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Risk Premia in European Electricity Futures Investigated

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Preface and acknowledgements

Writing this thesis provided me with an insightful look into the world of electricity trading, as well as the academic believes and research performed in this area. This thesis took me from the start of the theory of risk premia by Keynes in 1930 all the way to research published this very year, and while the theory may still suffer from contrasting results, its application to electricity futures seems to hold. In taking this particular road, thereby leaving many options for research aside, I found great help through Mehtap Kilic and Ronald Huisman. Together with them, many research options were discussed, resulting in this thesis. My acknowledgements therefore go to them, in helping me to complete my research.

Abstract

This paper investigates the existence and some explanatory factors of risk premia in the European electricity markets of The Netherlands, Belgium, Germany and Scandinavia. Analyses were performed in accordance with earlier research by Fama and French (1987) and Bessembinder and Lemmon (2002). Findings show that futures prices relate to current spot prices, and that the model by Bessembinder and Lemmon has lost power over the last years. Future research opportunities lie mainly in the many factors that explain electricity spot and futures pricing, and consequentially, the behaviour of risk premia.

Keywords:
Risk premia, electricity, futures.

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1 - Introduction

Electricity plays a vital role in modern day life. It provides us with the easy and ready-to-use energy needed for the simplest thing as brewing coffee or lighting our houses. Electricity therefore is as valuable to mankind as for instance water. This value and necessity is perhaps the reason why both electricity and water have been provided through government controlled and owned entities throughout the world. For electricity, this model has changed. The straightforwardness of government controlled electricity generation companies has been replaced by liberalization and nowadays many generating companies are privately owned. Another development in the world of electricity is that of deregulation, that is, the separation of generation, transmission and distribution activities to enable free entry and thereby competition in the electricity market. For Europe, the European Commission, has started this process by issuing Directive 96/92/CE, which was later replaced by Directive 2003/54/EC. The latter Directive enforced member states to unbundle the electricity generation, transmission and distribution activities before July 1st, 2004. Simply put, there should be separate companies for generating, transmitting and distributing electricity before said date. The goal of this Directive lies mainly in enabling consumers to choose freely between different operators and thereby introducing competition, which should drive prices down. Another consequence, however, is the emergence of financial markets for electricity. The case of Switzerland shows us that deregulation is no strict necessity for establishing electricity markets, but it is known to contribute to the emergence of these markets (Mork, 2001).

The emergence of financial markets for electricity puts electricity in the league of commodity trading. Oil, gold and corn are but a few of the commodities traded worldwide on a massive scale. These commodities are traded manifold their real consumption and know numerous derivatives allowing for hedging or more complex financial structures and transactions. One of the most basic derivatives is, perhaps apart from the put or call option, a futures contract. A futures contract is, in essence, an agreement between two parties agreeing to buy or sell some quantity of a commodity in the future for which they agree upon the price today. This protects both the buyer and the seller of the commodity against any price changes that may occur. The use of derivatives can, however, be more extensive as well, for instance through speculation. One can imagine that entering into a futures contract today whilst expecting, a price change can be beneficial. Another possibility could be buying a commodity today, storing it, and then sell it at an –expected– higher price. Modern trading and speculating revolves largely around looking for these kinds of opportunities, also known as arbitrage. As similar derivatives are also available for electricity, such arbitraging opportunities are also sought and exploited. Apart from being used in trading, commodities and their futures are also subject of extensive academic research. One can easily imagine that if price behaviour can be explained and predicted, money can be made. Apart from this financial motivation, the behaviour of prices is also interesting from an academic point of view in trying to explain it. One of the many studies undertaken to explain the behaviour of commodity spot and futures' prices is that by Fama and French in 1987. In their paper, Fama and French analyse the relation between spot and futures' prices behaviour for 21 commodities. They do this by testing for two views on futures' prices: the 'theory of storage' and risk premium and forecasting power of the futures' price. The former entails the price of the future being the sum of the current spot price, the costs of storing the commodity until the future matures, the interest rate forgone for this period and the marginal convenience yield from an additional unit of inventory. The latter, on the other hand, entails the futures' price being the sum of the spot price, an expected risk premium and an expected change in the price. According to Fama and French, the theory of storage is "*not controversial*" (p. 62), whereas the theory on forecasting power and risk premia is "*subject of long and continuous controversy*" (p. 62).

In trying to explain the behaviour of electricity futures prices, there is one fundamental difference with the commodities analysed by Fama and French: the fact that electricity can *de* facto not be stored. This simple but crucial fact renders the non-controversial theory of storage *a priori* useless. It does, however, leave the possibility of analysing the theory of forecasting power and risk premia for electricity futures, which is what I will be doing later on. The second and next section will discuss and describe the energy markets in The Netherlands, Belgium, Germany and Scandinavia. The following third section will review some of the current literature risk premia and on electricity spot and futures' prices. Thereafter, the fourth section will briefly discuss the data used for analyses. The fifth section will contain the results from analyses, which will be discussed in the sixth section. Finally, the seventh section will conclude and identify future research areas and opportunities.

2 – Energy markets

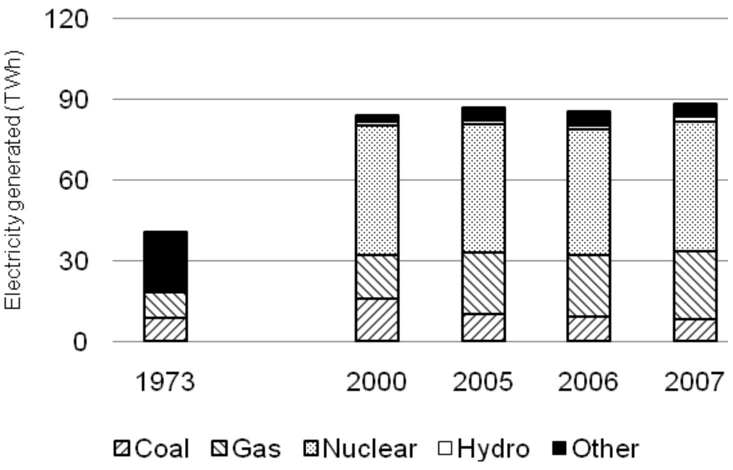
In this section, I will describe some European energy markets. Focus will be on both the physical aspects –generation, import, export– and financial –electricity exchange– aspects. Most information came from the International Energy Agency (IEA), part of the Organization for Economic Co-operation and Development, OECD. After describing the markets, a comparison based on similarities and differences across countries will be possible.

2.1 – Belgium

Energy generation in Belgium is mostly done through nuclear plants, after historically relying on oil, coal and gas, see also figure 2.2. The move into nuclear has pushed current generation from fossil fuels back to little under 40 percent. Over 2007, Belgium imported some 15.8 TWh and exported some 9.0 TWh, making up for respectively 19 and 11 percent of final consumption. Imports mainly came from France, followed by The Netherlands and Luxembourg whereas exports mostly went to The Netherlands, then France and Luxembourg (IEA, 2009a). Remarkably, Belgium does not share a cross border transmission point with Germany, and consequently does not import from, or export to, Germany. Belgium followed the EU directives for liberalizing the electricity market in 1999 and 2005 and, as a consequence, opened the Belgium Power Exchange, or BELPEX. BELPEX was formed as a cooperation between the Dutch, Belgium and French grid operators and the Dutch and French energy exchanges. Trade in the spot market exceeded 11 TWh in 2008, making for a rather liquid market (IEA, 2006a).

Figure 2.1 - Generation mix for Belgium

Source: IEA (2009a)



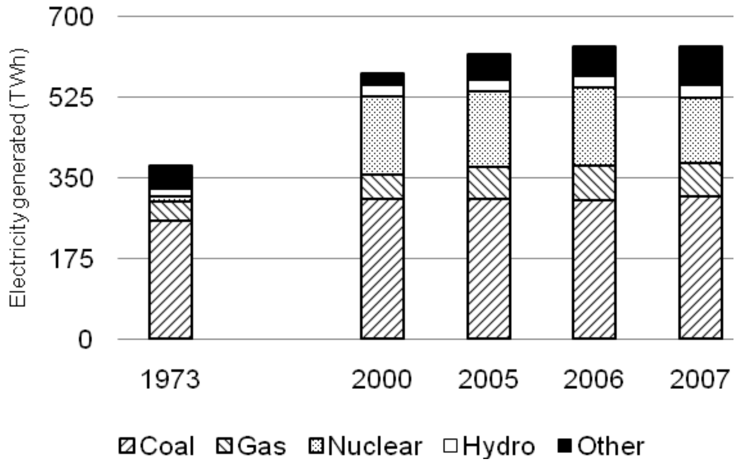
2.2 – Germany

Germany is the biggest electricity generator in Europe. Most of this electricity is historically generated through coal, but the emergence of nuclear plants over the last decades is also evident, see also figure 2.4. Altogether, fossil fuels are still responsible for little under 62 percent of all electricity generation. A net exporter, Germany exported some 62.5 TWh of electricity to neighbouring countries in 2007, whilst imports were only 46.0 TWh. Electricity exports were mainly bound for The Netherlands, Austria and Switzerland, whereas imports came from France, The Czech Republic, Denmark, Austria and Switzerland (IEA, 2009a). Germany's relatively central position in Europe is used in the grid connections it has with Austria, the Czech Republic, Switzerland, France, The Netherlands, Denmark, Poland and Sweden (IEA, 2007a).

Germany first started liberalizing its electricity market in 1998, and currently all customers can freely choose their electricity supplier. The current electricity exchange, EEX, was formed in 2002 by the merger between the German electricity exchanges of Leipzig and Frankfurt. Trading in 2006 has nearly reached 600 TWh, thereby proving high market liquidity.

Figure 2.2 - Generation mix for Germany

Source: IEA (2009a)



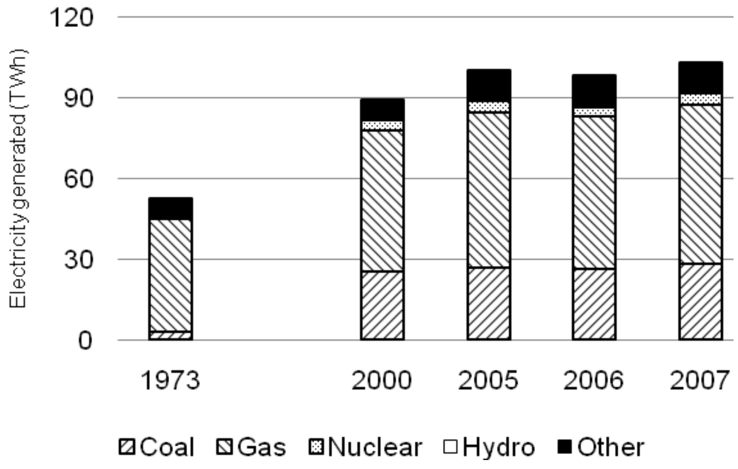
2.3 – The Netherlands

The Dutch energy market has always been one driven by gas. This is probably best explained through the presence of gas under Dutch soil, providing The Netherlands with their own energy supplies. Combined with the relatively large portion of coal generated electricity, The Netherlands use some form of fossil fuel for around 84 per cent of total generation. The evolution of the generation mix for The Netherlands is depicted in figure 2.5. Another critical aspect of the Dutch electricity usage is their imports and exports. Starting around the 1990s, The Netherlands have relied on energy imports ever since, adding up to some 21 percent of final consumption being imported in 2007. The lion's share of these imports came from Germany, but Belgium and France have also contributed to supplying the Dutch energy needs. Exports for 2007 summed up to some 5 percent, nearly all of which was transported to Belgium (IEA, 2009a).

Electricity import and exports are possible through The Netherlands' extensive connections with neighbouring countries, including of course Belgium and Germany, but also the United Kingdom and even Norway (IEA, 2009b). Electricity liberalization in The Netherlands has started in the late 1990s. Following liberalization, the Dutch power exchange APX was established in 1999, after which trade volumes have shown near consecutive growth. Following the inclusion of ENDEX in the APX group in December 2008, spot and futures trading now fall within the same organization. Total trade of the entire Dutch electricity market is estimated at some 400 TWh, providing more than sufficient liquidity (IEA, 2009b).

Figure 2.3 - Generation mix for The Netherlands

Source: IEA (2009a)



2.4 – Scandinavia

The Scandinavian electricity market differs somewhat from the abovementioned European companies as the Scandinavian countries –Denmark, Finland, Norway and Sweden– have jointly developed an electricity exchange: NordPool. I will therefore discuss the physical aspects of the four countries separately and the financial aspects for the Scandinavian countries combined.

Aggregate Scandinavian electricity generation is shown in figure 2.6, and is dominated by hydropower, responsible for some 53 percent of total electricity generation in 2007. Fossil fuels are responsible for only 16 percent of electricity generation. The individual contributions of the Scandinavian countries in 2007 are depicted in figure 2.7. Most striking are the differences in generation: where Denmark relies on fossil fuels for over 70 percent of generation, Norway uses almost exclusively hydropower. Sweden, the region's largest electricity generator uses a combination of hydro- and nuclear generated electricity, whereas Finland's generation mix is rather fragmented (IEA, 2005, 2006b, 2007b, 2008, 2009a).

With regards to imports and exports, Finland is the largest net importer, importing 15.4 TWh and exporting 2.9 TWh and Norway is the largest net exporter, importing 5.3 TWh whilst exporting 15.3 TWh. Denmark and Sweden are much more self sufficient, with Denmark importing 10.4 and exporting 11.4 TWh and Sweden importing 16.1 and exporting 14.7 TWh.

Not surprisingly, the Scandinavian countries are well connected, on top of which connections exists with neighbouring countries such as Germany (Denmark and Sweden), Poland (Sweden) and Russia (Norway and Finland). Imports and exports are also largely kept within the region, with Finland importing from Russia and Denmark exporting to Germany as the only major exceptions (IEA, 2009a). The Scandinavian electricity exchange was first established in Norway in 1993, following one of the earliest European decisions to liberalize their electricity in 1991. In 1996, Sweden joined the exchange to start the first multinational exchange in 1996, followed by Finland in 1998 and Denmark in 2000. Nowadays, NordPool is the biggest electricity exchange in Europe, trading some 287 TWh in 2009. NordPool is also the exchange that has moved beyond, rather extensive, cooperation between other electricity exchanges and is integrated amongst various countries.

Figure 2.4 - Generation mix for Scandinavia

Source: IEA (2009a)

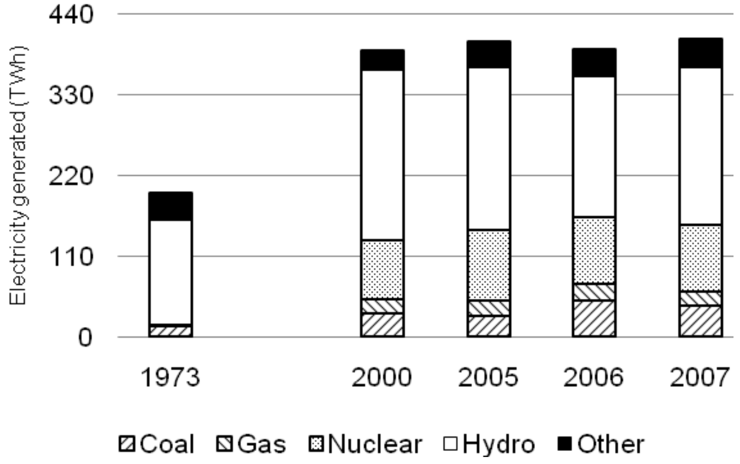
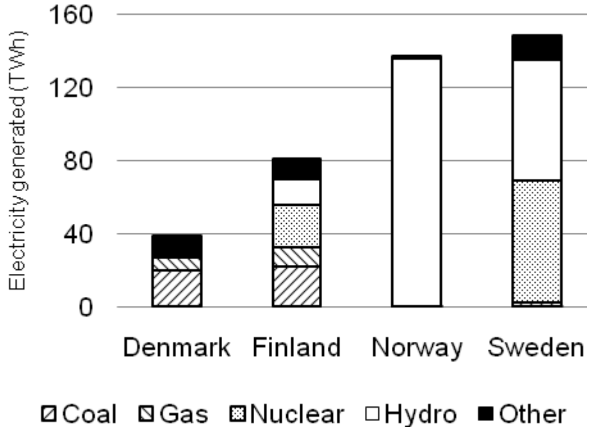


Figure 2.5 - Generation mix per country (2007)

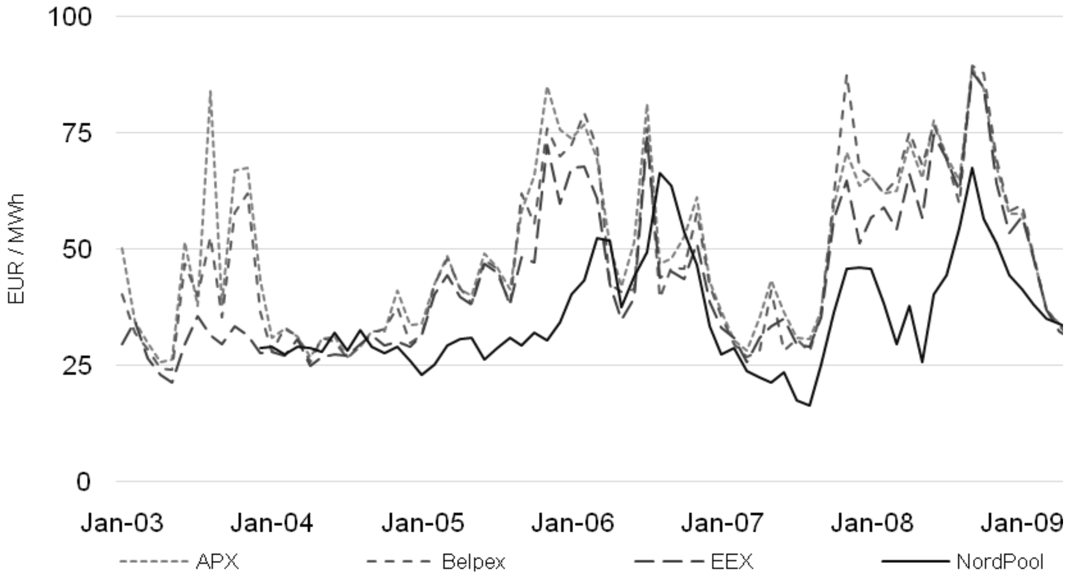
Source: IEA (2009a)



When comparing the energy markets described above, the chief differences appear in the generation mixes employed by the various countries. The Netherlands and Germany, for instance, seem to rely mainly on fossil fuels such as coal and gas, Belgium relies on nuclear power and Scandinavia relies on –Norwegian– hydropower. Another noteworthy point lies in the combined electricity exchange as present in Scandinavia. Using the data from the various exchanges, one can also look for differences in the spot price as quoted on the markets, monthly averages of which are depicted in the below figure 2.8.

The below prices show very similar development, something which is not really surprising when considering exchange and physical integration as described above. One striking aspect, however, lies in the behaviour of NordPool spot prices, which shows different movements than the others. In the next section, I will look at some of the current academic literature to explain this behaviour in the NordPool exchange, and look for further information on the behaviour of electricity spot and futures prices and the existence and behaviour of risk premia.

Figure 2.6 - Electricity spot prices



3 – Literature review

As mentioned before, this article builds largely on an article by Fama and French (1987) explaining the behaviour of futures using two different theories. The first, and largely non-controversial, theory entails the price of futures being equal to the costs involved when you would own and store the commodity until maturity. Put differently, the futures' price should be equal to the current spot price of the commodity, the interest rate forgone for owning the commodity rather than money and the storage costs, minus the convenience yield for holding the commodity. This above reasoning makes intuitive sense as such a structure is vulnerable for arbitrage. Would, for instance, the physical (financial) option be cheaper, then people would adhere to that option and the consequential increased spot (futures) demand would drive spot (futures) prices up, thereby cancelling out the advantage. Unfortunately, electricity cannot be stored efficiently or effectively, and such arbitrage opportunities cannot occur. This leaves the other option mentioned by Fama and French, which is, unfortunately, widely debated. This other option "*splits a futures price into an expected premium and a forecast of a future spot price*" (p.55). First, I shall go back to the roots of the theory and follow it through time. Afterwards, I will discuss some, more current, literature related to electricity specifically.

3.1 – Economic theory

The theory of risk premia was first introduced by Keynes in 1930. His reasoning was rather straightforward, as he explained futures as a method of insuring, or hedging, against price volatility, and this method of insurance should cost money. Imagine a farmer harvesting his crops sometime in the future: he does not know, nor does anyone else, what the price of grain will be in the future. While this may be beneficial when grain prices are high on harvest, he would rather hedge the possibility of them being low. Hence he sells, or goes short, in grain futures, ensuring him a price and thereby taking away the risk of a price drop. Keynes now refers to him as a hedger. The other party, buying the futures –going long– is not so much concerned with his own harvest, but wants to invest, and thereby earn a return, making him a speculator. The reasoning of Keynes simply says that as the price risk is transferred from the farmer (hedger) to the investor (speculator), the latter wishes to be compensated for bearing the risk. Therefore, the futures price should lie below the expected spot price, leaving the speculator a profit: the risk premium. This phenomenon has also been described as (normal) backwardation, or the futures price being a downward biased estimator of the expected spot price. From this theory, the futures price is also expected to rise as the time to maturity decreases. The opposite, called contango, is the case when futures' prices are an upward biased estimator of the expected spot price, decreasing whilst nearing maturity.

The theory as introduced by Keynes found some critique from, for instance, Hardy (1940) and Telser (1958), who find it hard to believe that hedgers loose money *per se*, and instead believe speculators are willing to participate in the futures market for 'love of the game', rather than expecting a risk premium. In short, they believe risk premia do in fact not exist. Cootner (1960) adds to the discussion by stating that:

> "*All too many studies of the commodity markets have argued that, since hedgers are almost always trained professional merchants of the commodities in which they deal, and since the speculator is, more likely than not, a clerk, a doctor or a housewife, it is difficult to see how the former could lose money to the latter*" (p. 399).

Cootner, however, supports Keynes' beliefs and through his analyses of returns for speculators in wheat, finds evidence of the existence of nonzero risk premia. His findings do, however, show both rising and falling futures' prices, showing backwardation and contango specifically. The latter, contango, is explained by Cootner as hedgers being net long instead of net short in futures, adding to assumptions by Keynes. If, for instance, buyers of grain –who want to hedge the grain they need to buy– were to be more risk averse than grain farmers –who sell the grain–, the former would be net long and the latter net short, making for contango, where the risk premia are paid by the –net long– buyers through paying a price that is higher than the expected spot price. Put differently, the most risk averse party will be most inclined to hedge, and thereby pay the associated risk premium. In contango, the buyers are more risk averse and thus net long, making for futures' price above the expected spot price, whereas risk averse sellers, being net short, accept futures' prices below expected spot prices, causing backwardation.

Over a decade later, Dusak (1973) introduced a new theory regarding the returns speculators can earn in futures' trading. Instead of the theory of Keynes where speculators earn money because they take on risk, or the theories of Hardy and Telser, who believe speculators do not need such returns, she "*makes no presumption as to whether returns to speculators are positive [...] or zeroish to negative*" (p. 1388). Rather, Dusak believes returns are influential to the extent they contribute to a portfolio of investments. The difference lies in the fact that, according to Dusak, Keynes assesses the risk of a future by its own price variability, whereas Dusak would rather compare it to the overall risk in a "*large and well diversified portfolio of* *assets*” (p.1388), by which she links the futures’ risk to the well known capital asset pricing model, or CAPM. Following her theory, she analyses futures contracts for wheat, corn and soybean in the period 1952 to 1967 with regards to the S&P 500, and found both returns and beta –thus the relation between specific and overall risk– for these commodities to be close to zero. Dusak concludes by stating “*these results are a serious blow to the theory of normal backwardation*” (p. 1400), as no evidence was found for speculators on average earning a positive return.

The introduction of the CAPM into the risk premium discussion has been continued by Breeden (1980). He does, however, make a change to the model as suggested by Dusak, namely that he does not adhere to the systematic risk of futures –their relation to the market–, but rather to the consumption risk, or consumption beta. Through this change, Breeden follows another model: the intertemporal CAPM. Breeden states that the price changes for assets should not so much depend on the market or portfolio returns, but rather that “*real price changes are correlated with changes in aggregate real consumption*” (p. 504). This change in model has lead Breeden to conclude that, contrasting earlier findings by Dusak, “*some futures contracts have significant systematic risks that should result in risk premia*” (p. 520).

Continuing on the paper of Breeden, Hazuka (1984) relates the consumption beta to the risk premium first mentioned by Keynes. In his paper Hazuka investigates fifteen commodities on their risk premia, consumption betas and the relationship between them. Perhaps more importantly in line with this research on electricity, he classifies the commodities with regards to their storability: non-storable (live cattle, live hogs, eggs, iced broilers and pork bellies), seasonal storable (for instance wheat, soybeans, and sugar) and non-seasonal storable (copper, silver). His analyses showed that the theory of risk premia as employed within the intertemporal –or as Hazuka refers to it: consumption– CAPM shows the strongest evidence for non-storable commodities. Furthermore, he empirically shows the existence of a –linear– relationship between risk premia and consumption betas.

Fama and French (1987) conduct a research that investigates both the theory of storage and that of risk premia for 21 commodities. As the theory of storage has been dubbed unusable for electricity futures, I will focus on the risk premia part of their paper. Fama and French investigate whether the current basis, that is the difference between the futures and spot price, contains information about either the spot price at maturity, or the premium realized at maturity. They find that seven commodities –lumber, soy oil, cocoa, corn, wheat, orange juice and plywood– show evidence of expected premia. More interestingly, they do not identify such evidence for cattle, hogs, eggs, broilers and pork bellies; the commodities identified by Hazuka

(1984) as having the strongest evidence for risk premia. These commodities show, according to Fama and French, stronger evidence with regards to forecasting future spot prices and "*show no reliable evidence of time-varying expected premiums*" (p.65). They do, however, note later in their paper that "*failure to identify time-varying expected premiums does not imply that expected premiums are zero*" (p. 70). Nonetheless, Fama and French conclude that their "*evidence is not strong enough to resolve the long-standing controversy about the existence of nonzero expected premiums*" (p.72).

In a large elaboration of research by Hazuka and Fama and French, Klob (1992) investigates futures pricing for 29 different commodities for the period 1957-1988, adding up to some 980,800 daily futures quotations. He does, however, disregard "*the question of whether speculators are net long or net short, and [...] tests whether the rising price pattern associated with normal backwardation prevails in futures markets*" (p.76). Using this approach, Klob finds evidence that "*four commodities (feeder cattle, live beef, live hogs, and orange juice) follow normal backwardation*", followed by his finding that "*somewhat weaker evidence suggests that copper, cotton, soybeans, soy meal and soy oil follow normal backwardation*" (p.87). These findings thereby correspond to earlier findings of Hazuka and Fama and French, and seem to reaffirm the observation of Hazuka with regards to storability.

Deaves and Krinsky (1995) repeat the research by Kolb for the relevant four 'backwardation commodities' and three 'contango commodities' that he also identified. Moreover, they expand the timeline of the analyses from 1957-1988 as used by Klob to 1994. This expansion of research data has lead to both contrasting and confirming results. Orange juice seems to confirm less to the theory of normal backwardation, whereas for the "*case of the [...] livestock futures, backwardation continues to prevail for all but the shortest term price changes*" (p. 643). Following these results, Deaves and Krinsky feel "*forced to question whether any commodity futures, perhaps with the exception of those associated with livestock, are characterized by consistent risk premiums*" (p.643). They do, however, point to the limited storability of the livestock commodities when concluding on the matter.

From the above research, it is obvious that the theory of normal backwardation and the associated risk premia is still subject of large controversy. There is, however, evidence that supports its existence in the commodities that are difficult to store, leaving room for the application of the theory to electricity. Below, I will look into some of the research on backwardation, contango and risk premia with regards to electricity futures.

3.2 – Electricity and the risk premium

One of the first, and most influential, papers on risk premia in electricity futures comes from Bessembinder and Lemmon (2002). In their paper, Bessembinder and Lemmon develop an equilibrium model in which the futures' price is a biased predictor of the future spot price. The factors influencing whether the bias is upward or downward with respect to future spot prices are expected demand and the associated demand risk. The actual variables used are, respectively, variance and skewness of the spot price. Following their model, Bessembinder and Lemmon predict the risk –or as they refer to it: forward– premium to be "*decreased by the anticipated variance of the wholesale spot price and increased by the anticipated skewness of wholesale spot prices*" (p. 1378). When explained through the level of risk aversion by sellers and buyers, the model also holds. When demand variability, for instance, is high, electricity producers will need to generate enough to satisfy any demand, thereby taking the risk of producing more than necessary. When supply exceeds demand, prices should fall, posing problems for producers, who want to hedge this risk. Would producers, or sellers, be more risk averse, then they would pay the risk premium, making for backwardation. If, on the other hand, price skewness is positive, price will more likely go up than down, something which buyers will want to hedge against. In this case, the reverse happens as buyers are more risk averse and pay the risk premium, resulting in futures prices lying above expected spot price, causing contango. Empirical research on the American PJM (Pennsylvania, New Jersey, Maryland) and CALPX (California) confirm the model and show "*a positive bias in forward prices for summertime delivery while the bias in forward prices for spring and fall delivery is zero or negative*" (p. 1378).

Shawky *et al* (2003) were one of the first to empirically investigate the existence of nonzero risk premia. In their paper, Shawky *et al* investigate 6 month futures contracts traded at the New York Mercantile Exchange for the years 1998 and 1999. They use a relatively straightforward method to estimate the *ex ante* risk premium by calculating the *ex post* risk premium as the difference between the spot price and the average realized spot price as a percentage of the realized spot price. These premia are then regressed against the days left to maturity, and show a highly significant trend, revealing a risk premium of approximately 4% per month.

In 2004, Longstaff and Wang perform analyses on the PJM market to look for risk premia. In contrast to Shawky *et al*, however, Longstaff and Wang perform what they call a 'high frequency analysis'. Chief difference between their approach and that of Shawky *et al* is that Longstaff and Wang use hourly spot and day-ahead prices, thereby drastically reducing the time horizon. Nevertheless, Longstaff and Wang also find evidence of "*significant forward premia in electricity forward prices*" (p.1898) for the period June 200 to November 2002. Moreover, Longstaff and Wang "*find that forward premia are negatively related to price volatility and positively related to price skewness [which] provides strong support for the model [...] presented by Bessembinder and Lemmon*" (p. 1898). Longstaff and Wang also shed light on the theory that the risk premium is actually a reward for the party assuming the risk by "*regressing forward premia on measures of price, quantity, and revenue risk*" and conclude "*each of these risk measures plays a significant role in explaining the forward premium*" (p.1898).

Whereas the above two papers examined the existence of risk premia in American markets, Diko *et al* (2006) did so for the European markets of Germany (EEX), The Netherlands (APX) and France (Powernext) for the period January 2001 to August 2005. Using various futures contracts, that is: weekly, monthly, quarterly and yearly, Diko *et al* find their results to be "*in very good agreement with the theoretical model of Bessembinder and Lemmon*" (p. 8). They further find that "*as the time to maturity increases, the influence of skewness becomes relatively less important compared to the variability, and so the risk premium decreases*" (p. 10).

Cartea and Villaplana (2008) analyse the behaviour of forward prices and consequentially, that of risk premia, for the American PJM, English and Welsh and Scandinavian NordPool markets. Their findings are, once again, "*broadly in agreement*" (p.2513) with the model of Bessembinder and Lemmon. More interestingly, however, are their findings on the seasonality of forward premia. Specifically, Cartea and Villaplana find negative risk premia, indicating backwardation, in all three of the markets they analysed. They indicate that "*the intuition behind this result is that during the periods of negative forward premium, monthly forwards trade at a large discount due to hedging pressure from sellers*", where the opposite holds for the English and Welsh markets in contango, where "*forward contracts [...] were trading at a high premium, indicating hedging pressures from buyers*" (p.2518). With these comments, Cartea and Villaplana reaffirm the theory on rewarding risk takers through risk premia and thus offering futures at a premium or discount, depending on hedging pressure from respectively buyers and sellers.

Herráiz and Monroy (2008) take a somewhat broader approach in their analyses of the existence of nozero risk premia: they analyse the Iberian power market, OMIP, the French Powernext and the Scandinavian NordPool, as well as the commodity markets on oil (ICE, Brent), natural gas (ICE, NBP) and coal (EEX, ARA delivery). For the investigated period from July 2006 to September 2008, they find evidence that the three electricity markets and the gas market are, on average, in contango, whereas the oil and coal markets show backwardation through respectively positive and negative risk premia. Whilst evidence that electricity markets are in contango may not be surprising judging the above research, Herráiz and Monroy do conclude that "*compliance with Bessembinder & Lemmon's testable hypothesis [...] is relatively low*" (p. 236). More specifically, Herráiz and Monroy find the French Powernext to comply to Bessembinder and Lemmon best, followed by the Scandinavian NordPool's medium compliance and the Iberian OMIP's least compliant market. They blame the latter to lower liquidity and efficiency. The fact that the much more liquid and mature NordPool market also shows low compliance is, unfortunately, disregarded. Two years later, Furio and Meneu (2010) published a paper in which they "*confirm that the implications from the [Bessembinder and Lemmon] model are partially supported*" (p. 793). Moreover, they find the "*forward premium is directly related to to risk factors such as unexpected demand and the unexpected level of hydroelectric energy capacity*" (p.793).

Redl *et al* (2009) not only compare the specifics of energy and electricity prices, buth also link them. In their research, Redl *et al* look at the German EEX and Scandinavian NordPool for "*crucial impact parameters of forward electricity prices and the relationship between forward and future spot prices*" (p. 356). They do this using two regression models: one testing for the model by Bessembinder and Lemmon, and one testing for futures price formation through short run marginal production costs for coal and gas fired plants, emission prices and current spot prices. The results of the latter model are show futures price formation depends on marginal production costs, but moreover, depend on current spot prices. Correlation coefficients show a slightly higher correlation between electricity and coal prices and electricity and gas prices for the German EEX, whereas NordPool prices seem to correlate more to current spot prices. This can be explained through their different generation mixes, see also chapter 2. Redl *et al* do, however, conclude that "*the main characteristics of price formation at the EEX and Nord Pool forward markets are alike*" (p. 363). When regressing for Bessembinder and Lemmon's model, the results are not so alike. The German EEX shows baseload prices to be influenced by skewness but not so much by spot price variance. For peak loads, spot price variance is significant, but shows the wrong sign, and skewness is not significant. The results for NordPool are altogether not significant, which Redl *et al* explain through the generation mix of the countries participating in the market, which consists mainly of hydro power. This result seems to be seconded by the relatively poor compliance of the Spanish markets which also use hydro power, albeit to much lesser extent than the NordPool countries.

Lucia and Torró (2008) perform analyses on the Scandinavian NordPool market over a period of 10 years for weekly futures contracts. They too find evidence of positive risk premia, indicating the NordPool futures market is in contango. In line with aforementioned research by Cartea and Villaplana, they also find evidence of seasonality. Apart from confirming the equilibrium model by Bessembinder and Lemmon, however, they also find hydro reservoir levels to have "*additional explicative power over past premiums and bases in explain future premiums*" (p.34). Combined with findings by Redl *et* al, these findings introduce the method of electricity generation into the pricing of futures contracts, rather than just futures prices depending solely on characteristics of the electricity spot price as such.

In the past papers, the fact that electricity is *de facto* non-storable has lead research to focus solely on the theory of risk premia. Fact of the matter is, however, that the commodities needed for electricity generation, such as coal and gas, are storable. Douglas and Popova (2008) have analysed the effects of gas storage on electricity risk premia, and found a relationship does exist. More specifically, Douglas and Popova predict "*a sharply negative effect of gas storage inventories on the electricity forward premium when demand for electricity is high and [...] demand for gas is low*" (p.1712), predictions which are strongly supported by empirical analyses of the American PJM market. One explanation for this is the fact that gas can be converted into electricity with relative ease, thereby reducing the risk of price spikes that have been shown to have a positive effect on risk premia. Douglas and Popova therefore conclude by stating that "*any complete model of the electricity forward premium must include information about natural gas storage inventories*" (p. 1726).

Where gas as a energy source may be rather straightforward, water is not. Nonetheless, water is used to produce electricity through hydropower plants, and more importantly, water can be stored in lakes or reservoirs, thereby showing similar characteristics to gas. Botterud *et al* (2009) use this fact to analyse the, hydro dominated, NordPool market. Moreover, they do not merely use the risk premium theory as used so often in the abovementioned articles, they also apply the theory of storage to over 11 years of NordPool market data. Their research shows existence of nonzero risk premia, but shows the markets tend to be in backwardation for the first half of the year, and shift to a contango state in the last half of the year. Their results on examining the theory of storage for the NordPool market show that "*the relationship between spot and futures prices is clearly linked to the physical state of the system, such as hydro inflow, reservoir levels, and demand*" (p. 11). However, they must also conclude that their "*regression analysis with a combination of physical and market variables only has limited explanatory power for the observed [...] risk premia*" (p. 11-12). Nevertheless, the statement by Douglas and

Popova about the inclusion of physical inventories to models on electricity futures pricing does seem to hold.

The above papers have left little doubt on whether nonzero risk premia exist in electricity futures markets, as they all confirm they exist. There are, however, varying results on which factors influence the size and sign of the risk premia, and whether a market is in backwardation or contango. These factors include, but are most probably not limited to, demand and spot price variance, spot price skewness, current spot prices as such, but evidence has also been found on marginal production costs, seasonal effects, and last but not least, physical properties such as inventories. It is further important to note that these factors appear not to be mutually exclusive, as some markets show evidence of both physical and financial factors influencing futures pricing.

4 – Data description

The data for this paper consists of daily settlement prices for spot and various futures in electricity, all in EUR/MWh. Data comes from four electricity markets in Europe: the APX for The Netherlands, the BELPEX for Belgium, the EEX for Germany, and the NordPool for Denmark, Finland, Norway and Sweden, or: Scandinavia. The various maturities for the futures range from 1 month through 6 months, and one and two quarters. As the BELPEX does not trade as many maturities as the other three markets, there is no data for Belgian 5 and 6 month contracts, whereas for the 4 month futures, there is too little data (n = 46) available for analyses. Therefore, BELPEX market data is limited to futures with maturities of 1, 2 and 3 months, and 1 and 2 quarters. Throughout the rest of this paper, each maturity will be noted as M1, where the M stands for month or Q for quarter, and the number stands for the quantity. An overview of the used maturities per market can be found in Table 4.1.

Table 4.1 – Data used per market

	APX	BELPEX	EEX	NordPool
M1	x	x	x	x
M2	x	x	x	x
M3	x	x	x	x
M4	x		x	x
M5	x		x	x
M6	x		x	x
Q1	x	x	x	x
Q2	x	x	x	x
Start date	30/12/2003	07/09/2004	13/01/2003	22/03/2005
End date	23/06/2008	23/06/2008	23/06/2008	23/06/2008

Using these maturities, this research will focus on the mid- to long term behavior of electricity futures.

Market data is available for different periods, but all ending on June 23rd, 2008. APX Data is available from December 30th, 2003, while BELPEX data starts on September 7th, 2004. EEX data has the broadest range, starting at January 13th, 2003, whereas NordPool data is available from March 22nd, 2005. Start and end dates for the data ranges per market can also be found in Table 4.1.

An overview of some descriptive statistics can be found in Table 4.2. Starting from the top, all mean values, with the exception of the EEX M1 contract, are larger than the mean values for the spot price, and larger with time to maturity. This is first evidence of the electricity futures markets being in contango. This also applies to the median values. A second interesting fact comes from the differences between the markets: NordPool spot prices appear to be the lowest, followed by EEX, APX and BELPEX spot prices. This can also be seen in the futures prices, where the same order applies.

In looking at the standard deviation for each market, the first interesting point lies in the difference between spot and futures prices: the former is much bigger than the latter, with the NordPool market as an exception. As the standard deviations are roughly the same per market, it seems the NordPool market show lower spot price volatility, as opposed to higher futures price volatility. This can also be seen in Figure 2.8, where NordPool prices show less and smaller price spikes. Lastly, an increasing pattern as with the mean values does not occur with the standard deviations.

Table 4.2 - Descriptive statistics per market per maturity

	Spot	M1	M2	M3	M4	M5	M6	Q1	Q2
APX									
Mean	51.02	53.53	55.35	56.32	58.36	58.74	58.99	55.78	57.03
Median	45.46	51.65	54.90	55.57	57.59	58.88	57.43	56.78	56.45
Std. deviation	23.42	15.84	15.98	16.17	15.40	15.26	15.25	15.43	15.24
Minimum	13.60	28.65	28.59	30.65	34.03	33.89	34.96	31.98	34.92
Maximum	277.41	90.43	90.67	98.14	99.72	104.05	100.94	94.97	100.40
Observations	1128	1046	1128	1128	1017	1002	1002	1099	1126
Skewness	2.21	0.28	0.34	0.56	0.49	0.55	0.62	0.41	0.62
Kurtosis	11.18	-1.24	-1.07	-0.58	-0.38	-0.08	-0.19	-0.80	-0.38
BELPEX									
Mean	52.39	53.20	54.06	58.86				54.36	61.56
Median	45.50	53.23	53.18	57.91				53.70	58.74
Std. deviation	25.64	15.76	15.18	14.43				14.23	12.84
Minimum	14.00	27.65	27.41	28.80				29.57	35.20
Maximum	314.27	94.73	94.57	90.25				87.75	101.64
Observations	959	886	957	654				931	634
Skewness	2.83	0.28	0.29	0.04				0.26	0.56
Kurtosis	18.89	-0.90	-0.75	-0.92				-0.91	0.00
EEX									
Mean	43.30	43.24	44.00	44.31	44.40	44.62	44.86	44.14	44.86
Median	37.70	39.29	41.04	41.74	42.50	43.67	42.87	42.12	43.92
Std. deviation	20.72	14.25	14.42	14.36	14.06	14.12	14.12	14.10	13.98
Minimum	3.12	21.50	21.70	21.22	20.80	21.24	21.52	22.15	22.63
Maximum	301.54	83.00	79.70	85.84	86.25	93.99	89.00	81.23	89.70
Observations	1362	1326	1362	1362	1362	1362	1361	1325	1362
Skewness	3.19	0.53	0.42	0.43	0.42	0.48	0.50	0.37	0.47
Kurtosis	24.53	-0.82	-0.89	-0.72	-0.66	-0.39	-0.45	-0.96	-0.56
NordPool									
Mean	37.20	39.13	40.85	42.25	43.34	44.22	44.58	43.05	44.49
Median	34.11	37.45	39.38	40.04	40.98	42.16	43.78	40.55	43.25
Std. deviation	12.34	12.41	12.70	13.02	12.81	12.26	11.29	12.36	10.94
Minimum	10.24	19.55	19.45	21.80	22.35	24.10	24.00	22.89	25.80
Maximum	80.41	82.00	81.75	85.00	84.95	86.50	88.50	83.00	84.73
Observations	820	820	820	820	820	820	799	750	813
Skewness	0.66	0.67	0.68	0.76	0.77	0.82	0.74	0.59	0.90
Kurtosis	0.152	0.01	-0.07	0.17	0.38	0.616	0.51	0.02	0.836

Minimum and maximum values obviously concur with the above conclusions from the standard deviations: the NordPool maximum spot price is considerably lower than that of the APX, BELPEX and EEX. The same can be seen in the futures prices, where maximum (minimum) values are much lower (higher) compared to maximum (minimum) spot prices. Minimum and maximum futures price show weak signs of increasing, especially when compared to mean values.

With the number of observations per market per contract being sufficient, the last statistics of interest are the skewness and kurtosis per contract. Once again, there are large differences between the statistics for the spot and futures prices, the former showing higher values for both skewness and kurtosis for the APX, BELPEX and EEX. These statistics also show a different picture for NordPool, where both skewness and kurtosis show little sign of deviating from a normal distribution.

First conclusions with regards to the differences between markets are difficult, as more powerfull statistic test need to be applied, rather than just descriptive statistics. First results do, however, seem to confirm earlier findings of electricity futures being in contango, thereby leaving room for risk premia. Furthermore, Bessembinder and Lemmon’s (2002) model predicts risk premia to be positively related to skewness and negatively related to variance of the spot price. Differences between the markets, and especially between the APX, BELPEX and EEX and the NordPool, are therefore to be expected. In the following section, I will apply various statistical tests to the available data, in order to identify and quantify any differences, if present.

5 – Data analyses

In this section, I will analyse the data as described in the previous section using models from previous research. Specifically, I will analyse the risk premia themselves first, followed by the research as done by Fama and French (1987), and lastly I will apply the model by Bessembinder and Lemmon (2002).

The first method is rather straightforward, and uses an *ex post* approach in analysing the risk premia of a futures contract. The *ex ante* approach in establishing the risk premia would be to take the difference between the futures price and the expected spot price at maturity. It is, however, nearly impossible to determine exactly the expected spot price at maturity, rendering this approach non-usable. The approach taken here, the *ex post* approach, therefore looks at the spot and futures prices in hindsight. To enable comparison between the markets, I will use a method as applied by Shawky *et al* (2003) and Redl *et al* (2009), expressing the risk premium as a percentage of the spot price at maturity:

$$RP = \frac{F(t,T) - S(T)}{S(T)} \tag{1}$$

With RP denoting the risk premium, $F(t,T)$ the price of the futures contract maturing at time T and $S(T)$ the average spot price over the futures delivery period. Using equation (1), I will

Figure 5.1 - Risk premia with averaged spot prices

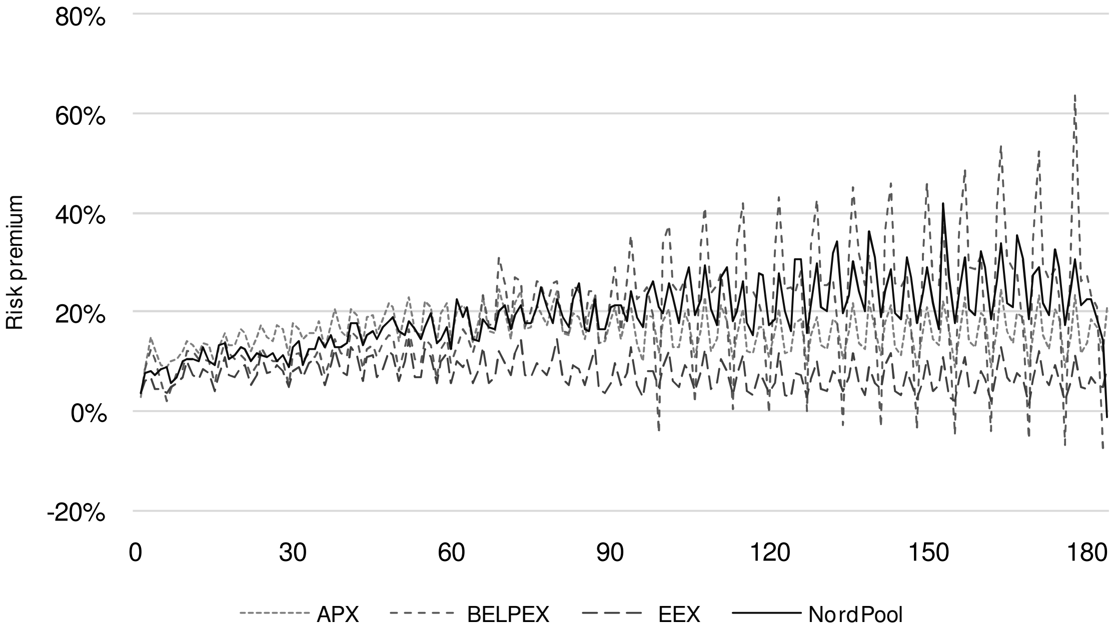
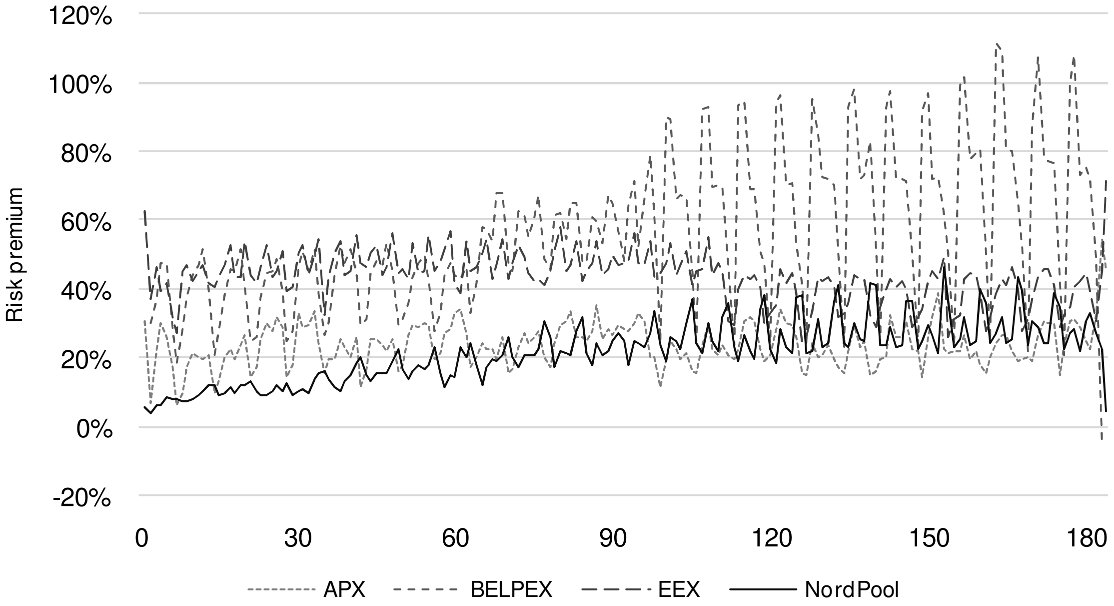


Figure 5.2 - Risk premia with last trading day spot prices



analyse the risk premia with regards to time to maturity, seasonality and per maturity.

In a similar approach to that of Shawky *et al* (2003), the first analyses is to regress the average risk premia per time to maturity, with time to maturity. Put differently, for each day to maturity, ranging from 1 to 184, the average risk premium per market is computed according to equation (1). This leads to risk premia as depicted in Figures 5.1 and 5.2.

The difference between the two graphs lies in the definition of $S(T)$. In Figure 5.1, spot prices have been averaged over the delivery period for the corresponding futures contract, whereas Figure 5.2 uses spot prices from the last trading day before maturity.

Table 5.1 - Pearson correlations

	Pearson correlation	Significance
APX	0.205	0.005
BELPEX	0.915	0.000
EEX	0.506	0.000
NordPool	0.947	0.000

Visual inspection of Figures 5.1 and 5.2 provides us with the first valuable information. It is obvious, for instance, that all risk premia are positive, with the exception of the BELPEX futures more than 90 days from maturity. Furthermore, the BELPEX futures beyond 90 days to maturity show much larger volatility than both the futures within 90 days to maturity and the other markets. Though this may seem a striking result, it may be due to the absence of monthly futures contracts beyond 90 days from maturity in the Belgian market. Furthermore, all markets, with the exception of NordPool, show larger volatility in risk premia when computed with the last trading day spot price, compared to the average spot price. Pearson correlation coefficients between the risk premia with average and with last trading day spot prices can be found in Table 5.1. As can be seen, results vary, and it is at this time unclear why there are such large differences between the BELPEX and NordPool at the one hand, and the EEX and especially the APX on the other. The rest of the analyses will be computed using the spot prices as averaged over the delivery time.

Having computed the risk premia per market and per time to maturity, it is now time to regress these risk premia against the days to maturity by using the following regression model:

$$RP = \alpha_1 + \beta_1 * t + \varepsilon_1 \tag{2}$$

where RP again denotes the risk premium and t denotes the number of days left to maturity. This regression has been computed for all markets, and the results are noted in Table 5.2. The results show, through the β_1 values, there is little evidence of time varying risk premia in all four markets. The fact that all β_1 values are positive is, however, evidence of rising futures prices with time to maturity, which is indicative of contango. Further, α_1 values show evidence of a constant risk premium, varying between 8.5% in Germany and 15.5% in The Netherlands, keeping in mind that R² values are rather low for all markets but NordPool.

Table 5.2 - Outcomes regression (2)

	α_1	Sig. (α_1)	β_1	Sig. (β_1)	R²(2)
APX	0.155	0.000	0.000	0.154	0.011
BELPEX	0.091	0.000	0.001	0.000	0.236
EEX	0.085	0.000	0.000	0.002	0.049
NordPool	0.108	0.007	0.001	0.000	0.484

The next step is to average the risk premia per contract. So, instead of averaging risk premia per day as above, I will compute the risk premia per contract for the contracts mentioned in Table 4.1. In a similar approach as in Table 4.2, descriptive risk premia statistics for all contracts and aggregate statistics for the monthly and quarterly statistics are mentioned in Table 5.3. Mean values per market for the monthly and quarterly contracts are also depicted in Figure 5.3. From Table 5.3 and Figure 5.3, we can once again learn that the futures markets adhere to contango through risk premia that are positive and, to a lesser extent, rising with time to maturity. It is, however, also evident that risk premia are not always positive, as all markets show minimum risk premia values that are negative, ranging from -27.4% to -44.8% for the monthly contracts and between -28.7% and -40.1%. Maximum values, on the other hand, range from 77.7% to 213.7% for the monthly and from 133.4% and 217.8% for the quarterly contracts. For the monthly contracts, there appears to be no trend when considering the minimum values, but maximum values do increase with time to maturity, which also shows itself through increasing skewness. Increasing standard deviations may indicate increasing uncertainty with longer time to maturity. Trend discovery for quarterly contract is difficult, considering there are only two quarterly contracts per market. Quarterly contracts as depicted in Figure 5.3 do, however, seem to fit trends as in the monthly contracts.

Table 5.3 - Descriptive statistics risk premia per market per maturity

	Overall	M1	M2	M3	M4	M5	M6	Q1	Q2
APX									
Mean	0.163	0.132	0.179	0.190	0.163	0.154	0.158	0.165	0.158
Median	0.064	0.105	0.144	0.107	0.024	-0.005	-0.045	0.085	0.059
Std. deviation	0.420	0.271	0.365	0.419	0.455	0.466	0.503	0.390	0.455
Minimum	-0.419	-0.344	-0.358	-0.326	-0.307	-0.400	-0.419	-0.305	-0.367
Maximum	1.958	0.985	1.368	1.834	1.839	1.853	1.958	1.582	1.808
Observations	8548	1046	1128	1128	1017	1002	1002	1099	1126
Skewness	1.710	0.707	0.975	1.430	1.699	1.770	1.823	1.593	2.039
Kurtosis	3.398	0.286	0.772	2.267	2.653	2.842	3.264	2.690	4.503
BELPEX									
Mean	0.153	0.098	0.123	0.249				0.106	0.249
Median	0.074	0.080	0.046	0.262				-0.014	0.098
Std. deviation	0.411	0.289	0.377	0.465				0.404	0.510
Minimum	-0.443	-0.405	-0.443	-0.429				-0.388	-0.321
Maximum	1.636	0.945	1.329	1.636				1.496	1.598
Observations	4062	886	957	654				931	634
Skewness	1.302	0.503	0.972	0.890				1.611	1.276
Kurtosis	1.954	-0.228	0.849	0.697				2.671	1.032
EEX									
Mean	0.074	0.073	0.095	0.088	0.075	0.066	0.066	0.076	0.054
Median	0.024	0.052	0.045	0.027	0.017	-0.016	-0.003	-0.007	0.013
Std. deviation	0.327	0.229	0.306	0.335	0.349	0.354	0.361	0.318	0.337
Minimum	-0.448	-0.420	-0.448	-0.424	-0.407	-0.427	-0.442	-0.287	-0.345
Maximum	1.725	0.903	1.275	1.420	1.518	1.725	1.407	1.394	1.334
Observations	10822	1326	1362	1362	1362	1362	1361	1325	1362
Skewness	1.637	0.753	1.190	1.479	1.730	1.736	1.619	1.754	1.961
Kurtosis	3.594	1.131	1.859	2.733	3.707	3.719	3.141	3.732	4.649
NordPool									
Mean	0.194	0.093	0.148	0.183	0.219	0.246	0.254	0.173	0.234
Median	0.090	0.066	0.116	0.098	0.070	0.056	0.086	0.151	0.115
Std. deviation	0.442	0.198	0.309	0.406	0.488	0.540	0.551	0.378	0.517
Minimum	-0.418	-0.274	-0.317	-0.403	-0.390	-0.390	-0.418	-0.354	-0.401
Maximum	2.178	0.777	1.276	1.693	1.947	2.137	2.070	1.712	2.178
Observations	6462	820	820	820	820	820	799	750	813
Skewness	1.678	0.681	1.197	1.420	1.458	1.455	1.335	1.529	1.522
Kurtosis	3.052	0.225	1.561	2.156	1.718	1.516	1.137	3.160	2.023

When considering the risk premia as such, the EEX shows the lowest values. The other markets all show the highest risk premia at different maturities, with the APX being highest for M1 and M2 contracts, the BELPEX being largest for M3 contracts, and NordPool showing the highest risk premia in M4, M5 and M6 contracts. It is also interesting to note that the BELPEX and NordPool show rapidly increasing risk premia, something also showing in their respective quarterly contracts, whereas the APX and EEX show peaks at respectively M3 and M2, after which they gradually decrease. This too can be seen in their quarterly contracts.

Figure 5.3 - Aggregate risk premia per futures contract

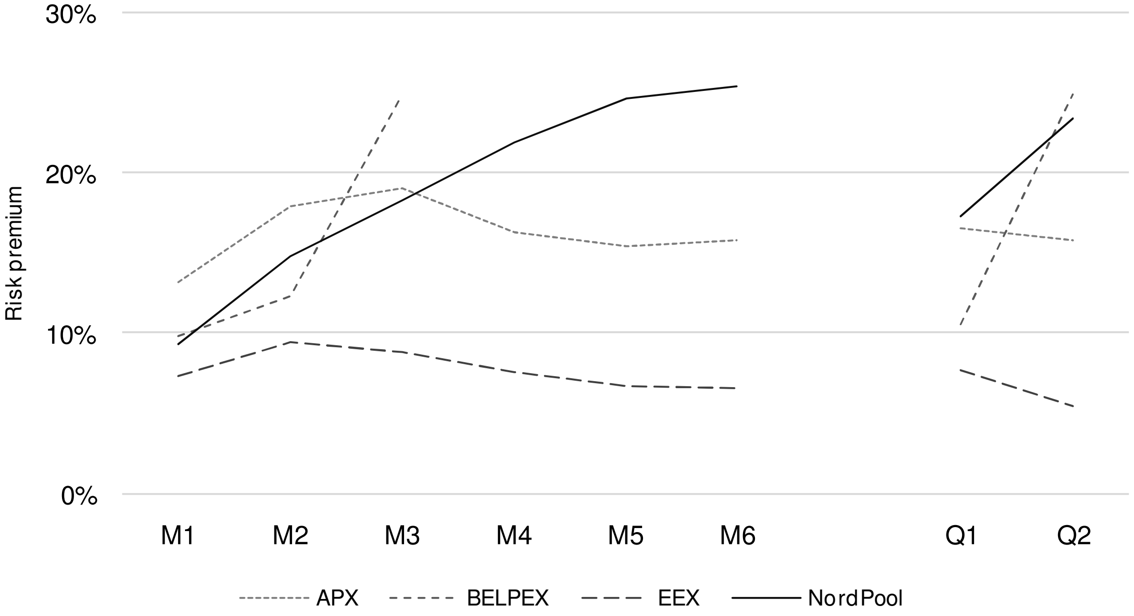
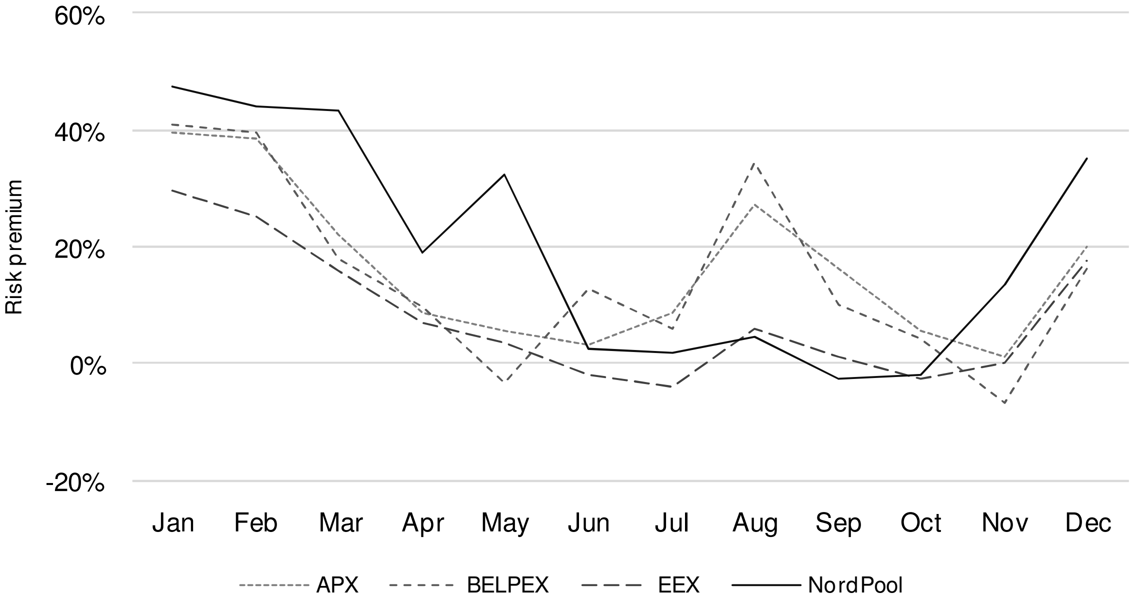


Figure 5.4 - Aggregate risk premia per delivery month



The last step in analysing risk premia through equation (1) is to look for seasonality effects in the risk premia. The results from averaging all risk premia for monthly contracts per delivery month are depicted in Figure 5.4. Quarterly results are left out in Figure 5.4, as these would distort the image by spanning over three months. The results show highest risk premia in the early –winter– months of the year. Throughout springtime, risk premia drop to close to zero, with the exception of a jump in May for NordPool. In the early summermonths, the risk premia appear to diverge, with APX and BELPEX risk premia spiking in August, whereas EEX and NordPool prices remain low or even negative. Starting in October and November, risk premia rise again to peak in January. The largest price range can be found in the NordPool, ranging between -2% and 48%, followed by the BELPEX ranging from -7% to 41%, the APX with1% and 40%, and lastly the EEX ranging from -4% to 29%. These results are largely in accordance with those in Table 5.3, where monthly risk premia are lowest at the EEX, followed by the BELPEX, APX and NordPool.

5.1 – Fama and French

Having analysed the risk premia as such, it is now time to apply some more intricate statistical tests to the futures data. Fama and French (1987) conducted a 21 commodity wide research on both the theory of storage and the theory of risk premia. As electricity storage is *de facto* impossible, I will focus on a replication of the analyses performed by Fama and French for the theory of risk premia. The two regression models they used to test for the theory of risk premia are the following (p.63):

$$S(T) - S(t) = \alpha_2 + \beta_2[F(t,T) - S(t)] + \varepsilon_2 \tag{3}$$

$$F(t,T) - S(T) = \alpha_3 + \beta_3[F(t,T) - S(t)] + \varepsilon_3 \tag{4}$$

In both equation (3) and (4), the basis $F(t,T) - S(t)$ or, the price difference between the futures and spot price at time t, is the independent variable. Using equation (3), the relation between the basis and changes in the spot price is analysed, whereas equation (4) identifies a relation between the basis and the risk premium. It is, however, important to mention that equation (3) and (4) are, as Fama and French mention, "*subject to an adding-up constraint*" (p. 63). This means that α_2 and α_3 and ε_2 and ε_3 must sum to zero and the β_2 and β_3 should add up to one. This is important as equations (3) and (4) force the basis to exert influence on either a change in spot price in equation (3), the premium in equation (4), or a combination of both. This 'forced' division may lead to erroneous outcomes when the variation in the basis is too low to be properly divided over equation (3) and (4). To predict whether this may happen, standard deviations of the basis, change in spot price and premium are listed in Table 5.4. For the standard deviations in Table 5.4, and all consecutive analyses, natural log prices are used. From Table 5.4, two things are important. First of all, all standard deviations seem large enough to enable proper statistical analyses. Furthermore, standard deviations for the basis, a change in spot price and risk premium rise with time to maturity, something also witnessed in Table 5.3.

Table 5.4 - Standard deviations for Fama and French variables

	Overall	M1	M2	M3	M4	M5	M6	Q1	Q2
					APX				
$F(t,T) - S(t)$	0.327	0.272	0.293	0.312	0.339	0.359	0.371	0.302	0.356
$S(T) - S(t)$	0.386	0.299	0.351	0.374	0.396	0.420	0.446	0.364	0.414
$F(t,T) - S(T)$	0.314	0.234	0.295	0.316	0.331	0.338	0.363	0.293	0.325
					BELPEX				
$F(t,T) - S(t)$	0.348	0.298	0.325	0.358				0.337	0.420
$S(T) - S(t)$	0.426	0.349	0.401	0.481				0.418	0.499
$F(t,T) - S(T)$	0.329	0.264	0.321	0.366				0.319	0.368
					EEX				
$F(t,T) - S(t)$	0.325	0.282	0.308	0.316	0.327	0.342	0.355	0.307	0.350
$S(T) - S(t)$	0.375	0.311	0.354	0.374	0.377	0.392	0.417	0.359	0.396
$F(t,T) - S(T)$	0.272	0.210	0.263	0.278	0.285	0.291	0.300	0.258	0.273
					NordPool				
$F(t,T) - S(t)$	0.237	0.124	0.164	0.211	0.248	0.273	0.293	0.211	0.280
$S(T) - S(t)$	0.411	0.218	0.306	0.388	0.450	0.481	0.505	0.377	0.476
$F(t,T) - S(T)$	0.322	0.177	0.250	0.310	0.352	0.377	0.390	0.290	0.366

Outcomes for regression (3) and (4) are listed in Table 5.5, and β_2's and β_3's are depicted in Figure 5.5. Not surprisingly, all β_2's and β_3's sum up to 1.0, as expected. More interestingly, all β_2's are significantly larger than β_3's for all markets, indicating that the basis has a strong forecasting power, rather than showing evidence of time varying risk premia. This was also established through the outcomes of equation (2), and is further strengthened by the R^2 values for regression (3), showing minimal values of 34.4%, 39.2%, 46.3% and 33.5% for respectively the APX, BELPEX, EEX and NordPool. R^2 values for regression (4) are much lower, with minimum values of 6.3%, 1.2%, 3.9% and 0.0% for APX, BELPEX, EEX and NordPool.

A further noteworthy point is that, for the APX, BELPEX and EEX, all β_2's and β_3's are highly significant, whereas NordPool also shows highly significant β_2's but much less significant β_3's. Furthermore, NordPool β_3's are all negative and close to zero. APX β_3 values range from .243 to .296, BELPEX from .118 to .228 and the EEX between .166 and .215, whereas

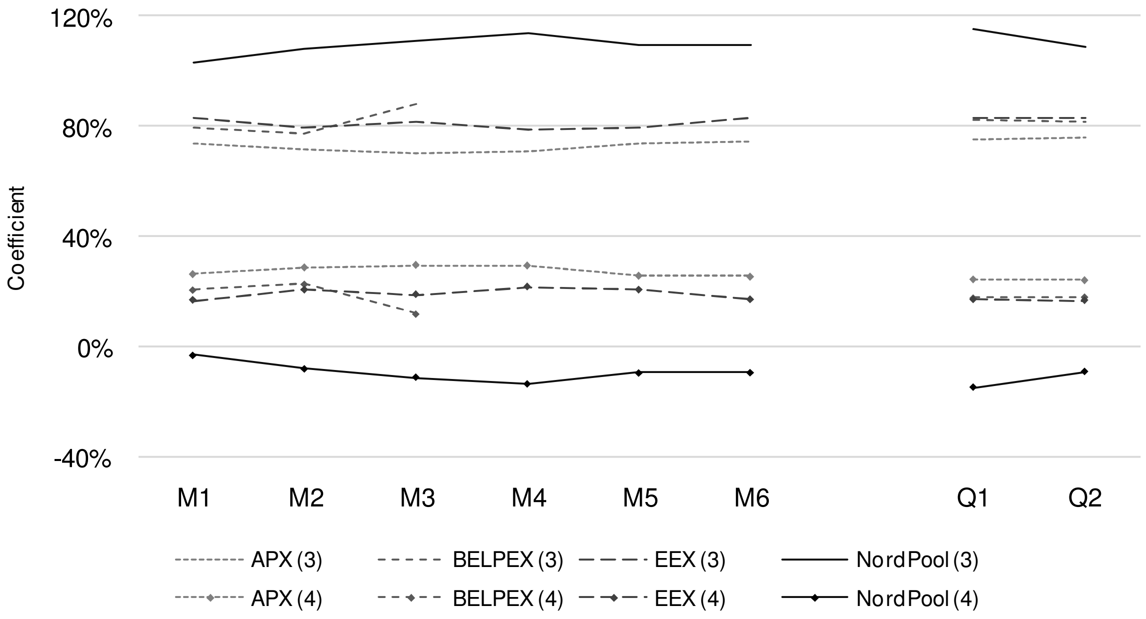
NordPool values range between -.150 and -.031. These values, being so close to zero, may explain the weak significance displayed for NordPool β_3's, as well as the low R^2 values.

Table 5.5 - Outcomes regression (3) and (4)

	Overall	M1	M2	M3	M4	M5	M6	Q1	Q2
					APX				
Observations	8548	1046	1128	1128	1017	1002	1002	1099	1126
β_2	0.735	0.736	0.713	0.704	0.706	0.741	0.745	0.754	0.757
β_3	0.265	0.264	0.287	0.296	0.294	0.259	0.255	0.246	0.243
Sig. (β_2)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sig. (β_3)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (3)	0.389	0.447	0.354	0.344	0.364	0.401	0.384	0.391	0.425
R^2 (4)	0.076	0.093	0.081	0.084	0.090	0.075	0.067	0.063	0.070
					BELPEX				
Observations	4108	886	957	654				931	634
β_2	0.803	0.793	0.772	0.882				0.823	0.820
β_3	0.197	0.207	0.228	0.118				0.177	0.180
Sig. (β_2)	0.000	0.000	0.000	0.000				0.000	0.000
Sig. (β_3)	0.000	0.000	0.000	0.003				0.000	0.000
R^2 (3)	0.431	0.458	0.392	0.429				0.440	0.477
R^2 (4)	0.044	0.053	0.052	0.012				0.034	0.041
					EEX				
Observations	10830	1327	1363	1363	1363	1363	1632	1326	1363
β_2	0.817	0.833	0.796	0.813	0.785	0.796	0.831	0.831	0.834
β_3	0.183	0.167	0.204	0.187	0.215	0.204	0.169	0.169	0.166
Sig. (β_2)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sig. (β_3)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (3)	0.500	0.568	0.479	0.472	0.463	0.482	0.502	0.504	0.544
R^2 (4)	0.048	0.049	0.056	0.045	0.060	0.057	0.039	0.390	0.045
					NordPool				
Observations	6462	820	820	820	820	820	799	750	813
β_2	1.081	1.031	1.082	1.113	1.138	1.097	1.096	1.150	1.091
β_3	-0.081	-0.031	-0.082	-0.113	-0.138	-0.097	-0.096	-0.150	-0.091
Sig. (β_2)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sig. (β_3)	0.000	0.533	0.125	0.028	0.005	0.045	0.041	0.003	0.048
R^2 (3)	0.389	0.343	0.335	0.366	0.394	0.386	0.404	0.414	0.411
R^2 (4)	0.004	0.000	0.002	0.005	0.008	0.004	0.004	0.011	0.004

Concluding, evidence for the forecasting power of the basis is much stronger than that for time varying risk premia. Evidence of the basis showing forecasting power is strongest in the NordPool market, followed by the BELPEX, EEX and APX. Consequentially, the NordPool also shows the weakest evidence of time varying risk premia, followed again by the BELPEX, EEX and APX. It is however, important to keep the research design, suffering from the aforementioned "*adding-up constraint*" in mind. Fama and French themselves also conclude that "*failure to identify time-varying expected premiums does not imply that expected premiums* *are zero*" (p. 70). Therefore, the results obtained from equations (3) and (4) do not contradict those found through equation (1), as risk premia clearly exist in the NordPool market as well, judging Figures 5.1-5.4 and Table 5.3.

Figure 5.5 - Coefficients for regression (3) and (4)



5.2 – Bessembinder and Lemmon

As a final test on the behaviour of electricity futures and their risk premia, I will test the model of Bessembinder and Lemmon (2002), as previously done by, amongst others, Redl *et al* (2009). Bessembinder and Lemmon predict that the risk premium should rise with the skewness of the electricity spot price, but fall with the variance of the spot price. This prediction can be traced back to the initial theory surrounding risk premia, see also section 3, where buyers being hedgers and thereby are net long in futures makes for contango, whereas risk averse sellers, being net short in futures, make for negative premia and backwardation. For buyers, large risks lay in the occurrence of price peaks, expressed through positive skewness. For sellers, or in this case electricity generators producers, a big risk lies in demand variance, as they will need to supply at least demand, and preferably, no more. This demand variance is expressed through price variance in the following model, testing Bessembinder and Lemmon's model:

$$F(t,T) - S(T) = \alpha_4 + \beta_4 * SKEW[S(t)] + \beta_5 * VAR[S(t)] + \varepsilon_4 \tag{5}$$

where $F(t,T) - S(T)$ represents the average risk premia over the futures contract for delivery at time T. Skewness and variance of the spot price are represented by $SKEW[S(t)]$ and $VAR[S(t)]$, with their respective coefficients being β_4 and β_5. Compliance with Bessembinder and Lemmon would show itself through positive values for β_4 and negative values for β_5. Results for regression (5) are listed in Table 5.6.

Table 5.6 - Outcomes regression (5)

	Overall	M1	M2	M3	M4	M5	M6	Q1	Q2
					APX				
Observations	356	54	55	55	55	48	48	22	19
$\beta4$	-0.681	-1.879	1.264	1.308	-1.773	-3.638	-2.318	-0.028	-1.237
$\beta5$	0.385	0.252	0.521	0.552	0.461	0.192	0.447	0.989	0.698
Sig. ($\beta4$)	0.007	0.005	0.008	0.007	0.008	0.008	0.007	0.020	0.017
Sig. ($\beta5$)	0.000	0.166	0.087	0.141	0.120	0.185	0.271	0.060	0.240
R^2	0.040	0.043	0.097	0.075	0.046	0.050	0.028	0.221	0.090
					BELPEX				
Observations	170	46	46	46				16	16
$\beta4$	-0.258	0.676	2.060	-0.286				-0.245	-3.244
$\beta5$	0.839	0.817	0.529	0.945				0.943	0.415
Sig. ($\beta4$)	0.007	0.003	0.004	0.009				0.013	0.011
Sig. ($\beta5$)	0.012	0.556	0.443	0.166				0.324	0.512
R^2	0.061	0.033	0.081	0.103				0.140	0.052
					EEX				
Observations	440	66	66	66	66	66	66	22	22
$\beta4$	1.362	1.966	3.402	3.207	1.411	-0.603	-2.339	3.501	0.431
$\beta5$	0.020	0.115	0.030	0.055	0.416	0.738	0.215	0.103	0.842
Sig. ($\beta4$)	0.003	0.002	0.000	0.001	0.002	0.006	0.008	0.003	0.017
Sig. ($\beta5$)	0.007	0.428	0.953	0.805	0.584	0.093	0.023	0.691	0.055
R^2	0.053	0.083	0.094	0.082	0.028	0.048	0.079	0.270	0.300
					NordPool				
Observations	265	40	40	40	40	40	40	12	13
$\beta4$	-1.038	-2.387	-3.306	-2.940	1.345	0.599	-0.591	0.670	0.887
$\beta5$	0.371	0.099	0.163	0.342	0.699	0.869	0.870	0.931	0.914
Sig. ($\beta4$)	0.138	0.063	0.036	0.017	0.138	0.224	0.303	0.195	0.310
Sig. ($\beta5$)	0.004	0.387	0.765	0.912	0.437	0.230	0.112	0.168	0.051
R^2	0.033	0.081	0.052	0.024	0.023	0.042	0.067	0.200	0.332

When looking at the overall results per market, compliance with Bessembinder and Lemmon shows to be very low. Considering β_4, APX, BELPEX and NordPool show negative coefficients, implying risk premia decrease with spot price skewness, the opposite of the predictions by Bessembinder and Lemmon. Only the EEX complies to their model, showing a positive relation between the skewness and risk premium. With regards to spot price volatility, expressed by β_5, none of the values comply with the model by Bessembinder and Lemmon,

whom predict negative values. All but the NordPool β_4 coefficients are significantly different from zero at a 5% confidence level.
Weak compliance with Bessembinder and Lemmon is also revealed through the low R^2 values, reaching between a 3.3% low for NordPool and a 6.1% high for the BELPEX.

When considering the contracts as such, results seem to adhere better to the model by Bessembinder and Lemmon. With regards to skewness, and thereby β_4, M2 and M3 contracts for the APX, M1 and M2 contracts for the BELPEX and M1, M2, M3, M4 and Q1 contracts for the EEX show positive values, significant at less than 1% confidence levels. Similar results cannot be found for spot price variance coefficients β_5, which are all positive as opposed to the predicted negative relation, and only one value –EEX, M6– is significant at a 5% confidence level. One critical point lies in the number of observations. Using only monthly and quarterly contracts, the number of observations ranges between 40 and 66 for the monthly contracts and between 12 and 22 quarterly contracts. This may cause the weak statistical power as presented through regression (5), it would, however, not explain the non-compliance with the predictions by Bessembinder and Lemmon. Overall, the results as listed in Table 5.6 show very weak compliance with the equilibrium model by Bessembinder and Lemmon. Results from the NordPool are weakest, showing the lowest R^2 values, and worst significance. Compliance with the model is somewhat stronger, but nonetheless weak, with the APX, BELPEX and EEX, which show some skewness coefficients compliant with Bessembinder and Lemmon, but the vast majority still being either opposite to expectations or statistically insignificant.

6 – Discussion

Having applied several statistical analyses to the data from the Dutch, Belgian, German and Scandinavian markets, it is now time to discuss the obtained results. I will discuss the results per market, after which synthesis should result in conclusions on the behaviour of electricity futures markets.

6.1 – The Netherlands, APX

Section 2 has shown that The Netherlands mainly depends on gas and oil for their electricity generation. From Table 4.2 can be seen that spot prices are relatively high and volatility, ranking just behind the Belgian BELPEX. Combined with positive skewness in the spot market, the APX shows typical electricity price behaviour. Further analyses showed risk premia between -41.9% and 195.8% of spot price at maturity, with peaks occurring in both winter and summer. Equations (3) and (4) show a strong relation between the basis and changes in the spot price, whereas evidence of time varying risk premia was weaker. The latter was also confirmed by regressing risk premia with time to maturity, showing stronger evidence of a constant risk premium than for one increasing or decreasing with time to maturity.

Compliance with Bessembinder and Lemmon's (2002) equilibrium model of electricity futures prices is quite low, showing only statistically significant and compliant results for skewness in M2 and M3. Coefficients between risk premia and variance are largely insignificant and show the wrong sign. The analyses in Section 5 have shown the predictive power of spot prices to be the most important one, while predictive factors on risk premia are weak.

6.2 – Belgium, BELPEX

Belgian power is mostly generated through nuclear plants. Further analyses showed the BELPEX to be the most volatile market, combined with the highest spot prices, on average. Analyses was somewhat hindered by the absence of Belgian M4, M5 and M6 contracts, but nonetheless showed little evidence of time varying risk premia. *Ex post* risk premia varied between -44.3% and 163.6% and show a seasonal pattern similar to that of The Netherlands, peaking in the winter and summer. Predictive power of the basis, as analysed by regression (2), turns out to be rather high, whereas evidence on time varying risk premia is, once again, low. Compliance with Bessembinder and Lemmon is low, with the exception of the relation between the risk premium and spot price skewness which shows the expected sign at acceptable significance.

The results obtained from analysing the Belgian market data is most probably influenced by the absence of M4, M5 and M6 contracts, but the results show great resemblance with those obtained in the APX. The relatively large proportions of fossil fuels gas and coal used for Belgian electricity generation may explain such resemblances to the Dutch electricity market. How the use of nuclear plants relate to the behaviour of Belgian electricity futures is unclear, and leaves room for future research.

6.3 – Germany, EEX

The German electricity market is one of the largest in Europe, and relies on a combination of mainly coal-fired and nuclear generation. Average spot and futures prices are noticeably lower when compared to those in The Netherlands and Belgium, and consequentially, absolute volatility is lower too. Relatively, however, price volatility is comparable to that as seen on the APX and BELPEX. Average risk premia, on the other hand, are considerably lower again, though showing similar ranges, varying between -44.8% and 172.5%. Seasonal effects are smaller and show a peak in winter, and only a small increase in summer. Evidence on time varying risk premia through equation (2) is weaker than for the BELPEX, though slightly higher than the APX. Regressions (3) and (4) again show strong forecasting power but weaker evidence on time varying risk premia. R^2 values for regression (3) are highest for the EEX, showing an overall R^2 of 50%.

Compliance with Bessembinder and Lemmon is highest for the EEX, but the results as such can still only be called weak. Skewness coefficients for M1 through M4 and Q1 and Q2 are compliant with predictions by Bessembinder and Lemmon and statistically significant, just as the overall coefficient for skewness. Variance coefficients show no compliance through, again, the wrong sign and mostly insignificant confidence levels.

6.4 – Scandinavia, NordPool

The NordPool market shows results that differ quite a lot from the other markets under analyses. Firstly, average spot and futures prices are the lowest of the four markets. Perhaps more importantly, spot price skewness and volatility are considerably lower, something rather uncommon for electricity spot markets. Furthermore, the NordPool market is known for its high reliance on hydropower, making up for over half of total electricity generation. All the above seems to have little effect on the range of risk premia however, stretching from -41.8% to 217.8%. Evidence of time varying risk premia as found through regression (2) shows the highest R^2 value at 48.4%, but the actual relation between days to maturity and risk premia is still neglectable. Regressions (3) and (4) again provide some surprising results. Predictive power over futures spot prices movements shows coefficients of over 1.0, pushing the coefficients for regression (4) below zero. The latter result would indicate an increase in the basis would actually relate negatively to the risk premia. R^2 values for regression (4) are, however, all zeroish, depriving the model of any statistical relevance.

Compliance with Bessembinder and Lemmon is lowest of all four markets, showing statistically significant values for only three coefficients, but these coefficients show, as do most, the wrong sign. Overall, the NordPool market shows to be different from the other three markets, both through spot price characteristics, and through compliance with the models of Fama and French and Bessembinder and Lemmon.

6.5 – Synthesis

The results in Section 5 pose two interesting question: how do the differences between the APX, BELPEX and EEX on one side and the NordPool on the other side occur, and why is compliance with the equilibrium model by Bessembinder and Lemmon so low?

Firstly, the difference between NordPool and the other markets analysed here are perhaps best explained through the generation profile. Section 2 revealed that Scandinavian power supply depends largely on hydropower for electricity generation. As mentioned by, for instance Botterud *et al* (2009), this dependence on hydropower enables unprecedented flexibility in electricity generation through the use of water reservoirs. Combined with the relatively fast start-up times for hydropower generators, these water supplies act as the storage facility lacking in other generations profiles. This results in a spot market behaving rather different from the APX, BELPEX and EEX through lower volatility and skewness –two of the most distinguishing factors in electricity spot market– see also Table 4.2 and Figure 2.8.

A second important results by Botterud *et al*, is their finding that the theory of storage, dubbed *de facto* unusable for electricity, seems to fit the NordPool market through their hydro reserves. In their article, Fama and French (1987) do note that the theory of storage and the theory of risk premia are "*alternative but not competing views of the basis*" (p. 62), but it would nonetheless make intuitive sense that when the non-controversial theory of storage seems to fit a certain market, the theory of risk premia shows a lower fit. This could very well explain for the differences found in regressions (3) and (4) for the APX, BELPEX and EEX on the one hand, and the NordPool on the other.

A further noteworthy point is the relatively strong fit of regression (3) to the four markets under analyses, showing strong relation between the futures price and future spot price movements. When compared to the results obtained by Fama and French, the R^2 statistics for the electricity markets are comparable to those obtained for broilers, eggs, pork bellies and oats

(Fama and French, 1987, Table 4), which are not easily storable commodities. Commodities that are more easily storable, such as metals (copper, gold, platinum, silver) or agricultural products (cocoa, coffee, cotton and others) hardly pass the R^2 mark of 10%, when compared to the timelines studied here. This strong relation as portrayed by electricity is further analysed by Redl *et al* (2009) who find that "*lagged values of spot prices can be used for forecasting forward prices. Hence, there is strong evidence that the predictive power of the forward price is weak*" (p. 361). The difference between the statements by Redl *et al* and those by Fama and French, with the latter stating that the results obtained through regression (3) indicate that "*the futures prices has power to forecast the future spot price*" (p. 63), lies in the direction of the analyses. Where Fama and French conclude that the "*basis observed at* t *contains imformation about the change in spot price from* t *to* T" (p.63), Redl *et al* conclude that "*lagged values of spot prices can be used for forecasting forward prices*" (p.361). Hence, both agree there is a relation between spot and futures prices, but as Redl *et al* find, through more in-depth analyses, spot price to influence futures prices, they conclude predictive power of futures prices is low. Analyses as performed by Fama and French, and in this paper for that matter, confirms the relation, but not whether spot price influence futures price or *vice versa*. Nonetheless, the relation between the two stands firm.

The second question occurs through the weak compliance of the studied markets with the equilibrium model of electricity futures prices by Bessembinder and Lemmon. This weak compliance is especially interesting as earlier studies have confirmed the model. Section 2 showed for instance that Longstaff and Wang (2004) confirmed the Bessembinder and Lemmon model for the American PJM market over the period 2000–2002, where Diko *et al* (2006) confirm the model for the European APX, EEX and Powernext for the period 2001–2005. It is therefore striking that two of these markets studied here, the APX and EEX, show such low compliance for the period 2003–2008. These results do, however, not stand alone, as Herraíz and Monroy (2008) have shown lower compliance with Bessembinder and Lemmon for the Spanish OMIP, French Powernext and Scandinavian NordPool for the period 2006–2008, as did Redl *et al* for the EEX and NordPool for the period 2003–2008.

One explanation could lie in the introduction of the EU Emission Trading System (EU ETS) in January 2005. Daskalakis and Markellos (2009), for instance, have shown "*a positive relationship exists between carbon allowance returns and electricity risk premia*" (p. 2601) for the German EEX, Scandinavian NordPool and French Powernext. Considering this implementation took place after the period researched by Longstaff and Wang and Diko *et al*, whereas research after the implementation of the EU ETS shows much lower compliance with Bessembinder and Lemmon. Other interesting results come, again, from Redl *et al* (2009) who show a relationship between short run marginal production costs for coal and gas fired plants and electricity futures prices for the EEX, and, to a lesser extent, the NordPool. These results show the formation of futures prices depend on much more than simply the skewness and variance of spot prices. Research by Douglas and Popova (2008) adds to the discussion by claiming that "*any complete model of the electricity forward premium must include information about natural gas storage inventories*" (p. 1726), a statements which can be seen in alignment with findings by Botterud *et al* (2009) that confirm that "*the relationship between spot and futures prices is clearly linked to the physical state of the system*" (p. 11), aiming at the storage possibilities provided by the hydropower backed NordPool market.

Concluding, the model by Bessembinder and Lemmon seems to have provided the early electricity markets with a tool to price electricity futures, but as the markets matured and for instance emission allowances were introduced, more complex models are used for price formation. Which variables take part in this price formation, and how their influence differs across markets provides academics with plentiful material for further studies.

7 – Conclusion

This paper set out to analyse the behaviour of electricity futures and the existence of a risk premium therein. To do so, models by Fama and French (1987) and Bessembinder and Lemmon (2002) were used to analyse the Dutch APX, Belgian BELPEX, German EEX and Scandinavian NordPool markets. The outcomes confirmed the existence of nonzero risk premia in all of the abovementioned markets, and showed these markets to often be in contango. Through the model by Fama and French, a relationship between futures and spot prices has been established. Analyses of the equilibrium model by Bessembinder and Lemmon shows low compliance, thereby indicating that, contrasting earlier research, spot price skewness and variance are no longer factors of large importance in risk premia formation and, consequentially, futures price formation. The factors that do influence futures price formation may include emission prices, generation costs and physical inventories, and leave room for future research.

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