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School of Economics and Management

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The Efficient Market Hypothesis at Nord Pool: A study of the forwards market

Melissa Proietti
Aeg10mpr@student.lu.se

***Abstract**:* In recent times the increasing economic importance of electricity raised new interest in the study of its market. In particular the existence of an efficient derivative market where players can mitigate their risk exposure has been considered fundamental. In this work an analysis on the weak form of efficiency for the forwards market at Nord Pool is carried through taking the three most traded contracts as indicators. Different statistical tests and a scenario analysis on extreme conditions on the supply side are employed in order to gain a greater understanding of the state of the market. Evidences of inefficiency are found for the monthly and quarterly contracts, while the market shows higher levels of efficiency in a situation with abundant hydro power resources.

Key words: Electricity derivatives, Nord Pool, random walk, variance ratio test, runs test, BDS test, hydro power.

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1. Introduction

In recent times the increasing economic importance of electricity has caused its demand to become significantly inelastic while its supply side suffers from physical constrains. These structural bottlenecks have a great influence on the price of electricity resulting in periods of extreme volatility. The existence of an efficient derivative market where players affected by this particular risk can mitigate their exposure is, thus, of fundamental importance.

Nord Pool is the world’s largest multinational market place for electricity. Born as a consequence of the liberalization of the Nordic electricity market, it was unique of its kind when it opened in 1996 as the world’s first multinational exchange place for financial power contracts (www.nasdaqomxcommodities.com). Due to this precocity, its good liquidity and continuous growth, the market has soon become a popular object for analysis. However, the majority of the research about Nord Pool focuses on electricity prices modeling, regulating power of the market and price risk management. Studies on its efficiency are instead few, especially those about the derivatives’ market, and often reach discordant conclusions, see Gjolberg and Johnsen (2001), Herràiz and Monroy (2009), Veka (2011a) and Veka (2011b).

Fama (1970) defines an efficient market as one in which assets’ prices fully reflect all the available information. More specifically, the Efficient Market Hypothesis (EMH) proposes three types of market efficiency: weak, semi-strong and strong. Prices in a weakly efficient market are assumed to reflect all the historical information. In the semi-strong form instead the information set reflected by the prices includes most information available to all market participants, while for the strong type of efficiency prices should reflect also “internal” information known by any market participant. Although these definitions might seem clear and theoretically valid, in reality it is very hard to test for strong and even semi-strong EMH. For simplicity, then, the majority of the studies focus only on the weak form of efficient market. If satisfied, in fact, this is sufficient to imply that it is not possible for any agent to forecast futures price changes based on historical analysis.

In this paper the predictability, and hence, the market efficiency of the Nordic electricity forward market is tested under different aspects. Furthermore, a scenario analysis is carried through to see the market reaction in different hydrological situations. Power markets differ from other markets as the underlying good is fundamentally not storable. Nevertheless, in the Nordic market, a significant part of power production comes from hydro reservoirs, playing such hydropower inventory an important role in the pricing of electricity (STEM, 2006).

Thus, differences in the hydrological level could possibly significantly influence the efficiency of the market.

The focus of this paper is on electricity forwards, instruments designed to reduce the exposure of the market players to spot prices volatility. These contracts make it possible to secure electricity prices for a period up to three years. Furthermore, other than risk mitigation, derivative market has a stabilization function on spot prices by reducing peak, depths and leads in the cash market for the underlying asset (Allanz and Vila, 1986). The importance of having a well-functioning derivative market is thus relevant also for the institutional framework.

1.1 Aim and contribution of the research

The purpose of this research is to assess whether the Nord Pool derivatives' market is efficient within the weak market efficiency hypothesis. In particular, taking into account the large share of electricity generated by hydropower in the Nordic market, the efficiency hypothesis is tested in a scenario analysis for, respectively, wet and extremely dry conditions.

Conclusions from existing studies measuring the efficiency of futures and forward markets vary considerably. Reviewed literature shows no uniformity regarding the results in particular because different approaches are applied and the selected method can slightly bias the outcome. This study will therefore contribute to shed light in this much debated topic by applying different efficiency measures to one of the world's most developed electricity forward market. Furthermore, to the author's knowledge, no previous study has analyzed Nord Pool market efficiency in different weather scenarios, thus this paper could bring some new insightful contribution to the research.

1.2 Limitation of the study

Although being one of the pillars of economic theory, market efficiency is rather an abstract concept to measure and define. Due to its elusive nature, many scholars have attempted to develop tests capable to give a clear answer to this question, with various fortunes. Up to date, in fact, a multitude of approaches exist, each analyzing a different aspect of the problem. In this paper, due to limited time and the characteristics of the data, four tests have been carried through, chosen among the most widely used. Furthermore, this work analyses whether returns are un-predictable, which, although being a direct effect of market efficiency, does not automatically imply it.

Another limitation of this study is that the time span of the data studied is of roughly four and a half years, a period long enough to significantly apply statistical tools and draw indications about market behavior, but still not sufficient to declare whether it is absolutely efficient or not. Moreover, the derivative market is not analyzed in its whole, but the three most frequently traded contracts are used as proxies.

Finally, in order to have an adequate number of observations to test, only two extreme condition scenarios could be constructed one of which, by chance, coincides with the last part of the dataset.

1.3 Thesis outline

The reminder of this paper is structured as follows: chapter 2 presents a brief overview of the Nordic power market, explaining the functioning of both the physical and the financial branches. In chapter 3 the theoretical background is introduced with a review of previous study on the subject. Chapter 4 contains a thorough description of the methodology and the four tests that will be applied, together with the presentation of the dataset. In chapter 5 the empirical finding are reported and discussed. Chapter 6 and 7 contain respectively policy recommendations and concluding remarks. Finally in chapter 8 some suggestions for further research are proposed.

2. Nord Pool overview

The origin of Nord Pool can be traced back to 1990 when Norway, with the Electricity Act, initiated the process of deregulation of her electricity market. This first act posed the basis for the establishment, in 1993, of Statnett Market AS, one of the first European wholesale electricity market. Then in the January of 1996, when Sweden decided to join, Nord Pool, the world’s first multinational electricity market, was created. In the following years the market was extended to the remaining Nordic countries (Finland in 1998 and Denmark in 2000), the

KONTEK[1] bidding area of Germany (2005) and Estonia (2010). Today Nord Pool is the largest international electricity market in the world and is divided in three main parts: a *physical market,* operated by Nord Pool Spot, where electric power contracts are traded for physical delivery; a *financial market* and a *carbon emission market,* operated by Nasdaq OMX.

The power market has a complex structure involving various players that act at different levels of the exchange, such as system operators, producers, distributors, traders, brokers and clearing companies. However, it is not the scope of this paper to analyze in deep the relationship between each of these actors and their influence on the price settlement. Oversimplifying, the structure the market can be expressed in term of the two most fundamental players: the electricity producers (on the supply side) and the end users (on the demand side).

On the production side, although more than 350 companies operated in the Nordic region, the market is greatly dominated by three major players: the Finnish Fortum, the Swedish Vattenfall and the Norwegian Statkraft, that together hold nearly the 50% of the market. Such concentration on the supply side is a direct effect of the large share that hydropower represent in the energy procurement of the Nordic Region. In normal years, in fact, hydro power covers half of the region need of power. This result can be obtained only with large hydroelectricity plants that started to be implemented in Norway, Sweden and Finland in the years after World War II by the respective national energy companies, which today still own the majority of them. Hydropower is a fundamental resource in the Nordic regions. Norway in particular depends almost entirely on it since more than 98% of her energy production comes from Hydro (IEA.org). Sweden and Finland, instead, rely less heavily on it with a share of respectively 46% and 16% of the total energy production (the rest coming from nuclear and thermal power). Denmark on the other hand has virtually no hydro power and relies predominantly on thermal power, although wind energy is becoming increasingly important. Hence, being Sweden and Norway the biggest producers and consumers of the whole region (see Figure 1) the influence of availability of hydropower is easy understood.

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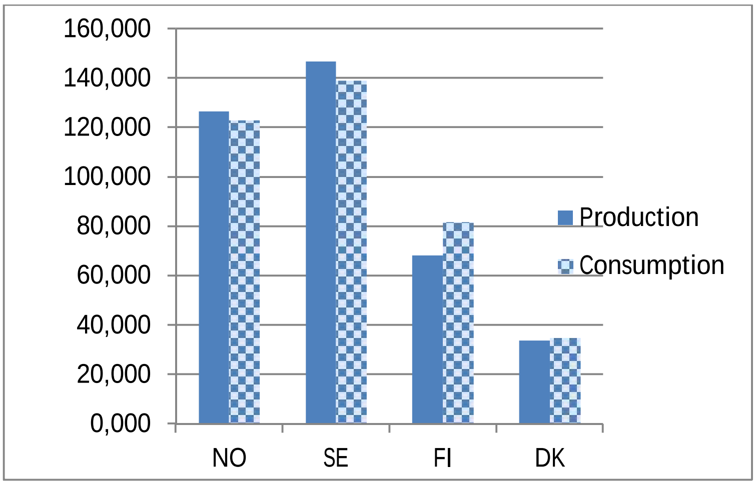
[1] Kontek is the link between East Denmark and Germany. The Kontek price is calculated for a small trading area on the German side created within the Nord Pool spot market.



Source: Nordpoolspot.com

Figure 1***: Production and consumption of electricity in the Nordic region (TWh) 2011***

Due to this particular production configuration, in dry years, the Nordic region becomes more dependent on imports from other countries such as Russia, Estonia, Netherlands, Poland and Germany. Furthermore, the production of electricity from hydropower is significantly cheaper than any other sources in the system, meaning that in case of low level of the hydro reservoirs, producers will recur to more expensive sources, resulting in an increase of the system production cost. The same way, production cost would go down with more water in the reservoirs. Hence, Nordic prices of power are highly dependent on precipitation levels, as well of course on access to the nuclear power and the price of other sources (www.nordpoolspot.com).

The demand side is constituted by the power end-users, which could be either a company or a private household. In the Nordic area there are approximately 14 million end-users and each of them pays not only its consumption, but also a fee for the power transmission and taxes. Power consumption can, thus, be considered the main price determinant on the demand side. If the electricity consumption rises at a fastest pace than the power generating capacity, demand might exceed supply and this would be reflected on increasing prices. Long term consumption growth depends, among others, on macroeconomic and demographical factors but these will not be considered in this study since their effect is not directly reflected on short term prices. Meteorological conditions, instead, can have an important impact on short term electricity prices. Electricity provides, in fact, about 30% of space heating in the Nordic countries. Therefore changes in temperatures are reflected on changes of the daily demand of power.

2.1 The physical market

When it was founded, in the early 90’s, Nord Pool Spot was the world first trading place for power exchange. Nowadays the market is one of the largest of its kind and it allocates the 74% of all the energy produced in the Nordic region. 310 TWh value of electricity were traded here only in 2010, considering also the UK exchange at N2EX[2], (www.nordpoolspot.com).

The physical market at Nord Pool is split in two: Elspot and Elbas. The first is the main trading place for power contracts in the Nordic region. It is a day-ahead market where buyers and sellers stipulate agreements for next day electricity delivery. Elbas instead is the intraday market for power exchange. It was established in order to secure the balance between supply and demand in the likely event of a higher/lower power generation than it was predicted the day before. The importance of this market is increasing as more and more unstable power source such as wind turbines are introduced in the system.

Elspot lies at the basis of Nord Pool, both for the physical and the financial market, being its system price the reference price for the majority of the electricity derivatives. The system price is calculated for every hour as the equilibrium point between the aggregated demand and supply curves which find their expression in the bids and offers of power contracts in the Nordic region. The spot market is thus the central pillar of the whole Nordic electricity market, providing the necessary balance between power supply and demand, fundamental in this case due to the particular non-storability characteristic of electricity and the high costs that a failure of its supply would carry.

If the market is competitive and efficient, then this balance price (system price) should be the lowest possible price at any particular moment of the day. The particular price determination at Nord Pool Spot is called “marginal price setting”. This ensures that the final price would represent the cost of producing one more KWh from the most expensive source of power, on the supply side, and the price that the consumers are willing to pay in order to satisfy their last KWh need, on the demand side.

Because of the particular configuration of the power sources in the Nordic Region, the introduction of a futures and forward market based on the system price of Nord Pool Spot has

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[2] N2EX is the name under which NASDAQ OMX commodities and Nord Pool Spot operate in UK. It was launched in 2010 and is the trading place for UK energy contracts.

had a great importance. The prices of these contracts, in fact, reflect the value of the hydro reservoirs at different times providing a valid instrument for an optimal use of the water resources during different periods of time.

2.2 The financial market

The financial market at Nord Pool began with the establishment, in 1993, of a forward market (then called Statnett Marked AS) in Norway where power contracts were traded through an action system and provided physical delivery at maturity. This last clause was removed already in 1994 when, in order to stimulate greater liquidity, the contracts were transformed in financial power contracts with only cash settlement at maturity.

Nowadays the types of contracts traded at Nord Pool's financial market are many including European Union Allowances[3] (EUA) and Certified Emission Reductions (CER)[4], which are forward contracts with physical delivery. The power derivatives are, in turn, divided in base and peak load futures and forwards, options and Contract for Difference[5].

The financial market at Nord Pool has been introduced with the scope of, on one hand, satisfy the need of risk management tools of producers, retailers and end-user of the electricity industry and, on the other hand, to increase the liquidity of the market by attracting traders who can drive profits from the volatility of the power market. Since its introduction in 1993, the volume of the exchange at the financial market has increased considerably, as much as surpass the trading volume of the physical market (Elspot) already in 1998 (see Fig.2).

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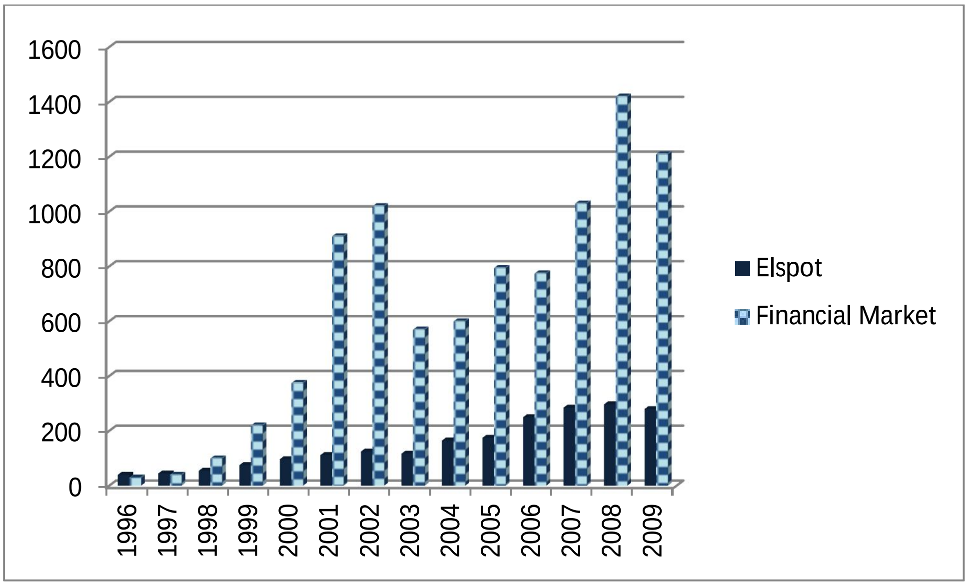
[3] EUA: Carbon credits used in the European Union Emissions Trading Scheme (EU ETS).

[4] CER: Carbon credits issued by the Clean Development Mechanism (CDM).

[5] Contracts for Difference: An agreement between the buyer and seller to exchange the difference in the current value of a share, currency, commodity or index and its value at the end of the contract.



Source: Nord Pool Spot

Figure 2: ***Trading Volume Development 1996-2009 (TWh)***

2.2.1 Forward contracts

Futures and forward contracts are used by market players to reduce their exposure to electricity price volatility, thus are a hedging instrument. They provide a joint expectation of future prices plus a risk premium. Furthermore, depending on the time horizon, these contracts might incorporate information about reservoirs levels, expectation about future events and other factors that might influence long-run electricity price. While futures at Nord Pool are daily and weekly contracts, forwards are traded for monthly, quarterly and yearly time periods. In particular: monthly contracts are listed on a continuous rolling base of six months, with no splitting, quarterly contracts are split into monthly contracts and yearly contracts are split into quarters (see Fig. 3). Moreover, in the case of the forward contracts, differently from the futures, there is no mark-to-market settlement during the trading period. This is instead accumulated as daily loss or profit and realized only at the time of maturity of the contract.

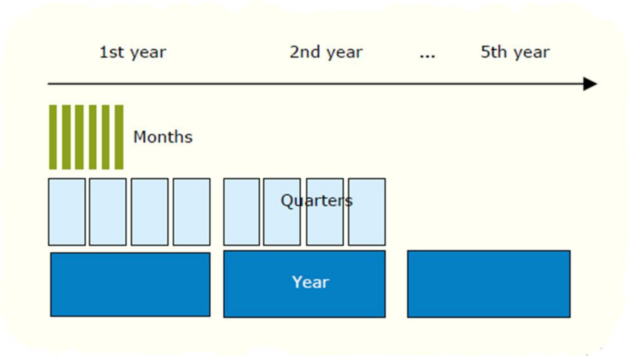


Figure 3: *Forward contracts*

Because the most commonly traded contracts on the Nord Pool financial market are monthly, quarterly and yearly forward contracts, these are also the object of this analysis.

3. Theoretical Background

3.1 Literature review

Since its introduction in the early 70's by Eugene Fama, the market efficiency hypothesis has attracted the interest of many scholars in the finance field. However, the great majority of the studies have as subject of interest equity markets and fixed income markets, see Summers (1986), Dimson and Mussavian (2002), Liu and Maddala (1992) and Masih and Masih (1995) for examples, while the application of the efficiency hypothesis to younger markets such as those of commodities is still comparatively limited, although growing. In particular, research around the electricity market and on its efficiency is gaining momentum as the number of deregulated markets in the world increases and the first fruits of the deregulative wave of the 90's start to show their true shape.

When it comes to testing the efficiency of electricity and power derivatives markets, methods and conclusions vary greatly among researchers. Peroni and MacNown (1998) propose to adopt stationarity and cointegration tests in order to determine the efficiency of three different power futures (heating oil, gasoline and crude oil), finding these more appropriate than other methods because able to account for problems such as endogeneity, cointegration and non-normality that are usually found in commodities futures markets.

One of the first empirical studies about electricity derivatives and the efficiency of their markets was carried out by Avsar and Goss (2001). In the paper, the US electricity futures market is analyzed from 1996 to 1999 utilizing stationarity and cointegration tests. After applying unit root, Augmented Dickey-Fuller (ADF) and Philipp-Perron tests to the dataset, the authors reject the efficient market hypothesis for the aggregated trading period 1996-1999 but cannot reject the hypothesis for the trading period 1998-1999, implying the market condition have improved as it has grown older and more geographical areas have joined the trading.

The same approach was followed by Arcinegas *et al* (2003). to test the efficiency of three different US power markets from 1998 to 2001. Similarly to Avsar and Goss, the authors cannot reject the null hypothesis of efficiency and find the markets reaching a higher grade of efficiency as they become more mature.

Yang *et al.* (2009), instead, propose to use the variance ratio test to analyze the EMH at Nord Pool futures market. The use of the test is justified due to the presence of heteroskedasticity and non-normality in the electricity prices distribution. Using this method, the authors are able to conclude that the market satisfies the condition for the weak form of efficiency and, in particular, they found the market to be more efficient in the period 2000-2003 than during 1996-1999.

More recently, the Norwegian author Steinar Veka has published two studies about the market efficiency of power derivatives at Nord Pool. In his first paper the researcher uses the martingale difference hypothesis as market efficiency condition, testing the price process of 4-weeks block and monthly forward contracts for both linear and nonlinear dependence. He used Choi’s (1999) Automatic Variance Ratio test, to test linear dependence, and the Generalized Spectral test proposed by Escanciano and Velasco (2006) that takes into consideration also nonlinear dependence. In this study Veka found that while in the long run the prices behave conformingly to the Martingale difference hypothesis of no dependence, this equilibrium appear to be disturbed in periods of particular market stress. More interesting, the author finds the efficiency of the futures market at Nord Pool to be influenced by extreme weather conditions since inefficiency is observed in periods with particularly low hydro reservoirs.

In his second paper Steinar Veka tests, instead, the week form of EMH on those who appear to be the most traded forward contracts at Nord Pool (next month, next quarter and next year) for the period 2005-2010. In order to analyze the behavior of these three contracts, the author employs four different tests: The Ljung Box test, the Run test, Dickey Fuller univariate unit root test and, finally, Fisher combined test. Although some evidence of dependent returns for specific contracts have been encountered, the study has not found strong evidences against the efficiency hypothesis for the most traded forward contracts.

The interesting findings brought to light from Veka are at the foundation of the present work. For this reason some of the test applied from the author will be utilized here. Furthermore, in order to investigate the independence and identical distribution hypothesis of the returns from a nonlinear perspective, the Brock, Dechert, and Sheinkman (BDS) test is applied. The BDS has been widely used in the literature to study the behavior of time series residuals and to test the efficient market hypothesis. In particular Solibakke (2006) applied the BDS on forward price changes in the Nordic electricity power market for the period 1995-2003, finding nonlinear dependence in the data series. Similarly Green (2009) employs the BDS test on daily log-returns on different forward contracts and spot prices at Nord Pool observed between 2000 (for the spot prices, 2002 for the forwards) and 2005 strongly rejecting IID assumption for the raw returns but confirming it when these where devolatilized and transformed in approximated Lévy increments.

Table 1: Summary of some empirical studies on EMH in power markets

Author(s)	**Market**	**years**	**Approach**	**Findings**
Avsar and Gross (2001)	US electricity futures	1996-1999	ADF and Philipp-Perron	The authors reject the EMH for the aggregate period 1996-1999 but cannot do so for the period 1998-9 implying market conditions improved with time
Archinegas *et al* (2003)	three different US power markets	1998-2001	ADF and Philipp-Perron	The authors cannot reject the EMH and find the market becoming more efficient with time
Yang *et al* (2009)	Nord Pool futures market	1996-2003	Variance Ratio	The market satisfies the condition for weak form EMH, in particular it appears more efficient in the period 2000-2003 than 1996-1999.
Veka (2011)	Nord Pool futures market	2005-2010	Ljung-Box, ADF, Runs and Fisher combined test	The study does not found strong evidence against the weak form of market efficiency
Veka (2011)	Nord Pool Futures markt	1996-2010	Automatic Variance Ratio, Generalized Spectral test	The study founds indications of both linear and nonlinear independence when the market is in nervous conditions, but improving with time
Solibakke (2006)	Nord Pool forwards contracts	1995-2003	BDS	The author finds nonlinear dependence in price changes
Green (2009)	Nord Pool forwards contracts and spot prices	2000-2005	BDS	The author finds nonlinear dependence in the returns but confirms the IID hypothesis once the returns are transformed in Lévi increments.

Table 1 above summarizes the results and approaches used in some of the main empirical literature. This study employs all the major approaches utilized by previous researchers in order to make the results as comparable as possible.

3.2 Market efficiency theory and tests

3.2.1 Efficient Market Hypothesis

The modern definition of the Efficient Market Hypothesis (EMH) has been formally phrased by Eugene Fama in his classic paper "Efficient Capital Market: A Review of Theory and Empirical Works" of 1970. The concept of an information efficient market though was already circulating in the academic world at the beginning of the century thanks to the works of Bachelier (1900), which first introduced the idea of market prices behaving as a Random Walk, and Cowles (1933), whom empirically tested the forecasting ability of different groups of market players, and represents one of the founding pillar of modern finance theory.

A market is said to be efficient according to the EMH "*[…] if it fully and correctly reflects all relevant information in determining security prices. […] Moreover, efficiency with respect to an information set implies that it is impossible to make economic profits by trading on the basis of [that information set]*"(Malkiel, 1992, in Campbell *et al*, 1997, pp. 20-21). Meaning that the extent and rate of speed at which a market adjusts to information has exceptionally important implications for how well a market functions and if the markets can be used for speculation through technical and fundamental analysis.

According to Fama (1970) market efficiency can be divided in three categories that o describe how efficient a market is in terms of adjusting to and reflecting information: the weak, semi-strong and strong forms of efficiency.

(1) **Weak-form efficiency** can be found in a market that fully incorporates historical price movements in future ones. This means that the returns (or price movements) must be serially independent of each other over time. If this would not be the case, agents could make profits by forecasting future prices based on historical ones. In statistical terms, the weak market efficiency is often compared to the random walk model.

(2) **Semistrong-form efficiency** implies that in addition to the properties of a weakly efficient market, the prices also reflect all public information. In this case for investors there is no possibility to realize excess returns neither by analyzing historical or any other public information. This would imply that not even fundamental analysis would be of any use to draw abnormal profits from the market.

(3) **Strong-form efficiency** is the higher level of efficiency and it basically impossible to achieve in the real word. In a market that is strongly efficient prices reflect all information available, including insider information. The consequence for a strongly efficient market is that no excess returns can be made even when in possess of superior information, since this is already incorporated into the price.

3.2.2 Hypotheses for weak form of market efficiency

Although Fama's definition of market efficiency is broadly accepted in the academic world, the case is not the same when considering efficiency tests. In the years ,researchers in the field of economics and finance have proposed a great number of tests, dependent on different data characteristics and hypothesis. The three most popular hypotheses for the weak form of market efficiency are: Rationale expectations, Martingale process and Random Walk Hypothesis (Campbell *et al*, 1997).

(1) **Rationale Expectations (RE)**: According to John Muth (1961), who pioneered this approach, because at time t it is not possible to predicts happenings at time t+1 then prices changes will behave randomly and the expected forecasted error will be equal to 0. The model is described as:

$$P_{t+1} = E_t[P_{t+1}] + \varepsilon_{t+1} \qquad (1)$$

Where $E_t[P_{t+1}]$ is the expectation at time t of P_{t+1} and ε_{t+1} is the forecast error. And:

$$E_t[\varepsilon_{t+1}] = E_t\big[P_{t+1} - E_t[P_{t+1}]\big] = 0 \qquad (2)$$

This last condition implies that the expectation of the price at time t+1 is unbiased and that the forecast error "*[…] must be uncorrelated with the entire set of information that is available to the forecaster at the time the prediction is made*" (Muth, 1961), i.e. the error should be serially uncorrelated for all leads and lags.

(2) **Martingale Process**: The Martingale is one of the oldest asset pricing models used in finance. Theorized by Cardano already in 1565 (Hald, 2005), it has its foundation in the notion of *fair game*, i.e. a game for which none of the adversaries has any advantage. A martingale is, thus, defined as a stochastic process P_t for which:

$$E_t[P_{t+1} | P_t, P_{t-1}, \dots] = P_t \qquad (3)$$

Where if P_t is taken as the cumulative winning at time t from playing a game of chance, then it would be a fair game if the expected winning at time t+1 would be equal to the winning at time t given the winnings in all the previous periods. If, instead, P_t is defined as asset price at time t, then according to the martingale hypothesis the best forecast of tomorrow's price would be today's price. Furthermore, the martingale implies that non-overlapping price changes are uncorrelated at all leads and lags (Campbell *et al*, 1997, pp. 29-31).

(3) **Random Walk Hypothesis (RWH)**: The random walk hypothesis is virtually the basis of almost all the modern models describing dynamics. It finds its origins in the martingale of which it incorporates the main assumptions and it is defined as: a stochastic process which trajectory is made of consequent random steps. More precisely three different forms of random walk hypothesis have been theorized:

- **RW1**: Is the simplest type of random walk and assumes that increments are independently and identically distributed (IID.). It is defined as:

$$P_t = \mu + P_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim IID\ (0, \sigma^2), \tag{4}$$

  Where P is the price, μ is the drift term and ε_t is the error term, or increment, identically distributed with mean 0 and variance σ^2. The assumption of independence in the increments, makes RW1 not only a fair game but implies also that any nonlinear function of ε_t is uncorrelated (Campbell *et al*, 1997, pp.32).

- **RW2:** Although the popularity of RW1 and its theoretical simplicity, in reality it would be extremely naïve to assume the probability distribution of stock returns to remains unchanged over long periods of time. Therefore RW2 relaxes the probability distribution assumption of RW1 and defines a random walk process one where the increments are still independent but not identically distributed (INID). This form of the RW allows, thus, for one of the most commonly observed characteristics of stock returns, unconditional heteroskedasticity, while still maintaining the most fundamental assumption of the RW 1, i.e. the unforecastability of future price increments based on historical price increments.
- **RW3:** Due to the characteristics of real asset returns, it is virtually impossible to find a real price process who respects the strict assumptions of RW1 or even RW2.

> Therefore, in the majority of the cases, empirical studies rely on a more general form of RW which drops also the assumption of independence in the increments to include processes that satisfy only the non-correlation requirement.

The underlying hypothesis of efficient market analyzed in this work is, in conformity with the majority of recent studies, that of prices following the last and more general random walk hypothesis.

4. Methodology and data

The biggest share of empirical literature on market efficiency defines its null hypothesis as the statistical relationship that asset prices follow a unit root data generating process (also referred to as a random walk). Such a process cannot be predicted in any profitable way because the optimal forecast of future prices will simply be the current price. The alternative is a stationary data generating process, implying the time series of prices tends to revert toward its mean. Such mean reversion excludes market efficiency because investors observing price deviating from its mean can appropriately buy or sell the asset in anticipation of realizing a profit when the asset price moves back toward its mean (Dorfman, 1993).

In this study, four econometric tests of efficiency are employed chosen because of their different power and null hypotheses. These are some of the most widely utilized test for investigating the distribution of asset returns. By applying different approaches we hope to gain a greater understanding of the characteristics of Nord Pool financial market. In particular, this will make it easier to compare the results obtained with those of previous studies.

4.1 Tests for the Random Walk Hypothesis

Four tests have been chosen for this research: serial autocorrelation and Ljung-Box Q statistic, Variance Ratio test, Runs test and BDS test. The first approach is used in order to analyze the relation between the series of returns and their values at different lags; in an ideally efficient market this relation should be inexistent. The variance ratio test is employed to verify whether the return series satisfy the RW condition of having a variance that is a linear function of the time interval between which the return is computed. The Runs test instead is here included with the scope of investigating the serial independence of the returns, i.e. whether succeeding price changes appear to be influenced by each other. Finally, the BDS test is applied in order to measure the probability of the return being dependent in a non-linear fashion.

Although various approaches have been developed in order to test for RW1 and RW2, the assumption of identical distribution and independence of stock return is empirically implausible and, thus, out of the scope of this work. Nevertheless, even under the weakest form of the RW, the assumption of unpredictability of price changes remains valid. Therefore all the tests chosen in this study are compatible with, at least RW3, assumptions.

4.1.1. Serial autocorrelation and the Ljung-Box test

One of the first intuitive steps to take when studying market efficiency is to look at serial autocorrelation in the returns. According to the RW hypothesis the returns should be uncorrelated at all leads and lags, thus the presence of autocorrelation is per se already a sign of predictability of future returns, i.e. inefficiency. The autocorrelation coefficient at lag k is defined as:

$$\rho(k) = \frac{Cov(r_t, r_{t+k})}{\sqrt{Var(r_t)}\sqrt{Var\ (r_{t+k})}} \qquad (5)$$

In a process with perfectly uncorrelated returns the autocorrelation function $\{\rho(k)\}$ should be equal to 0 for every k > 0.

In order to test whether all the autocorrelation are zero at the same time a number of test statistics, the so called *portmanteau statistics*, have been developed. Among these that implemented by Ljung and Box (1978) is the most widely applied due to its good power in finite sample. This statistic tests whether all the autocorrelations up to lag *m* are different from zero and it's defined as:

$$Q'_m \equiv T(T+2)\sum_{k=1}^{m}\frac{\rho^2(k)}{T-k} \qquad (6)$$

Where T is the sample size.

This formulation, by summing the squared autocorrelation, allows us to see whether the autocorrelation wanders from zero for all lags and in each direction. The statistic follows a χ^2 distribution with *m* degrees of freedom and has no serial autocorrelation as null hypothesis, i.e. a rejecting the null hypothesis would mean rejecting RW assumption.

4.1.2. The Variance Ratio test

The Variance Ratio test investigates the assumption of RW that wants the variance of the increments, or returns, to be a linear function of the time interval. This property is harder to demonstrate for the two weakest RW models due to the relaxation on the assumption of constant variance trough time. Nevertheless, this ratio is based on the particular property that the variance of the sum of the increments should be equal to the sum of their variances, and this is a property that must be valid also for RW2 and RW3.
The ratio is defined as:

$$VR(q) = \frac{Var[r_t(q)]}{q\,Var[r_t]} = 1 + 2\sum_{k=1}^{q-1}\left(1 - \frac{k}{q}\right)\rho_k \tag{7}$$

Where r_t is the increment, or return, at time *t* and q is the time interval. Because the RW assert that the increments are uncorrelated over all lags, VR(q) must be equal to 1 for all the q. In case the VR is greater than one the returns have a positive autocorrelation, while the relation would be inverse for VR smaller than one.

The test statistic employed in this study is that formulated by Lo and MacKinlay (1988) for a sample of nq+1 observations $\{p_0, p_1, \dots, p_{nq}\}$ using overlapping q-period returns and is defined as (assuming heterosckedastic returns):

$$Z(q) = \frac{\overline{VR} - 1}{\phi_e(q)} \approx N(0,1) \tag{8}$$

Where $\overline{VR}$ is the adjusted variance ratio estimator, defined by:

$$\overline{VR} \equiv \frac{\overline{\sigma_c^2}(q)}{\overline{\sigma_a^2}}; \tag{9}$$

Where:

$$\overline{\sigma_a^2} = \frac{1}{nq-1}\sum_{k=1}^{nq}(p_k - p_{k-1} - \hat{\mu})^2; \tag{10}$$

and

$$\overline{\sigma_c^2} = \frac{1}{m}\sum_{k=q}^{nq}(p_k - p_{k-1} - q\hat{\mu})^2; \tag{11}$$

with

$$m \equiv q(nq - q + 1)\left(1 - \frac{q}{nq}\right); \tag{12}$$

and

$$\hat{\mu} \equiv \frac{1}{nq}\sum_{k=1}^{nq}(p_k - p_{k-1}) = \frac{1}{nq}(p_{nq} - p_0); \tag{13}$$

Finally, $\phi_e(q)$ is the correction for heterosckedasticity. Under the null hypothesis the Z statistic has a normal distribution with mean 0 and variance 1 corresponding to RW.

4.1.3. The Runs test

Another commonly used test to investigate linear dependence in the price changes is the Runs test. This is a non-parametric statistical test which analyses how the sequence of consecutive negative and positive increments (runs) is distributed. The actual distribution is then compared with that of a RW with the same number of observations.

In this study, rather than define positive and negative runs as positive and negative returns we decided to employ a different approach, standard in MatLab, that considers a return positive (+) if above the mean return and negative (-) if below it. This particular approach is widely use in the empirical literature and, in respect to the standard one, it has the advantage of allowing for an eventual time drift in the mean while at the same time correcting for it. The null hypothesis of the runs test is RW, thus in order for this not to be rejected the number of runs, sequences of returns with the same sign, actually registered should be as close as possible to the expected number according to a RW.

Let P_+ and P_- be respectively the number of positive and negative returns in a sample of N observation, a RW process should have an expected number of runs defined as:

$$E[R] = \frac{N + 2P_+P_-}{N} \tag{14}$$

With a variance of:

$$\sigma^2(R) = \frac{2P_+P_-(2P_+P_- - N)}{N^2(N-1)} \tag{15}$$

If N is large enough then the returns will approximately follow a normal distribution with a test statistic defined as:

$$Z = \frac{r - E[R]}{\sqrt{\sigma^2(R)}} \tag{16}$$

4.1.4. The BDS test

Originally introduced by Brock, Dechert and Scheinkman in 1987 from which it takes the name, the BDS test is “a non-parametric method for testing for serial dependence and non-linear structure in a time series”(Brock *et al*, 1987). The test is founded on the concept of spatial correlation from chaos theory and can be computed as follows:

Given a time series with N observations, the data is firstly organized into *n-histories* x_t^n, defined as:

$$x_t^n = \{x_{t-n}, \dots, x_t\} \tag{17}$$

Where *n* is the embedding dimension.

Successively the fraction of pairs of x_t^n that are “close enough” to each other is computed. Two x_t^n are defined “close enough” if the greatest absolute difference between any of the corresponding observations of the pair is comprised between 0 and a closeness indicator k.

The fraction of close pairs is thus defined as:

$$C_{n,T}(k) = \frac{1}{T(T-1)} \sum_{i \neq j} I_{i,j,k} \tag{18}$$

Where T is the size of the sample of *n*-histories and $I_{i,j,k} = 1$ if $\left\| x_i^n - x_j^n \right\| \leq k$ and 0 otherwise.

Finally, the probability that a randomly selected pair of *n*-histories is closed is given by the *correlation integral*, that is the limit of (18) as the sample size increases.

Brock, Dechert and Scheinkman (1987) showed that even when k is finite if the time series is IID then $C_{n(k)} \approx [C_1]^n$ for any *n*.

In order to test this characteristic the authors theorized the BDS test statistic:

$$J_{n,T}(k) = \sqrt{T} \frac{C_{n,T}(k) - C_{1,T}(k)^n}{\hat{\sigma}_{n,T}(k)} \tag{19}$$

Where $\hat{\sigma}_{n,T}(k)$ is an estimation of the standard deviation of $C_{n,T}(k) - C_{1,T}(k)^n$. Under RW $J_{n,T}(k)$ is asymptotically standard normal and has IID as null hypothesis (Campbell *et al,* 1997, pp. 476-9).

4.2 The Dataset

The base dataset of the study consists of daily (closing) prices of rolling forward electricity contracts traded in the period January 2nd 2006 – May 11th 2011. The observations were extracted from the database of Nasdaq OMX Commodities and consist of 1321 daily prices in euros per time series. The forward contracts have a delivery period of respectively one month, one quarter (four months) and one year.

Because the underlying hypothesis of a Random Walk process assumes the process' continuously compounded single period returns r_t to be random and, more in particular IID (RW1), continuously compounded returns for each of the three price series are computed as:

$$r_t = Ln(P_t) - Ln(P_{t-1}) \tag{20}$$

Furthermore, because the price series are given by rolling forward contracts, i.e. switching contract at maturity, in order to eliminate any eventual disturbance created by the change of contract, the returns at the switching date have been removed.

Successively, in order to analyze the market efficiency in extreme scenario on the supply side, data on the hydrological balance in the Nordic System have been collected. The Hydrological balance indicates the deviation from normal of the hydro reservoirs, including also the potential energy embodied in the snow reservoirs that will melt in the spring and flow into the hydro reservoirs.

5. Data Analysis

In this section the three sets of data will be analyzed in respect to the Efficient Market Hypothesis. Firstly a general check of the raw data will be carried through in order to get a good understanding of its characteristic and to see whether there are any adjustments that need to be made. Secondly the extreme scenarios are defined based on data on the hydrological balances. Finally the four tests are carried through on each set of data.

5.1 Seasonality check

Among all the factors influencing electricity demand weather conditions are definitely one of the most significant. In the winter people need more electricity to heat and light up their houses, especially in the Nordic countries where the temperatures are very rigid and the days short. This increasing demand tends to drive the prices of electricity up in the winter months and down in the summer. Because the objects of this analysis are electricity forward contracts it might be possible that, especially for monthly contracts, the seasonality of electricity prices would be mirrored in the prices of forward contracts. In order to avoid distortion in the results due to this effect, a seasonality check is carried through for all the three series of closing prices (see appendix).

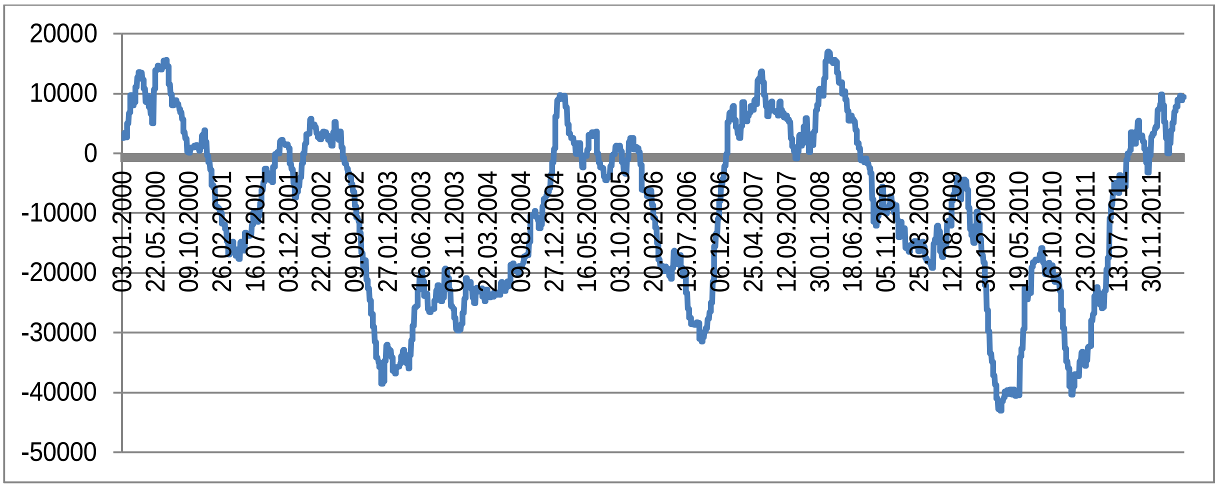
No clear evidence of seasonal effects was observed in the quarterly and yearly forwards prices datasets, while this is partially evident for the monthly contracts. However, because the magnitude of the effect does not appear to be significant and its pattern is rather unclear, no seasonal adjustment is considered necessary in this analysis for any of the data series.

5.2 Scenario definition

The relationship between electricity prices and hydrological resources availability at Nord Pool is a well documented fact due to the characteristics of power generation of the Nordic region, where the two biggest consumer and producers of electricity, Sweden and Norway, have hydropower representing respectively more than the 98% and the 45% of the total internal energy production. The double nature of electricity as non storable good on the consumers side and storable, to a certain extent, on the producers side since it could be stored as water in their reservoirs, give rise to possible asymmetry between demand and supply, hence to arbitrage possibilities. Recently Gjolberg and Johnsen (2001) have furthermore demonstrated the relationship between hydro reservoir availability and electricity derivatives prices. Interestingly, the two authors have found the futures market at Nord Pool inefficient in incorporating the available information on hydro reservoirs.

In this study, two scenarios with extreme conditions have therefore being constructed in order to analyze whether the availability of hydro reservoirs has any influence on the efficiency of the market.

Due to the particular meteorological situation of the recent years (see figure 4 below), and in particular of the periods in which the observations have been collected, it was possible to construct only two extreme condition scenarios where the number of observations was large enough to conduct statistical analysis.



Notes: The hydrological balance is given as deviation from the normal level of hydrological reservoirs. Source: Modity Trading.

Figure 4: ***Hydrological balance 2000-2012 (GWh)***

The first scenario is defined as “wet” scenario and is computed by taking the returns observations in the period January 8st 2007 and July 18th 2008, where the hydrological level registered was above the normal one. The second scenario instead is defined as “extremely dry” and is computed by taking the returns observations between October 26th 2009 and the end of the dataset, i.e. May 11th 2011. In this period the hydrological level registered was at least 10000 GWh below the normal level.

5.3 Augmented Dickey Fuller unit root test

One of the most common tests for Random Walk is the unit root test, in particular that developed by Dickey and Fuller (1979). This approach was originally designed to investigate whether a process has a unit root, i.e. if the nature of the shocks of a process $\{P_t\}$ is permanent or temporary. Defining $\{P_t\}$ as:

$$P_t = \mu + \phi P_{t-1} + \epsilon_t \qquad (21)$$

Where μ is a drift term and ϵ_t is an arbitrary zero-mean stationary process. The process has a unit root if ϕ is equal to one.

Under $H_0 : \phi = 1$ $\{P_t\}$ has a unit root and in order to be a RW its first difference must be stationary ($\phi \neq 1$). Nevertheless, although being difference stationary, I(1), is a prerequisite for a RW, this does not say anything about the predictability of the returns, since ϵ_t is allowed to be any zero-mean stationary process under both the null and alternative hypothesis. Hence this test cannot be considered a test for EMH but is carried through here with the sole scope of see whether $\{P_t\}$ satisfies the precondition for RW.

The test is thus conducted for the series of prices as well as for the return and the results are shown in Table 2.

Table 2: Augmented Dickey-Fuller (ADF) test for prices and returns series

	Price series			Return series		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**
ADF test statistic	-2,397566	-2,29886	-2,251269	-15,884**	-12,518**	-26,375**
p-value	0,1426	0,1725	0,1884	0,0000	0,0000	0,0000
# of lags.	5	8	10	4	7	1

Notes: The number of lags included is determined by the Akaike Info Criterion. The p-values are MacKinnon (1996) one sided p-values.
Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

According to the ADF test the results are conform to RW since the null hypothesis of unit root cannot be rejected for the series of prices while it is rejected with a level of significance greater than 99% for the returns. The price series appear thus to be integrated of order one, (difference stationary) which is the prerequisite for RW.

5.4 Test for ARCH effect

The behavior of returns volatility both in capital and commodities markets has been extensively studied and to assume constant volatility over a relatively long period of time would be both naïve and statistical inconsistent. Furthermore, observing the graphs (see Figure 5) of the series of returns analyzed in this study, the presence of volatility clustering appears evident for every contract and scenario.

Table 3: Test for Arch effect

	Base dataset			Wet scenario			Ex. Dry scenario		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**
ARCH(1)									
F-statistic	19,234**	14,955**	44,508**	5,314*	10,482**	1,913428	8,357**	0,805202	0,404399
P-value	0,0000	0,0001	0,0000	0,0218	0,0013	0,1674	0,0041	0,3701	0,5252
ARCH(5)									
F-statistic	10,628**	18,33**	23,502**	1,822878	5,357**	4,352**	14,535**	7,348**	4,695**
P-value	0,0000	0,0000	0,0000	0,1078	0,0001	0,0007	0,0000	0,0000	0,0004

Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

This pattern is very common when analyzing empirically financial data and is not per se a sign of market inefficiency,(see RW2 hypothesis). However, the presence of volatility cluster is likely to affect test’s results invalidating their output and, eventually, lead to erroneous conclusions on the efficiency of the market.

In order not to fall in this mistake, the actual presence of conditional heteroskedasticity is tested assuming the return series follows a process (consistent with the RW hypothesis) such as:

$$r_t = \mu + \epsilon_t \qquad (22)$$

Where μ is a constant, close to zero, and ϵ_t the error term.

Once this equation is estimated its residuals are tested for ARCH (AutoRegressive Conditional Heteroskedasticity) effect (see Table 3) utilizing the well known Engle test (1995) for lags up to 5. As shown on the table, although for the scenarios some results are not very clear, the test statistic in the majority of the cases rejects the null hypothesis of no ARCH effect.

Once the presence of heterosckedasticity has been confirmed, its effect must be removed and we do so by estimating a Generalized AutoRegressive Conditional Heteroskedasticity model, GARCH(1,1), where the mean equation is given by (22) and the variance is defined as:

$$\sigma^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \qquad (23)$$

The residuals obtained by this system of equation are now corrected for heteroskedasticity. Moreover before proceeding to test for EMH the returns are standardized using (24) (This is done automatically by Eviews).

$$Standardized\ Residual\ i = \frac{Residual\ i}{Standard\ Deviation\ of\ Residual\ i} \qquad (24)$$

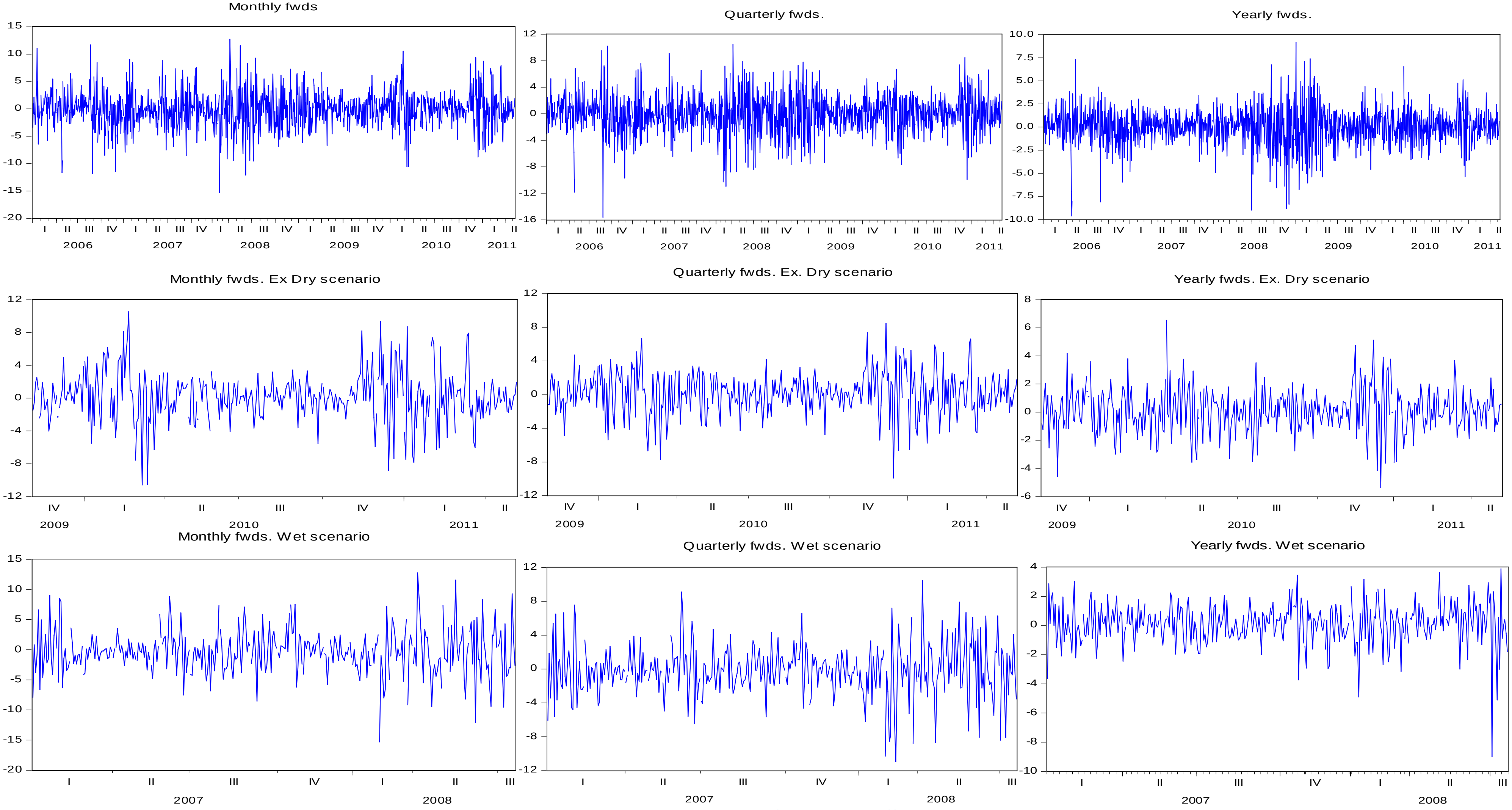


Figure 5: ***Daily log returns for the three different contract***

5.5 Adjusted data descriptive statistics

The descriptive statistics of the clean datasets of returns, obtained after these have been adjusted for ARCH effects and the returns at the switching date are shown in table 4 below.

Table 4: Descriptive statistics for the adjusted returns

	Base dataset			Wet scenario			Ex. Dry scenario		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly Fwds**	**Yearly Fwds.**
Observations	1256	1299	1315	343	355	360	364	377	381
Mean	0,010855	0,008721	-0,003565	0,007734	0,01443	0,030994	0,074254	0,046598	0,026445
Max	4,209728	4,153703	3,822847	3,620645	3,993552	3,19031	3,758478	3,486928	3,927081
Min	-6,252977	-4,623938	-5,48025	-5,660156	-4,143368	-5,588258	-3,401324	-3,116858	-3,739149
St. Dev.	1,000706	1,000162	1,000333	1,001489	1,001846	1,001431	0,998376	1,000386	1,001945
Skewness	-0,120457	-0,163038	-0,250151	-0,204447	0,014415	-0,618573	0,007054	-0,111278	0,040697
Kurtosis	5,348523	4,209078	4,595932	6,426428	4,456622	5,856531	3,857797	3,549915	4,014391
Jarque - Bera	291,685**	84,8786**	153,268**	170,179**	31,3964**	145,354**	11,163**	5,52836	16,440**
JB p-value	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0038	0,0630	0,0003

Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

The returns show a relatively high deviation from the mean with minimum and maximum peak up to more than 6 euros. These high values are not surprising due to the particular volatility that characterizes electricity contracts.

Furthermore all the series, apart from the yearly forwards in the dry scenario, have negative skewness meaning that large negative returns tend to be greater than large positive ones. All the series also show a value of kurtosis that is in excess of that of normal distribution (3) indicating that the distribution of returns is leptokurtic, i.e. showing higher peaks than a normal distribution.

The rejection of normal distribution is confirmed also by the Jarque-Bera test which presents extremely low p-values (with the exception of returns on quarterly contracts for dry scenario), therefore strongly rejecting the null hypothesis of Normal distribution.

5.6 Serial autocorrelation and Ljung-Box statistic

The results for the tests on autocorrelation of the returns completed with the Ljung-Box Q statistic at lag 10 are presented in Table 5.

Table 5: Serial ACF coefficients and Ljung-Box Q statistic for the returns

	Base dataset			Wet scenario			Ex. Dry scenario		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly Fwds**	**Yearly Fwds.**
ρ(1)	0.135**	0.081*	0.068*	0.037	0.006	0.051	0.205**	0.102	0.078
ρ(2)	0.043	0.005	-0.031	-0.064	-0.137*	-0.047	0.021	-0.018	-0.086
ρ(3)	0.065*	0.020	-0.008	0.083	0.034	0.009	-0.011	-0.051	-0.056
ρ(4)	0.030	0.054*	0.032	0.062	0.094	0.031	-0.019	0.024	0.038
ρ(5)	-0.041	-0.026	-0.004	-0.062	0.019	-0.005	0.001	-0.019	-0.016
ρ(6)	-0.037	-0.045	-0.010	-0.045	-0.003	0.030	0.037	-0.023	-0.028
ρ(7)	0.013	-0.006	-0.012	0.033	-0.057	-0.161*	-0.033	0.038	0.058
ρ(8)	0.052	0.056*	-0.007	0.027	0.141*	0.089	0.008	-0.004	-0.014
ρ(9)	-0.015	0.005	0.008	-0.090	-0.018	-0.047	0.010	0.044	0.050
ρ(10)	-0.019	-0.003	0.028	-0.047	-0.079	0.019	-0.103	-0.102	-0.091
Ljung-Box Q	40.03**	20.53*	10.461	12.027	21.50*	16.057	20.78*	11.046	12.987
p-value	0.000	0.025	0.401	0.283	0.018	0.098	0.023	0.354	0.224

Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

There is evidence of autocorrelation at lag 1 for all the three contracts in the base dataset, while in the scenario analysis it shows significance only for the monthly contracts in the extremely dry scenario. Traces of autocorrelation at lags greater than one are also found in the

However, the autocorrelation seems to decay as the number of lag increase and in particular, according to Ljung-Box statistics it would not be significant for the yearly contracts both in the base dataset and in the two scenarios. The hypothesis of RW would be rejected instead for the daily returns on monthly contracts both in the base dataset, strongly, and in the extremely dry scenario and for the daily returns on quarterly contracts in the base dataset and wet scenario with 95% significance level.

5.7 Variance ratio test

The results for the variance ratio test, which are strongly connected with those of the ACF, are presented in Table 6 below. The number of lags has been selected in conformance of that utilized in previous studies and by Campbell *et al* (1997).

Table 6: Variance ratio tests for lags 2, 4, 8 and 16

	Base dataset			Wet scenario			Ex. Dry scenario		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly Fwds**	**Yearly Fwds.**
VR(2)	1.1357**	1.0812**	1.0699*	1.054249	1.040699	1.022894	1.2083**	1.10591*	1.082291
p-value	0.0000	0.0042	0.0142	0.3243	0.4601	0.6485	0.0001	0.0338	0.0957
VR(4)	1.2819**	1.1400**	1.071905	1.109362	0.980536	1.011084	1.3384**	1.121823	1.013590
p-value	0.0000	0.0072	0.1670	0.2625	0.8447	0.9051	0.0003	0.1841	0.8814
VR(8)	1.3794**	1.19594*	1.095281	1.232107	1.059911	0.998851	1.4171**	1.132667	0.994740
p-value	0.0000	0.0170	0.2448	0.1295	0.7019	0.9940	0.0054	0.3690	0.9715
VR(16)	1.4682**	1.28336*	1.129808	1.277716	1.152710	0.980440	1.428843	1.109606	0.961360

p-value	0.0001	0.0205	0.2844	0.2287	0.5123	0.9322	0.0557	0.6237	0.8623

Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

In concordance with what observed in the serial correlation and Ljung-Box test , the Variance Ratio strongly reject the null hypothesis of no autocorrelation for the returns on monthly contracts both for the base dataset and for the extremely dry scenario, with a decaying fashion after lag 10. The returns on quarterly contracts also show autocorrelation in the base dataset while this is confirmed in the extremely dry scenario only for VR(2). Interestingly the variance ratio test is not able to reject RW assumptions for none of the three contracts analyzed in the wet scenario. Furthermore, in accordance with the previous test, the returns on yearly contract show sign of efficiency in all the scenarios analyzed.

5.8 Runs test

The results of the runs test are presented in Table 7 below. This is a non-parametric statistical test, it does not depend on the underlying distribution of the returns but it tests whether these can be compared to those of a randomly generated series with the same number of observation. Due to its characteristics therefore the test could be done on the original series of returns. Nevertheless, in order to maintain consistency with the previous results, also this test is run on ARCH adjusted returns.

Table 7: Runs test

	Base dataset			**Wet scenario**			**Ex. Dry scenario**		
	Monthly Fwds	**Quarterly Fwds.**	**Yearly Fwds.**	**Monthly Fwds**	**Quarterly Fwds.**	**Yearly Fwds.**	**Monthly Fwds**	**Quarterly Fwds.**	**Yearly Fwds.**
R	586	630	640	171	181	179	164	190	188
P+	633	641	677	166	170	193	177	190	191
P-	623	658	638	177	185	167	187	187	190
z	-2,3973*	-1,1043	-0,9621	-0,0892	0,2467	-0,0595	-0,929	0,0012	-0,3077
p-value	0,0165	0,0695	0,336	0,9289	0,8052	0,9525	0,0536	0,9991	0,7585

Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

According to the Runs test all the return series, with the exception of returns on monthly contracts in the base dataset, are distributed randomly. The null hypothesis of RW is therefore here rejected only for the monthly contracts in the base scenario at a 95% level of significance.

5.9 BDS test

The results of the BDS test for nonlinear dependence are reported in Table 8 below.

Table 8: BDS test

	Base dataset			Wet scenario			Ex. Dry scenario		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly Fwds**	**Yearly Fwds.**
dimension(2)	0.3647	0.5060	0.3238	0.1268	0.5154	0.4389	0.5879	0.5071	0.7543
dimension(3)	0.4118	0.4258	0.1413	0.4043	0.5327	0.2311	0.7392	0.1971	0.3231
dimension(4)	0.6120	0.2490	0.0808	0.8580	0.8693	0.1203	0.9081	0.1393	0.5972
dimension(5)	0.5120	0.2221	0.1371	0.8611	0.9474	0.1727	0.9143	0.2208	0.7684
dimension(6)	0.3829	0.4112	0.2955	0.8548	0.6993	0.2297	0.7635	0.3864	0.9041

Null hypothesis rejection significant at 95% level. Null hypothesis rejection significant at the 99% level.*

Once the ARCH effects have been eliminate, although some residual autocorrelation has been found by the previous tests, the BDS is not able to reject the null hypothesis of IID returns for any of the series analyzed independently from the scenarios. Hence no sign of nonlinear dependence is found in the ARCH adjusted returns, in accordance with the RW hypothesis.

6. Summary and conclusions

Table 9 summarized the results of all the tests performed in accordance with the weak EMH approximated by RW3.

Table 9: Summary of test results

	Base dataset			**Wet scenario**			**Ex. Dry scenario**		
	Monthly fwds.	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly fwds.**	**Yearly fwds.**	**Monthly fwds.**	**Quarterly Fwds**	**Yearly Fwds.**
ACF at $\rho(1)$	NO	NO	NO	YES	YES	YES	NO	YES	YES
Ljung-Box Q	NO	NO	YES	YES	NO	YES	NO	YES	YES
VR(2)	NO	NO	NO	YES	YES	YES	NO	NO	YES
Runs test	NO	YES	YES	YES	YES	YES	YES	YES	YES
BDS	YES	YES	YES	YES	YES	YES	YES	YES	YES

**Notes: NO if the results of the tests contradict the EMH, YES otherwise.*

According to our analysis there are mixed evidences of weak form of efficient market, according to the EMH definition, for the derivative markets at Nord Pool.

The ARCH effect test has found clear signs of the presence of heteroskedasticiy in the distribution of results, contradicting thus the RW1 assumptions. However assuming independency in the distribution of daily asset returns over time would not be realistic. It is common knowledge in fact that most stock returns are characterized by periods of relative tranquility followed by periods of turbulence (Bollerslev and Hodrick, 1992). In particular volatility clustering in electricity markets has been widely documented and modeled, see Byström (2005), Clewlow and Strickland (2000), Green (2009). Due to this characteristic, the efficiency of the market is here measured allowing for heteroskedasticity, RW2 and RW3, on standardized returns from a GARCH(1,1) model.

For the yearly contracts most of the evidence does not allow the rejection of the null hypothesis of RW distribution, hence for market efficiency. Quarterly contracts show more mixed results, implicating the presence of some kind of correlation between the returns. While for monthly contracts results more difficult to accept the assumption of efficiency since traces of autocorrelation are detected by all the tests both for the base and extra dry scenario. These results could be explained by the nature of monthly and quarterly contacts which, because of their shorter maturity, are more influenced by fundamentals and thus weather conditions. Furthermore, the inefficiency here observed could also be only apparent and be a sign of low liquidity in the market of the specific contracts.

Interestingly all the contracts seems to perform better in the two sub dataset, in particular, for the wet scenario only the Ljung-Box test finds traces of inefficiency in the quarterly contracts. These results appear to support the hypothesis of less arbitrage possibilities in case of abundance of hydro reservoirs. Meaning that when the need of fossil fuels or other more expensive power sources is lower than the normal the prices are less predictable.

On the other hand, the result observed in the extremely dry scenario at a first look might seem to provide evidence in the opposite. However, in order to not interpret these results erroneously, it is important to consider that the dataset has been collected in a period of particularly low hydrological reservoirs. Furthermore, by pure coincidence the scenario with extremely dry conditions contains the newest observation of the dataset. In this sense, thus, a greater evidence of efficiency in the extremely dry scenario could be the effect of the market becoming more mature and able to incorporate the weather information more efficiently. Evidences of these phenomena have been already documented and would be in accordance with previous studies.

7. Policy recommendations: Was it worth to deregulate?

The deregulation boom that hit electricity markets all over the world in the 90’s has been object of praise as much as of critics in the following years. In particular the institution of financial instruments to answer the need of risk management has raised issues relatives to gaming, market power, price spikes and reliability. The analysis of Nord Pool in this sense is extremely interesting being it not only one of the oldest of its kind but also the largest in terms of number of countries involved. Furthermore with the *not-so-long-term* planning of a pan-European power market the importance of Nord Pool being efficient is further amplified as this is seen as a prototype.

In this paper signs of the market moving towards efficiency are founds. In particular in those contracts which provide longer run hedging, such as the yearly and quarterly ones. However we have also observed that in condition of shortage of cheap energy sources market returns show higher level of predictability. Nevertheless the data seems to indicate the presence of a trend towards increasing efficiency also in presence of low hydro power availability. This last result would then support the deregulation cause and indicate that as the market matures and expands in new regions the presence of a larger number of players improves its general efficiency.

The results presented in this analysis overall appear to endorse the cause of a more integrated European market based on the success of Nord Pool. However an in-depth study of the market in the single regions would be needed in order to reach a more informative conclusion on the matter.

8. Suggestions for further studies

Due to the limited amount of time and data available in this occasion, only two scenarios could be constructed and it has not been possible to compare results in similar condition through time. However it would probably be interesting to include in the analysis returns from previous wet/extremely dry condition on the supply side and thus gain a greater understanding about the evolution of the market and the speed at which information about weather conditions is incorporated in the prices.

Furthermore, the present study has analyzed extreme conditions only on the supply side, due to the more complex situation of the demand side and limited information about normal and exceptional electricity consumption. Nevertheless, we believe that an analysis on this side of the market could bring new interesting insights on the way it functions.

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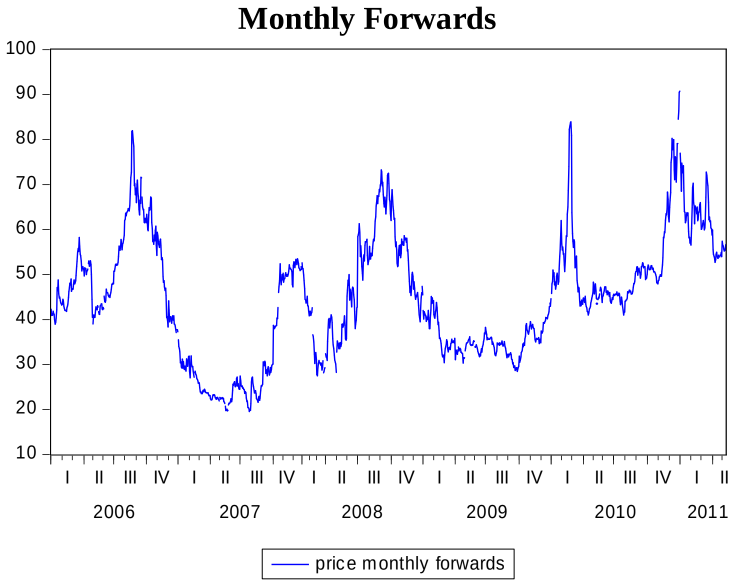
International Energy Agency (IEA): www.iea.org

Nasdaq OMX commodities: www.nasdaqomxcommodities.com

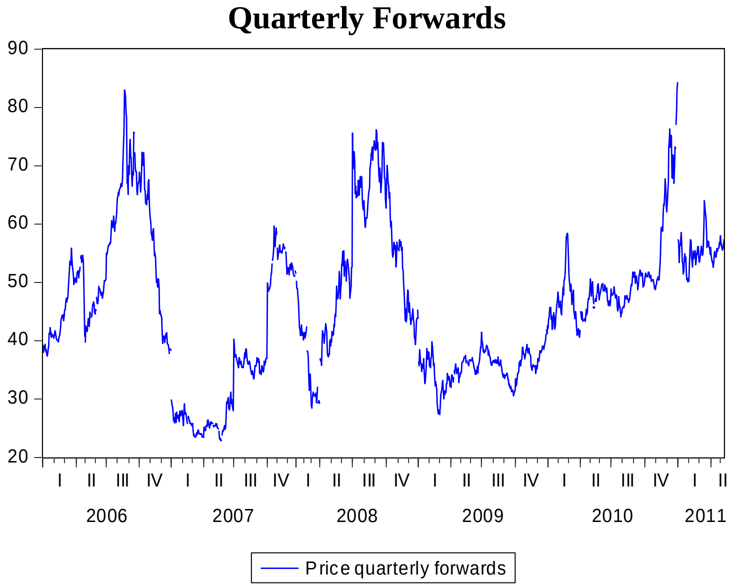
Nord Pool Spot: www.nordpoolspot.com

Appendix

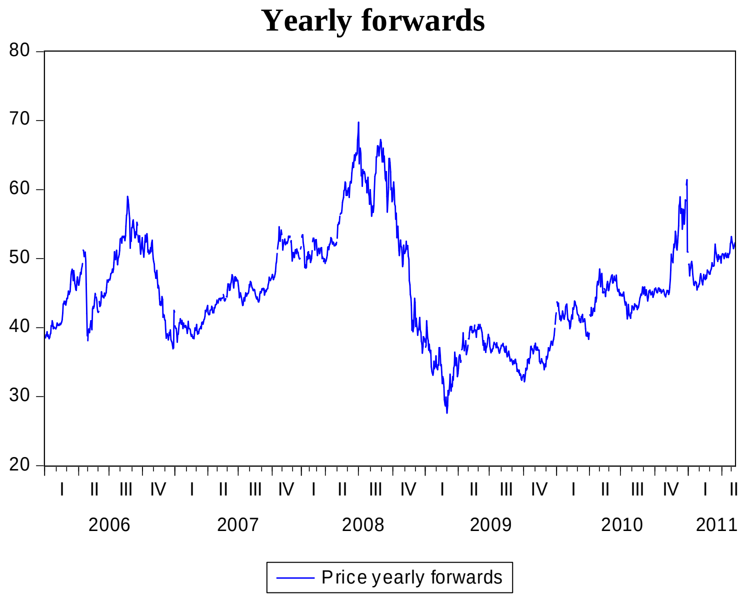
1. Seasonality check



Seasonal behavior is evident only in part of the dataset, although this could occasionally create ambiguity in the interpretation of the analysis, in this particular case the author consider the magnitude of the seasonal pattern to be such that it could be ignored without causing significant problems to the analysis.



No evident seasonality. No adjustment needed.



No evident seasonality. No adjustment needed.