Regression Model-Based Analysis of the Impact of Emissions Trading on Electricity Spot Market Price Behavior

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***Abstract*—Under the Kyoto protocol, emissions trading was imposed upon the Nordic Nord Pool Spot market in 2005. We seek to characterize the impact of emissions trading on electricity spot market price behavior by statistically comparing the prices before and after emissions trading was introduced. The analysis is based on the skill of regression models in explaining price behavior before and after 2005. It turns out that regression models based on background variables such as temperature, water reservoir levels, and even the price of emission rights themselves lose much of their skill from 2005 onwards. The histogram of the residual time series of an optimally calibrated regression model demonstrates a considerably more 'fat-tailed' behavior after 2005. This may be a sign that the increased medium- and long-term uncertainty brought about by emissions trading has introduced a strong 'psychological' component into price behavior, increasing its volatility and making it prone to more frequent price spikes.**

***Index Terms*—Electricity Spot Price, Emissions Trading Scheme, Multiple Regression Model**

I. Introduction

Nord Pool Spot's system price acts as the reference price for many financial instruments: futures, forwards, and options, as well as for the Nordic OTC/bilateral wholesale market, and it is used by electricity distributors as the basis for quoting prices to end consumers. Therefore, understanding the price micro-behavior and its short- and long-term trends is of high importance for different parties. It is already known that electricity spot prices are the most volatile of all financial time series, reaching a volatility value of up to 50%. Despite this challenge, both the short- and long-term mean levels of the price display some regularity, as do most electricity markets worldwide, and this can be partly explained with the use of background variables through multiple regression models.

A new factor was introduced to Nord Pool Spot pricing in 2005, namely trading of carbon dioxide emission allowances. Emission trade is known to have influenced the prices; however, there has been so far no mathematical evidence of how strong and of what character that influence is. The emissions trading itself has faced a number of challenges and controversies, including different timelines when trading commenced in different countries, or uncertainty over assigned emission credits. Most research related to the Emission Trading Scheme (ETS) done so far has covered identified benefits and failures of introducing the scheme. Also its influence on industries of particular countries has been studied [?], but the total impact of emissions trading on spot prices has received little attention. For instance, Kara *et al.* in [?] have analyzed the effects of ETS on Finnish industries, and Sousa *et al.* in [?] for the Iberian electricity market. Some more mathematically based studies have focused on short-term relations between emission price changes and electricity price responses to it [?], or the influence of ETS news on the spot price in the case of the Australian market [?]. Keppler and Mansanet-Bataller have found that gas and carbon prices have some influence on emissions prices and that this effect carries on to electricity prices [?]. Finally, knowing that electricity prices in overall rose after the beginning of the ETS, Bonacina and Gulli tested the impact of market power by studying whether the influence of allowances on spot prices would have been stronger or weaker under market power than under perfect competition [?]. There have been attempts to propose options for market policy makers, and to bring the prices back from the ETS-caused lifted level to the previous one [?]. None of the studies, however, provided any quantitative insight into how the spot market behavior actually changed.

The aim of this paper is to statistically verify how the electricity spot price behavior has changed since the beginning of emissions trading. As the prices are known to be highly seasonal and dependent on specific driving factors, we set the foundations of our methodology in classical time series theory and multiple regression modeling. The residual time series from a properly designed regression model can be split in time with respect to the date when the European emission allowance (EUA) trading started, and the behavior of the two series compared through an extensive statistical analysis.

The paper is organized as follows. Section **??** presents the characteristics of the Nordic electricity market, the principles of its system price formation, and a review of researchers' approaches to modeling electricity prices. Section **??** briefly revises the emissions trading scheme and its controversies. Section **??** presents the data, the mathematical framework of our study, and the results. Finally, Section **??** presents the conclusions.

II. Framework

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IN this section, we present the market framework of Nord Pool Spot price formation, as well as the general mechanism and controversies standing behind the European carbon dioxide emissions trading.

A. Nordic electricity spot market

The deregulated Nordic electricity market is characterized as an 'energy-only' market with a single, uniform market clearing price. Geographically, the market is composed of Norway, Sweden, Denmark, Finland, and Estonia. When set up in 1996, it became the first international electric power exchange [?], even though not being the first electricity trading deregulated region in the world. Its initial goal was to establish a common Nordic market that would guarantee strong competition between suppliers in the area. At present 317 companies from 20 countries trade on the exchange. Offering both day-ahead and intraday trades to its participants, Nord Pool is also the largest electricity market in the world. In 2009, the group reached 288 TWh in turnover, representing a value of EUR 10.8 billion and more than 70% of the total electricity consumption in the Nordic countries.

1) Price formation in Nord Pool: A marginal pricing scheme is applied to the price formation in the Nordic electricity spot market. The market clearing price is found at the intersection of the supply and demand curves that are formulated in the day-ahead spot markets for each hour of the following day, based on the supply offers of electricity generators and the demand bids of electricity retailers and large electricity users. Generators' offers reflect the marginal costs of producing electricity, whereas the demand bids indicate the buyers' willingness to pay. The spot market is organized by the power exchange Nord Pool Spot. The trading cycle is characterized as a closed auction and it takes place once a day. The power exchange contributes to balancing the supply and demand in the short and long term. It provides incentives to use the power plants in the right merit order and enables the efficient use of the generation plants located across the market area. The market price formed at the power exchange also acts as a reference price in the bilateral electricity trading that takes place outside the power exchange.

A uniform market clearing price applied in the Nordic electricity market means that the market is, in principle, cleared with a single price that is applied to all electricity trades taking place in the electricity spot market. However, in case of transmission constraints, the market is divided into predefined price areas that are separated by congested transmission lines. Within the price areas, congestion is not expected to occur. In the Nordic electricity market, Norway is divided into five price areas, Denmark consists of two price areas, and Sweden, Finland, and Estonia each compose one price area.

According to the logic of marginal pricing, the generator with the highest marginal costs needed to satisfy the demand defines the market clearing price. All the employed generators are paid the same market price. Generators that are called to operate are always guaranteed to receive enough money to cover their variable costs. For the generator at the margin, the compensation will be exactly equal to its variable costs. For the other generators, the obtained revenues also cover some of their fixed costs. The principles of price formation are illustrated in Fig. ??.

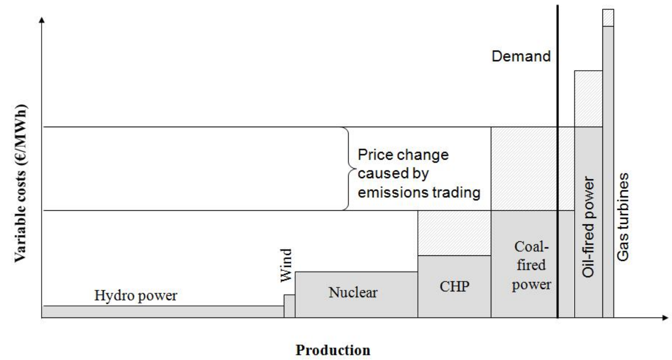

Fig. 1. Principles of marginal price formation in the Nordic electricity market.

In addition to the spot market revenues, the generators may also earn money by operating in the regulating power markets. In the Nordic electricity market, the regulating power markets are organized for reliability reasons by the national transmission system operators. Demand resources may also participate in the regulating power markets.

The fact that the Nordic electricity market is an 'energy-only' market means that the revenues earned by the generators in the electricity spot market suffice to cover the short-term marginal costs as well as the long-term, 'going-forward' costs of the electricity generation plants. Generators' offers are not subject to offer capping. In shortage situations, prices are allowed to peak and the demand's willingness to pay for electricity settles the market price. During these shortage hours, generators are able to earn profits on their fixed costs. Separate capacity markets are not considered necessary as the energy market alone, by default, provides the generators with adequate revenues that facilitate new entry and allow keeping the existing power plants in operation.

2) Electricity spot price modeling and forecasting: It is well understood that being able to forecast electricity spot and forward prices is of high importance in both long and short term. Most recent studies focus on seeking the best methods for day-ahead price forecasting, as the spot price's high volatility and prominent spikes are the basic risk factors for market participants. Their main reason lies in the competitive character of the deregulated markets, as a big number of traders can significantly lower the mean price level, but will also make it more volatile at the same time [?].

Due to the spot price nature, we know that accurate prediction with classical time series models is not possible. Most recently proposed approaches are based on background deterministic variables known to be influencing electricity prices, such as load [?], production type [?], [?], temperatures [?], and other different climatic factors [?]. To reduce the electricity price forecasting errors, one can also account for the known types of spot price periodicity. Among those, we consider seasonal weather influence [?], as well as weekday effects [?].

As no perfect model for short term spot price forecasting has been found so far, it is crucial from the risk-management point-of-view to know at least confidence intervals of the computed predictions [**?**]. Also, being able to model long-term price trajectories is equally important. The latter has been proposed through, for example, a price duration curve approach [**?**]. Moreover, on top of all forecasting efforts, we should be aware of any possible economic impacts of electricity market price forecasting errors [**?**]. Thus each new better model should always be revised in an on-going fashion because, as we discuss in the following sections, the influence of price driving factors, as well as new economic situation and policies, can significantly change model parameters and, therefore, its forecasting performance.

B. Emissions trading

1) Emissions allowances and trading: Emissions trading is a market-based methodology used to control pollution by providing economic incentives to achieve reductions in the emissions of pollutants [**?**]. It is agreed that a central authority of a country sets a limit (also known as a cap) on the amount of a pollutant that can be emitted. The total agreed limit is allocated or sold to all the country's emitting industrial sites in the form of emissions allowances that represent the right to emit or discharge a specific volume of the specified pollutant. Firms are obliged to hold a number of permits (or credits) equivalent to their emissions. The total number of permits cannot exceed the cap, limiting total emissions to that level.

It is often the case that some of the allowance holders emit more than allocated, and thus need to increase their emission permits by buying credits from those who use less of their allowances. This process is called emissions trading. In effect, the buyer is paying a charge for polluting, while the seller is being rewarded for having reduced emissions. This way, it is expected that those who can reduce emissions most cheaply will do so, achieving pollution reduction at the lowest overall cost to society [**?**].

2) Allowance price and trading controversies: The emission allowances were allocated to the actors after the pre-Kyoto-period had actually started. In Finland this took place around February 2005, and in some countries it did not happen until 2006. Thus, at the beginning there was actually no market for emissions, and consequently, no price for emissions. Moreover, some actors knew better than others what would and especially should happen to prices; that is, they would rise.

There was a lot of uncertainty in the amount of allocated emissions. At the beginning there was no general knowledge of whether there are enough permits allocated to cover all emissions. When the EU published the result of 2005 showing that there were plenty of emissions for every actor, in April 2006 the prices decreased immediately to about 20–25%, and at the end of the pre-Kyoto period, emission allowances became temporarily worthless. Overall, emissions trading can be seen to have introduced a substantial amount of medium- to long-term uncertainty to the electricity markets. In this paper, we have set out to characterize the consequences of this uncertainty on the spot market prices by statistical modeling.

III. DATA, METHODOLOGY, AND RESULTS

THIS section presents an example of our regression modeling approach to describe the varying mean level of electricity spot prices. The focus of this paper is on the system price that is obtained from the total supply and demand curves in the Nordic market area. We first consider the most influential factors driving the price (part **??**); further, we list the specific characteristics of our proposed model (part **??**) and, finally, we study the model residuals split with respect to the Kyoto protocol enforcement date, 16 Feb 2005 (part **??**).

A. Factors driving electricity spot prices

Electricity spot price is not a purely stochastic process. However, even though the price reveals so far unexplainable high changes and price spikes, it also has long- and short-term mean levels, which can, at least partly, be explained by background variables that are used to build the regression models. The type and level of explanatory power in such supporting data is very much dependent on individual markets.

Prices in the Nordic electricity market are characterized as being highly volatile. This follows partly from the fact that prices are allowed to peak when the market is short. Another thing that contributes to the high volatility is the large variations in the demand and supply of electricity. For instance, temperature strongly affects the demand; in total, the demand varies between 50–100%. A similar phenomenon can be seen in many northern regions, such as Russia and North America. We have also learnt that demand is a strong factor in influencing the local trend in the spot price of electricity. In specific markets, the demand is significantly correlated with the local temperature. On the other hand, demand is lower over the weekends and during the nights.

On the supply side, markets with high thermal or gas-based production will have their price variations caused mainly by the changes in fossil fuel prices and the prices of European emission allowances (EUA). For strongly hydro-based markets, the water reservoir levels will rule the price trends. For instance, in 2007 Nordic power generators produced around 397.6 TWh of electric power, of which 40% came from Sweden, 35% from Norway, 16% from Finland, and the remaining 9% from Denmark. Most energy producers aim to maintain a balance between different energy sources, in order to ameliorate the risk in the price of raw materials to produce electricity. Table **??** presents a repartition of electric energy production methods among the Scandinavian countries. We can see that water reservoir levels, especially those from Norway and Sweden, can be of great significance to the availability of cheap power, and hence to the level of spot prices.

Historically, being a hydro-dominated market, Nord Pool has shown that the deviations of water levels from normal have been reflected in the electricity spot prices. However, the introduction of the emission trading of the EU changed the dynamics of the market, as depicted in Fig. **??**. Here, we plot the normalized time series of both the Nordic system price and the deviation of Scandinavian hydrological situation from normal. Specifically, we calculate it as the difference between