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Impact of Vertical Integration on Electricity Prices in Turkey

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ABSTRACT

Government's active participation in to the energy markets requires us to understand its vertical and horizontal integrated involvement. Coherently, in order to diversify their portfolios and reduce their business risks, vertical integration of the major private players in the market is another important topic. Under these market conditions market power becomes prominent. Our paper utilizes ARX models to analyze market power and portfolio diversification impact on electricity prices. In the aggregate models since we used high frequency time series data for all bidding hours of day ahead market, autoregressive structure within the system marginal prices vitiated the effect of power production type. Accordingly, we benefited different hours of the day as separate time series where a baseload (hour 24) and a peak hour (hour 11) were selected. The contribution of our paper to the policy debate is to highlight that such issues exist in the first place and that market power remains an important concern in Turkish electricity market.

Keywords: Electricity Prices, Renewable Energy, Time Series, Market Power, Vertical Integration
JEL Classifications: Q2, Q4, Q41

1. INTRODUCTION

Turkish energy sector has been in a liberalization process since 1993. In this liberalization process big conglomerates invested and established vertically integrated business structures while government held its position as both a vertically and horizontally integrated market player who still has the market power both in electricity generation, wholesale and retail. In energy sector, strategic targets for Turkey are to maintain the security of energy supply as well as to increase competition for the benefit of the customers and reducing the costs within all steps of the value chain.

Coherent with global benchmarks renewable energy investments expanded rapidly which provided diversity in the energy production portfolio of Turkey. YEKDEM[1] mechanism is one of the most encouraging factors for both strategic and financial investors. Renewable projects can easily secure financing due to hard currency feed-in tariff and available funding. However,

renewable producers who sell in the market help market clearing price (MCP) to settle at a lower rate in the merit order, has an important impact on electricity prices.

Electricity prices have different stochastic properties to those of standard financial products and even other commodities mainly because of its non-storable nature. Electricity prices contain strong seasonality, very short-lived spikes and mean-reverting behavior. Models studies to describe and forecast the dynamics of electricity quantity has been continued since many years before deregulation process began in other countries. Electricity market models require energy prices for balancing, spot and short-term forward transactions. Short term load forecasting plays an important role in power system operation and planning. The obtained electricity price forecast models will in turn help develop bidding strategies and negotiation skills in order to maximize profits in an extremely volatile market.

In this study we try to understand the relationship between electricity prices and production type of electricity as an application study of merit order based on regression models. Our contribution to the growing literature on Turkish electricity market is applying models incorporating newly established EXIST high

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1   YEKDEM is a support mechanism for electricity manufacturers from renewable energy resources, which has been regulated in the Regulation on Documentation and Support of Electricity Manufacturing from Renewable Energy Resources ("Regulation") which has entered into force in 2013.

frequency data. To our knowledge, our paper is one of the first attempts which incorporates hourly EXIST data in applied models for electricity prices.

The paper is organized as follows: In the sub-parts of Section 1, market fundamentals of Turkish electricity market is summarized. Section 2 includes the literature review on previous research on electricity price modeling and market power. Section 3 presents the data used and we discussed our empirical results in Section 4. Finally section 5 provides conclusion remarks and further study areas within this topic. Our analysis are based on basic ARx models so we included brief information about the methodology only in the appendix part.

1.1. Power Generation Market in Turkey

Privatization of utilities in Turkey has proved to be a complex issue, often involving three separate stages, one of which is obviously a shift in ownership from the public to private hands. The second is the restructuring of the companies, while the third one is a change in the way the sector operates, usually involving an adoption of competitive procedures.
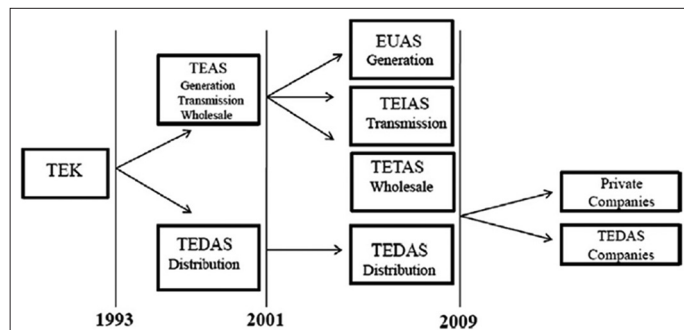
Turkish electricity sector was dominated by the state-owned vertically integrated company Turkiye Elektrik Kurumu ("TEK") until the early 1990s. In 1993, as a result of market liberalization and privatization approach, TEK was separated into TEAS (generation, transmission and wholesale) and TEDAS (distribution). Then, with the enactment of the Electricity Market Law in 2001, TEAS was further unbundled into EUAS (generation), TETAS (wholesale) and TEIAS (transmission), each being organized as a separate legal entity.

As exhibites in Figure 1, the privatization process in the electricity distribution sector was initiated in 2009 and completed in a total of 12 regions by early 2013. As of 2017 there are 21 regions in the market but accordingly, vertically integrated energy groups exist in the market as major players.

It is stated in the strategy paper that during the transition period 2006-2010, distribution companies were to procure 85% of the regional energy demand consumed by non-eligible customers from TETAS and the portfolio generation companies carved out of EUAS.

TETAS was created to conduct wholesale operations and take over the existing energy sale and purchase agreements from TEAS and TEDAS. TETAS was also held responsible for managing the stranded costs associated with the build operate ("BO"), build operate transfer ("BOT") and TOR generation contracts.

EUAS was envisaged to take over the ownership and the operation of the State thermal power plants from TEAS and the hydroelectric power plants from the Devlet Su Isleri ("State Water Works"). EUAS was also empowered to build, lease and operate new generation facilities, if deemed necessary, in accordance with the EMRA approved generation capacity projections and taking into consideration the generation investments by the private sector.

As stated by the Privatization Administration of the Prime Ministry, the primary outcomes desired with the privatization in the sector can be summarized with the following properties:
- Lowering costs through effective and efficient operation of electricity distribution assets.
- Decreasinglossandtheftratios,byreducingtechnicallossesindistributionandpreventingillegaluse,andhence.
- Reducing consumer prices by reflecting all the gains obtained on to consumers.

Regulations are the main market shapers in Turkey like other energy regulators in other countries. Most of the companies are obliged to In Turkey, more than 67% of the electricity is generated from fossil fuels. Suppliers who use the networks are obliged to input the same amount of electricity as their customers take out and are charged by the network operator for any imbalances. The network operator also maintains some generating reserves with which to ensure that the network can remain in balance. The result is that the power generation companies have restrictions on their productivity and have to comply with grid operator requests ultimately affecting overall profitability whilst creating a difficult trading environment.

Securing the supply of a particular resource, such as natural gas, can become crucial. Supply from countries with large natural resources increases their supplier power. These situations can also become politically problematic where the supplier is a state owned facility.

For example, with the announcement made by EPİAŞ on November 22, 2016, the restriction on the amount of natural gas provided by BOTAŞ to TETAŞ and EÜAŞ natural gas power plants was increased to around 50% as a result of further increase in consumption on 14 December 2016. According to sector sources, BOTAŞ increased the amount of cuts applied to natural gas plants to 75% on 21 December 2016 and to 90% on 22 December 2016. Continuation of the shortfall to natural gas power plants carried average electricity prices to record levels in the day-ahead market (DAM) between December 15 and December 21.

In this context:
- Power plants are ordered according to their short-term

Figure 1: The restructuring process in the Turkish electricity market

Figure 2: Merit order scheme
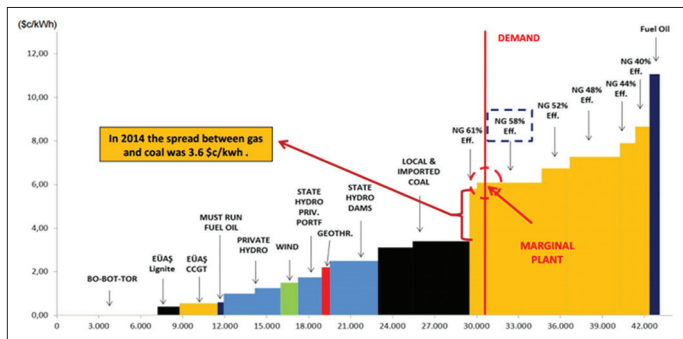
Source: Garanti Bank 2015 Electricity Market Report

marginal costs to form the merit order[2] (Figure 2).
- Marginal plant determines the price. All power plants to left of demand dispatch and ones to right do not dispatch.
- Competition between different types of plants[3] and within the same group of plants determine pricing strategy.
- Above 90% of the time electricity prices are determined by plants whose fuel costs are in USD (CCGT and imp.coal).
- Since CCGTs are the marginal plants 85% of the time natural gas prices are the most important determinant of electricity prices.

Renewable energy has become a priority for Turkish policymakers over the past few years as they realized the role that this energy source can play in expanding power generation and diversifying the energy supply mix. Turkey's reliance on imported natural gas for power generation has given rise to concerns over both supply security and the country's increasing current account deficit. However further analysis and more developed forecast models should be studied in order to not to experience negative electricity prices in the market as it happened in Germany with the tremendous renewable energy production increase.

Accordingly, the degree of rivalry in this industry depends first of all on industry structure, which is usually decided at a national or state level. Some countries' electricity industries are fully liberalized, with complete unbundling of generation, transmission, distribution, and retail operations, the ability of all end-users to switch suppliers, and so on. Others have a much less liberal structure, with features such as suppliers operating as monopolies within particular geographical regions.

1.2. DAM in Turkey

DAM, which became effective on 1st December 2012, is the organized wholesale spot electricity market established for purchase and sale of electricity to be delivered in the day ahead on the basis of settlement period (1 hour) and that is operated by the market operator. It provides the opportunity to the market participants for balancing their production, consumption and bilateral contract obligations.

An important aspect of DAM brought to electricity market is chance of demand side to adjust its consumption based on price levels. Coherently, demand side began to actively participate to market thus has the chance of hedging itself against price volatility. Participation to DAM is not mandatory. Moreover, DAM enabled financial settlement in daily basis and performance of daily clearing of payables/receivables due to commercial transactions at next day after commercial transactions date. This situation allowed market participants to receive revenues generated by sales of generated electricity on daily basis rather than monthly basis which provides them liquidity.

1.3. Balancing Power Market (BPM) in Turkey

BPM is designed as a mechanism to maintain the physical supply and demand equilibrium through a transparent market application. The need for essentially arises from market participants' inability to comply with their accepted bids/offers in the DAM.

Offers and bids submitted by the market participants on BPM are ranked by System Operator according to their prices. In case there is energy deficit in the system, maximum accepted hourly offer price applied to up-regulated balancing entities to correct this deficit in the system is accepted as the system marginal price (SMP). On the other hand, if there is energy surplus in the system, the minimum accepted bid price applied to down-regulated balancing entities to correct the energy surplus in the system is accepted as the SMP.

Figure 3 shows the relation of DAM and BPM prices, where there is energy deficit in the system and up-regulation instructions are given to the market participants. Price calculated in BPM is higher than price calculated in DAM. BPM price is used for settlement of imbalances and this relationship incentives market participants for trading into a balance on the DAM to avoid imbalanced price.

1.3.1. General offering principles of DAM in Turkey

Participants can submit hourly and daily for a particular period of hour/hours and/or flexible offers to DAM.

- Offers are composed of quantity and price information that can change for different hours:
  - Submitted offer prices have centesimal sensitivity.
  - Offers can be made in terms of Turkish Lira, US Dollar, and Euro currencies.
  - Offer prices submitted other than Turkish Lira are

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2   The merit order is a way of ranking available sources of energy, especially electrical generation, based on ascending order of price (which may reflect the order of their short-run marginal costs of production) together with amount of energy that will be generated. In a centralized management, the ranking is so that those with the lowest marginal costs are the first ones to be brought online to meet demand, and the plants with the highest marginal costs are the last to be brought on line. Dispatching generation in this way minimizes the cost of production of electricity. Sometimes generating units must be started out of merit order, due to transmission congestion, system reliability or other reasons.

3   Increasing the supply of renewable energy tends to lower the average price per unit of electricity because wind energy and solar energy have very low marginal costs: They do not have to pay for fuel, and the sole contributors to their marginal cost is operational and maintenance. With cost often reduced by feed-in-tariff revenue, their electricity is as a result, less costly on the spot market than that from coal or natural gas, and transmission companies buy from them first. Moreover, solar energy is typically most abundant in the middle of the day, coinciding closely with peak demand in warm climates, so that it is in the best position to displace coal and natural gas electricity when those sources are charging the highest premium. Solar and wind electricity therefore substantially reduce the amount of highly priced peak electricity that transmission companies need to buy, reducing the overall cost.

Figure 3: Price relationship between day-ahead market and balancing power market
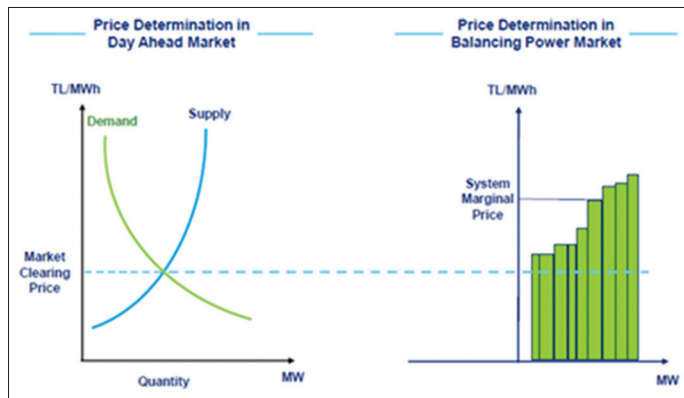
assessed by converting these prices into Turkish Lira by using daily CBRT bid rate.

- Offer quantities are submitted in terms of Lot as an integer number. 1 Lot is equivalent to 0.1 MWh.
- Offers can be submitted as both buying and selling offers. Depending on the sign in front of the quantity, the offer is either buying or selling offer. (For instance 100 Lot indicates a buying offer whereas-100 Lot indicates a selling offer).
- Minimum and maximum price limits are determined by the market operator between 0 TL and 2000 TL respectively. Depending on changing market circumstances, the market operator updates minimum and maximum price limits and announce them via Market Management System to market participants.
- Minimum and maximum offer quantities are determined by the market operator as 0 Lot and 100.000 Lot respectively.
- Offers submitted for same delivery date are recorded to the system as a new version in case they are updates.
  - Latest version of an offer is considered during matching.
  - Older version of offers can be viewed via version filter.

2. LITERATURE REVIEW

Although industry concentration and individual firm market share are often correlated market power, this is not always the case. There are many factors beyond the number and size of firms in a market that impact the degree of a competition within an industry such as the incentive of producers, the price-responsiveness of demand (elasticity) and the potential for expansion of output by competitors and potential competitors. Concentration measures indicate the current distribution of sales or capacity, but can not tell us what will happen to prices when one firm reduces its output. This is a crucial questions in the electricity industry where the product is not storable and short-run demand is relatively inelastic. In this context analyzing the strategic behaviors of the firms becomes important.

Stoft (2002) also argues against applying the Herfindahl-Hirschman index to the electricity industry because it ignores some key factors that are crucial in this context: (1) demand elasticity, (2) style of competition, (3) forward contracting, (4) vertical integration of firms, (5) geographical structure. Furthermore, Borenstein et al. (2002) and Fabra and Toro (2005) conclude that given the non-

storability of electricity, market power can exhibit huge inter-temporal variations.

Nevertheless, the Cournot-Nash approach is to assume that strategic firms employ quantity strategies: Each strategic firms chooses its quantity to produce taking as given the output being produced by all other strategic firms, not all the firms are likely to behave strategically. Very small firms are more likely to simply take the market price as given and produce all output for which its incremental cost is less than the market price. Thus, Borenstein et al. (1999) modeled only the large firms as Cournot competitors where very small firms were modeled as price takers, both in their own behavior and in how they were viewed by strategic players in the market. Furthermore, Andersson and Bergman (1995) and Oren (1997) utilized Cournot model to analyze electricity markets.

One game-theoretic concept that has been prominently applied to electricity markets is the modeling of equilibria when bidders specify cost/quantity supply functions. The strategies of the firms are actual price quantity bid functions, rather than the inflexible quantity bid given by the Cournot model. However in some markets, trades do not occur exclusively through a supply-function bid process. Bilateral trading of specified quantities is common in many restructured markets around the world. In many of these markets firms bid not only energy prices, but also startup costs, ramping rates, and other supply characteristics. The supply function approach also does not lend itself well to markets where there is a competitive fringe whose capacity may be limited due to either generation or transmission constraints.

Nevertheless, the potential to exercise market power is often present from the supply side. Initiatives to mitigate market power and pursue market efficiency are indeed among the most delicate and debated issues concerning the deregulation process in many countries. This issue is particularly interesting because the exploitation of market power can significantly erode the consumer benefits that would be expected to result from the transition from regulated to competitive markets for electricity generation (Fezzi, 2015). In this context, the centralized price mechanism and capacity-constrained suppliers in electricity markets (at least during peak periods) support the use of Cournot model for a base case analysis.

Moreover, government's active participation to the energy markets requires us to understand its vertical and horizontal integrated involvement. Private companies operating in the energy market are also vertically integrated in order to diversify their portfolios and reduce their business risks.

Bosco et al. (2016) focus on the degree of vertical integration effects of bidding strategy of monopolistic players in Italian energy markets. In this paper they addressed the question of how the supply conduct of a vertically integrated power generator can be coordinated in a wholesale market with the buying activity of a downstream retailer. Their model shows the relationship of a vertically integrated energy group composed of a holding company, production and retailer companies along with Principal-Agent model. In the absence of an incentive, the generation branch would behave in an opportunistic manner raising equilibrium prices in

the market to its own advantage which will reduce profits of the retailer branch which buys electricity in the wholesale market and sells it to customers to fixed prices. The crucial point here is that the holding that parents generator and retailer companies should be pivotal one who has the power to make the market.

Aid et al. (2011) claim that vertical integration restores the symmetry between producers' and retailers' exposure to demand risk. Their analysis predict that there is a negative relationship between the development of forward markets and firm's incentives to merge with vertically related segments. Other things equal their expectation is that vertical integration to be higher in industries that are more subject to uncertainty and where other risk management mechanisms are less readily available. In addition to that Aid et al. (2011) also state that with or without developed forward markets, they expect vertical integration to be more widespread in industries that are subject to greater risk aversion especially through greater regulatory pressure and higher bankruptcy costs.

3. ECONOMETRIC DATA DESCRIPTION

After establishment of Energy Exchange Istanbul (EXIST) the day a head electricity settlement data is not provided by Market Financial Settlement Center (PMUM[4]). Moreover the publicly available data on EXIST transparency platform is not sufficient for such a vertical integration and degree of market power study since we cannot see the generator company and region information from these data series. Therefore we worked on an aggregated model to analyze the SMP in electricity market with publicly available hourly data on EXIST.

We can emphasize the factors that affect spot prices based on two approaches such as production approach and consumption approach.

3.1. Production Approach
- Installed capacity
- Power plant type (natural gas, fuel-oil, hydro etc.)
- Power plant efficiency, maintenance and breakdown, management policy (private or public company)
- Gas restrictions
- Water flow, drought, wind, snow depth
- Generation by renewables resources (wind, solar, hydro, geothermal etc.)
- Generation by BOT model and BO models.

3.2. Consumption Approach
- Macroeconomics growth
- Weather conditions
- Seasonality
- Consumption variance between peak-off and peak hours
- Consumption variance between weekend and weekdays, public holidays.

A new commercial instrument has been introduced to electricity markets after the Intra Day Market (IDM) was opened on 1st of July

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4   Piyasa Mali Uzlastirma İş Merkezi.

2015 which reduced the imbalance and electricity trade volume in spot markets. Moreover new feed in tariff (FIT) regulation for renewables became effective at the end of April 2016. In this context Model 2 is based on the dataset between 01.07.2016 and 01.09.2016 in order to analyze the regulation change and IDM opening effect on SMP. Most of the data set are stationary. (see Table 7 in the appendix part for ADF test results and Table 8 for LM test results).

The dataset definitions which are used in our models are as exhibited in Table 1.

4. APPLICATIONS AND FINDINGS

In this study our main intention was to use electricity consumption, production and price hourly data provided by EXIST to drive models with high frequency data. For this reason we applied simple ARX models since we faced high degree of autocorrelation in hourly time. Our first goal was not to find an innovative econometric model but to apply models via newly established EXIST database in order to check the energy policy effects on electricity prices.

Consequently we analyzed the data in two aspects; first we tried to find the relationship between the SMP and electricity production type to see the impact of merit order mechanism on settlement prices. Secondly, we used hourly production data of Enerjisa and Aksa along with EUAS and TETAS who affect the price levels significantly by their level of production in the merit order. Enerjisa and Aksa are among the biggest private companies who operate in energy market with their well-diversified portfolios.

4.1. Aggregate Models
Briefly, two I(1) variables could exhibit significant correlation, without an underlying relationship however the regression must make economic "sense." This is called spurious regression problem. To avoid this problem we checked whether the variables are stationary or not in our dataset via Augmented Dickey-Fuller (ADF) tests. We also included a @trend variable in Model 1 and Model 2 (exhibited in Table 2) to eliminate spurious relationships between independent variables.

Model 1 and Model 2 are based on same independent variables with two different times zones, 18.12.2015-01.09.2016 and 01.07.2016-01.09.2016 respectively. In this context econometric model equation for Model 1 and Model 2 is as mentioned below:

$$\log(SMP) = \beta_1 \log(brentusd) + \beta_2 \log(blocksales) + \beta_3$$
$$\log(wind) + \beta_4 \log(lignite) + \beta_5 \log(geothermal) +$$
$$\beta_6 \log(natura\,lg\,as) + \beta_7 \log(dammed) + \beta_8 \log\,(pibid)$$
$$+ \beta_9 \log(fuel\_oil) + \beta_{10} \log(LNG) + \beta_{11} \log\,(mcp) +$$
$$\beta_{12}\,systemproxy + \beta_{13}trend$$

When we compare Model 1 and Model 2 primarily we can clearly see that Model 2 has a greater power to explain SMP changes with a R^2 of 0.7413 which means that we can explain 74% of SMP changes with Model 2 while we can explain only 62% of SMP changes with Model 1. Since @trend variable is

Table 1: Model dataset descriptions

#	Variable	Description	Frequency
1	log(brent usd)	Logarithm of daily brent oil prices	Daily
2	log(blocksales)	Logarithm of block matched sales amount	Hourly
3	log(wind)	Logarithm of injection quantity by wind	Hourly
4	log(lignite)	Logarithm of injection quantity by lignite	Hourly
5	log(geothermal)	Logarithm of injection quantity by geothermal	Hourly
6	log(natural gas)	Logarithm of injection quantity by natural gas	Hourly
7	log(dammed)	Logarithm of injection quantity by dammed hydro	Hourly
8	log(pibid)	Logarithm of hourly aggregate price independent bid quantity at 2000 TL/MWh	Hourly
9	log(fuel_oil)	Logarithm of injection quantity by fuel oil	Hourly
10	log(biomass)	Logarithm of injection quantity by biomasss	Hourly
11	log(LNG)	Logarithm of injection quantity by LNG	Hourly
12	log(mcp)	Logarithm of market clearing price is the hourly energy price that is determined with respect to oders that are cleared according to total supply and demand	Hourly
13	log(smp)	Logarithm of price that corresponds to the net regulation quantity of the balancing power market	Hourly
14	log(usdtry)	Logarithm of Dolar against Turkish Lira FX closing rates	Daily
15	log(mcp)	Logarithm of market clearing price is the hourly energy price that is determined with respect to oders that are cleared according to total supply and demand	Hourly
16	log(tetas)	Logarithm of TETAS final daily production program	Hourly
17	log(consumption)	Logarithm of total hourly real-time consumption	Hourly
18	log(aksa)	Logarithm of Aksa final daily production program	Hourly
19	log(enerjisa)	Logarithm of Enerjisa final daily production program	Hourly
20	log(renewables)	Logarithm of wind, geothermal, biomass, river and dammed injection quantity sum	Hourly
21	systemproxy	Proxy variable which gets the value "1" for energy excess and "0" for energy deficit in the system	
22	daypeak	Proxy variable which gets the value "1" for hours between 07:00 and 21:00 and "0" for other hours	
23	@trend	Trend variable	

Table 2: Model 1 and Model 2 for system marginal price estimations

Variables	Model 1			Model 2		
	Est.	S.E.	t-statistics	Est.	S.E.	t-statistics
log(brent usd)	−0.80	0.24	−3.37	0.84	0.33	2.55
log(blocksales)	0.23	0.05	4.74	0.10	0.04	2.29
log(wind)	0.24	0.03	6.90	0.01	0.03	0.30
log(lignite)	−0.61	0.21	−2.90	−0.13	0.17	−0.77
log(geothermal)	0.71	0.25	2.90	0.13	0.19	0.66
log(natural gas)	2.13	0.16	1.34	0.00	0.16	−0.02
log(dammed)	0.86	0.11	7.95	0.23	0.09	2.66
log(pibid)	−2.18	0.24	−9.08	−0.30	0.20	−1.48
log(fuel_oil)	0.32	0.10	3.10	0.01	0.07	0.11
log(biomass)	−1.26	0.29	−4.31	−0.31	0.19	−1.59
log(LNG)	0.14	0.03	4.08	0.00	0.02	0.21
log(mcp)	0.72	0.02	3.07	0.75	0.02	3.77
systemproxy	−0.87	0.04	−2.12	−0.69	0.03	−2.42
@trend	0.00	0.00	−1.93	0.00	0.00	−0.05
R^2	0.62			0.74		
Durbin-Watson	0.99			1.21		
df	6187			1483		

S.E.: Standard error

not statistically significant in Model 2 we can conclude that Model 2 does not include a significant trend impact as Model 1 do. Although comparing models based on R^2 values is a poor econometric approach, it is a good signal to conclude that after new tariff regulation and IDM establishment efficiency of the model increases. This is important to check the impact of energy policies.

Singularly wind, lignite, natural gas, fuel oil, LNG, geothermal generation amount variables lose their strength in order to explain SMP changes individually in Model 2 however F-statistics is quite significant which makes us suspicious for multicollinearity between variables. Since generation power plants are expected to behave and produce in the same way due to demand trend in the market, existence of multicollinearity is not an unexpected result.

In this situation the coefficient estimates of the multiple regression may change erratically in response to small changes in the model or the data but it does not reduce the predictive power or reliability of the model as a whole, at least within the sample data set; it only affects calculations regarding individual predictors. That is, a multiple regression model with correlated predictors can indicate how well the entire bundle of predictors predict the outcome variable, but it may not give valid results about any individual predictor, or about which predictors are redundant with respect to others. Even extreme multicollinearity (so long as it is not perfect) does not violate OLS assumptions. OLS estimates are still unbiased.

In Model 2, although significant varices are observed between average SMP and MCP, MCP is more active to explain SMP changes between 01.07.2016 and 01.09.2016 which suggests that IDM works efficiently. After the energy generation by renewable resources increased in the system, balancing demand and supply became harder but new FIT regulation and establishment of IDM seem to reduce this instability based on the results in Model 2.

Due to Model 1 when generation by wind, geothermal and dammed hydro power plants increase 1%, SMP is expected to increase 0.23%, 0.71% and 0.85% respectively. Although a substantial amount of electricity is generated from hydro, wind and other renewable sources, the dominant production process is still fossil fuels such as gas and coal.

In Table 3 we tried to model SMP changes with a more compact model. Similarly OLS estimations in Model 3 and Model 4 are based on same independent variables with two different times

Table 3: Model 3 and Model 4 for system marginal price estimations

Variables	Model 3			Model 4		
	Est.	S.E.	t-statistics	Est.	S.E.	t-statistics
log(mcp)	0.82	0.01	5.79	0.62	0.02	3.18
systemproxy	−0.98	0.02	−4.13	−0.86	0.03	−2.56
daypeak	0.13	0.03	4.94	0.08	0.03	2.29
log(consumption)	0.11	0.01	1.59	0.20	0.01	2.09
R^2	0.55			0.60		
Durbin-Watson	0.85			0.89		
df	5910			1491		

S.E.: Standard error

zones, 18.12.2015-01.09.2016 and 01.07.2016-01.09.2016 respectively. In this context econometric model equation, for Model 3 and Model 4 are as mentioned below:

$$\log(SMF) = \beta_1 \log(mcp) + \beta_2 systemproxy + \beta_3 daypeak$$
$$+ \beta_4 \log(consumption) + u$$

Daypeak proxy variable gets the value "1" for hours between 07:00 and 21:00 and "0" for other hours. Based on Durbin-Watson (DW) statistics and R^2 values we do not suspect for multicollinearity in Model 3 and Model 4.

If we compare Model 1 and Model 2 with Model 3 and Model 4 we can see that production based approach model is more efficient than consumption approach models due to higher R^2 values. However since R^2 is not a sufficient decision point to compare regression models the important take away from Models 1-4 are the relationship of variables and their consistency with energy policies.

Electricity markets can be characterized by dynamic relations. If the supply function shifts upwards (and hence, the clearing price increases), the reduction of the quantity cleared on the market can be instantaneous or take place with some delay, because demand can require time to adjust to the shock. On the other hand, the effect of an impulse can be completely absorbed only after many lags (Fezzi, 2015). If the supply function shifts upwards (where the clearing price increases), the reduction of the quantity cleared on the market can take place with some delay since the demand can require time to adjust to the shock. Even when demand is completely inelastic to price, the quantity traded on the market responds to past equilibrium in the supply function. This asymmetric effect is due to the fact that demand reacts if prices are higher than the equilibrium but does not show any significant feedback if price is lower. Zhang (2015) suggest that when there is a positive relationship between electricity price elasticity (in absolute terms) and households' income, a uniform increase in the price of electricity can be quite regressive.

It is very common to see reported in applied econometric literature time series regression equations with an apparently high degree of fit, as measured by the coefficient of multiple correlation R^2 or the corrected coefficient R^2, but with an extremely low value for the DW statistic. The effects of economic and other variables are rarely instantaneous, it takes some time for consumers, producers,

and other economic agents to respond. Because of the equilibrium effect is felt only after the passage of some time, econometric models using time series data are often formulated with lags in behavior (dynamic model). Lags in behavior might also take the form of the lags in the dependent variable.

Weron and Misiorek (2005) used ARMA and ARMAX models which are tested on a time series of California power market system prices and loads for forecasting electricity prices. They obtained best results with pure ARX models which included AR(i) processes and exogenous variables.

For this reason Model 5 (exhibited in Table 4) specifies that the SMP depends linearly on its own previous values and on a stochastic term (an imperfectly predictable term); Model 5 is based on same independent variables between 18.12.2015 and 01.09.2016.

In this context equation for Model 5 is as mentioned below:

$$\log(SMP) = \beta_1 \log(brentusd) + \beta_2 \log(wind) +$$
$$\beta_3 \log(geothermal) + \beta_4 \log(natura\,lg\,as) +$$
$$\beta_5 \log(dammed) + \beta_6 \log(pibid) + \beta_7 \log(fuel\_oil) + \beta_8$$
$$\log(mcp) + \beta_9 systemproxy + \sum_{i=1}^{5} \beta_{9+i} \log(SMP)_{t-i} + u$$

The serial correlation LM test results for this equation with 2 lags in the test equation strongly reject the null of no serial correlation for Model 1 while for Model 5 test equation cannot reject the null of no serial correlation. Another fundamental aspect to consider when analyzing electricity market outcomes is the existence of excess capacity on the system, i.e., the amount of power plants willing to produce (and bidding into the market) in a specific hour or day. This is often indicated with the term "margin" and can vary a lot during the year, according to the maintenance schedule of power plants but also to the strategic interaction of the suppliers (Borenstein et al. 1999 and Borenstein et al. 2002).

In Models 1-5 we can see that systemproxy variable is always significant and has a negative effect on SMP. The phenomenon might be explained by the fact that the electricity prices are an outcome of the bids which are submitted without knowledge of the future actual system load.

As a result in the aggregate models since we use high frequency data for all bidding hours of DAM, the effect electricity production type on SMP is vitiated. Following this consideration Model 6 and Model 7 were implemented considering market outcomes of different hours as separate time series where a baseload (hour 24) and a peak hour (hour 11) were selected.

Fezzi (2015) identified peak hour as hour 19 due to Pennsylvania, New Jersey and Maryland (PJM) market data however based on our analysis for EXIST which is exhibited in Figure 4, we decided to use hour 11 as our peak hour since both average electricity prices (MCP and SMP) and average consumption series intersect each other in this time period of the day hours at their highest levels.

Table 4: Model 5 for system marginal price estimations

Variables	Model 5		
	Est.	S.E.	t-statistics
log(brent usd)	−0.52	0.18	−2.93
log(wind)	0.11	0.04	2.92
log(geothermal)	−0.44	0.14	−3.07
log(natural gas)	2.06	0.14	14.61
log(dammed)	1.31	0.08	16.69
log(pibid)	−2.79	0.19	−14.69
log(fuel_oil)	0.14	0.08	1.73
log(mcp)	0.76	0.01	54.43
systemproxy	−0.55	0.03	−20.77
AR (1)	0.56	0.02	35.66
AR (2)	0.04	0.02	2.14
AR (3)	0.07	0.02	3.87
AR (4)	0.05	0.02	2.68
AR (5)	−0.03	0.01	−2.06
R^2	0.71		
Durbin-Watson	1.77		
df	5442		

S.E.: Standard error

Table 5: Model 6 and Model 7 for HR11 and HR24

Variables	Model 6			Model 7		
	Est.	S.E.	t-statistics	Est.	S.E.	t-statistics
c	−2.20	1.97	−1.11	0.38	7.27	0.05
log(blocksales)	−0.12	0.05	−2.19	0.11	0.14	0.84
log(d(brentusd))	0	0.02	0.22	−0.01	0.07	−0.12
systemproxy	−0.51	0.04	−14.13	−0.69	0.14	−5.05
log(impcoal)	−0.06	0.15	−0.42	−0.63	0.53	−1.20
log(ng)	0.1	0.14	0.73	0.2	0.37	0.53
log(ptf)	0.76	0.12	6.17	0.78	0.11	7.04
log(renewable)	0.44	0.15	2.84	0.39	0.44	0.88
R^2	0.83			0.66		
Durbin-Watson	2			2.12		
df	246			246		

S.E.: Standard error

In this context econometric model equation for Model 6 and Model 7 are as mentioned below:

$$\log(SMP_{HR11/HR24}) = \beta_1 \log(blocksales) + \beta_2 (d(brentusd))$$
$$+ \beta_3 systemproxy + \beta_4 \log(impcoal) +$$
$$\beta_5 \log(ng) + \beta_6 \log(ptf) + \beta_7 \log(renewable)$$

Differing from Models 1-5, in models 6 and 7[5] we summed up all renewable based production amounts in "renewable" variable.

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5   For model 6 and 7, we also tested alternatives with a weighted renewable production index (renweg) variable instead of totbal renewable production (renewable). Index was calculated as.

$$\frac{\text{production by wind}}{\text{total renewable production}} \times wind\ production + \frac{\text{production by dammed}}{\text{total renewable production}}$$

$$\times dammed\ production + \frac{\text{production by river}}{\text{total renewable production}} \times river\ production +$$

$$\frac{\text{production by geothermal}}{\text{total renewable production}} \times geothermal\ production + \frac{\text{production by biomass}}{\text{total renewable production}}$$

$$\times biomass\ production +$$

In section 8.4, Table 9 exhibits that alternative model results are not significantly different. Our expectation was to be able to find a better explanatory variable with Index terms compared to single production amount variables. However due to the test results we have concluded that Index terms do not contribute significantly better to the model efficiency. You can compare the results of Tables 5 and 9 to compare both models more detailed.

Figure 4: Electricity price and consumption trends

Source: EXIST
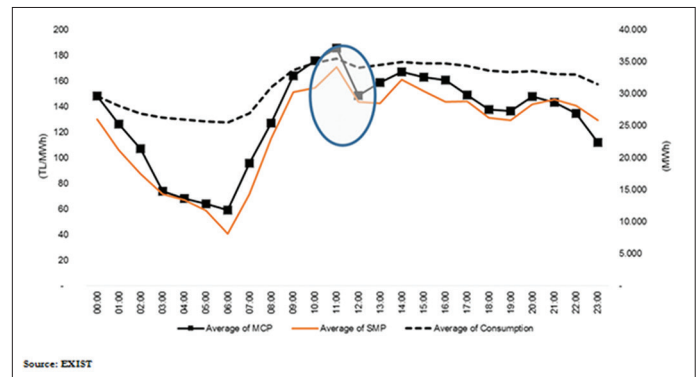
We also incorporated imported coal (impcoal) and natural gas (ng) based productions and first difference of brent oil prices (d(brentusd)) as well. Furthermore, we included blocksales as explanatory variable in to the model considering the market power approach.

Block offers contain information regarding to price, quantity and time period encompassed and they are determined as consecutive and whole hours. If the block offers are under the average price of the encompassed time period, then the block offers are accepted or if block offers are higher than the average prices of the encompassed time period are accepted.

This market mechanism may have a pressure on the peak time electricity prices in favor of consumers. Block offers can be accepted only if they maximize total surplus in case supply and demand do not intersect and several offers are linked with each other. Coherently we observe that block sales has a significant negative effect on SMP at peak times while it is not a significant explanatory variable for base load.

These results bring additional support to the modeling philosophy that the estimation of separate models for each hour of the day can be a more efficient way to predict the exogenous variable effect on the electricity prices.

4.2. Company Models
Depending on the regulatory regime, power generation companies may have the ability to move forward into their buyers' industry through entry into the power retail industry, selling electricity to end-users. While it is not often possible for generation companies to literally sell their own power direct to end-users (this depends on issues such as the electricity industry structure, which is also usually controlled by the regulatory system), presence in the retail industry means that power generators have an additional revenue stream that can defend their margins against volatile prices for wholesale power and their own inputs, such as coal or gas. Some industries do have large energy supply companies with strong buyer power over other power generation companies.

Vertical integration of generation, supply and network activities, which reduces the incentives to trade and for new companies to enter the industry, has remained a dominant feature in the

Table 6: Model 8 and Model 9 for Enerjisa and Aksa final daily production program

Variables	Model 8			Model 9		
	Est.	S.E.	t-statistics	Est.	S.E.	t-statistics
c	−15.89	2.87	−5.54	−58.20	3.77	−1.54
log(usdtry)	−7.42	2.41	−3.08	−7.46	3.22	−2.31
log(mcp)	−0.02	0.01	−3.60	−0.11	0.01	−1.32
log(tetas)	0.50	0.05	9.26	0.23	0.07	3.21
log(consumption)	2.11	0.15	14.02	6.93	0.18	3.76
log(aksa)	0.10	0.01	10.10	-	-	-
log(enerjisa)	-	-	-	0.18	0.02	10.10
log(renewables)	0.42	0.06	6.69	−0.42	0.08	−4.99
@trend	0.00	0.00	3.27	0.00	0.00	4.39
AR (1)	0.90	0.01	152.97	0.89	0.01	151.25
R^2	0.89			0.90		
Durbin-Watson	1.98			2.06		
df	5704			5704		

S.E.: Standard error

electricity industry in many countries. However, moderate growth in recent years, coupled with a forecast for slightly faster growth through to 2018, makes the industry still attractive to new entrants.

For example in addition to four main business lines being electricity generation, distribution, trading and sales, Enerjisa also manages a portfolio in natural gas. Although all these activities have different dynamics Enerjisa tries to leverage its business in an integrated way based on an efficient and flexible portfolio strategy focused on operational excellence.

Accordingly, Kazancı Group, parent company of Aksa Energy, companies operate in all areas and carry out their operations in synergy with each and every link of the energy value chain, from production to distribution. The production portfolio of Aksa Energy includes 16 power plants which produce electricity using natural gas, lignite, wind, hydroelectricity, fuel-oil.

Model 8 and Model 9 (exhibited in Table 6) are based on same independent variables with two different times zones, 18.12.2015-01.09.2016 and 01.07.2016-01.09.2016 respectively. Model equation for Model 8 is as mentioned below:

$$log(enerjisa) = \beta_1 log(usdtry) + \beta_2 log(mcp) + \beta_3 log(tetas)$$
$$+ \beta_4 log(consumption) + \beta_5 log(aksa) + \beta_6 log(renewable)$$
$$+ \beta_9 \ trend + \beta_9 log(enerjisa)_{t-1}$$

And for Model 9 equation is as below:
$$log(aksa) = \beta_1 log(usdtry) + \beta_2 log(mcp) + \beta_3 log(tetas) +$$
$$\beta_4 log(consumption) + \beta_5 log(enerjisa) + \beta_6 log(renewable)$$
$$+ \beta_9 trend + \beta_9 log(aksa)_{t-1}$$

Electricity production in renewables has a positive effect on Enerjisa production planning while it has a negative effect on Aksa. The main reason of this fact is that Enerjisa production portfolio consists of approximately 30% renewables while most of the Aksa production is based on natural gas power plants. Moreover, production of TETAS have a positive impact on Enerjisa and Aksa production since they have a decreasing effect on MCP and reduces the equilibrium prices in the merit order.

TETAŞ and EUAŞ produce approximately 40% of the whole market which makes it in fact an oligopoly market. An oligopoly is a market structure in which a few firms dominate. When a market is shared between a few firms, it is said to be highly concentrated. Although only a few firms dominate, it is possible that many small firms may also operate in the market. In this case it is clear that TETAŞ and EUAŞ have the market power with their huge production capacity and they can force the market in to a Cournot[6] equilibrium.

A typical oligopoly market strategy is based on interdependency. Because firms cannot act independently, they must anticipate the likely response of a rival to any given change in their price, or their non-price activity. In other words, they need to plan, and work out a range of possible options based on how they think rivals might react.

- Oligopolists have to make critical strategic decisions, such as:
- Whether to compete with rivals, or collude with them.
- Whether to raise or lower price, or keep price constant.

Whether to be the first firm to implement a new strategy, or whether to wait and see what rivals do. The advantages of "going first" or "going second" are respectively called 1st and 2nd-mover advantage. Sometimes it pays to go first because a firm can generate head-start profits. Second mover advantage occurs when it pays to wait and see what new strategies are launched by rivals, and then try to improve on them or find ways to undermine them.

However this is not the case in electricity markets. TETAŞ and EUAŞ make their production plans due to the collimation of government in line with Petroleum Pipeline Company's (BOTAŞ) current portfolio position. There are BO-BOT power plants with purchase guarantee from BOTAŞ until the end of 2018. There are no volume or price risk since the government has guaranteed the production of BO-BOT PPs. Approximately 1/3 of BOTAŞ' gas is consumed in BO-BOT plants. BOTAŞ has been trying to offset its losses elsewhere by selling expensive gas to these plants. As a result

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6   Cournot competition is an economic model used to describe an industry structure in which companies compete on the amount of output they will produce, which they decide on independently of each other and at the same time. It is named after Antoine Augustin Cournot (1801-1877) who was inspired by observing competition in a spring water duopoly. It has the following features.

regardless of the demand functions dynamics BO-BOT operators produce electricity which reduce the MCP in the merit order.

5. CONCLUSION

This study focuses on the relationship between electricity prices and production type of electricity as an application study of merit order based on regression models. Our contribution to the growing literature on Turkish electricity market is applying models incorporating newly established EXIST high frequency data. To our knowledge, our paper is one of the first attempts which incorporates hourly EXIST data in applied models for electricity prices.

The main difficulty we faced in the study is the limitations to high frequency in EXIST. We tried to show the impact of renewable energy generation increase in the market to both electricity prices and private company production strategies where we chose Enerjisa and Aksa companies as benchmark companies.

Another avenue for future research may be to examine bidding strategies of private companies if sales and consumption data by company and industry are provided publicly by EXIST in the transparency platform. Hortaçsu and Puller (2008) suggest some amount of caution when analyzing and predicting the behavior of smaller players in newly restructured markets. Smaller firms submit bids that differ substantially from the benchmarks we construct for optimal bidding. This finding is not inconsistent with rational economic behavior by these bidders.

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APPENDIX

Linear Projection and Ordinary Least Squares Regression

In statistics, ordinary least squares (OLS) or linear least squares is a method for estimating the unknown parameters in a linear regression model, with the goal of minimizing the sum of the squares of the differences between the observed responses in the given dataset and those predicted by a linear function of a set of explanatory variables (visually this is seen as the sum of the vertical distances between each data point in the set and the corresponding point on the regression line - the smaller the differences, the better the model fits the data). The resulting estimator can be expressed by a simple formula, especially in the case of a single regressor on the right-hand side.

A linear regression model relates an observation on y_{t+1} to x_t;

$$y_{t+1} = \beta'X_t + u_t \tag{3.1.1}$$

Given an sample of T observations on y and x, the sample sum of squared residuals is defined as:

$$\sum_{t=1}^{T} y_{t+1} - \beta'X_t)^2 \tag{3.1.2}$$

The value of β that minimizes (3.1.2) denoted by b, is the OLS estimate of β. The formula for b turns out to be:

$$b = \left[\sum_{t=1}^{T} x_t x'_t\right]^{-1}\left[\sum_{t=1}^{T} x_t y_{t+1}\right] \tag{3.1.3}$$

Which equivalently can be written:

$$b = \left[\left(\frac{1}{T}\right)\sum_{t=1}^{T} x_t x'_t\right]^{-1}\left[\left(\frac{1}{T}\right)\sum_{t=1}^{T} x_t y_{t+1}\right] \tag{3.1.4}$$

In the OLS models natural logs for variables are used on both sides of the models. Such specification is called a log-log model. This

model is handy when the relationship is nonlinear in parameters, because the log transformation generates the desired linearity in parameters (you may recall that linearity in parameters is one of the OLS assumptions).

In principle, any log transformation (natural or not) can be used to transform a model that's nonlinear in parameters into a linear one. All log transformations generate similar results, but the convention in applied econometric work is to use the natural log. The practical advantage of the natural log is that the interpretation of the regression coefficients is straightforward.

Autoregressive Process

Let's say we are studying a variable whose value at date t is denoted by y_t. Suppose we are given a dynamic equation relating the value y takes on at date t to another variable w_t and to the value y took on in the previous period:

$$y_t = \varphi y_{t-1} + w_t \tag{3.2.1}$$

Equation (3.2.1) is a linear first order difference equation. A difference equation is an expression relating a variable y_t to its previous values. Equation (3.2.1) can also be rewritten using a lag operator as:

$$y_t = \varphi L y_t + w_t \tag{3.2.2}$$

This equation, in turn, can be rearranged using standard algebra;

$$(1 - \varphi L) y_t = w_t \tag{3.2.3}$$

The basic building block for all the processes considered in this part is a sequence;

$$\{\varepsilon_t\}_t^\infty = -\infty \text{ whose elements have mean zero and variance } \sigma^2.$$

$$E(\varepsilon_t)=0 \tag{3.2.4}$$

$$E\left(\varepsilon_t^2\right) = \sigma^2 \tag{3.2.5}$$

and for which the ε's are uncorrelated across time.

$$E(\varepsilon_t \varepsilon_\tau)=0 \text{ for } t \neq \tau \tag{3.2.6}$$

A process satisfying (3.2.4) through (3.2.6) is described as white noise process.

In this context, a first order autoresgression, denoted AR(1), satisfies the following difference equation:

$$y_t = c + \theta y_{t-1} + \epsilon_t \tag{3.2.7}$$

Again, $\{\varepsilon_t\}$ is a white noise sequence satisfying (3.2.4) through (3.2.6). Notice that (3.2.7) takes the form of the first order difference equation (3.2.2) or (3.2.3) in which the input variable w_t is given by $w_t = C + \varepsilon_t$. We know from the analysis of first order difference equation that if $|\theta| \geq 1$, the consequences of the ε's for Y accumulate rather than die out over time. It is thus perhaps not surprising that when $|\theta| \geq 1$, there does not exist a covariance

stationary process for Y_t with finite variance that satisfies (3.2.7). In the case when $|\theta| < 1$, there is a covariance stationary process for Y_t satisfying (3.2.7).

Unit Root Test

The common procedure in economics is to test for the presence of a unit root to detect non-stationary behavior in a time series. This thesis uses the conventional ADF for unit root tests.

In the terminology of time series analysis, if a time series is stationary, it is said to be integrated of order zero, or I(0) for short. If a time series needs one difference operation to achieve stationarity, it is an I(1) series; and a time series is I(n) if it is to be differenced for n times to achieve stationarity. An I(0) time series has no roots on or inside the unit circle but an I(1) or higher order integrated time series contains roots on or inside the unit circle. So, examining stationarity is equivalent to testing for the existence of unit roots in the time series.

A pure random walk, with or without a drift, is the simplest non-stationary time series:

$$y_t = \mu + y_{t-1} + \varepsilon_t, \varepsilon_t \sim N(0, \sigma_\varepsilon^2) \tag{8.1.1}$$

Where μ is a constant or drift, which can be zero, in the random walk. It is non-stationary as $Var(y_t) = t\sigma_\varepsilon^2 \to \infty \text{ as } t \to \infty$. It does not have a definite mean either. The difference of a pure random walk is the Gaussian white noise, or the white noise for short:

$$\Delta y_t = \mu + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_\varepsilon^2) \tag{8.1.2}$$

The variance of Δy_t is σ_ε^2 and the mean is μ. The presence of a unit root can be illustrated as follows, using a first-order autoregressive process:

$$y_t = \mu + \rho y_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_\varepsilon^2) \tag{8.1.3}$$

Equation (8.1.3) can be extended recursively, yielding:

$$\begin{aligned} y_t &= \mu + \rho y_{t-1} + \varepsilon_t \\ &= \mu + \rho\mu + \rho 2 y_{t-2} + \rho\varepsilon_{t-1} + \varepsilon_t \\ &\vdots \end{aligned}$$

$$\left(1 + \rho + ... + \rho^{n-1}\right)\mu + \rho^n y_{t-n} + \left(1 + \rho L + ... + \rho^{n-1} L^{n-1}\right)\varepsilon_t \tag{8.1.4}$$

Where L is the lag operator. The variance of y_t can be easily worked out:

$$Var((y_t)) = \frac{1 - \rho^n}{1 - \rho} \sigma_\varepsilon^2 \tag{8.1.5}$$

It is clear that there is no finite variance for y_t if $\rho \geq 1$. The variance is $\sigma_\varepsilon^2 / (1 - \rho)$ when $\rho < 1$.

Alternatively, Equation (3) can be expressed as:

$$y_t = \frac{\mu + \varepsilon_t}{(1 - \rho L)} = \frac{\mu + \varepsilon_t}{\rho((1/\rho) - L)} \tag{8.1.6}$$

which has a root $r = 1/\rho$. Comparing Equations 5 with 6, we can see that when y_t is non-stationary, it has a root on or inside the unit circle, that is, $r \geq 1$; while a stationary y_t has a root outside the unit circle, that is, $r < 1$. It is usually said that there exists a unit root under the circumstances where $r \geq 1$. Therefore, testing for stationarity is equivalent to examining whether there is a unit root in the time series. Having gained the above idea, commonly used unit root test procedures are introduced and discussed in the following.

Unit Root Test Results

Table 7: Augmented Dickey-Fuller unit root test

#	Variable	t-statistics
1	log(brent usd)	−1.30
2	log(blocksales)	−6.15
3	log(wind)	−10.50
4	log(lignite)	−4.66
5	log(geothermal)	−5.86
6	log(natural gas)	−5.82
7	log(dammed)	−7.11
8	log(pibid)	−5.87
9	log(fuel_oil)	−5.23
10	log(biomass)	−6.66
11	log(LNG)	−9.24
12	log(mcp)	−6.52
13	log(smp)	−8.49
14	aksa	−19.14
15	enerjisa	−20.60
16	renewable	−12.98

LM Tests for Model 1 and Model 5

Table 8: Breusch-Godfrey serial correlation LM tests

Model 1			
F-statistic	771.84	Prob. F(2.5889)	0.0000
Obs*R^2	1225.99	Prob. Chi-Square(2)	0.0000
Model 5			
F-statistic	3.12	Prob. F(2.5440)	0.044
Obs*R^2	6.25	Prob. Chi-Square(2)	0.044

Alternative Renewable Index Model for HR11 and HR24

Table 9: Model 6 and Model 7 for HR11 and HR24

Variables	Model 6			Model 7		
	Est.	S.E.	t-statistics	Est.	S.E.	t-statistics
c	0.79	1.32	0.59	1.79	6.37	0.28
log(blocksales)	−0.08	0.05	−1.55	0.08	0.13	0.59
log(d(brentusd))	0.00	0.02	0.20	−0.01	0.07	−0.11
systemproxy	−0.50	0.04	−13.81	−0.66	0.15	−4.46
log(impcoal)	−0.07	0.14	−0.52	−0.61	0.53	−1.15
log(ng)	−0.05	0.14	−0.35	0.21	0.38	0.54
log(ptf)	0.68	0.12	5.62	0.78	0.11	6.93
log(renweg)	0.32	0.09	3.50	0.26	0.32	0.81
R^2	0.84			0.66		
Durbin-Watson	2.13			2.09		
df	246			246		

S.E.: Standard error

Dickey and Fuller

The basic Dickey–Fuller (DF) test (Dickey and Fuller 1979, 1981) examines whether $\rho < 1$ in Equation (8.1.3), which, after subtracting y_{t-1} from both sides, can be written as:

$$\Delta yt = \mu + (\rho-1)y_{t-1} + \varepsilon_t = \mu + \theta y_{t-1} + \varepsilon_t \tag{8.1.7}$$

The null hypothesis is that there is a unit root in y_t, or H_0: $\theta=0$, against the alternative H_1: $\theta<0$, or there is no unit root in y_t. The DF test procedure emerged since under the null hypothesis the conventional t-distribution does not apply. So whether $\theta<0$ or not cannot be confirmed by the conventional t-statistic for the θ estimate. Indeed, what the DF procedure gives us is a set of critical values developed to deal with the non-standard distribution issue, which are derived through simulation. Then, the interpretation of the test result is no more than that of a simple conventional regression. Equations (8.1.3) and (8.1.7) are the simplest case where the residual is white noise. In general, there is serial correlation in the residual and Δy_t can be represented as an autoregressive process:

$$\Delta y_t = \mu + \theta y_{t-1} + \sum_{i=1}^{\rho} \varphi i \Delta y_{t-i} + \varepsilon_t \tag{8.1.8}$$

Corresponding to Equation (8.1.8), DF's procedure becomes the ADF test. We can also include a deterministic trend in Equation (8.1.8). Altogether; there are four test specifications with regard to the combinations of an intercept and a deterministic trend.