is estimated, λ^*, the mean-reverting part of forward price $F_{0,\tau}^M$ can be calculated.

4.2.2 Spike Part

In the spot price model, the spike regime was assumed to be drawn from a Gaussian distribution. Since I used the natural logarithm of spot prices, the spot price itself is log-normally distributed too. The expected value of spike part is given by;

$$\mathbb{E}\left(P_{S,t}\right) = \exp\left[\mathbb{E}\left(\ln P_{S,t}\right) + \frac{1}{2}\mathrm{Var}\left(\ln P_{S,t}\right)\right] \tag{4.12}$$

The spike part of the forward curve is then given by;

$$F_{0,\tau}^S = e^{rt}\pi_{S,\tau}\exp\left(f(t)+\mu_S+\frac{1}{2}\sigma_S^2\right) = \pi_{S,\tau}\exp\left(f(t)+\mu_S+\frac{1}{2}\sigma_S^2+rT\right) \tag{4.13}$$

where, $\pi_{S,\tau}$ = probability of S_τ being in spike regime

$f(t)$ = deterministic function at time t

μ_S = long term mean of spike regime

r = risk-free interest rate

σ_S^2 = variance of spike regime

Like the mean-reverting part, the probability of price being in the spike regime $\pi_{S,\tau}$ can be calculated by raising the transition matrix TM to the τ power, which is the number of periods until contract maturation. For the risk-free interest rate, the benchmark interest rate of the Central Bank of Turkey, which is 4.5%, is used. Equations 4.2 through 4.13 complete the specification for the expected futures prices.

4.2.3 Futures Contract Price

Futures contracts traded on energy exchanges are usually settled during a period of time such as a week, a month, a year, etc. Let $f_t^{[T_1,T_2]}$ denote the price of a futures contract settled during period $[T_1,T_2]$ at time t, where T_1 and T_2 represents the starting and expiration dates of the contract, respectively. The price of the contract is given by;

$$f_t^{[T_1,T_2]} = \int_{T_1}^{T_2} w(T_1,T_2,\tau)\, F_{t,\tau} d\tau \tag{4.14}$$

where $w(T_1,T_2,\tau)$ is a weight function representing the time value of money. According to Benth et al. [2008b], the weight function for a contract settled at maturity is given by;

$$w(T_1,T_2,\tau) = \frac{1}{T_1 - T_2} \tag{4.15}$$

Substituting the weight function in Eq. (4.14) gives the equation for the price of a futures contract at time t which is settled during period $[T_1,T_2]$:

$$f_t^{[T_1,T_2]} = \frac{1}{T_1 - T_2} \int_{T_1}^{T_2} F_{t,\tau} d\tau \tag{4.16}$$

4.3 Results

4.3.1 Market price of risk

Most of the parameters needed to calculate the forward price curve are already estimated for the spot price model. The only unknown parameter necessary for the calculations is the market price of risk. This step ideally requires the knowledge of the forward prices in the market. However, as Turkey does not have a fully operational futures market, that data is not available.

On the other hand, Kolos and Ronn [2008] suggests a procedure, the details of which are given in Section 4.2, to estimate the market price of risk. I estimated daily volatility to be $\widehat{\sigma} = 0.27492$ and the market price of risk to be $\hat{\lambda} = -0.14827$. The coefficient λ^* was found to be 0.10338. The negative $\hat{\lambda}$ suggests that expected forward prices are upward-biased predictors of expected spot prices, a situation which is known as

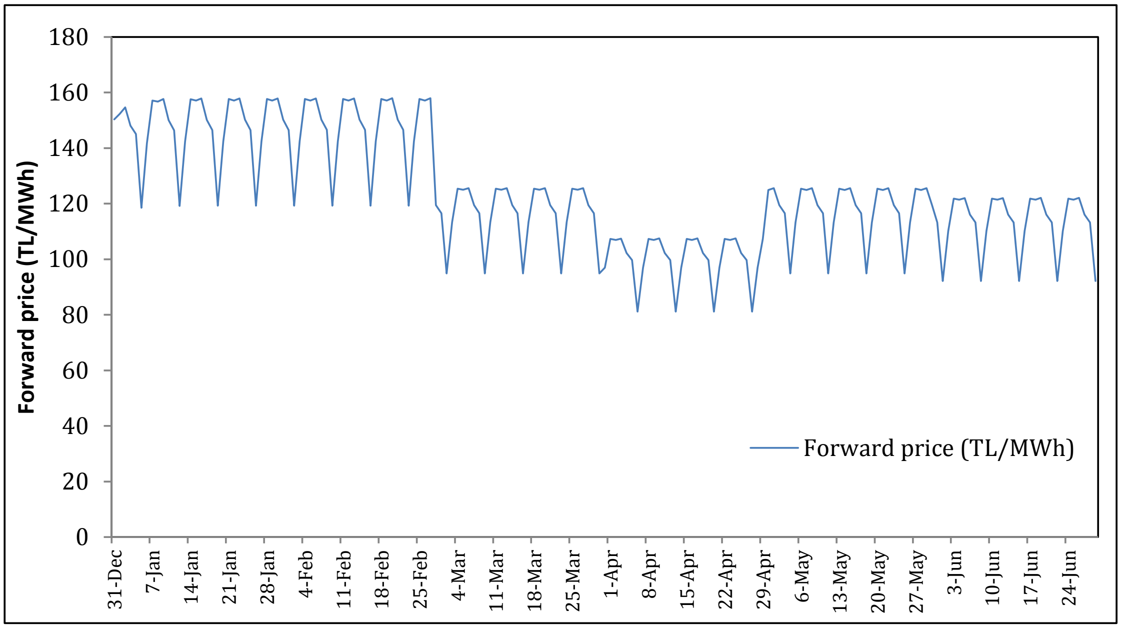


Figure 4.1: Forward price curve.

contango, i.e.,

$$F_{0,\tau} > \mathbb{E}(S_\tau) \tag{4.17}$$

This implies that the market participants' perception of the level of volatility of the market is higher than the real volatility of the market. This result is also consistent with the results reported by Botterud et al. [2002] and Bierbrauer et al. [2007], among others.

4.3.2 Estimation of Futures Prices

I follow the procedure given in Section 4.2 and calculate futures prices for weekly and monthly contracts for the first six months of 2013. Figure 4.1 shows the estimated forward price curve. I chose 12/30/2012 as the date to enter into contracts because this is the last day which is in the normal regime for the data used for spot price model calibration. Table 4.1 summarizes estimated futures contract prices.

Effect of the deterministic (seasonal) component of the spot price model is very large on the estimated futures prices. My calculations revealed that nearly 86.5% of the prices of futures contracts are described by deterministic component. This result also verifies the characteristics of electricity prices stating that there is a strong seasonal fluctuation

Table 4.1: Summary of futures price estimation.

Month of delivery	Days to maturation	Mean reverting part (TL/MWh)	Spike part (TL/MWh)	Estimated futures contract price (TL/MWh)	Average of realized spot price (TL/MWh)
January	32	140.97	6.18	147.14	142.55
February	60	141.11	6.18	147.29	125.13
March	91	112.58	4.93	117.51	108.41
April	121	95.95	4.20	100.16	137.88
May	152	112.59	4.93	117.53	117.74
June	182	108.79	4.77	113.55	140.11

$t_0 =$12/30/2012
$P(0) = 105.80 \frac{TL}{MWh}$

in prices.

These results also verify the high volatility of electricity prices. Estimations of expected values of average prices give fairly close results to actual average spot prices in January, March and May, while realized prices in February, April and June deviates significantly from their expectations, probably due to unexpected changes in the demand.

Chapter 5

Estimating the Value of an Energy Exchange for Turkey

A spot price model for the Turkish electricity market is developed in Chapter 3 and making use of this spot price model, prices for the monthly futures contracts are calculated in Chapter 4. The prices of the derivatives are necessary in order for a company to be able to develop a hedging strategy. Since I have the estimations for futures contracts from the previous Chapter, in this Chapter, I will continue my discussion with a procedure to calculate an optimal electricity purchasing strategy for a hypothetical company.

After finding an optimal purchasing strategy, the value of the prospective energy exchange for Turkey can be estimated simply by comparing the two cases:

- All energy requirement is purchased on the spot market.
- The estimated optimal amount of futures contracts are purchased on the futures market and the remaining amount is purchased on the spot market.

5.1 Optimal Purchasing Strategy

Woo et al. [2004] developed an optimal procurement strategy for a local distribution company. In their work, they define a constrained minimization problem in which the objective function, which is the procurement cost function of the company, is minimized subject to a risk tolerance constraint. A threshold level for the procurement cost is defined as a constraint such that the sum of expected cost and some level of variance will not exceed the threshold. It is assumed in the study that both the price and the quantity of electricity to be delivered are normal random variables and contribute to the volatility of the procurement cost. I refer the reader to the body of their paper for a more detailed explanation of the model [pp. $636-637$].

In my case, I assumed the hypothetical company to be a retail company which purchases electricity from the spot market at a price which is highly volatile and sells at a regulated constant price, exposing the company to a very high price risk. In the Turkish electricity market, all retail licensees are actually the distribution companies. Since there are 21 distribution companies, in order to estimate a reasonable electricity requirement for the hypothetical retail company, it is assumed that the company supplies 5% of Turkey's total electricity consumption to its customers.

The consumption data for the first six months of 2013 is available, so for the sake of simplicity, I set a constant value for the amount of electricity consumption. Assuming the quantity Q as constant and the spot price P is a random variable makes the procurement cost C a random variable as well. Let μ_P is the expected value, σ_P^2 is the variance of the spot price and F is the futures contract price. The expected value of the procurement cost equals;

$$\mathbb{E}[C] = \mu_C = \mu_P Q + (F - \mu_P)\, q \tag{5.1}$$

The proxy measure for risk management, which is the variance of procurement cost σ_C^2 is then given by;

$$\sigma_C^2 = (Q - q)^2\, \sigma_P^2 \tag{5.2}$$

It is assumed that the company expects the spot price and the variance of a respective month to be the average of its spot purchases and variances of the prices for those purchases in the previous years. Table 5.1 shows the electricity requirement, the expected values of average price and variance and estimated price of the futures contract for the first six months of 2013. The reason for choosing a six months period is that I have six months of ex-post spot price data available to me after 12/31/2012 which is the last day of the data used for spot price model calibration.

It is also assumed the hypothetical company can tolerate its procurement cost to exceed its expected value by 20% and wants to be 95% certain about the cost will not

Month	Amount of electricity required (MWh)	Expected average spot price (TL/MWh)	Expected Variance	Price of futures contract
January	1,063,762	132.01	41.11	147.14
February	942,120	139.60	83.25	147.29
March	1,023,198	105.09	29.91	117.51
April	956,962	92.88	31.12	100.16
May	976,960	106.28	30.80	117.53
June	980,623	107.42	38.49	113.55

Table 5.1: Inputs for the optimal purchasing strategy problem.

exceed the maximum tolerable value, i.e., $\theta = 1.2$ and $z_\alpha = 1.645$. Here a one-tailed critical value is used as a price drop does not constitute a risk for the company. The multiplier θ is a measure for the risk tolerance of the company, i.e., if the company can tolerate a high cost exposure θ is above 1, otherwise it is closer to 1. z_α is the critical value for the specified confidence interval under normal distribution. Risk tolerance is arbitrarily chosen as I don't have any measures to estimate it for a hypothetical company. I choose desired confidence level as 95% as this is very typical.

In order to find the optimal purchasing strategy for this company, I need to choose q, the amount of futures contracts or in other words, the amount of electricity bought on the futures market rather than the spot market, which minimizes the expected procurement cost described by Eq. 5.1, subject to the cost-exposure constraint. Hence the problem becomes;

$$\begin{aligned} &\underset{q}{\text{minimize}}\ \mu_C \\ &\text{subject to } z_\alpha \sigma_C + (1-\theta)\,\mu_C \leqslant 0 \end{aligned} \tag{5.3}$$

Let λ be the Lagrangian multiplier, the Lagrangian is given by;

$$\mathscr{L} = \mu_C + \lambda\left(z_\alpha \sigma_C + (1-\theta)\,\mu_C\right) \tag{5.4}$$

Substituting Eqs. 5.1 and 5.2 into Eq. 5.4, the Lagrangian becomes;

$$\mathscr{L} = \mu_P Q + (F - \mu_P) q + \lambda \left[z_\alpha \sqrt{(Q-q)^2 \sigma_P^2} + (1-\theta)(\mu_P Q + (F - \mu_P) q) \right] \quad (5.5)$$

The first order conditions are;

$$\frac{d\mathscr{L}}{dq} = F - \mu_P + \lambda \left[-q\sigma_P + (1-\theta)(F - \mu_P) \right] = 0 \quad (5.6)$$

$$\frac{d\mathscr{L}}{d\lambda} = z_\alpha (Q-q)\sigma_P + (1-\theta)(\mu_P Q + (F - \mu_P) q) = 0 \quad (5.7)$$

The solution to first order conditions are given by;

$$q^* = \frac{Q\left(z_\alpha \sigma_P + \mu_P (1-\theta)\right)}{z_\alpha \sigma_P - (F - \mu_P)(1-\theta)} \quad (5.8)$$

$$\lambda^* = \frac{F - \mu_P}{q^* \sigma_P + (1-\theta)(F - \mu_P)} \quad (5.9)$$

Hence, q^* gives the optimal amount of futures contract purchase for the company.

5.2 Results

I did an analysis for the first six months of 2013, with values $\theta = 1.2$ and $z_\alpha = 1.645$. Once values for θ and z_α are chosen, I calculate the optimal amount of futures contracts to be purchased by Eq. (5.8). Table 5.2 shows the results.

My analysis shows that if there had been an energy exchange, the hypothetical company would have paid a sum of TL15,000,596 or \$ 7,812,810 less for its energy requirement. This means that the value of the exchange, which is the value of being able to hedge price risk, to the hypothetical company and to its customers is around \$ 7.8M for the first six months of 2013.

The amount of savings from purchasing an optimal portfolio is affected by the value of θ. In order to investigate the effect of θ on the procurement cost, a sensitivity analysis is carried out to see how the choice of θ changes the obtained value. Recall the equation that gives the optimal amount of futures contract purchases as a function of θ is given

Months	Amount of electricity required (MWh)	Expected spot price	Futures contract price	Optimal amount of futures contracts	Percentage of futures contracts	Realized spot price	Total procurement cost of optimal portfolio (TL)	Total procurement cost if all purchased in spot market (TL)
January	1,063,762.15	132.01	147.14	620,633.94	58.34%	142.55	154,492,631	151,643,926
February	942,119.55	139.60	147.29	741,713.20	78.73%	125.13	134,326,359	117,890,995
March	1,023,198.43	105.09	117.51	557,948.37	54.53%	108.41	116,001,251	110,923,099
April	956,962.44	92.88	100.16	592,871.85	61.95%	137.88	109,580,185	131,946,088
May	976,959.81	106.28	117.53	542,987.75	55.58%	117.74	114,911,925	115,030,360
June	980,623.08	107.42	113.55	635,583.13	64.81%	140.11	120,515,940	137,394,418
						Σ	749,828,290	764,828,886

Table 5.2: Results of the optimal purchase strategy analysis.

Month	θ
January	1.512
February	1.981
March	1.468
April	1.551
May	1.477
June	1.589

Table 5.3: Upper limits for θ

by;

$$q^*(\theta) = \frac{Q\left(z_\alpha \sigma_P + \mu_P(1-\theta)\right)}{z_\alpha \sigma_P - (F-\mu_P)(1-\theta)} \tag{5.10}$$

θ is a measure of risk tolerance or risk-averseness of the company. The lower limit of θ is $\theta = 1$ which makes $q^* = Q$, so the company does not want to take any risks and makes all purchases from futures.

The upper limit of θ is where all requirement is purchases on the spot market, i.e., $q^* = 0$. Setting $q^* = 0$ in Eq.(5.10) and solving for θ yields;

$$\theta = 1 + \frac{z_\alpha \sigma_P}{\mu_P}$$

Table 5.3 shows the upper limits for θ for each month.

The procurement cost C as a function of θ is given by;

$$C(\theta) = PQ + (F-P)\,q^*(\theta) \tag{5.11}$$

where P is the realized spot price, F is the futures contract price, Q is the total electricity requirement and q^* is the optimal amount of futures contracts.

Figure 5.1 shows a graph of the total procurement cost as a function of θ. It can be seen from the graph that after some point, the procurement cost of the optimal portfolio exceeds the procurement cost of the all spot purchase case and then converges to the value of the all spot purchase cost. The reason for this is, after the upper limit for θ reached for each month, q^* takes the value of 0 beyond that point, which makes the procurement cost of optimal portfolio equal to all spot cost for that month. The highest upper limit for θ value is 1.981 for February and the price of futures contract is higher

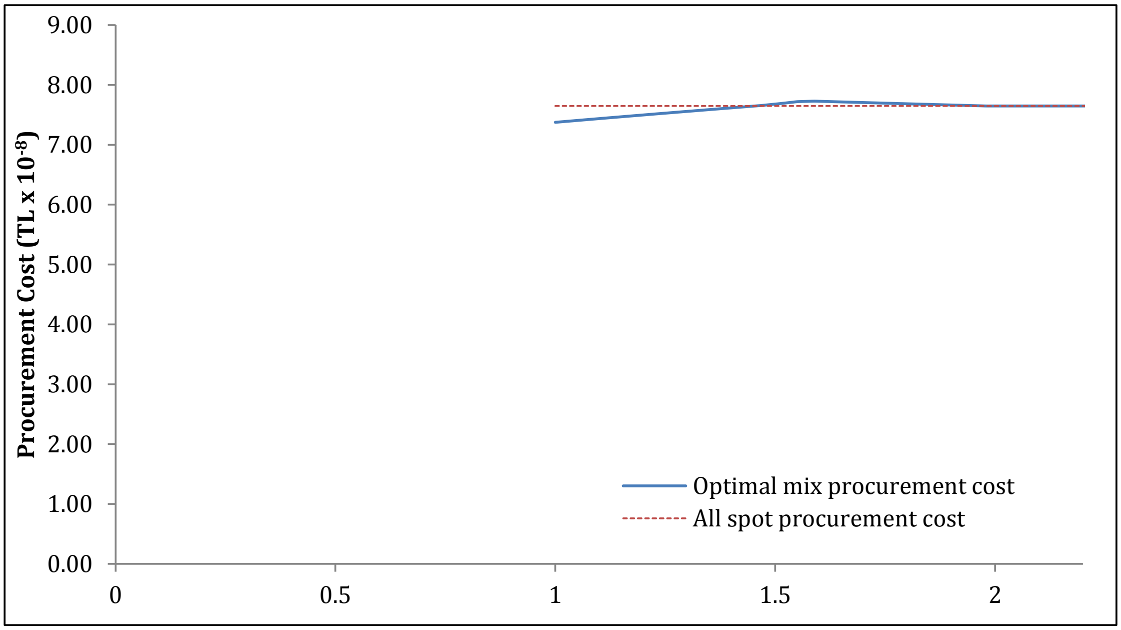


Figure 5.1: Total procurement cost vs. θ for the period January 2013 - June 2013.

than the realized price in February. Maximum θ values for other months are around 1.5 and as I approach to $\theta = 1.5$, q^* values for other months other than February become smaller and smaller. Since the cost of purchasing futures contracts is higher than the cost of purchasing from the spot market in February, that makes the total cost higher than all spot cost after a certain value of θ, which is $\theta = 1.4545$. It is obvious from the graph that the procurement cost is the lowest when all requirement is purchased using the futures contracts, i.e., $\theta = 1$. The savings of the company is around TL 27.3M or \$14.2M in this case. Table 5.4 shows the amount of savings from entering into futures contracts for various values of θ.

Of course these estimations are based on simplifying assumptions and valid only for the period that has been investigated. The realized average spot price for the months of April and June are happened to be 48.4% and 30.4% higher than their historical averages, which means the high prices that the company had been trying to avoid was actually happened in this period. Hence, the company benefited from hedging the risk.

Consider the analysis is repeated only for the first three months. It is obvious from Table 5.2 that for these three months, the procurement cost of the optimal portfolio is actually higher than the sole spot purchase case. However, even if the spot prices were around their means or below their means for the period under investigation, which would

θ		January	February	March	April	May	June	Total
1.0	q*/Q	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	
	Savings (million TL)	-4.88	-20.88	-9.31	36.10	0.21	26.04	27.28
1.1	q*/Q	78.72%	89.30%	76.71%	80.71%	77.31%	82.24%	
	Savings (million TL)	-3.84	-18.64	-7.14	29.14	0.16	21.42	21.09
1.2	q*/Q	58.34%	78.73%	54.53%	61.95%	55.58%	64.81%	
	Savings (million TL)	-2.85	-16.44	-5.08	22.37	0.12	16.88	15.00
1.3	q*/Q	38.83%	68.27%	33.39%	43.71%	34.76%	47.72%	
	Savings (million TL)	-1.90	-14.25	-3.11	15.78	0.07	12.43	9.02
1.4	q*/Q	20.11%	57.92%	13.23%	25.95%	14.78%	30.94%	
	Savings (million TL)	-0.98	-12.09	-1.23	9.37	0.03	8.06	3.15
1.5	q*/Q	2.15%	47.69%	0.00%	8.67%	0.00%	14.47%	
	Savings (million TL)	-0.10	-9.96	0.00	3.13	0.00	3.77	-3.16
1.6	q*/Q	0.00%	37.57%	0.00%	0.00%	0.00%	0.00%	
	Savings (million TL)	0.00	-7.84	0.00	0.00	0.00	0.00	-7.84
1.7	q*/Q	0.00%	27.56%	0.00%	0.00%	0.00%	0.00%	
	Savings (million TL)	0.00	-5.75	0.00	0.00	0.00	0.00	-5.75
1.8	q*/Q	0.00%	17.66%	0.00%	0.00%	0.00%	0.00%	
	Savings (million TL)	0.00	-3.69	0.00	0.00	0.00	0.00	-3.69
1.9	q*/Q	0.00%	7.86%	0.00%	0.00%	0.00%	0.00%	
	Savings (million TL)	0.00	-1.64	0.00	0.00	0.00	0.00	-1.64
2.0	q*/Q	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
	Savings (million TL)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.4: The savings from hedging the price risk for different values of θ. The negative savings imply that after a certain level of threshold value, it is cheaper to buy from the spot market.

mean the company loses money for getting into futures contract, in a market which is extremely volatile such as electricity market, an exchange would still be valuable to the companies in the market in the long run as it provides tools that remove a lot of uncertainty from their trade.

Chapter 6

Conclusion

In this study, I estimated a value for an energy exchange that is planned to be established in Turkey for a hypothetical company. To this end, first a spot price model, then a forward price model, and finally an optimal procurement strategy for the Turkish electricity market were developed. Since there are currently no fully operational energy exchanges in Turkey, apart from bilateral agreements, the only alternative for the market participants to supply their energy requirements is the spot market. With the establishment of the energy exchange, electricity derivatives will become available to market participants thus creating a new market to trade in. Our argument in this study is that the difference between the procurement costs of the market participant in the current situation and the procurement costs when an optimal mix of spot and forward purchases were used to meet demand, gives the value of the energy exchange for Turkey. In this context, my analysis shows that the value of the exchange for the company will be around TL 27.3M or $ 14.2M for the first six months of 2013. Therefore my analysis shows that the new exchange may be valuable to Turkey.

I believe this study will be beneficial in two different ways. First, the developed spot price model can be used by the companies in the Turkish electricity market as a tool to forecast future spot electricity prices. Second, the forward price model can be used by the exchange operator to price derivatives or by the market participants to estimate a fair value for the derivatives they are going to buy or sell.

I have faced a couple of challenges during this study. The first one is the size of the data. Although the deregulation of Turkish electricity market started in 2001, a competitive day-ahead and spot market was established only in December 2009. Therefore, the amount of the historical price data is relatively less than it is in more mature markets. Secondly, a lack of forward price data makes it necessary to use estimates instead of real world data. This, of course, can affect the accuracy of the results obtained. On the other hand, as the market is operating, the data continue to accumulate. Once the forward market becomes active, it will be possible to access forward data which will result in more accurate estimates of risk premiums. Thus, I suggest a future study to repeat this work with the larger set of data in the following years. I hope this study to be a good reference for the future studies to come regarding the Turkish electricity market.

Appendix A

Tables

Table A.1: Trading procedures for TurkDEX-Base Load Electricity Futures Contract. (Source: TurkDEX Circular Number: 2011/146)

Underlying Asset	The basic arithmetic average of the Day Ahead Market Prices announced by the Turkish Electricity Transmission Company for each hour of the contract month. After Day Ahead Market becomes effective instead of Day Ahead Planning, the underlying asset shall be the basic arithmetic average of the Unconstrained Market Clearing Prices announced by Turkey Electricity Transmission Company for each hour of the contract month.
Contract Size	Number of hours in the contract month x 0.1 MWh (Per contract) Number of hours in the contract month: Number of days in the contract month x 24 The contract size shall vary depending on the number of days in the contract month and summer/winter time. For the day of transition from winter time to summer time, the number of hours shall be applied as 23. For the day of transition from summer time to winter time, the number of hours shall be applied as 25.
Price Quotes	1 MWh of electricity shall be quoted significant to two decimals. (Example: 121.20)
Tick Size & Tick Value	0.1 (Example: Tick value is TRY 7.2 for the contracts with size 72 MWh, TRY 7.44 for the contracts with size 74.4 MWh.)

Contract Months	All calendar months (The current contract month and the nearest three contract months shall be concurrently traded) (The contracts to be listed on the first listing date are December 2011 and the nearest three contract months.)
Settlement Type	Cash settlement as prescribed in the Clause 1.8. set forth in this Contract.
Daily Settlement Price	Daily Settlement Price is calculated at the close of each trading session as follows: 1. Weighted average price of all the transactions performed within the last 10 minutes before the close of the trading session based on the quantity thereof shall be established as the daily settlement price. 2. If the number of transactions executed within the last 10 minutes before the close of the trading session is less than 10, the weighted average of the last 10 transactions before the close of the session shall be calculated. If the daily settlement price cannot be calculated using the above-mentioned methods, daily settlement price may be determined by using below mentioned methods separately or in combination. (a) weighted average price of all the transactions performed throughout the trading session, (b) previous day's settlement price, (c) average of the best bid and best ask quotes at the close of the trading session, (d) theoretical futures prices to be calculated using the interest rate to be determined by the Exchange for the time period until the expiry date of the contract, spot price of the underlying asset, seasonal effects in production and consumption or daily settlement price valid for other contracts with different contract months. Amendment of the Daily Settlement Price by the Settlement Price Committee pursuant to the Clause 1.5. of the Contract is reserved.

Last Settlement Price	The basic arithmetic average of the Day Ahead Market Prices announced by the Turkish Electricity Transmission Company for each hour in the contract month. After Day Ahead Market becomes effective instead of Day Ahead Planning, the underlying asset shall be the basic arithmetic average of the Unconstrained Market Clearing Prices announced by Turkey Electricity Transmission Company for each hour of the contract month. The last settlement price determined with the above mentioned methods is rounded to the nearest price tick.
Last Trading Day	Last business day of each contract month. In case domestic markets are closed for half day due to an official holiday, last trading day shall be the preceding business day.
Expiry Date	Last day of each contract month. In case the last day of the contract month is not a business day, the expiry date is the business day following the last day of the contract month. In case domestic markets are closed for half day, the expiry date shall be the following business day.
Initial Margin	TRY 1,200 (Per Contract)
Daily Price Limit	±10 % of the established Base Price for each contract with a different maturity. Daily price limits may be removed temporarily limited to the concurrent and the next session in accordance with the relevant provisions of the Exchange Regulation.
Position Limits	Absolute (threshold) position limit is 20,000, pro-rata (percentage) position limit is 10%. Position limits are applied on account basis.

Appendix B

Source Code

B.1 Spot Price Model

```
import numpy as np
from scipy.optimize import *
import matplotlib.pyplot as plt
from spike_filter import *
from myplot import *

# Read the data
data = np.genfromtxt('data_stoc_v.2.txt')
price = np.genfromtxt('data_new.txt')

def deseason(data = 'data_described_new.txt'):
    return np.array(np.genfromtxt(data))

# define the model
def Model(S, theta, NR):
    alpha = theta[0]
    mu_N = theta[1]
    sigma_N = theta[2]
    mu_S = theta[3]
    sigma_S = theta[4]
    if NR:
        R = [1.,0.]
    else:
        R = [0.,1.]
    return (np.log(S)+alpha*(mu_N - np.log(S))+ sigma_N*np.random.randn())*R[0]
```

```
+ (mu_S + sigma_S*np.random.randn())*R[1]

# log-likelihood functions
def llm_N(S,x):
    alpha = x[0]
    mu = x[1]
    sigma = x[2]
    return (((np.log(S[1:])-np.log(S[:-1])-alpha*(mu-np.log(S[:-1])))**2.)
/(2*sigma**2.)+np.log(sigma)+.5*np.log(2*np.pi))

def llm_S(S,x):
    mu = x[3]
    sigma = x[4]
    return (np.log(S[1:])-mu)**2./(2*sigma**2.)+np.log(sigma)
+.5*np.log(2*np.pi)

F = freq

# Weighed log-liklihood function
llma = lambda x: sum((1-F)*llm_N(data,x) + F*(llm_S(data,x)))

# Maximize log-likelihood
theta  = fmin(llma,[.5,0.1,.5,0.1,.3])
print theta

def simulate(S0,params,N=100,TM=TM):
    S=S0
    theta = params
    data = [S]
    R = 0
    n = s = 0
    for i in range(N):
        p = np.random.rand()
        if R ==0:
            if p < 0.95619:
                NR = True
                R = 0
                n+=1
            else:
                NR = False
                R = 1
                s+=1
```

```
            S = Model(S,theta,NR)
            S = np.exp(S)
        else:
            R = 0
            NR = True
            S = Model(S,theta,NR)
            S = np.exp(S)
        data.append(S)
    print 'M: %s S: %s f: %s' %(n,s,s/float(n+s))
    return np.array(np.log(data))

# Simulate and plot
out = simulate(data[0],theta,N=1095)
t = len(out)
prices = np.exp(deseason()+out)
print min(prices), max(prices)
plt.plot(range(t),np.log(prices), "r",label = 'estimated prices')
plt.plot(range(t),np.log(price), label = 'actual prices')
plt.xlabel('t')
plt.ylabel('Log of spot prices')
plt.legend(bbox_to_anchor=(0., 1.02, 1., .102), loc=3, ncol=2,
mode="expand", borderaxespad=0.)
plt.show()
```

B.2 Spike Filtering

```
import numpy as np
from scipy.optimize import *
from scipy.stats import *
import matplotlib.pyplot as plt

#data = np.genfromtxt('data_stoc.txt')
data = np.genfromtxt('data_stoc_v.2.txt')
data = np.log(data)
def filter_spikes(data):
    spikes = np.sort(data[np.absolute(data - np.mean(data))/np.std(data)>=3])
    data = np.array([d for d in data if d not in spikes])
    if len(spikes) == 0:
        return data
    else:
        return filter_spikes(data)
```

```
filtered_data = filter_spikes(data)
spikes = np.array([x for x in data if x not in filtered_data])
freq = 1.0*len(spikes)/len(data)

print 'normal regime: mean: %3.3f  var: %3.3f'
% (np.mean(filtered_data), np.var(filtered_data))
print 'spike regime: mean: %3.3f  var: %3.3f'
% (np.mean(spikes), np.var(spikes))
print 'frequency of spikes: ', freq


TM = np.matrix([[0.971428571, 0.028571429], [0.652173913, 0.347826087]])

print 'transition matrix: ', TM
```

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