The relation between the excess capacity of electricity and the tail fatness of electricity prices

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Preface

This thesis covers the final step of my Master study. With this thesis, I am not only hoping to finish my educational journey on the Erasmus University Rotterdam but also hoping to add a small piece of knowledge to the scientific world and literature.

Because of the recent deregulation of the electricity markets, many questions regarding the new electricity market have not yet been answered. By writing my thesis, I am able to provide an answer to one of those questions. In addition, I like to think that this thesis could be used for further research into the interesting world of electricity finance. For these reasons, I am glad that I have had the opportunity to write my thesis about this subject.

I could not have written my thesis without help. I therefore owe much gratitude to my supervisor at the Erasmus University, Dr. Ronald Huisman. Without his knowledge, guidance and his clear but out-of-the-box way of thinking, this thesis would not have reached its current level.

I also need to thank my parents and my brother. Their continuous support and feedback really helped me write this thesis and helped me to overcome the problems I encountered during the writing process.

Furthermore, I would also like to thank the following electricity markets: APX (the Netherlands), UKPX (United Kingdom), Powernext (France), EEX (Germany), Nord Pool (Norway, Sweden, Finland and Denmark) and PJM (United States). For without their help and assistance in providing the necessary electricity price data, my thesis could not have drawn any conclusions at all.

Abstract

This thesis is about the relationship between the excess capacity of electricity (the difference between demand and supply at some point in time) and the tail fatness of electricity prices. Many different authors assume that such a relationship exists and base their theories on this assumption. However, this relationship has, to the best knowledge of the author, never been empirically tested. Based on the hourly 2008 day-ahead electricity prices of the Dutch APX-, the British UKPX-, the French Powernext- and the American PJM market and the hourly 2008 spot prices of the German EEX- and the Scandinavian Nord Pool market, this thesis does test this relationship. The results of this research show a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices for each tested electricity market. This thesis concludes with a discussion about the theoretical and practical applicability of these findings.

KEYWORDS: electricity price; excess capacity; tail fatness; normal distribution

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1. Introduction – electricity prices

It is common knowledge that on a market (on the most basic level), prices are determined by demand and supply. Less commonly known but equally true is that electricity prices on electricity markets tend to be very volatile. They may experience some heavy price spikes (as will be discussed in more detail in paragraph 1.1.1). Does this imply that these price spikes are the consequence of the (difference between the) supply and demand of electricity? This is the question which this thesis tries to answer.

Many different researchers assume that this relationship exists and base their theories on this assumption. However, because this relationship has never been empirically tested (to the best knowledge of the author), the foundations of their theories might be unstable

This introductory chapter first discusses the characteristics of electricity and the electricity market (paragraph 1.1). The second paragraph (1.2) describes the research objective of this thesis and consequently focuses on the main research question and hypotheses.

1.1 Characteristics of electricity and the electricity market

In most countries, electricity is being traded on a market like many other commodities. However, this is only possible since the recent deregulation of many electricity markets. For example, the Dutch electricity market was deregulated in several phases, starting in 1998 and ending in 2004. Because of these recent deregulations, there is relatively few scientific literature available regarding the different characteristics of the electricity market.

In the Netherlands (and in many other countries), the electricity prices are settled on a public electricity market. Demand and supply determine, like on any other regular market, at which price electricity is purchased/sold. A typical electricity demand- and supply curve is shown in figure 1.1. This figure clearly shows that the demand of electricity is almost completely inelastic. This is the result of the lifestyle we have these days. Electricity is continuously needed for our current lifestyle, regardless of the circumstances. The figure furthermore shows (by the steep increase of the supply curve) that producers of electricity are able to generate additional electricity, but only at much higher (marginal) costs.

Figure 1.1: Electricity demand- and supply curves

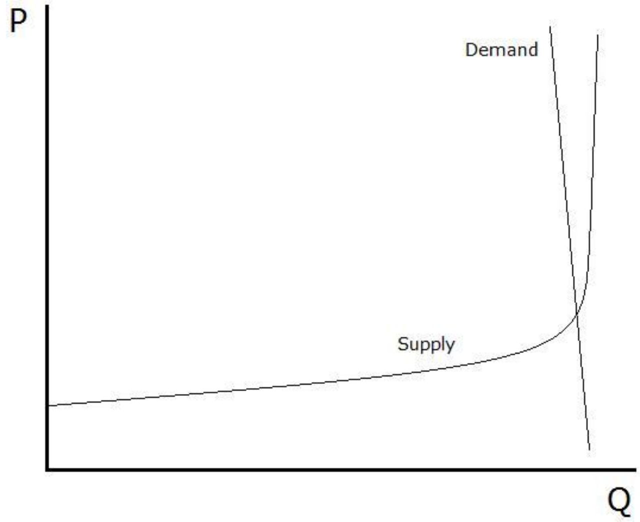
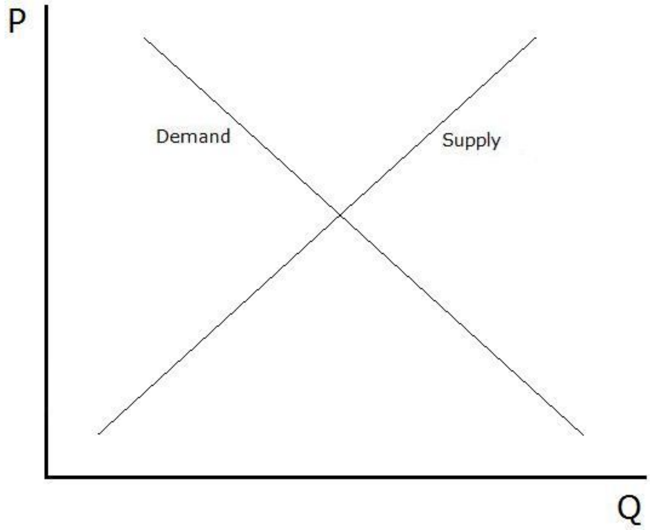


Figure 1.2: 'Standard' demand- and supply curves

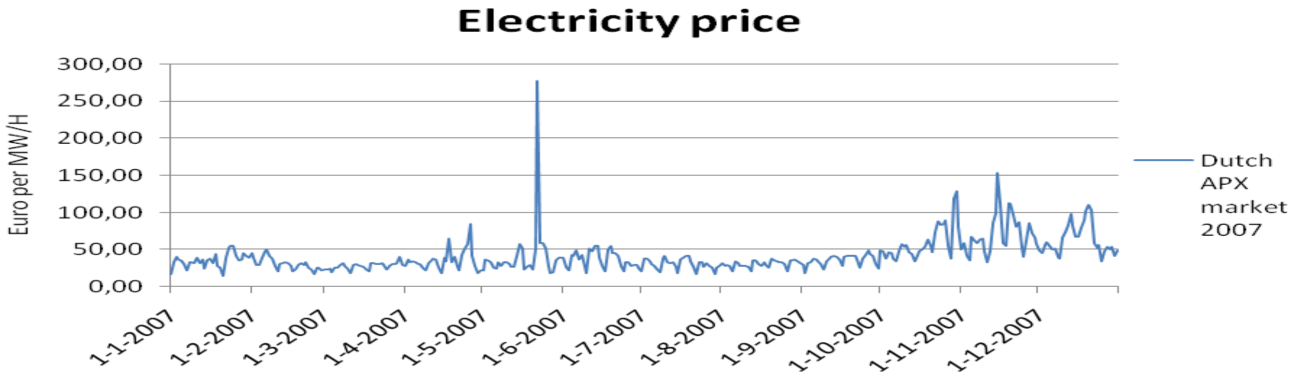


One of the main reasons why the electricity market shows large differences compared with a 'standard' supply- and demand curves (of which an example is given in figure 1.2) is the fact that it is economically not feasible to store electricity[1]. This implies that generated electricity has to be used instantly and that any non-used electricity is wasted. As a consequence, producers are unwilling to generate large quantities of 'reserve electricity' as it is not economically feasible to do so. Furthermore, the electricity market experiences some other features which also cause its current way of operating. These features will be discussed in the following subparagraphs.

1.1.1 Volatility and price spikes

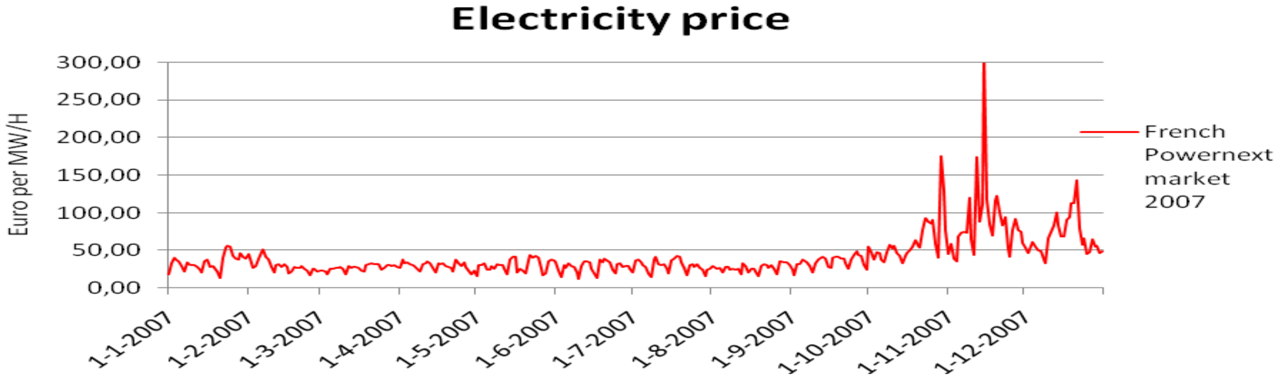
The electricity market is very volatile. Electricity prices can increase with enormous percentages on one day, and decrease with an even higher percentage the next day. To visualize this statement, graphs displaying the electricity price of the Dutch electricity market APX and the French Powernext market for 2007 are shown (figures 1.3 and 1.4).

Figure 1.3: Dutch APX electricity price for 2007



[1] Stated by, among others, Lucia and Schwartz (2000), Sayers and Shields (2001) and Borenstein (2002).

Figure 1.4: French Powernext electricity price for 2007



Figures 1.3 and 1.4 show that the electricity price can be very volatile. Furthermore, these figures display the possibility of price spikes. A price spike is a sudden (and large) increase of the price. For the Dutch 2007 market, the best example of a price spike is on 22/05. On this date, the electricity spot price reached a stunning € 277.41 per Megawatt hour (MW/H). The average Dutch APX price in 2007 was (only) € 41.92. So in one single day, there was a price increase of 661.7% (compared to the annual average). However, the next day a decrease of 78% resulted in an average price of € 59,46, 141.8% of the annual average.

Another example of the volatility of electricity prices is given by Rafal Weron (2005). He calculated the volatility of electricity prices for the Nord Pool region. For this he used hourly electricity prices from May 1992 until December 2004. He then compared the calculated volatility with the volatility of other commodities (of which Weron claims that these are normally noted to be 'extreme volatile'). The results of this comparison are displayed in table 1.1. The table clearly shows that electricity prices are much more volatile compared with the other discussed commodities.

Table 1.1: Comparison of the volatility of commodities by Rafal Weron (2005, p. 3)

Commodity	**Volatility**
Treasury bills / notes	Less than 0.5%
Stock indices	Between 1% and 1.5%
Commodities like crude oil and natural gas	Between 1.5% and 4%
Very volatile stocks	Not exceeding 4%
Electricity prices of the Nord Pool exchange for 1992-2004	Up to 50%

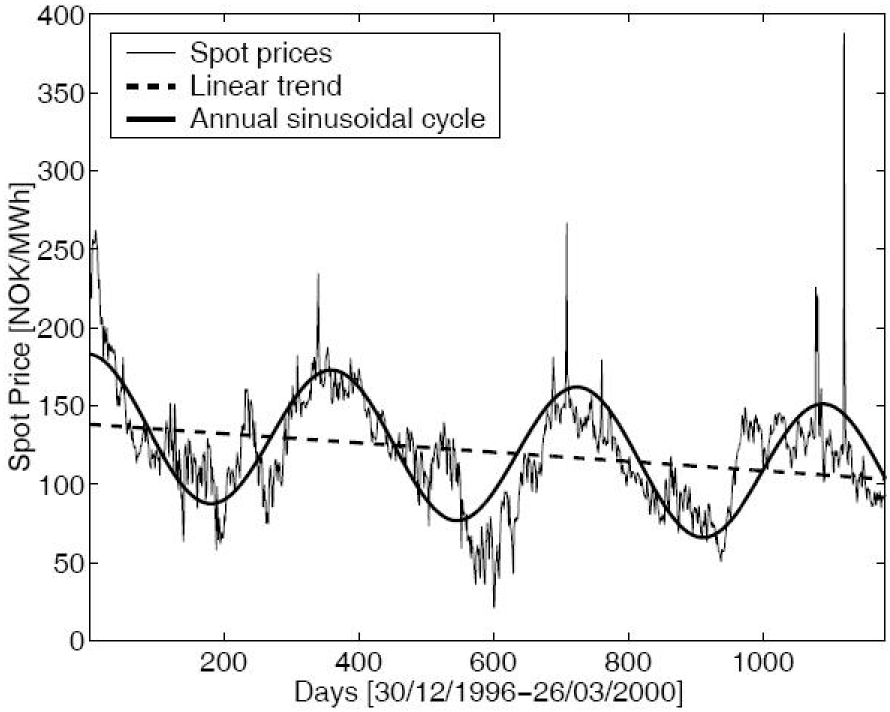
1.1.2 Mean reversion and seasonality

The electricity market is however not only characterized by volatile prices and by price spikes. Another important characteristic is that the electricity prices are mean reverting. This implies that the price of electricity will tend to be around its mean. During some periods, the price will be higher than the average price. During other periods, the electricity price will be lower than the average price. The electricity price will, however, normally always revert back to its mean.

Furthermore, the electricity price experiences seasonality. With this is meant that the electricity price is characterized by a seasonal pattern. For instance, during the winter period, the electricity price tends to be higher than in the summer period. However, annual seasonality is not the only existing pattern. Electricity prices also follow patterns on a daily basis, with high prices during the start and end of a working day and with low prices during the night. A third type of seasonality is a weekly pattern with higher prices during working days and lower prices during the weekends.

Weron (2005) points at factors as climate conditions (temperature and daylight hours) as the main cause of seasonality. He stresses that seasonality can be found on both the demand- and the supply side. Where one usually only discusses the demand side of seasonality, Weron states that seasonality also exists on the supply side of electricity. As an example, Weron mentions regions in which the production of electricity is depending on the amount of rain and melted snow. These factors can experience seasonality and can cause electricity generators based on hydro power to experience seasonality in the quantity of electricity they are able to generate. Weron's (2005, p.5) figure gives a good example of the seasonality of electricity. The figure displays the electricity price of the Nord Pool market for 1996-2000.

Figure 1.5: Spot prices, linear trend and annual cycle of the Nord Pool market, 1996-2000, by Rafal Weron (2005, p. 5)

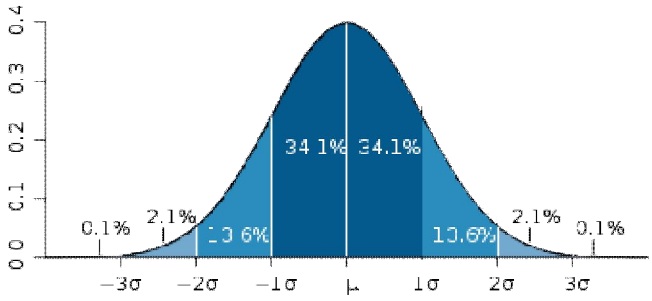


1.1.3 Non-normal distribution of prices

Another important feature of the electricity market is that the electricity prices are, in general, non-normally distributed. Among others, Henney and Keers (1998), Huisman and Huurman (2003) and Weron (2005) came to this conclusion.

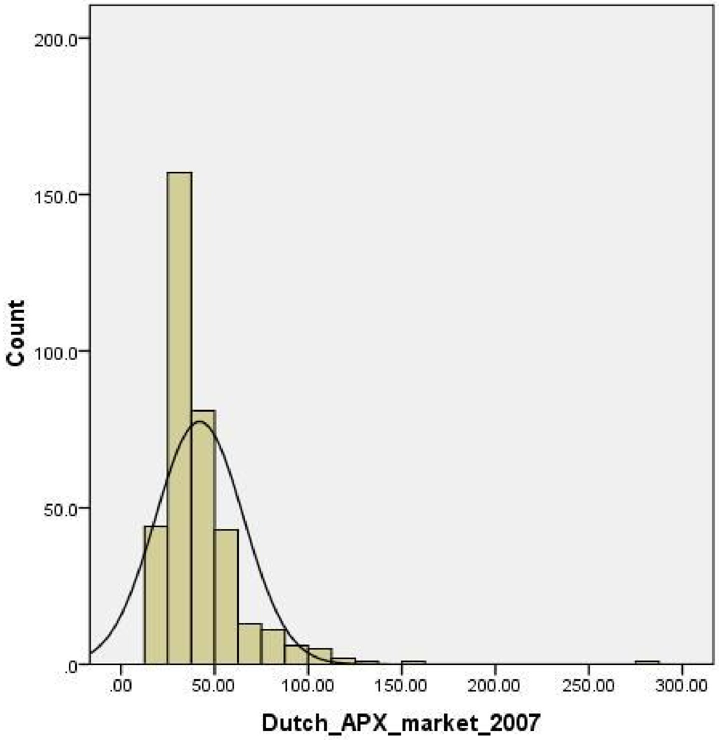
A normal (Gaussian) distribution provides information about how many outcomes, as a percentage, normally fall within a certain number of standard deviations from the mean (as can be seen in figure 1.6).

Figure 1.6: An example of a normal distribution[2]



In the case of electricity prices, a normal distribution cannot be applied. That is, electricity prices are suffering from a high quantity of values around the mean and are suffering from tail fatness. Tail fatness results in a more-than-normal quantity of outliers/spikes in the electricity price distribution. As a consequence, there is a higher-than-normal probability of the electricity price on a certain moment being an outlier. An example of this is given by figure 1.7: a histogram showing the results of the 2007 Dutch APX electricity prices. The black bell-shaped line represents the distribution the electricity prices should have if the prices were normally distributed, and the yellow columns represent the actual distribution. Figure 1.7 shows that there is a more-than-normal quantity of prices around the mean and that the tails of the distribution are fatter than they should be. Therefore, the prices of this example are not normally distributed. This is confirmed by, among others, Kaminski. In his (1997) paper, Kaminski states that electricity prices usually tend to be leptokurtic. This implies that the distribution of the prices is not normal as it experiences a higher peak and fatter tails.

Figure 1.7: Histogram of the Dutch APX 2007 prices



[2] http://en.wikipedia.org/wiki/File:Standard_deviation_diagram.svg , viewed on 28-10-2009

1.2 Research objective

As is stated before, this thesis attempts to answer some of the questions regarding the settlement of electricity prices on the electricity market.

1.2.1 Research question

More specifically, the research question of this thesis is:

"Is there a significant relationship between the excess capacity of electricity and the probability of a price spike?"

1.2.2 Usage of excess capacity as an estimator

'Excess capacity' as it is mentioned in the research question, is the difference between the supply and demand of electricity on a certain moment. This thesis uses hourly electricity prices in order to estimate the excess capacity of a certain hour. There are two reasons for using hourly electricity prices as an estimator.

Scarcity

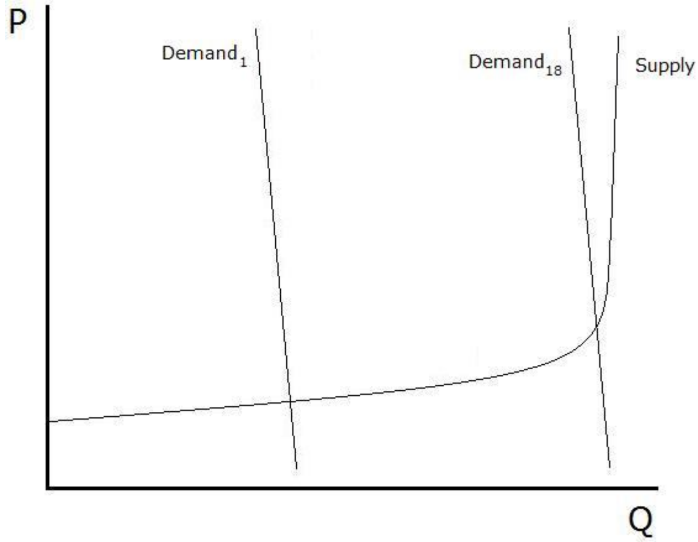
Firstly, the electricity price can be used to estimate the excess capacity because electricity is a scarce good. Because electricity is being traded on a market, it is assumed that each price reflects the supply and demand (and thus the excess capacity) of electricity for that specific moment. This implies, for instance, a decreased excess capacity in the case of an increased price. The underlying cause of this example is either an increase of demand, a decrease of supply or both.

Different types of generators

Secondly, electricity is normally produced via a variety of different types of generators. Examples of these different types of generators are: coal-based generators, oil-based generators, gas-based generators, nuclear generators and hydro-based generators. These generators differ in the fuel they use and in operating costs. As a result, some generators are cheaper to operate than others. Of course, the generating companies first use generators with the lowest marginal costs. Only when demand increases and their 'low marginal cost generators' cannot meet the demand, generators with high marginal costs are also put in use. The usage of these expensive generators directly affects the market price of electricity because the generating companies are only willing to produce and sell their electricity if they receive a higher price for it. They need this money to cover the extra costs of the additional and more-expensive generators. This is visualized in the following figure.

Figure 1.8 shows the same supply and demand curve as figure 1.1, only this time it contains multiple demand curves. $Demand_1$ stands for the demand of electricity at 01:00 hours while $Demand_{18}$ stands for the demand of electricity at 18:00 hours. These demand curves are based and placed under the assumption that on certain moments, the demand of electricity is higher than on other moments. Furthermore, the convexity of the supply curve visualizes the statements made in this paragraph about the costs experienced by generating companies in order to produce a certain quantity of electricity. The first few quantities of electricity can be produced relatively cheap. At a certain quantity however, the costs of generating one quantity more rises sharply.

Figure 1.8: Electricity demand- and supply curves: multiple demand curves



Many papers describe the fact at 09:00 and 18:00 hours, the demand of electricity is much higher compared to the demand of electricity at, e.g., midnight. This is visualized by two figures displaying a demand profile of electricity. In his (2004) paper, Bunn shows the electricity demand of two specific Wednesdays: the 19th of January, 1994 and the 18th of January, 1995, both based on the electricity pool of England and Wales. Both figures consist of a series of columns, which represents the electricity price, and a horizontal line which represents the demand of electricity. Although both figures (figures 1.9 and 1.10) are obviously not exactly the same, the demand profile of both figures is roughly similar. This demand profile shows that the demand of electricity differs over the hours, with peaks around the start and the end of the business day. Such a pattern is actually a type of seasonality as is described in paragraph 1.1.2.

Figure 1.9: Pool prices and demand for Wednesday 19th January 1994, by Bunn (2004, p. 14)

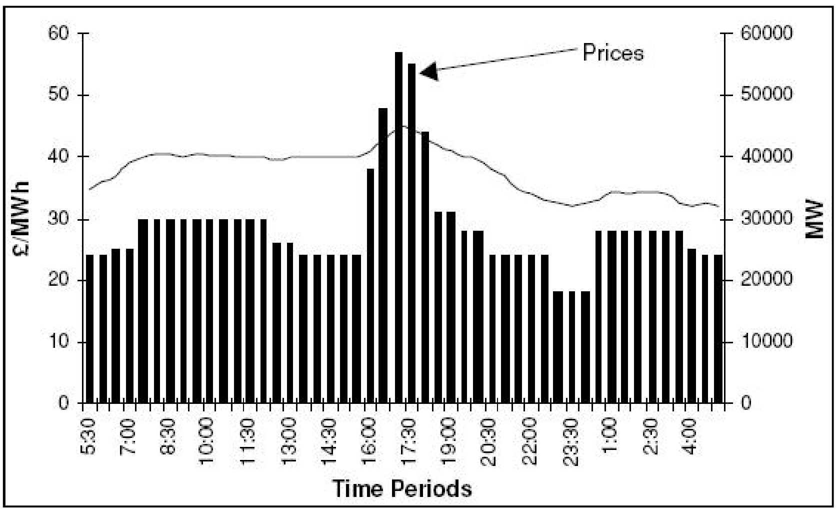
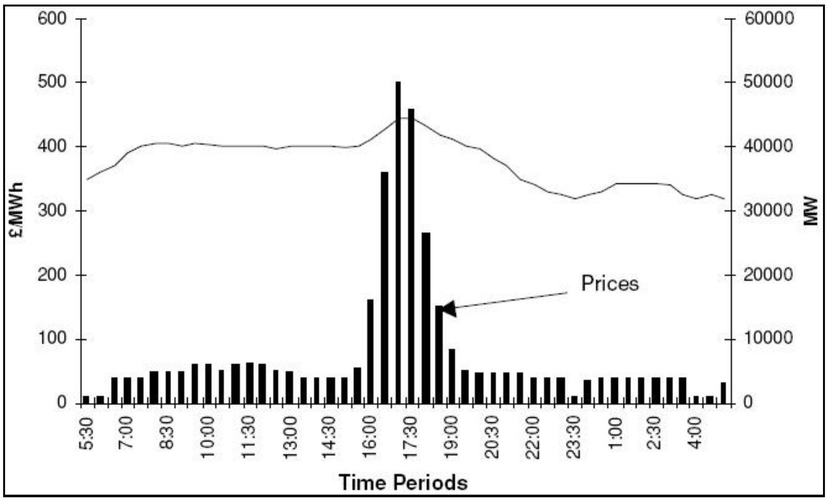


Figure 1.10: Pool prices and demand for Wednesday 18th January 1995, by Bunn (2004, p. 15)



In short, because electricity is a scarce good and because of the different types of generators (and their respective operating costs), an increase of the electricity price implies an increase in the demand of electricity or a decrease in the supply of electricity. Consequently, the excess capacity has decreased in this example. Based on this theory does this thesis use the electricity price to estimate the excess capacity.

1.2.3 Hypotheses

Based on the research question and mentioned assumptions of paragraph 1.2.2, the following hypotheses are formulated:

H_0: *There is no significant relationship between the excess capacity of electricity and the tail fatness of electricity prices.*

H_A: *There is a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices.*

In order to answer the research question and test the hypotheses, the remainder of this thesis has the following structure: chapter 2 covers an overview of the most relevant literature while chapter 3 discusses the data used in this thesis. In chapter 4, the research methodology is described and chapter 5 analyzes the results. Chapter 6 concludes.

2. Literature review

This chapter provides an overview of the most relevant literature regarding the subject of this thesis. The overview this chapter provides covers the occurrence of tail fatness in general (paragraph 2.1), discusses the tail fatness and volatility of electricity prices (paragraph 2.2) and covers the relationship between tail fatness/volatility and the excess capacity of electricity (paragraphs 2.3 and 2.4). Paragraph 2.3 and 2.4 differ from each other because paragraph 2.3 focuses on literature which describes a direct link between tail fatness/volatility and the excess capacity of electricity. This is in contrast with paragraph 2.4 because this paragraph focuses on an indirect link between tail fatness/volatility and the excess capacity of electricity. The final paragraph of this chapter summarizes the literature overview and provides a short conclusion.

2.1 Tail fatness

As is stated in the introduction, tail fatness is about the distribution of values. There is a more-than-normal probability of the occurrence of extreme values if a distribution suffers from tail fatness. In the financial world, the assumption of normality is very important for all sorts of analyses. Especially in the risk analysis- and insurance branch, it is important to know what the actual probability of an event is. However, although normality is frequently assumed when dealing with financial data, financial data is commonly non-normal. This was, among others, found by Mandelbrot: *"The empirical distributions of price changes are usually too peaked to be relative to samples from Gaussian populations"* (1963, p. 394). In addition, he stated that in some cases *"the tails of the distribution of price changes are in fact so extraordinarily long that the sample second moments typically vary in an erratic fashion"* (1963, p. 395).

Considering this, it is surprising that many important and well-known (financial) theories assume normality. For instance, the Capital Asset Pricing Model (CAPM) and the Black and Scholes-formula assume normality of the distribution of the returns of the underlying asset. Huisman and Huurman (2003) researched the effect of assuming normality in situations of non-normality while trying to model the electricity prices. They state that: *"The normality assumption that researchers and practitioners often make in their simulation or valuation method can lead to erroneous conclusions"* (p. 17).

2.2 Tail fatness and volatility of electricity prices

With respect to electricity prices, Deng, Jiang and Xia (2002) state: *"Commodities such as electricity have erratic price behaviors due to their non-storable nature and dependence on capacitated physical networks. Ever since the moment that electricity became a traded commodity, its price has been displaying the highest level of volatility and the most complex features among all commodity prices"* (p. 1). Many different authors make similar statements. For instance, Hinz (2003) states that the price spikes in the deregulated electricity market are a consequence of electricity being a *"flow commodity, which cannot be economically stored"* (p. 1-2). In his (2001) paper, Byström refers to the "*general problem of storing electricity*" (p. 2), when explaining the very large price changes in the electricity market. To this, Bottazzi, Sapio and Secchi (2005) add that it is *"widely recognized that daily price fluctuations in energy markets display very fat tails"* (p. 2). Bottazzi et al. specify their statement by referring to several researchers who all concluded that electricity prices experience tail fatness[3].

2.3 Papers which describe a direct link

In his (2002) paper, Severin Borenstein points at the demand and supply of electricity when explaining the volatility of electricity prices. Borenstein states that, because both are very inelastic, the lack of flexibility on both sides results in a high volatility. He also discusses the effect of an increase or decrease of demand on the electricity price (and the volatility of this price). For this, he refers to the following figure:

Figure 2.1: A shift in variable demand in the electricity market, Borenstein (2002, p. 198)

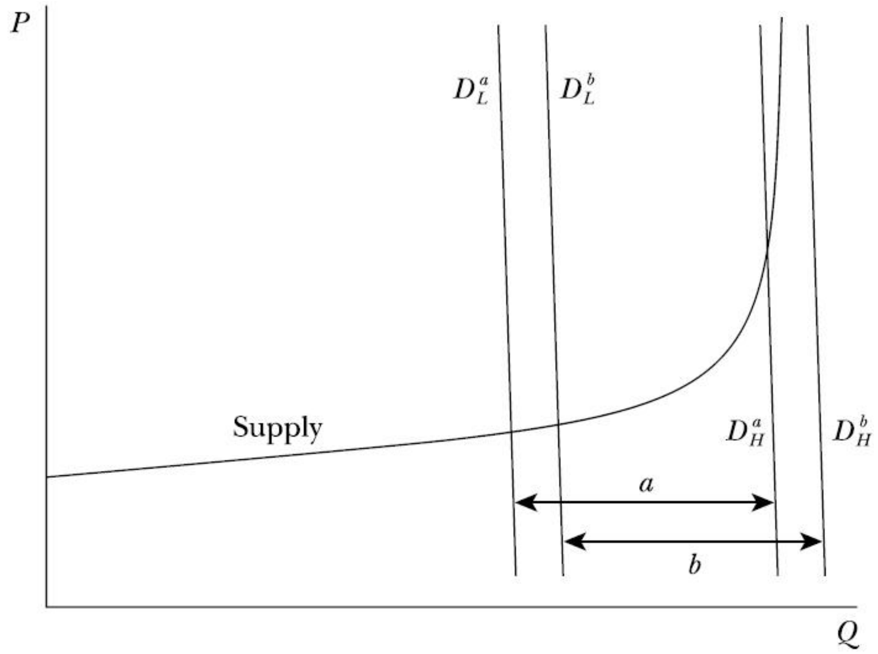


Figure 2.1 shows the effect of changes in the demand of electricity. Here Borenstein assumes that on a certain moment, the demand of electricity is somewhere between D^a_L and D^a_H. Then he assumes that on another point in time, demand increases. Consequently, the new demand curve would then lie somewhere between D^b_L and D^b_H. Borenstein states that the change in demand *"replaces hours that where at very low prices on the left of the distribution with hours that are at extremely high prices at the right side of the distribution, causing the average price to increase drastically"* (p. 197). This implies that changes in demand during moments with a relatively high electricity demand result in higher price changes (and therefore, a higher volatility) compared with changes of demand during periods with a relatively low demand of electricity.

[3] Bottazzi et al. hereby refer to: Deng (2000), Knittel and Roberts (2001), Lucia and Schwartz (2000), Escribano, Pena and Villaplana (2002), Geman and Roncoroni (2002), Weron, Bierbrauer and Truck (2004), Bellini (2002, Bystroem (2001), Deng, Jiang and Xia (2002) and De Rozario (2002)

Borenstein also finds, while referring to previous research he has conducted (Borenstein, 2000), that the high electricity prices are also, to some extent, a consequence of the market power exercised by electricity generators. He states that: “*Because market power is easier to exercise in electricity markets when the competitive price would have been high anyway, it exacerbates the volatility of prices and further reduces the chance that prices will remain in a reasonable range*” (p. 196). He also draws attention to the non-storability of electricity, the fact that demand is difficult to forecast and that suppliers face a supply constraint at a certain production level. In addition, Borenstein also mentions some solutions to these problems. First, he states that more usage of long-term contracts would decrease the level of volatility. These contracts inform the generators of electricity in advance about the amount of electricity needed on a certain moment, and the fixed price of these contracts would eliminate the consequences of a possible decrease in the electricity (spot) price. On the other side, long-term contracts also eliminate the consequences of a sudden price spike on the electricity spot market for the buyers of electricity. Borenstein also advocates the usage of real-time retail pricing. With real-time retail pricing, the consumer would also feel the impact of the electricity price volatility, while currently these effects are (in general) only felt by the electricity distributors.

Sayers and Shields (2001) describe in their paper the characteristics of electricity supply. They find that different types of generators result in different marginal costs and that, depending on the quantity of demand, different types of generators are used. Sayers and Shields state: *“Thus, costs of supplying electricity to satisfy short-run peak loads within a network increase rapidly, as the quantity demanded increases and quick-start generators are progressively engaged”* (p. 22) and “*As demand increases and quick-start generators are engaged, prices jump as a reflection of increased costs”* (p. 22).

In his paper, Bunn (2004) describes how electricity prices develop according to his ideas. By doing so, he acknowledges the statements of Sayers and Shields (2001). That is, Bunn also mentions the different types of generators that produce electricity, hereby dividing generators in generators which are cheap- and generators which are expensive to operate. The latter results in higher prices (and an increased probability of price spikes) in periods characterized by a high demand. In addition, Bunn also mentions other factors which enlarge the consequences of the usage of the different types of generators. He discusses technical disruptions, congested transmission systems, fluctuations of demand and the monopolistic characteristics of the electricity market. Bunn then links these arguments to the shape of the supply curve of electricity.

Tippig (2007) also investigated the volatility of electricity prices. Tippig states, (just like, among others, Bunn (2004) and Sayers and Shields (2001)) that this volatility is a result of the convexity of the supply curve. This volatility he calls ‘*price-dependant volatility*’. He then starts explaining why this volatility is a result of the price. He states that when the demand is low, (and the spot price is low), small changes in the demand of electricity will have little influence on the spot price because of the flat supply curve. However, when demand is high, the supply curve has become rather steep. So in the case of changes of demand during periods of a high demand of electricity, this has much bigger consequences for the price and thus results in a higher volatility. The situation as described by Tippig seems to be true but also seems to lack some depth. For one could argue that this price volatility is actually based on the pricing principle of a market: demand and supply. Demand and supply are mentioned by Tippig in his description. But rather than noting demand and supply as the key generators of the whole pricing process, Tippig makes them sound irrelevant.

However, further on in his paper, Tippig does make a note to his own statement: *"Strictly-speaking the volatility is dependent on the load, rather than the price. However, if the only information available was price data, the volatility in prices would appear to depend on the level of prices"* (p. 15). With this note, Tippig turns the essence of his own statement. Now he states that the volatility in electricity prices are actually based on changes in the demand of electricity.

In addition, Tippig mentions some other factors which cause price spikes/price volatility which can all be directly related to supply or demand. Here he mentions: sudden problems with generators which are forced to go offline (supply-related), transmission problems (supply-related) or increased demand (demand-related). Further on in his paper, Tippig makes his closing argument regarding the cause of the high volatility of electricity prices: *"At times when the electricity system is not transmission-constrained and there is a large amount of excess capacity, the spot price is relatively well behaved* [...]*"* (p. 17).

Following a path quite similar to, among others, the researchers stated above, Cartea, Figueroa and Geman (2009) also describe the demand- and supply side of the electricity market. They also state that the composition and structure of the supply side determines the form of the supply curve. And since the sudden change in the form of the supply curve represents the change between low marginal cost generators and high marginal cost generators, Cartea et al. conclude that the composition of the supply curve therefore has a big impact on the probability of price spikes.

Additionally, Lucia and Schwartz state in their (2000) paper that: *"These limitations make electricity contracts and prices highly local, i.e. strongly dependent on the local determinants of supply and demand"* (p. 2). With *'these limitations',* Lucia and Schwartz refer to the non-storability of electricity and transportation constraints. Lucia and Schwartz then further classify 'supply and demand': *"such as characteristics of the local generation plants, and local climate and weather conditions together with their derived uses of electricity"* (p. 2).

Villaplana (2005) attempts to discover an empirical relationship between the difference of supply and demand of electricity and the behavior of electricity derivative prices. He first mentions that price spikes mostly occur in periods which experience a high demand of electricity, where the price spike is a consequence of the shape of the supply curve. He also mentions a decrease in generating capacity as a possible cause of price spikes. Villaplana finds that it is difficult to implement the supply factor in his analysis, which leads him to the conclusion that it is this difficulty which has prevented anyone from making such an analysis before. Furthermore, Villaplana's framework shows that the: "*risk premium depends positively on the degree of convexity between spot price and the state variables, on the volatility of the state variables and on the price of risk*" (p. 25). Hereby, 'state variables' refers to demand and supply. Villaplana claims that his framework does explain the volatility of the forward risk premium. Although Villaplana does not try to answer the research question of this thesis, his work does point quite in the same direction. As such, Villaplana is one of the first (as far as the author knows) who actually researched the influence of demand and supply on the price of electricity. Even though Villaplana only researched the effects of supply and demand on the forward risk premium, it might be assumed that if Villaplana's framework holds for the forward risk premium, it might also show a significant influence on the total (forward) price. Villaplana's paper might therefore be a first step in the right direction.

Lucheroni (2007) finds another way of explaining price spikes. He states that there are five main reasons for price spikes:

1. Generation costs: at a certain level of demand, extra and more costly generators have to be used in order to meet demand;
2. Fuel costs: especially for gas-based generators, because the fuel price is mean reverting itself and also experiences heavy volatility;
3. Grid congestion;
4. Correlation with other spiking grids;
5. Action protocol: because producers can undertake strategic actions in determining the quantity of electricity to be produced on a certain moment. Lucheroni therefore states that if the auction protocol is not designed in a good way, it can result in a "*powerful mechanism for nonlinear and threshold behavior of prices*" (p. 5).

The first three reasons of Lucheroni's enumeration can, to some extent, be linked to a direct relation between tail fatness/volatility of electricity prices and the excess capacity of electricity.

Birnbaum, Aguila, Dominquez and Lekander (2002) find many reasons for the occurrence of price spikes which are already mentioned before. Examples of this are the seasonality of demand and the fact that electricity cannot be stored in an economical way. However, in their paper, Birnbaum et al. also focus on a problem which was not previously mentioned before in this literature overview. Although almost every paper which has electricity as its subject starts with explaining the recent deregulation of the electricity market, the deregulation was not previously mentioned as a cause of the high price volatility. Birnbaum et al. state that, prior to the deregulation, the government forced the electricity generating companies to always have a high excess capacity in order to always be able to meet the demand of electricity.

This governmental force and the fact that there was no market competition caused the electricity prices to be high. Birnbaum et al. state that for many markets, the deregulation had the purpose of decreasing the electricity prices by decreasing the huge excess capacities. On average, the deregulation indeed diminished the prices but, as Birnbaum et al. state it: "*In many markets, deregulation was meant to secure lower prices for end users by eliminating excessive reserve* *margins. And it has indeed eliminated them—only too effectively, it now turns out*" (p. 67). Hereby Birnbaum et al. refer to a figure in their paper which displays the quantity of excess capacity for different markets, before and after the deregulation. This thesis contains two graphs (figures 2.2 and 2.3) which are based on the data provided by the figure of Birnbaum et al. For these figures, the years prior to 2000 stand for the regulated electricity markets while the year 2000 represents the deregulated markets.

Figure 2.2: Peak demand and max. capacity, before and after the deregulation

Based on Birnbaum et al. (2002, p. 68, exhibit 2)

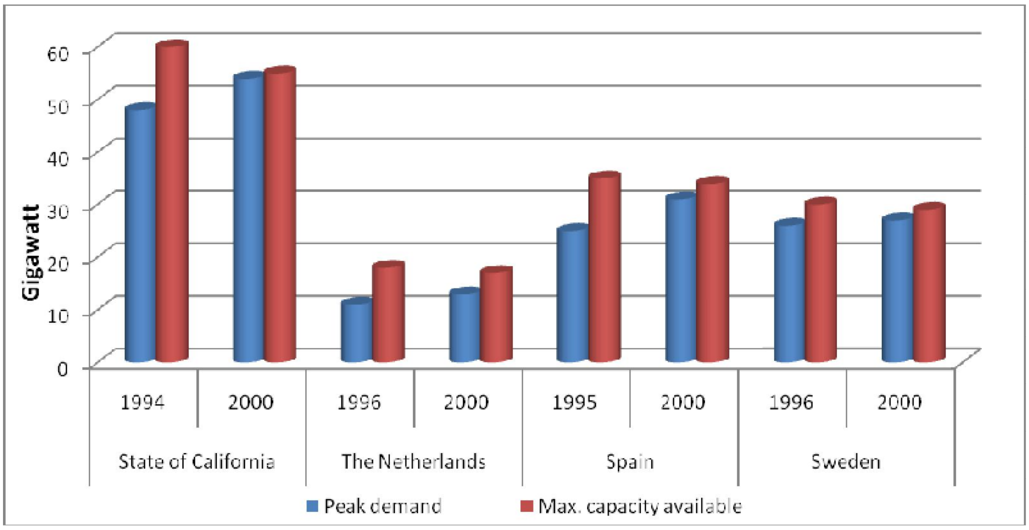
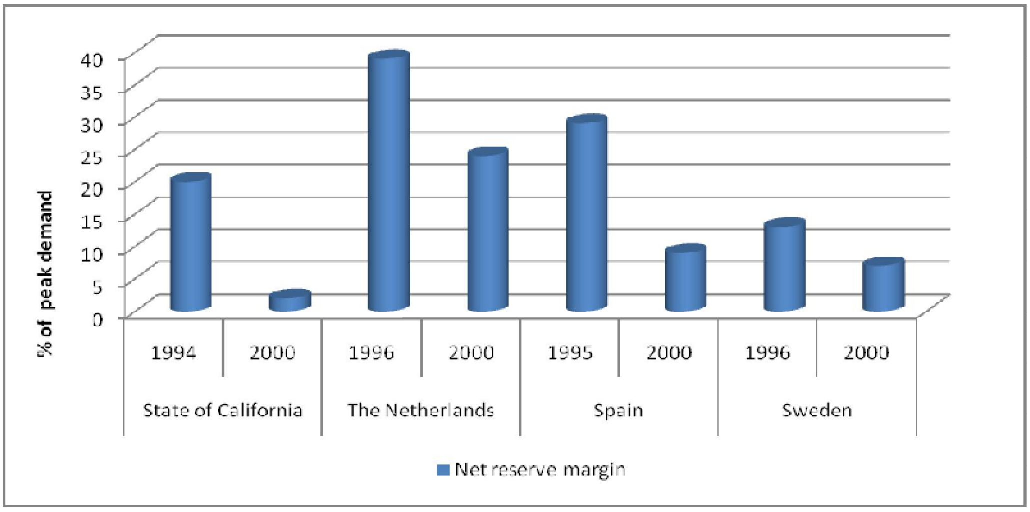


Figure 2.3: Excess capacity available; before and after the deregulation

Based on Birnbaum et al. (2002, p.68, exhibit 2)



Keeping the excess capacity on the same level as it was before the deregulation was, according to Birnbaum et al., not economically feasible for the generating companies. However, because of the diminished excess capacity, the electricity market is becoming less and less able to meet demand on its peak moments. This is causing the prices to rise dramatically on these moments. Birnbaum et al. therefore claim that the deregulation is a big contributor to the occurrence of price spikes.

2.4 Papers which describe an indirect link

The papers discussed in this paragraph are somewhat different compared to the previously discussed papers. That is, the relationship between the excess capacity of electricity and tail fatness of electricity prices which is described in these papers, appears to be indirect instead of direct.

A first example of such an indirect relationship is given by Caves, Eakin and Faruqui (2000). Caves et al. start their (2000) paper with a reference to a report of the Federal Energy Regulatory Commission (FERC). This report investigated a major electricity price spike in 1998 in the USA. In their report, the FERC concluded that the spike was a consequence of the combination of different factors. They found that, on the supply side, there were some production- and distribution problems while there was a larger than normal demand of electricity because of high temperatures. The FERC concluded that the combination of such events (decreased supply and increased demand) would be very unlikely to happen again. However, an even bigger price spike occurred only one year later. This time, according to Caves et al.: *"unexpected supply constraints, buyers' panic and trader default were conspicuously absent"* (p. 13). This leads Caves et al. to the conclusion there is another mechanism which is causing the price spikes in the electricity market. In their paper, Caves et al. find that the high volatility of price spikes is caused by the absence of a connection between the wholesale market and the retail market. Somewhat similar to the conclusion of Borenstein (2002), Caves et al. state that a solution to this problem would lie within, as they call it, a "*voluntary spot-price product"* (p. 14). Their arguments are quite similar to Borenstein because they argue that if the consumer would feel the difference in the current (spot) electricity price, it would adjust its demand of electricity.

Robinson and Baniak (2002) describe a different kind of link between demand of electricity and the probability of price spikes regarding the British electricity market. They state that (in England and Wales) the price paid by, as they call it, Regional Electricity Companies to the electricity generating companies is derived from the following formula:

"PPP = SMP + LOLP(VOLL-SMP)" (p. 1488).

The different abbreviations of the formula are elaborated in the following table.

Table 2.1: Abbreviations Robinson and Baniak (2002) pricing formula

PPP	Pool Purchase Price
SMP	System Marginal Price
LOLP	Loss of Load Probability
VOLL	Value of Lost Load

According to Robinson and Baniak, the SMP is a price which is calculated by the National Grid Company in advance, based on expected demand and announced availability by each generator. The SMP is the standard market price for all generating companies. However, on top of the SMP comes an extra amount, the so-called 'capacity payment'. This payment is based on each unit of capacity a generating company has declared available. Robinson and Baniak state that LOLP is a *"measure of risk that there may be unexpected plant outages or spurts in demand" (p. 1488)* as where the VOLL is an estimation of the costs of this LOLP for the consumer. As a result of this, Robinson and Baniak state, does the extra amount on top of the SMP and therefore the PPP, depend heavily on the demand of electricity. If the expected demand is smaller than the capacity, the capacity payments are relatively small. The capacity payments are quite large however, if the expected demand is near the generating capacity.

Robinson and Baniak therefore conclude that the capacity payments *"being formula driven, increase to a high level when demand is near capacity. Spikes can therefore occur when demand is exceptionally high and when there have been unpredictable reductions in capacity"* (p. 1488).

2.5 Short summary and conclusion

Summarized, there appear to be several papers which describe the relation between supply and demand and the volatility of electricity prices. However, they all do this from a theoretical point of view. Though their arguments seem to make sense and they could very well be right, their arguments are not empirically tested. Furthermore, the relation which they most frequently describe is the relation between supply and demand and the volatility of price spikes and therefore not the relationship between supply and demand and the tail fatness of electricity prices. This is of great importance because price volatility and tail fatness are not the same (see the introduction of chapter 4). After carefully reviewing the most relevant literature regarding the subject of this thesis, the conclusion can be drawn that, as far as the author knows, the relationship between supply and demand and tail fatness of electricity prices is not yet empirically tested. This thesis did perform such an empirical research, and the data used for this research is discussed in the next chapter.

3. Data

This chapter describes the data used for the empirical tests of this thesis and discusses the following topics: the choice of using hourly data (paragraph 3.1), the usage of six electricity markets (paragraph 3.2) and the reasons for using only the electricity prices of working days (paragraph 3.3). Furthermore, paragraph 3.4 provides some additional information regarding the used samples.

3.1 Hourly data

Because the price spikes discussed in this thesis can occur in very short time periods, it is important that the data used to test the hypotheses is able to capture the sudden changes in the electricity price. To be able to do that, the interval between observations should be very small. Therefore, this thesis uses hourly day-ahead/spot electricity prices as data-input.

3.2 Six electricity markets

To strengthen its conclusions, this thesis uses the hourly day-ahead/spot electricity prices of six electricity markets. The 2008 hourly day-ahead electricity prices of the following markets are used: APX (the Netherlands), UKPX (United Kingdom), Powernext (France) and PJM (United States). In addition, because the EEX (Germany) and Nord Pool (Finland, Sweden, Denmark and Norway) could not provide day-ahead electricity prices, the 2008 hourly spot prices of these markets are used instead.

These six markets are specifically chosen because the respective countries are all strong economical players in the European Union (except for the PJM market which is U.S.-based) and all markets are deregulated. Furthermore, by using these six markets, an internal comparison is also possible.

3.3 Working days only

The used data only consists of the day-ahead/spot electricity prices of working days. The weekends are excluded because it is known that the electricity prices are much lower on weekends than on working days. This is stated by, among others, Lucia and Schwartz (2000) and Tippig (2007).

3.4 Additional sample information

For each market, the sample consists of all hourly data of each working day for 2008.
The electricity prices display the market price for one MWh and are stated in the currency of the respective market.

The next chapter discusses the methodology used to analyze the data of the six electricity markets.

4. Research methodology

Hans Byström states in his (2001) paper the following:

"When one is to describe a financial price series that exhibits many "extreme" price changes one usually refers to it as a volatile time series and summarizes this by presenting the series (high) variance, or volatility. Such a series might of course be a very "volatile" series, but it may also just have some large price changes and for the rest be very tranquil. In fact, another series with much fewer extreme changes may have a much higher volatility. The point is that if one wants to assess the probability for an extreme price change to occur, then the use of the single parameter, volatility, is not necessary the proper way to go. Instead, an explicit modelling of the extreme movements themselves, the tails of the price change distribution, should be considered. In this way one models the tails directly, not as an indirect result of modelling the entire distribution (of which the extreme tails are just small portions)" (p. 1).

Following Byström, chapter 4 discusses the measurement of tail fatness. Paragraph 4.1 examines different methods for the measurement of tail fatness. The second paragraph of this chapter describes why the Huisman-Hill estimator is chosen to estimate the tail fatness while paragraph 4.3 shows how the outcome of the tail fatness estimator (alpha) should be interpreted.

4.1 Measurement of tail fatness

There are a few different methods for the measurement of tail fatness. However, the Hill estimator is the one which is widely accepted as the leading measurement. This is, among others, stated by Pictet, Dacorogna and Müller (1996), by Bassi, Embrechts and Kafetzaki (1998) and by Adler, Feldman and Gallagher (1998) who mention the Hill estimator in their 'survival kit on quantile estimation'.

In their (1996) paper, Pictet, Dacorogna and Müller discuss four different tail estimators. They discuss the method of Pickands (Pickands III, 1975), Hill (Hill, 1975), De Haan and Resnick (De Haan and Rasnick, 1980) and an extended Hill estimator (Dekkers et al., 1990). While comparing the different estimators, Pictet et al. come to the conclusion that *"the Hill estimator remains among the best estimators when it comes to fat-tailed distributions"* (p. 284). Pictet et al. do however signal a potential weakness of the Hill estimator. They find that the Hill estimator shows biased results when using it on a, as they call it, "*finite sample*" (p. 285). This potential bias leads Pictet et al. to the conclusion that the practical applicability of the Hill estimator is questionable.

This is acknowledged by Huisman et al. (2001). In their paper, Huisman et al. call the Hill estimator *"the benchmark in the literature"* (p. 208) with respect to the measurement of tail fatness. Equally like Pictet et al., Huisman et al. also mention the fact that the Hill estimator produces biased results when the estimator is used with relatively small samples. Consequently, Huisman et al. find an improved version of the Hill estimator which is based on a different methodology.

This different methodology results in a correction for the bias caused by the usage of small samples. In their 2001 paper, Huisman et al. use simulations to find out whether or not their modified Hill estimator provides less biased results. The results of these simulations lead Huisman et al. to the conclusion that the modified Hill estimator (from now on called the Huisman-Hill estimator) indeed provides less biased outcomes and therefore outperforms the conventional Hill estimator when using small samples. This is true even up to samples including only 100 observations.

4.2 Using the Huisman-Hill estimator

Because the Huisman-Hill estimator has proven to be a good measurement of tail fatness of small samples and this research consists of six samples each containing only 260 observations, this thesis uses the Huisman-Hill estimator.

To calculate the tail index estimations, a Scilab[4] format containing the Huisman-Hill estimator was build by Huisman. This format produces a tail index estimation for every hour for each of the six electricity markets. Hereby, the format focuses on the highest prices and thus only uses (positive) price spikes in its calculations. It thus ignores any possible negative price spikes. This is because this thesis only focuses on the event of price spikes and not on any sudden price breakdowns. Consequently, the Scilab format only focuses on the right side of the price distribution.

4.2.1 Information provided per tail index estimation

Each tail index estimation consists of the following information:

γ: Gamma: the outcome of the Huisman-Hill estimator. However, tail fatness is denoted in α so therefore γ has to be converted into α. This conversion can be performed by the following formula: $\alpha = \frac{1}{\gamma}$

α: Alpha: this symbol denotes the actual tail fatness.

S.E.: The standard error: is needed to test whether γ and the differences in γ are significant or not.

4.3 The interpretation of alpha

Because alpha (α) denotes tail fatness, it is alpha which is the actual outcome of this research. It is therefore important to know, how alpha should be interpreted: an alpha of 1 stands for extreme tail fatness of the distribution of the underlying sample and an infinite alpha stands for a normal distribution of the underlying sample. So, the higher alpha, the less the distribution suffers from tail fatness and the more the distribution approaches normality. There is however no clear boundary which states from what alpha on, a distribution is experiencing fat tails or from what alpha on a distribution should be characterized as being normal.

[4] Scilab is an open source software which can be used for difficult mathematical and statistical calculations.

In this thesis however, it is assumed that with an alpha of 15 or higher, a distribution can be characterized as being normal. Any distributions with an alpha lower than 15 are therefore stated to be experiencing tail fatness. This assumption is based on the following figures in which a histogram displays the price distribution of a certain hour of the UKPX market. This distribution is then reflected against the curve of the normal distribution. Figure 4.1 displays the price distribution of h20 (hour 20) and has an alpha of 2.4. As can be seen, this figure suffers from tail fatness. This is in contrast with the distribution of h4 (figure 4.2) which has an alpha of 27 and shows almost no fat tails at all. However, because a distribution roughly approaches the curve of the normal distribution with an alpha of 15 (see the distribution of h6, figure 4.3), a distribution with an alpha of 15 is assumed to be normal.

Figure 4.1: Distribution of h20, alpha = 2.7

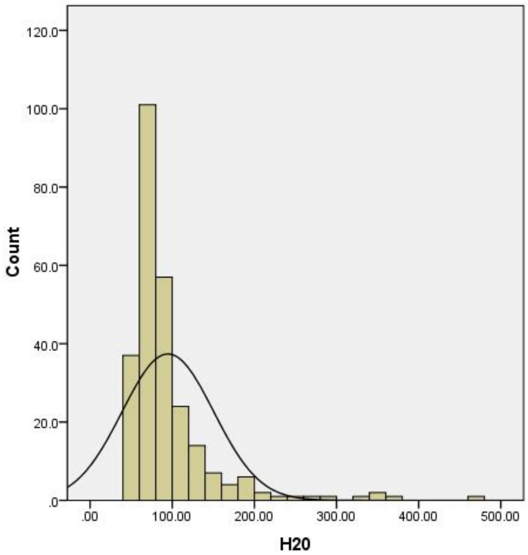


Figure 4.2: Distribution of h4, alpha = 27

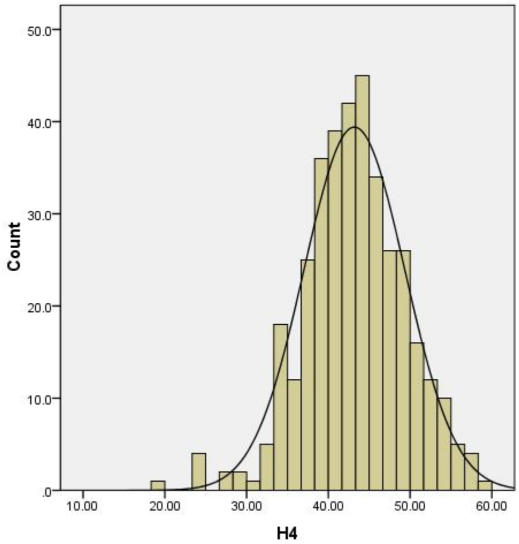
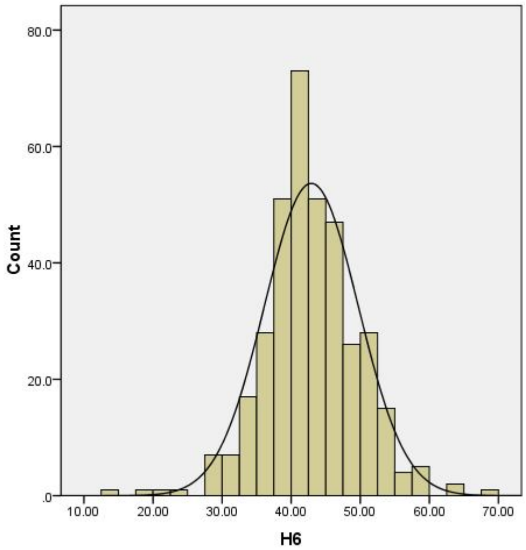


Figure 4.3: Distribution of h6, alpha = 15



In short, the Huisman-Hill estimator appears to be a good measurement of tail fatness. For that reason, this thesis uses this estimator for the estimation of the tail fatness of the six electricity markets. These estimations are shown and discussed in the next chapter.

5. Results

Chapter 5 analyzes the tail index estimations. The results of the APX market are discussed in paragraph 5.2 while the UPKX market is described in paragraph 5.3. This is followed by the Powernext market (paragraph 5.4) and the EEX market (paragraph 5.5). After these analyses, the results of the Nord Pool market (paragraph 5.6) and the results of the PJM market (paragraph 5.7) are analyzed as well.

As stated before, I expect to find a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices. More specifically, it is my expectation that the electricity price distributions experiences significantly more tail fatness during hours with a relative high electricity demand compared to hours with a relative low electricity demand

5.1 Analysis of the results

For each of the six samples, the tail index estimations (containing gamma, the standard error and alpha) for every hour are displayed in the tables presented below. The gamma is also shown in a graph in order to visualize the changes in tail fatness over the hours. For these graphs, gamma is used instead of alpha because otherwise, no statements regarding the significance of any changes of the tail fatness could be made (for an elaboration about the testing of significance, see below).

5.1.1 Test of significance

To discover whether the tail index estimations are a result of the assumptions of this research or that they are a result of chance alone, the significance of each tail index estimation is tested on the 95% confidence level by using a T-test. These tests are based on the gamma of each tail index estimation. The reason for using gamma for these tests (and not alpha), is that gamma is the actual outcome of the Huisman-Hill estimator.

From the total of 144 tail index estimations of this research, 132 have proven to be significant. This implies that 12 estimations are not significant and, as a consequence, one should be cautious when basing a conclusion on these estimations. In the tables below, significant tail index estimations are displayed in **green**, while non-significant estimations are displayed in **red**.

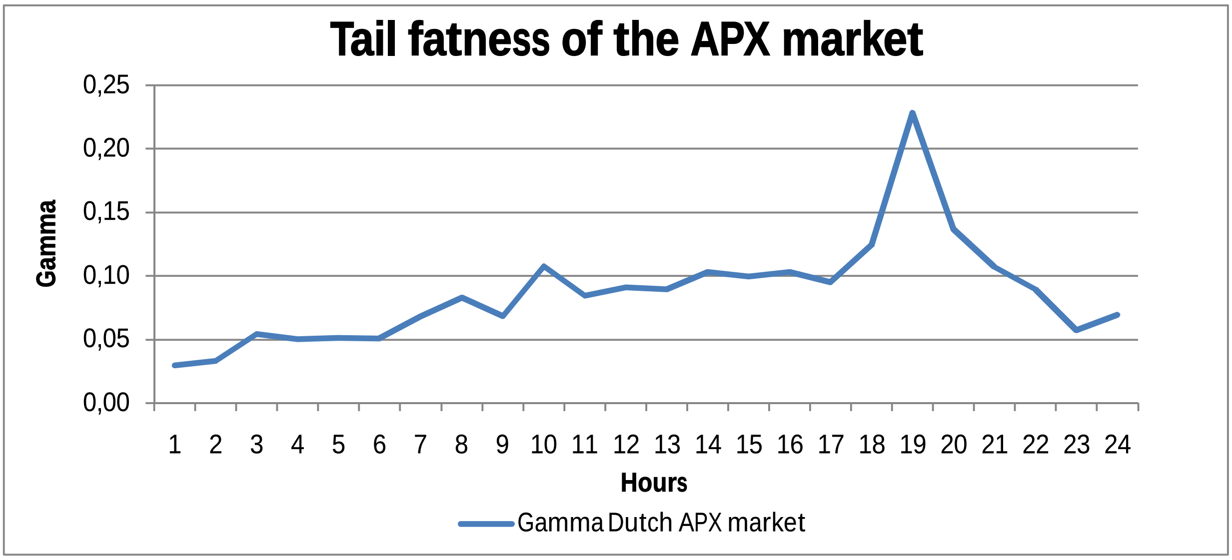
In addition, the significance of the change in tail fatness over time is also tested, again on the 95% confidence level. That is, the significance of the change in tail fatness between each hour with respect to every other hour is also tested. The results of these tests are stated below as well. For each comparison between two unequal hours, two results are displayed. First, the change in tail fatness is given. Below the change, the result of the significance test (again a T-test) is given (in parentheses). Again, for a better view of the results, significant changes are displayed in **green** while non-significant changes are displayed in **red**.

5.2 Results of the Dutch APX market

Table 5.1: Tail fatness estimations of the APX market

Hour	γ	s.e.	α	Hour	γ	s.e.	α
1.	0.0296	0.0185	33.825	13.	0.0897	0.0199	11.144
2.	0.0333	0.0186	30.035	14.	0.1034	0.0199	9.6713
3.	0.0542	0.0187	18.465	15.	0.0994	0.0197	10.061
4.	0.0502	0.0186	19.906	16.	0.1030	0.0200	9.7089
5.	0.0514	0.0194	19.445	17.	0.0950	0.0196	10.528
6.	0.0508	0.0185	19.679	18.	0.1245	0.0209	8.0345
7.	0.0678	0.0199	14.750	19.	0.2284	0.0210	4.3784
8.	0.0830	0.0188	12.049	20.	0.1369	0.0211	7.3028
9.	0.0685	0.0195	14.596	21.	0.1070	0.0202	9.3470
10.	0.1075	0.0201	9.2999	22.	0.0898	0.0199	11.137
11.	0.0848	0.0200	11.788	23.	0.0573	0.0190	17.452
12.	0.0911	0.0193	10.973	24.	0.0693	0.0193	14.428

Figure 5.1: Tail fatness of the APX market



5.2.1 Analysis of the tail index estimations

Table 5.1 shows the three parts of the tail index estimations of the Dutch APX electricity market. The table starts with gamma, the outcome of the Huisman-Hill estimator. For the first hour (from now on called h1), gamma is estimated on 0.0296. The standard error of this gamma is 0.0185. And because $\frac{1}{\gamma} = \alpha$, this thesis finds that the tail fatness of the APX electricity market of h1 is 33.825 (this statement can be made since alpha is used to denote tail fatness). Because the tail fatness (alpha) of h1 is larger than 15 (the perimeter established in paragraph 4.3), the distribution of the electricity prices of h1 can be classified as being normal.

Unfortunately, a T-test shows that the gamma of h1 is not significant and the tail index estimation of h1 is therefore printed in red. As a result, one should be cautious when using the tail index estimation of h1 to draw any conclusions about the tail fatness of this hour.

The table clearly shows that the tail fatness is not constant over time. The first few hours of the day have a relative large alpha and thus a relative low tail fatness. As a consequent, the first few hours of the day can be classified as normal. However, as the working day commences and the electricity demand increases, the tail fatness also seems to be increasing. For instance, on h3, the tail fatness is estimated on 18.465. The estimation is cut into half a few hours later. That is, on h10, tail fatness is estimated on only 9.299. Furthermore, tail fatness continues to increase over the working day. On the APX market, the tail fatness reaches its highest point at the end of the working day while everybody is going home: h19 has a tail fatness estimation of 4.378. During the next few hours, most businesses are closing and electricity demand decreases. The tail fatness consequently also decreases, reaching 17.452 on h23. Therefore, at the end of the day, the tail fatness is reaching more or less the same level as it started the day with.

This analysis is confirmed by figure 5.1. This graph shows the tail fatness of the APX market by using gamma (as is stated before). Because gamma works the opposite way of alpha, the higher gamma is, the more fat tailed the electricity price on a certain moment is. The graph shows that the tail fatness starts low at the beginning of the day but increases while the demand of electricity increases. When the working day is reaching its end, the tail fatness reaches its highest point of the day. From this moment on, tail fatness starts to decline again.

The statements about the tail fatness of the APX market can be made with confidence because all of the tail index estimations of the APX market are significant, with an exception of h1 and h2.

5.2.2 Analysis of the change of tail fatness

The last table associated with the APX market, table 5.2, displays the change of tail fatness for every hour compared with every other hour. By means of a T-test, the significance of these changes is also tested. The results of these tests are displayed below the changes in tail fatness. For example: the change of tail fatness of h2 compared with h1 is -0.0037. Because the change in tail fatness is calculated by subtracting the 'vertical' tail index estimation of the 'horizontal' tail index estimation $(\gamma_X - \gamma_Y)$, the -0.0037 implies that the tail index estimation of h2 is 0.0037 higher compared with h1. This implies that h2 experiences more tail fatness compared with h1 because the higher the tail index estimation is, the more fat tailed a distribution is,.

Below the amount of '-0.0037', another number is stated (in parentheses). This number is the result of the significance test. In this case, the test shows that the change in tail fatness for h1 compared with h2 is non-significant and is therefore printed in red.

Table 5.2 indicates that the hours in which the change of tail fatness is significantly different from zero, are the hours which are normally characterized by a high electricity demand. The best example of this is provided by h19, an hour which is assumed to be one of the peak demand-hours of the day. The change of tail fatness of h19 with respect to every other hour of the day is proven to be statistically significant. This is in contrast with low-demand hours. An example of this is h1. The only significant changes of h1 are the changes compared with high-demand hours (e.g., h8 and h19).

The overview the table provides makes clear that there are significant changes of tail fatness over the hours, especially when the level of tail fatness of low-demand hours is compared with the level of tail fatness of high-demand hours.

In short, the results of the APX market all confirm the expectations of this thesis: the tail fatness of the APX market is not constant over time; the excess capacity of electricity significantly influences the tail fatness of the electricity prices. Specifically, the prices of high-demand hours generally experience more tail fatness compared with low-demand hours.

Table 5.2: Significance test of the change of tail fatness over the hours (APX)

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2	-0,0037 -(0,14)																							
3	-0,0246 -(0,94)	-0,0209 (0,79)																						
4	-0,0206 -(0,79)	-0,0169 (0,64)	0,0040 -(0,15)																					
5	-0,0218 -(0,81)	-0,0181 (0,67)	0,0028 -(0,10)	-0,0012 (0,04)																				
6	-0,0212 -(0,81)	-0,0175 (0,67)	0,0034 -(0,13)	-0,0006 (0,02)	0,0006 -(0,02)																			
7	-0,0382 -(1,41)	-0,0345 (1,27)	-0,0136 (0,50)	-0,0176 (0,65)	-0,0164 (0,59)	-0,0170 (0,63)																		
8	-0,0534 -(2,02)	-0,0497 (1,88)	-0,0288 (1,09)	-0,0328 (1,24)	-0,0316 (1,17)	-0,0322 (1,22)	-0,0152 (0,56)																	
9	-0,0389 -(1,45)	-0,0352 (1,31)	-0,0143 (0,53)	-0,0183 (0,68)	-0,0171 (0,62)	-0,0177 (0,66)	-0,0007 (0,03)	0,0145 -(0,54)																
10	-0,0779 -(2,85)	-0,0742 (2,71)	-0,0533 (1,94)	-0,0573 (2,09)	-0,0561 (2,01)	-0,0567 (2,08)	-0,0397 (1,40)	-0,0245 (0,89)	-0,0390 (1,39)															
11	-0,0552 -(2,03)	-0,0515 (1,89)	-0,0306 (1,12)	-0,0346 (1,27)	-0,0334 (1,20)	-0,0340 (1,25)	-0,0170 (0,60)	-0,0018 (0,07)	-0,0163 (0,58)	0,0227 -(0,80)														
12	-0,0615 -(2,30)	-0,0578 (2,16)	-0,0369 (1,37)	-0,0409 (1,53)	-0,0397 (1,45)	-0,0403 (1,51)	-0,0233 (0,84)	-0,0081 (0,30)	-0,0226 (0,82)	0,0164 -(0,59)	-0,0063 (0,23)													
13	-0,0601 -(2,21)	-0,0564 (2,07)	-0,0355 (1,30)	-0,0395 (1,45)	-0,0383 (1,38)	-0,0389 (1,43)	-0,0219 (0,78)	-0,0067 (0,24)	-0,0212 (0,76)	0,0178 -(0,63)	-0,0049 (0,17)	0,0014 -(0,05)												
14	-0,0738 -(2,72)	-0,0701 (2,57)	-0,0492 (1,80)	-0,0532 (1,95)	-0,0520 (1,87)	-0,0526 (1,94)	-0,0356 (1,26)	-0,0204 (0,75)	-0,0349 (1,25)	0,0041 -(0,14)	-0,0186 (0,66)	-0,0123 (0,44)	-0,0137 (0,49)											
15	-0,0698 -(2,58)	-0,0661 (2,44)	-0,0452 (1,66)	-0,0492 (1,82)	-0,048 (1,74)	-0,0486 (1,80)	-0,0316 (1,13)	-0,0164 (0,60)	-0,0309 (1,11)	0,0081 -(0,29)	-0,0146 (0,52)	-0,0083 (0,30)	-0,0097 (0,35)	0,004 -(0,14)										
16	-0,0734 -(2,69)	-0,0697 (2,55)	-0,0488 (1,78)	-0,0528 (1,93)	-0,0516 (1,85)	-0,0522 (1,92)	-0,0352 (1,25)	-0,02 (0,73)	-0,0345 (1,24)	0,0045 -(0,16)	-0,0182 (0,64)	-0,0119 (0,43)	-0,0133 (0,47)	0,0004 -(0,01)	-0,0036 (0,13)									
17	-0,0654 -(2,43)	-0,0617 (2,28)	-0,0408 (1,51)	-0,0448 (1,66)	-0,0436 (1,58)	-0,0442 (1,64)	-0,0272 (0,97)	-0,012 (0,44)	-0,0265 (0,96)	0,0125 -(0,45)	-0,0102 (0,36)	-0,0039 (0,14)	-0,0053 (0,19)	0,0084 -(0,30)	0,0044 -(0,16)	0,008 -(0,29)								
18	-0,0949 -(3,40)	-0,0912 (3,26)	-0,0703 (2,51)	-0,0743 (2,66)	-0,0731 (2,56)	-0,0737 (2,64)	-0,0567 (1,96)	-0,0415 (1,48)	-0,056 (1,96)	-0,017 (0,59)	-0,0397 (1,37)	-0,0334 (1,17)	-0,0348 (1,21)	-0,0211 (0,73)	-0,0251 (0,87)	-0,0215 (0,74)	-0,0295 (1,03)							
19	-0,1988 -(7,10)	-0,1951 (6,95)	-0,1742 (6,20)	-0,1782 (6,35)	-0,177 (6,19)	-0,1776 (6,35)	-0,1606 (5,55)	-0,1454 (5,16)	-0,1599 (5,58)	-0,1209 (4,16)	-0,1436 (4,95)	-0,1373 (4,81)	-0,1387 (4,79)	-0,125 (4,32)	-0,129 (4,48)	-0,1254 (4,32)	-0,1334 (4,64)	-0,1039 (3,51)						
20	-0,1073 -(3,82)	-0,1036 (3,68)	-0,0827 (2,93)	-0,0867 (3,08)	-0,0855 (2,98)	-0,0861 (3,07)	-0,0691 (2,38)	-0,0539 (1,91)	-0,0684 (2,38)	-0,0294 (1,01)	-0,0521 (1,79)	-0,0458 (1,60)	-0,0472 (1,63)	-0,0335 (1,16)	-0,0375 (1,30)	-0,0339 (1,17)	-0,0419 (1,45)	-0,0124 (0,42)	0,0915 -(3,07)					
21	-0,0774 -(2,83)	-0,0737 (2,68)	-0,0528 (1,92)	-0,0568 (2,07)	-0,0556 (1,99)	-0,0562 (2,05)	-0,0392 (1,38)	-0,024 (0,87)	-0,0385 (1,37)	0,0005 -(0,02)	-0,0222 (0,78)	-0,0159 (0,57)	-0,0173 (0,61)	-0,0036 (0,13)	-0,0076 (0,27)	-0,004 (0,14)	-0,012 (0,43)	0,0175 -(0,60)	0,1214 -(4,17)	0,0299 -(1,02)				
22	-0,0602 -(2,22)	-0,0565 (2,07)	-0,0356 (1,30)	-0,0396 (1,45)	-0,0384 (1,38)	-0,039 (1,44)	-0,022 (0,78)	-0,0068 (0,25)	-0,0213 (0,76)	0,0177 -(0,63)	-0,005 (0,18)	0,0013 -(0,05)	-0,0001 (0,00)	0,0136 -(0,48)	0,0096 -(0,34)	0,0132 -(0,47)	0,0052 -(0,19)	0,0347 -(1,20)	0,1386 -(4,79)	0,0471 -(1,62)	0,0172 -(0,61)			
23	-0,0277 -(1,04)	-0,024 (0,90)	-0,0031 (0,12)	-0,0071 (0,27)	-0,0059 (0,22)	-0,0065 (0,25)	0,0105 -(0,38)	0,0257 -(0,96)	0,0112 -(0,41)	0,0502 -(1,81)	0,0275 -(1,00)	0,0338 -(1,25)	0,0324 -(1,18)	0,0461 -(1,68)	0,0421 -(1,54)	0,0457 -(1,66)	0,0377 -(1,38)	0,0672 -(2,38)	0,1711 -(6,04)	0,0796 -(2,80)	0,0497 -(1,79)	0,0325 -(1,18)		
24	-0,0397 -(1,48)	-0,036 (1,34)	-0,0151 (0,56)	-0,0191 (0,71)	-0,0179 (0,65)	-0,0185 (0,69)	-0,0015 (0,05)	0,0137 -(0,51)	-0,0008 (0,03)	0,0382 -(1,37)	0,0155 -(0,56)	0,0218 -(0,80)	0,0204 -(0,74)	0,0341 -(1,23)	0,0301 -(1,09)	0,0337 -(1,21)	0,0257 -(0,93)	0,0552 -(1,94)	0,1591 -(5,58)	0,0676 -(2,36)	0,0377 -(1,35)	0,0205 -(0,74)	-0,012 (0,44)	

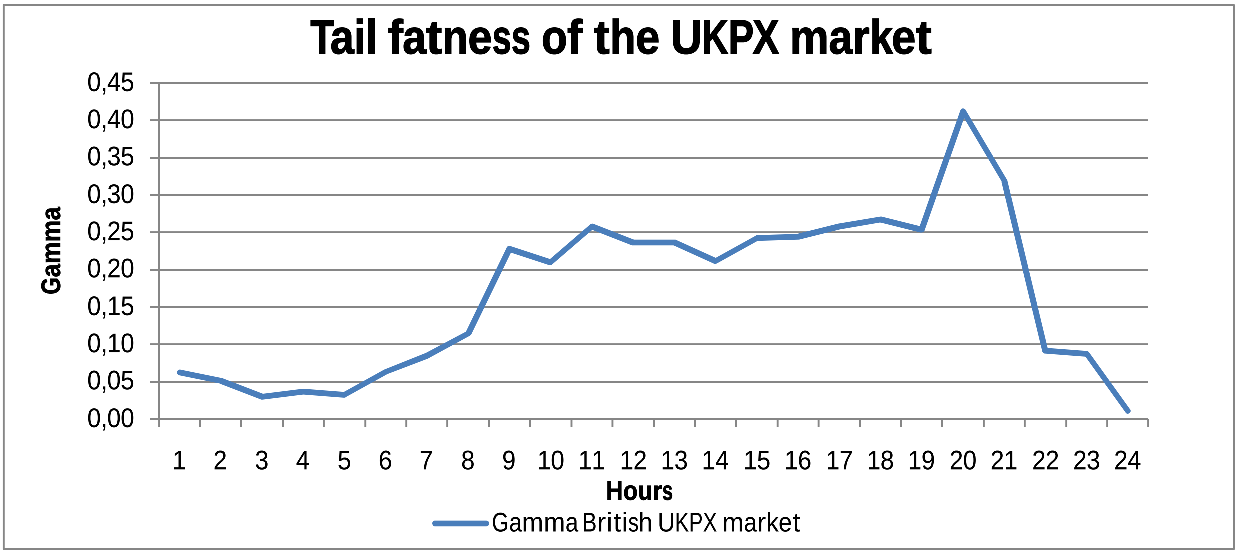
(Change in tail fatness (gamma) = $\gamma_X - \gamma_Y$)

5.3 Results of the British UKPX market

Table 5.3: Tail fatness estimations of the UKPX market

Hour	γ	s.e.	α	Hour	γ	s.e.	α
1.	0.0624	0.0187	16.036	13.	0.2368	0.0155	4.2232
2.	0.0516	0.0193	19.387	14.	0.2114	0.0768	4.7299
3.	0.0301	0.0185	33.235	15.	0.2422	0.0152	4.1289
4.	0.0369	0.0186	27.098	16.	0.2438	0.0311	4.1023
5.	0.0322	0.0186	31.102	17.	0.2580	0.0245	3.8755
6.	0.0631	0.0246	15.843	18.	0.2671	0.0156	3.7436
7.	0.0848	0.0200	11.788	19.	0.2538	0.0363	3.9404
8.	0.1152	0.0205	8.6813	20.	0.4124	0.0389	2.4249
9.	0.2275	0.0149	4.3956	21.	0.3196	0.0278	3.1290
10.	0.2101	0.0269	4.7598	22.	0.0920	0.0299	10.875
11.	0.2576	0.0191	3.8826	23.	0.0876	0.0172	11.421
12.	0.2363	0.0304	4.2321	24.	0.0113	0.0184	88.362

Figure 5.2: Tail fatness of the UKPX market



5.3.1 Analysis of the tail index estimations

The tail index estimations of the UKPX market show a pattern which is quite similar to the pattern of the estimations of the previously discussed the APX market. That is, the tail index estimations show more tail fatness during working hours compared with the hours at the beginning of the day. And after business hours, the tail fatness immediately starts to decrease again.

A difference between the two markets is that the tail fatness of the UKPX market shows less volatility compared to the tail fatness of the APX market. The UKPX tail index estimations stay roughly the same during the working hours while the estimations of the APX market continue to rise and fall during those same hours.

Another big difference between the two markets is that, once business hours are over and people are returning to their homes, the tail fatness of the UKPX market decreases quite abruptly. The tail index estimations of the UKPX stayed relatively stable during working hours (around 3 to 4) but suddenly increase from 3.129 to 10.875 and 11.421 during h22 and h23. The tail index estimations of the APX market show a more gradual increase with estimations of 7.3028, 9.3470, 11.137 and 17.452 during, respectively, h20, h21, h22 and h23.

Furthermore, it has to be noted that the enormous decrease of tail fatness of h24 (as can be seen in figure 5.2) is not significant. This implies that one has to be careful when taking this sudden decrease into its conclusions.

5.3.2 Analysis of the change of tail fatness

Table 5.4, displaying the significance of the changes of tail fatness, displays quite a different 'significant-structure' compared with the respective table of the APX market (table 5.2). Where the table of the APX market shows gradual increase of significant changes, the table of the UKPX market displays a 'block-structure'. That is, during hours with a high electricity demand (h8-h21) the changes with low-demand hours (h1-h7 and h22-h24) are, generally speaking, all significant. Furthermore, the changes of high-demand hours with other high-demand hours prove to be non-significant. This is also true for the changes of low-demand hours with respect to other low-demand hours, they are also found to be non-significant. Changes of low-demand hours with high-demand hours however do turnout to be significant. The table consequently shows a clear line between significant and non-significant changes. These lines result in the previously mentioned 'block-structure'.

Based on the results regarding the UKPX market can be concluded that the tail fatness of the electricity prices of this market are significantly influenced by the excess capacity of electricity. The tail fatness of the UKPX market increases during hours of a relative high electricity demand.

Table 5.4: Significance test of the change of tail fatness over the hours (UKPX)

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2	0,0108 (0,40)																							
3	0,0323 (1,23)	0,0215 -(0,80)																						
4	0,0255 (0,97)	0,0147 -(0,55)	-0,0068 (0,26)																					
5	0,0302 (1,15)	0,0194 -(0,72)	-0,0021 (0,08)	0,0047 -(0,18)																				
6	-0,0007 -(0,02)	-0,0115 (0,37)	-0,0330 (1,07)	-0,0262 (0,85)	-0,0309 (1,00)																			
7	-0,0224 -(0,82)	-0,0332 (1,19)	-0,0547 (2,01)	-0,0479 (1,75)	-0,0526 (1,93)	-0,0217 (0,68)																		
8	-0,0528 -(1,90)	-0,0636 (2,26)	-0,0851 (3,08)	-0,0783 (2,83)	-0,0830 (3,00)	-0,0521 (1,63)	-0,0304 (1,06)																	
9	-0,1651 -(6,90)	-0,1759 (7,21)	-0,1974 (8,31)	-0,1906 (8,00)	-0,1953 (8,19)	-0,1644 (5,72)	-0,1427 (5,72)	-0,1123 (4,43)																
10	-0,1477 -(4,51)	-0,1585 (4,79)	-0,1800 (5,51)	-0,1732 (5,30)	-0,1779 (5,44)	-0,1470 (4,03)	-0,1253 (3,74)	-0,0949 (2,81)	0,0174 -(0,57)															
11	-0,1952 -(7,30)	-0,2060 (7,59)	-0,2275 (8,56)	-0,2207 (8,28)	-0,2254 (8,45)	-0,1945 (6,25)	-0,1728 (6,25)	-0,1424 (5,08)	-0,0301 (1,24)	-0,0475 (1,44)														
12	-0,1739 -(4,87)	-0,1847 (5,13)	-0,2062 (5,79)	-0,1994 (5,60)	-0,2041 (5,73)	-0,1732 (4,43)	-0,1515 (4,16)	-0,1211 (3,30)	-0,0088 (0,26)	-0,0262 (0,65)	0,0213 -(0,59)													
13	-0,1744 -(7,18)	-0,1852 (7,48)	-0,2067 (8,56)	-0,1999 (8,26)	-0,2046 (8,45)	-0,1737 (5,97)	-0,1520 (6,01)	-0,1216 (4,73)	-0,0093 (0,43)	-0,0267 (0,86)	0,0208 -(0,85)	-0,0005 (0,01)												
14	-0,1490 -(1,89)	-0,1598 (2,02)	-0,1813 (2,30)	-0,1745 (2,21)	-0,1792 (2,27)	-0,1483 (1,84)	-0,1266 (1,60)	-0,0962 (1,21)	0,0161 -(0,21)	-0,0013 (0,02)	0,0462 -(0,58)	0,0249 -(0,30)	0,0254 -(0,32)											
15	-0,1798 -(7,46)	-0,1906 (7,76)	-0,2121 (8,86)	-0,2053 (8,55)	-0,21 (8,74)	-0,1791 (6,19)	-0,1574 (6,27)	-0,127 (4,98)	-0,0147 (0,69)	-0,0321 (1,04)	0,0154 -(0,63)	-0,0059 (0,17)	-0,0054 (0,25)	-0,0308 (0,39)										
16	-0,1814 -(5,00)	-0,1922 (5,25)	-0,2137 (5,91)	-0,2069 (5,71)	-0,2116 (5,84)	-0,1807 (4,56)	-0,159 (4,30)	-0,1286 (3,45)	-0,0163 (0,47)	-0,0337 (0,82)	0,0138 -(0,38)	-0,0075 (0,17)	-0,007 (0,20)	-0,0324 (0,39)	-0,0016 (0,05)									
17	-0,1956 -(6,35)	-0,2064 (6,62)	-0,2279 (7,42)	-0,2211 (7,19)	-0,2258 (7,34)	-0,1949 (5,61)	-0,1732 (5,48)	-0,1428 (4,47)	-0,0305 (1,06)	-0,0479 (1,32)	-0,0004 (0,01)	-0,0217 (0,56)	-0,0212 (0,73)	-0,0466 (0,58)	-0,0158 (0,55)	-0,0142 (0,36)								
18	-0,2047 -(8,41)	-0,2155 (8,68)	-0,237 (9,79)	-0,2302 (9,48)	-0,2349 (9,68)	-0,204 (7,00)	-0,1823 (7,19)	-0,1519 (5,90)	-0,0396 (1,84)	-0,057 (1,83)	-0,0095 (0,39)	-0,0308 (0,90)	-0,0303 (1,38)	-0,0557 (0,71)	-0,0249 (1,14)	-0,0233 (0,67)	-0,0091 (0,31)							
19	-0,1914 -(4,69)	-0,2022 (4,92)	-0,2237 (5,49)	-0,2169 (5,32)	-0,2216 (5,43)	-0,1907 (4,35)	-0,169 (4,08)	-0,1386 (3,32)	-0,0263 (0,67)	-0,0437 (0,97)	0,0038 -(0,09)	-0,0175 (0,37)	-0,017 (0,43)	-0,0424 (0,50)	-0,0116 (0,29)	-0,01 (0,21)	0,0042 -(0,10)	0,0133 -(0,34)						
20	-0,35 -(8,11)	-0,3608 (8,31)	-0,3823 (8,88)	-0,3755 (8,71)	-0,3802 (8,82)	-0,3493 (7,59)	-0,3276 (7,49)	-0,2972 (6,76)	-0,1849 (4,44)	-0,2023 (4,28)	-0,1548 (3,57)	-0,1761 (3,57)	-0,1756 (4,19)	-0,201 (2,33)	-0,1702 (4,08)	-0,1686 (3,39)	-0,1544 (3,36)	-0,1453 (3,47)	-0,1586 (2,98)					
21	-0,2572 -(7,68)	-0,268 (7,92)	-0,2895 (8,67)	-0,2827 (8,45)	-0,2874 (8,59)	-0,2565 (6,91)	-0,2348 (6,86)	-0,2044 (5,92)	-0,0921 (2,92)	-0,1095 (2,83)	-0,062 (1,84)	-0,0833 (2,02)	-0,0828 (2,60)	-0,1082 (1,32)	-0,0774 (2,44)	-0,0758 (1,82)	-0,0616 (1,66)	-0,0525 (1,65)	-0,0658 (1,44)	0,0928 -(1,94)				
22	-0,0296 -(0,84)	-0,0404 (1,14)	-0,0619 (1,76)	-0,0551 (1,56)	-0,0598 (1,70)	-0,0289 (0,75)	-0,0072 (0,20)	0,0232 -(0,64)	0,1355 -(4,06)	0,1181 -(2,94)	0,1656 -(4,67)	0,1443 -(3,38)	0,1448 -(4,30)	0,1194 -(1,45)	0,1502 -(4,48)	0,1518 -(3,52)	0,166 -(4,29)	0,1751 -(5,19)	0,1618 -(3,44)	0,3204 -(6,53)	0,2276 -(5,57)			
23	-0,0252 -(0,99)	-0,036 (1,39)	-0,0575 (2,28)	-0,0507 (2,00)	-0,0554 (2,19)	-0,0245 (0,82)	-0,0028 (0,11)	0,0276 -(1,03)	0,1399 -(6,15)	0,1225 -(3,84)	0,17 -(6,61)	0,1487 -(4,26)	0,1492 -(6,44)	0,1238 -(1,57)	0,1546 -(6,74)	0,1562 -(4,40)	0,1704 -(5,69)	0,1795 -(7,73)	0,1662 -(4,14)	0,3248 -(7,64)	0,232 -(7,10)	0,0044 -(0,13)		
24	0,0511 (1,95)	0,0403 -(1,51)	0,0188 -(0,72)	0,0256 -(0,98)	0,0209 -(0,80)	0,0518 -(1,69)	0,0735 -(2,70)	0,1039 -(3,77)	0,2162 -(9,13)	0,1988 -(6,10)	0,2463 -(9,29)	0,225 -(6,33)	0,2255 -(9,37)	0,2001 -(2,53)	0,2309 -(9,67)	0,2325 -(6,43)	0,2467 -(8,05)	0,2558 -(10,60)	0,2425 -(5,96)	0,4011 -(9,32)	0,3083 -(9,25)	0,0807 -(2,30)	0,0763 -(3,03)	

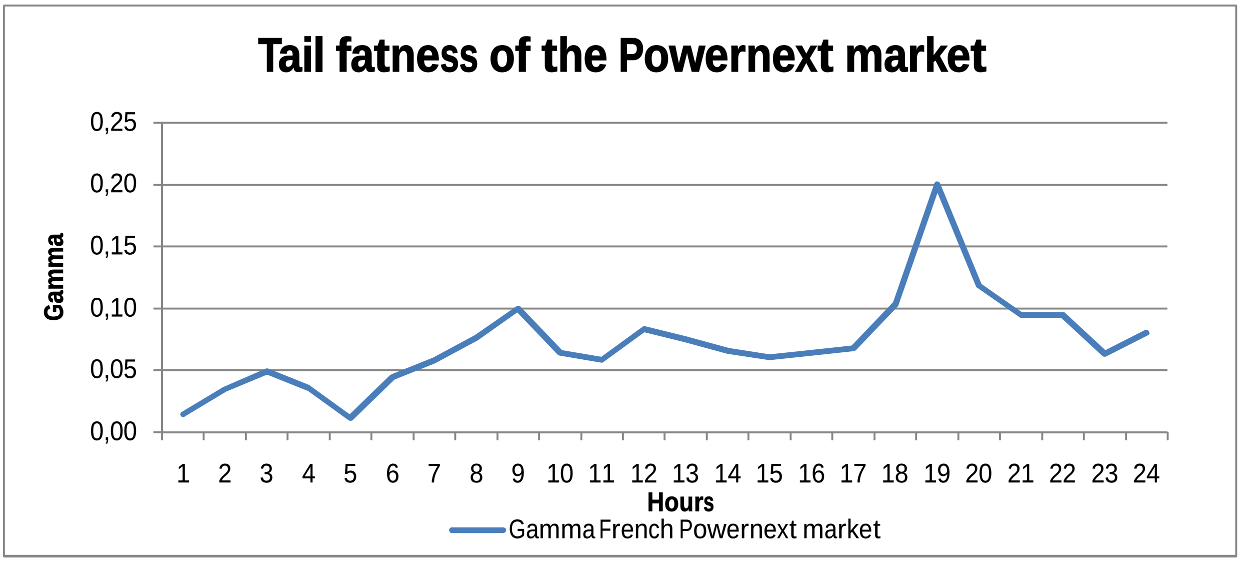
(Change in tail fatness (gamma) = $\gamma_X - \gamma_Y$)

5.4 Result of the French Powernext market

Table 5.5: Tail fatness estimations of the Powernext market

Hour	γ	s.e.	α	Hour	γ	s.e.	α
1.	0.0145	0.0184	69.109	13.	0.0749	0.0183	13.344
2.	0.0347	0.0184	28.834	14.	0.0659	0.0190	15.180
3.	0.0494	0.0188	20.263	15.	0.0608	0.0192	16.439
4.	0.0359	0.0187	27.822	16.	0.0643	0.0194	15.554
5.	0.0116	0.0184	86.283	17.	0.0677	0.0201	14.777
6.	0.0443	0.0188	22.550	18.	0.1033	0.0200	9.6850
7.	0.0579	0.0188	17.264	19.	0.2003	0.0232	4.9931
8.	0.0760	0.0202	13.161	20.	0.1186	0.0204	8.4338
9.	0.0998	0.0193	10.024	21.	0.0946	0.0198	10.576
10.	0.0640	0.0195	15.617	22.	0.0949	0.0197	10.538
11.	0.0584	0.0186	17.121	23.	0.0630	0.0390	15.876
12.	0.0833	0.0179	12.004	24.	0.0801	0.0204	12.481

Figure 5.3: Tail fatness of the Powernext market



5.4.1 Analysis of the tail index estimations

The graph of the tail index estimations of the Powernext market shows quite clearly that the tail fatness of the Powernext market is not constant over the day.

At the beginning of the day (h1), the tail fatness is very small. The second hour, h2, shows a highly decreased tail index estimation compared with h1. However, both estimations are non-significant. This implies that the remarkable low starting point and the immediate increase of the tail fatness have to be interpreted with caution. This is also true for the following steep decrease and sharp increase during h4 and h5 for the estimations of these hours are also non-significant.

Because the tail index estimations of the next hours are significant, it can be noted that the tail fatness increases while the business day commences and electricity demand increase. During business hours, the tail fatness continues to increase and decrease slightly. A sharp increase of tail fatness can be found at the end of the business day, around h19.

From that moment on however, electricity demand normally decreases and so does the tail fatness, it decreases gradually the next few hours. This comes to a halt, however, at h24 where the tail index estimation suddenly increases slightly.

In despite of the many non-significant tail index estimations of the Powernext market, it becomes clear that the excess capacity of electricity significantly affects the tail fatness of the electricity price distribution. Tail fatness increases during business hours (with a peak at the end of the business day) and decreases after business hours.

5.4.2 Analysis of the change of tail fatness

Furthermore, table 5.6 shows a (gradual) pattern of significant changes of tail fatness, a pattern which is a bit similar to the pattern of changes of the APX market and therefore does not show the ‘block-structure’ of the UKPX market. The changes of tail fatness which turn out to be significant can only be found while comparing high-demand hours with very low-demand hours. The only exception of this statement is h19. This hour, which is assumed to be one of the hours which experiences the highest electricity demand of a day, has significant changes of tail fatness in comparison with every other hour of the day.

It can therefore be concluded that, roughly speaking, only the hours which experience a high demand of electricity show (some) significant changes of tail fatness when compared to very low-demand hours.

Equally like the conclusions regarding the APX and UKPX market, the results of the Powernext market show that the tail fatness of the French electricity market experiences significant influence from the excess capacity of electricity.

Table 5.6: Significance test of the change of tail fatness over the hours (Powernext)

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2	-0,0202 -(0,78)																							
3	-0,0349 -(1,33)	-0,0147 (0,56)																						
4	-0,0214 -(0,82)	-0,0012 (0,05)	0,0135 -(0,51)																					
5	0,0029 (0,11)	0,0231 -(0,89)	0,0378 -(1,44)	0,0243 -(0,93)																				
6	-0,0298 -(1,13)	-0,0096 (0,36)	0,0051 -(0,19)	-0,0084 (0,32)	-0,0327 (1,24)																			
7	-0,0434 -(1,65)	-0,0232 (0,88)	-0,0085 (0,32)	-0,0220 (0,83)	-0,0463 (1,76)	-0,0136 (0,51)																		
8	-0,0615 -(2,25)	-0,0413 (1,51)	-0,0266 (0,96)	-0,0401 (1,46)	-0,0644 (2,36)	-0,0317 (1,15)	-0,0181 (0,66)																	
9	-0,0853 -(3,20)	-0,0651 (2,44)	-0,0504 (1,87)	-0,0639 (2,38)	-0,0882 (3,31)	-0,0555 (2,06)	-0,0419 (1,56)	-0,0238 (0,85)																
10	-0,0495 -(1,85)	-0,0293 (1,09)	-0,0146 (0,54)	-0,0281 (1,04)	-0,0524 (1,95)	-0,0197 (0,73)	-0,0061 (0,23)	0,0120 -(0,43)	0,0358 -(1,30)															
11	-0,0439 -(1,68)	-0,0237 (0,91)	-0,0090 (0,34)	-0,0225 (0,85)	-0,0468 (1,79)	-0,0141 (0,53)	-0,0005 (0,02)	0,0176 -(0,64)	0,0414 -(1,54)	0,0056 -(0,21)														
12	-0,0688 -(2,68)	-0,0486 (1,89)	-0,0339 (1,31)	-0,0474 (1,83)	-0,0717 (2,79)	-0,0390 (1,50)	-0,0254 (0,98)	-0,0073 (0,27)	0,0165 -(0,63)	-0,0193 (0,73)	-0,0249 (0,96)													
13	-0,0604 -(2,33)	-0,0402 (1,55)	-0,0255 (0,97)	-0,0390 (1,49)	-0,0633 (2,44)	-0,0306 (1,17)	-0,0170 (0,65)	0,0011 -(0,04)	0,0249 -(0,94)	-0,0109 (0,41)	-0,0165 (0,63)	0,0084 -(0,33)												
14	-0,0514 -(1,94)	-0,0312 (1,18)	-0,0165 (0,62)	-0,0300 (1,13)	-0,0543 (2,05)	-0,0216 (0,81)	-0,0080 (0,30)	0,0101 -(0,36)	0,0339 -(1,25)	-0,0019 (0,07)	-0,0075 (0,28)	0,0174 -(0,67)	0,0090 -(0,34)											
15	-0,0463 -(1,74)	-0,0261 (0,98)	-0,0114 (0,42)	-0,0249 (0,93)	-0,0492 (1,85)	-0,0165 (0,61)	-0,0029 (0,11)	0,0152 -(0,55)	0,039 -(1,43)	0,0032 -(0,12)	-0,0024 (0,09)	0,0225 -(0,86)	0,0141 -(0,53)	0,0051 -(0,19)										
16	-0,0498 -(1,86)	-0,0296 (1,11)	-0,0149 (0,55)	-0,0284 (1,05)	-0,0527 (1,97)	-0,02 (0,74)	-0,0064 (0,24)	0,0117 -(0,42)	0,0355 -(1,30)	-0,0003 (0,01)	-0,0059 (0,22)	0,019 -(0,72)	0,0106 -(0,40)	0,0016 -(0,06)	-0,0035 (0,13)									
17	-0,0532 -(1,95)	-0,0330 (1,21)	-0,0183 (0,66)	-0,0318 (1,16)	-0,0561 (2,06)	-0,0234 (0,85)	-0,0098 (0,36)	0,0083 -(0,29)	0,0321 -(1,15)	-0,0037 (0,13)	-0,0093 (0,34)	0,0156 -(0,58)	0,0072 -(0,26)	-0,0018 (0,07)	-0,0069 (0,25)	-0,0034 (0,12)								
18	-0,0888 -(3,27)	-0,0686 (2,52)	-0,0539 (1,96)	-0,0674 (2,46)	-0,0917 (3,37)	-0,059 (2,15)	-0,0454 (1,65)	-0,0273 (0,96)	-0,0035 (0,13)	-0,0393 (1,41)	-0,0449 (1,64)	-0,02 (0,75)	-0,0284 (1,05)	-0,0374 (1,36)	-0,0425 (1,53)	-0,039 (1,40)	-0,0356 (1,26)							
19	-0,1858 -(6,27)	-0,1656 (5,59)	-0,1509 (5,05)	-0,1644 (5,52)	-0,1887 (6,37)	-0,156 (5,22)	-0,1424 (4,77)	-0,1243 (4,04)	-0,1005 (3,33)	-0,1363 (4,50)	-0,1419 (4,77)	-0,117 (3,99)	-0,1254 (4,24)	-0,1344 (4,48)	-0,1395 (4,63)	-0,136 (4,50)	-0,1326 (4,32)	-0,097 (3,17)						
20	-0,1041 -(3,79)	-0,0839 (3,05)	-0,0692 (2,49)	-0,0827 (2,99)	-0,107 (3,89)	-0,0743 (2,68)	-0,0607 (2,19)	-0,0426 (1,48)	-0,0188 (0,67)	-0,0546 (1,93)	-0,0602 (2,18)	-0,0353 (1,30)	-0,0437 (1,59)	-0,0527 (1,89)	-0,0578 (2,06)	-0,0543 (1,93)	-0,0509 (1,78)	-0,0153 (0,54)	0,0817 -(2,64)					
21	-0,0801 -(2,96)	-0,0599 (2,22)	-0,0452 (1,66)	-0,0587 (2,16)	-0,083 (3,07)	-0,0503 (1,84)	-0,0367 (1,34)	-0,0186 (0,66)	0,0052 -(0,19)	-0,0306 (1,10)	-0,0362 (1,33)	-0,0113 (0,42)	-0,0197 (0,73)	-0,0287 (1,05)	-0,0338 (1,23)	-0,0303 (1,09)	-0,0269 (0,95)	0,0087 -(0,31)	0,1057 -(3,47)	0,024 -(0,84)				
22	-0,0804 -(2,98)	-0,0602 (2,23)	-0,0455 (1,67)	-0,059 (2,17)	-0,0833 (3,09)	-0,0506 (1,86)	-0,037 (1,36)	-0,0189 (0,67)	0,0049 -(0,18)	-0,0309 (1,11)	-0,0365 (1,35)	-0,0116 (0,44)	-0,0200 (0,74)	-0,029 (1,06)	-0,0341 (1,24)	-0,0306 (1,11)	-0,0272 (0,97)	0,0084 -(0,30)	0,1054 -(3,46)	0,0237 -(0,84)	-0,0003 (0,01)			
23	-0,0485 -(1,12)	-0,0283 (0,66)	-0,0136 (0,31)	-0,0271 (0,63)	-0,0514 (1,19)	-0,0187 (0,43)	-0,0051 (0,12)	0,013 -(0,30)	0,0368 -(0,85)	0,001 -(0,02)	-0,0046 (0,11)	0,0203 -(0,47)	0,0119 -(0,28)	0,0029 -(0,07)	-0,0022 (0,05)	0,0013 -(0,03)	0,0047 -(0,11)	0,0403 -(0,92)	0,1373 -(3,03)	0,0556 -(1,26)	0,0316 -(0,72)	0,0319 -(0,73)		
24	-0,0656 -(2,39)	-0,0454 (1,65)	-0,0307 (1,11)	-0,0442 (1,60)	-0,0685 (2,49)	-0,0358 (1,29)	-0,0222 (0,80)	-0,0041 (0,14)	0,0197 -(0,70)	-0,0161 (0,57)	-0,0217 (0,79)	0,0032 -(0,12)	-0,0052 (0,19)	-0,0142 (0,51)	-0,0193 (0,69)	-0,0158 (0,56)	-0,0124 (0,43)	0,0232 -(0,81)	0,1202 -(3,89)	0,0385 -(1,33)	0,0145 -(0,51)	0,0148 -(0,52)	-0,0171 (0,39)	

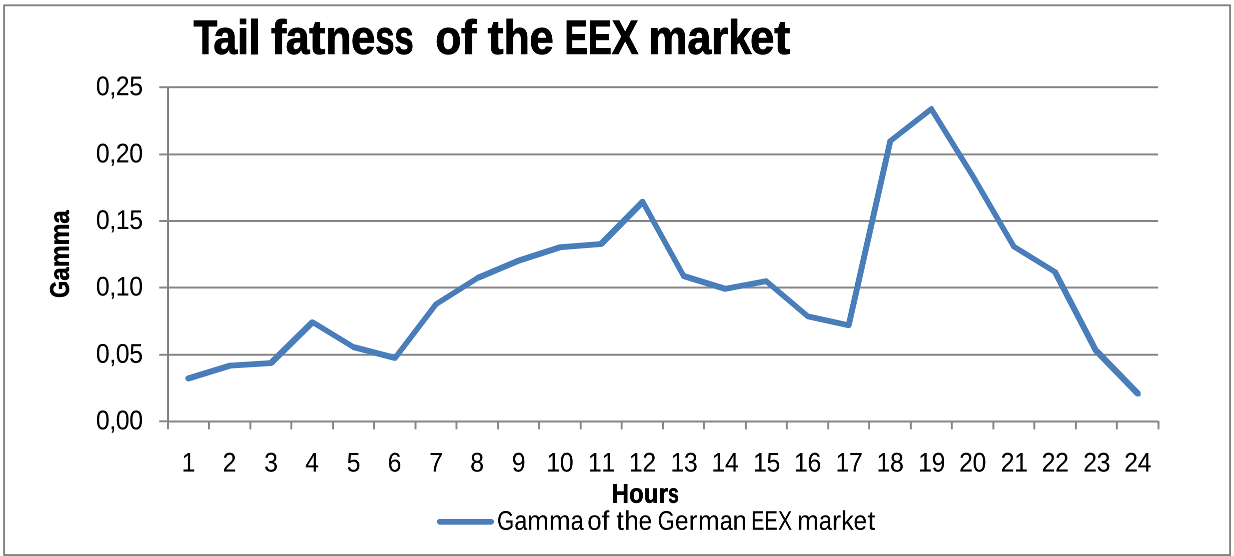
(Change in tail fatness (gamma) = $\gamma_X - \gamma_Y$)

5.5 Results of the German EEX market

Table 5.7: Tail fatness estimations of the EEX market

Hour	γ	s.e.	α	Hour	γ	s.e.	α
1.	0.0320	0.0186	31.238	13.	0.1086	0.0189	9.2069
2.	0.0416	0.0186	24.038	14.	0.0994	0.0197	10.058
3.	0.0436	0.0190	22.945	15.	0.1052	0.0207	9.5094
4.	0.0745	0.0190	13.428	16.	0.0787	0.0189	12.705
5.	0.0558	0.0193	17.924	17.	0.0717	0.0204	13.950
6.	0.0474	0.0192	21.099	18.	0.2097	0.0234	4.7698
7.	0.0875	0.0179	11.433	19.	0.2341	0.0313	4.2713
8.	0.1072	0.0202	9.3259	20.	0.1836	0.0576	5.4479
9.	0.1204	0.0208	8.3027	21.	0.1309	0.0194	7.6384
10.	0.1306	0.0180	7.6584	22.	0.1116	0.0203	8.9624
11.	0.1328	0.0211	7.5283	23.	0.0529	0.0190	18.897
12.	0.1643	0.0243	6.0851	24.	0.0208	0.0184	48.142

Figure 5.4: Tail fatness of the EEX market



5.5.1 Analysis of the tail index estimations

The tail index estimations of the German electricity market fit the profile created by the previous discussed electricity markets (see table 5.7). Again, there appears to be relatively little tail fatness during the first hours of the day. While the business day commences, tail fatness increases. From h13 on, the tail fatness decreases slightly in the upcoming hours. There is one last (sudden) increase of tail fatness around h18, but from h19 on, tail fatness only decreases during the last hours of the day. This does not happen very fast at the first few hours. At h20, the tail fatness reaches 5.448. H21 has a tail fatness of 7.638 while an hour later the tail fatness estimation reaches 8.962. Only when h23 is reached, the estimation rises quickly to 18.897. The last hour of the day shows a sharp decrease of tail fatness but this tail index estimation is, unfortunately, not significant. In short can be claimed that the tail fatness is estimated to be relatively low at the start of the day, then increases during working hours but only to decrease while the day reaches its last few hours. This analysis is displayed by figure 5.4, with the sharp increase of tail fatness during h18 and the following steep decrease during h20-h24 being the most noteworthy moments.

5.5.2 Analysis of the change of tail fatness

Table 5.8 is the final table discussing results regarding the EEX market and displays the gradual changes of tail fatness over the hours. The high-demand hours show significant changes of tail fatness compared to low-demand hours. And the low-demand hours show no significant changes compared to other low-demand hours. There is however no clear ‘block-structure’ because one can very well spot a gradual increase and decrease of the amount of significant changes over the hours.

With respect to the German EEX market, based on the above analyzed results, can therefore be concluded that the tail fatness of its electricity prices is significantly related to the excess capacity of electricity.

Table 5.8: Significance test of the change of tail fatness over the hours (EEX)

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2	-0,0096 -(0,36)																							
3	-0,0116 -(0,44)	-0,0020 (0,08)																						
4	-0,0425 -(1,60)	-0,0329 (1,24)	-0,0309 (1,15)																					
5	-0,0238 -(0,89)	-0,0142 (0,53)	-0,0122 (0,45)	0,0187 -(0,69)																				
6	-0,0154 -(0,58)	-0,0058 (0,22)	-0,0038 (0,14)	0,0271 -(1,00)	0,0084 -(0,31)																			
7	-0,0555 -(2,15)	-0,0459 (1,78)	-0,0439 (1,68)	-0,0130 (0,50)	-0,0317 (1,20)	-0,0401 (1,53)																		
8	-0,0752 -(2,74)	-0,0656 (2,39)	-0,0636 (2,29)	-0,0327 (1,18)	-0,0514 (1,84)	-0,0598 (2,15)	-0,0197 (0,73)																	
9	-0,0884 -(3,17)	-0,0788 (2,82)	-0,0768 (2,73)	-0,0459 (1,63)	-0,0646 (2,28)	-0,0730 (2,58)	-0,0329 (1,20)	-0,0132 (0,46)																
10	-0,0986 -(3,81)	-0,0890 (3,44)	-0,0870 (3,32)	-0,0561 (2,14)	-0,0748 (2,83)	-0,0832 (3,16)	-0,0431 (1,70)	-0,0234 (0,86)	-0,0102 (0,37)															
11	-0,1008 -(3,58)	-0,0912 (3,24)	-0,0892 (3,14)	-0,0583 (2,05)	-0,0770 (2,69)	-0,0854 (2,99)	-0,0453 (1,64)	-0,0256 (0,88)	-0,0124 (0,42)	-0,0022 (0,08)														
12	-0,1323 -(4,32)	-0,1227 (4,01)	-0,1207 (3,91)	-0,0898 (2,91)	-0,1085 (3,50)	-0,1169 (3,77)	-0,0768 (2,54)	-0,0571 (1,81)	-0,0439 (1,37)	-0,0337 (1,11)	-0,0315 (0,98)													
13	-0,0766 -(2,89)	-0,0670 (2,53)	-0,0650 (2,43)	-0,0341 (1,27)	-0,0528 (1,95)	-0,0612 (2,27)	-0,0211 (0,81)	-0,0014 (0,05)	0,0118 -(0,42)	0,0220 -(0,84)	0,0242 -(0,85)	0,0557 -(1,81)												
14	-0,0674 -(2,49)	-0,0578 (2,13)	-0,0558 (2,04)	-0,0249 (0,91)	-0,0436 (1,58)	-0,0520 (1,89)	-0,0119 (0,45)	0,0078 -(0,28)	0,0210 -(0,73)	0,0312 -(1,17)	0,0334 -(1,16)	0,0649 -(2,07)	0,0092 -(0,34)											
15	-0,0732 -(2,63)	-0,0636 (2,29)	-0,0616 (2,19)	-0,0307 (1,09)	-0,0494 (1,75)	-0,0578 (2,05)	-0,0177 (0,65)	0,002 -(0,07)	0,0152 -(0,52)	0,0254 -(0,93)	0,0276 -(0,93)	0,0591 -(1,85)	0,0034 -(0,12)	-0,0058 (0,20)										
16	-0,0467 -(1,76)	-0,0371 (1,40)	-0,0351 (1,31)	-0,0042 (0,16)	-0,0229 (0,85)	-0,0313 (1,16)	0,0088 -(0,34)	0,0285 -(1,03)	0,0417 -(1,48)	0,0519 -(1,99)	0,0541 -(1,91)	0,0856 -(2,78)	0,0299 -(1,12)	0,0207 -(0,76)	0,0265 -(0,95)									
17	-0,0397 -(1,44)	-0,0301 (1,09)	-0,0281 (1,01)	0,0028 -(0,10)	-0,0159 (0,57)	-0,0243 (0,87)	0,0158 -(0,58)	0,0355 -(1,24)	0,0487 -(1,67)	0,0589 -(2,16)	0,0611 -(2,08)	0,0926 -(2,92)	0,0369 -(1,33)	0,0277 -(0,98)	0,0335 -(1,15)	0,007 -(0,25)								
18	-0,1777 -(5,94)	-0,1681 (5,62)	-0,1661 (5,51)	-0,1352 (4,49)	-0,1539 (5,07)	-0,1623 (5,36)	-0,1222 (4,15)	-0,1025 (3,32)	-0,0893 (2,85)	-0,0791 (2,68)	-0,0769 (2,44)	-0,0454 (1,35)	-0,1011 (3,36)	-0,1103 (3,61)	-0,1045 (3,34)	-0,131 (4,36)	-0,138 (4,45)							
19	-0,2021 -(5,55)	-0,1925 (5,29)	-0,1905 (5,20)	-0,1596 (4,36)	-0,1783 (4,85)	-0,1867 (5,08)	-0,1466 (4,07)	-0,1269 (3,41)	-0,1137 (3,03)	-0,1035 (2,87)	-0,1013 (2,68)	-0,0698 (1,76)	-0,1255 (3,43)	-0,1347 (3,64)	-0,1289 (3,43)	-0,1554 (4,25)	-0,1624 (4,35)	-0,0244 (0,62)						
20	-0,1516 -(2,50)	-0,142 (2,35)	-0,14 (2,31)	-0,1091 (1,80)	-0,1278 (2,10)	-0,1362 (2,24)	-0,0961 (1,59)	-0,0764 (1,25)	-0,0632 (1,03)	-0,053 (0,88)	-0,0508 (0,83)	-0,0193 (0,31)	-0,075 (1,24)	-0,0842 (1,38)	-0,0784 (1,28)	-0,1049 (1,73)	-0,1119 (1,83)	0,0261 -(0,42)	0,0505 -(0,77)					
21	-0,0989 -(3,68)	-0,0893 (3,32)	-0,0873 (3,21)	-0,0564 (2,08)	-0,0751 (2,74)	-0,0835 (3,06)	-0,0434 (1,64)	-0,0237 (0,85)	-0,0105 (0,37)	-0,0003 (0,01)	0,0019 -(0,07)	0,0334 -(1,07)	-0,0223 (0,82)	-0,0315 (1,14)	-0,0257 (0,91)	-0,0522 (1,93)	-0,0592 (2,10)	0,0788 -(2,59)	0,1032 -(2,80)	0,0527 -(0,87)				
22	-0,0796 -(2,89)	-0,07 (2,54)	-0,068 (2,45)	-0,0371 (1,33)	-0,0558 (1,99)	-0,0642 (2,30)	-0,0241 (0,89)	-0,0044 (0,15)	0,0088 -(0,30)	0,019 -(0,70)	0,0212 -(0,72)	0,0527 -(1,66)	-0,0030 (0,11)	-0,0122 (0,43)	-0,0064 (0,22)	-0,0329 (1,19)	-0,0399 (1,39)	0,0981 -(3,17)	0,1225 -(3,28)	0,072 -(1,18)	0,0193 -(0,69)			
23	-0,0209 -(0,79)	-0,0113 (0,42)	-0,0093 (0,35)	0,0216 -(0,80)	0,0029 -(0,11)	-0,0055 (0,20)	0,0346 -(1,33)	0,0543 -(1,96)	0,0675 -(2,40)	0,0777 -(2,97)	0,0799 -(2,81)	0,1114 -(3,61)	0,0557 -(2,08)	0,0465 -(1,70)	0,0523 -(1,86)	0,0258 -(0,96)	0,0188 -(0,67)	0,1568 -(5,20)	0,1812 -(4,95)	0,1307 -(2,15)	0,078 -(2,87)	0,0587 -(2,11)		
24	0,0112 (0,43)	0,0208 -(0,80)	0,0228 -(0,86)	0,0537 -(2,03)	0,035 -(1,31)	0,0266 -(1,00)	0,0667 -(2,60)	0,0864 -(3,16)	0,0996 -(3,59)	0,1098 -(4,27)	0,112 -(4,00)	0,1435 -(4,71)	0,0878 -(3,33)	0,0786 -(2,92)	0,0844 -(3,05)	0,0579 -(2,20)	0,0509 -(1,85)	0,1889 -(6,35)	0,2133 -(5,87)	0,1628 -(2,69)	0,1101 -(4,12)	0,0908 -(3,31)	0,0321 -(1,21)	

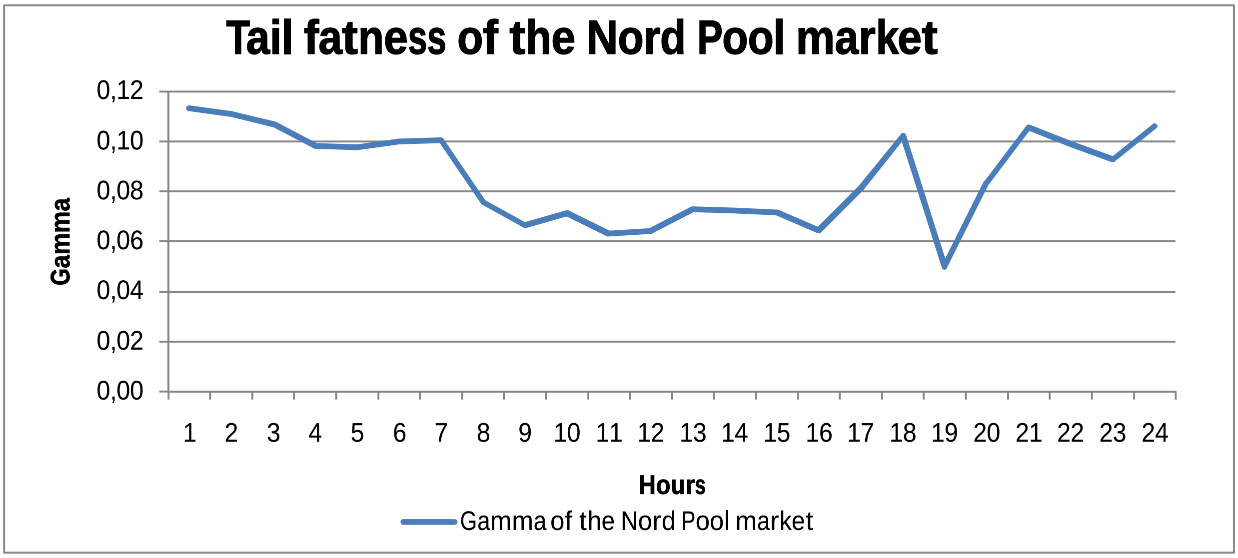
(Change in tail fatness (gamma) = $\gamma_X - \gamma_Y$)

5.6 Results of the Scandinavian Nord Pool market

Table 5.9: Tail fatness estimations of the Nord Pool market

Hour	γ	s.e.	α	Hour	γ	s.e.	α
1.	0.1133	0.0206	8.828	13.	0.0730	0.0195	13.693
2.	0.1110	0.0204	9.0077	14.	0.0724	0.0197	13.818
3.	0.1068	0.0202	9.3627	15.	0.0716	0.0208	13.975
4.	0.0983	0.0200	10.176	16.	0.0645	0.0194	15.508
5.	0.0978	0.0202	10.228	17.	0.0813	0.0197	12.293
6.	0.0999	0.0190	10.010	18.	0.1022	0.0202	9.7836
7.	0.1006	0.0215	9.9396	19.	0.0499	0.0187	20.030
8.	0.0756	0.0212	13.222	20.	0.0837	0.0242	11.947
9.	0.0666	0.0186	15.018	21.	0.1057	0.0204	9.4615
10.	0.0713	0.0278	14.033	22.	0.0989	0.0199	10.115
11.	0.0632	0.0226	15.832	23.	0.0929	0.0204	10.764
12.	0.0643	0.0194	15.561	24.	0.1061	0.0203	9.4214

Figure 5.5: Tail fatness of the Nord Pool market



5.6.1 Analysis of the tail index estimations

The tail index estimations based on the electricity prices of the Nord Pool electricity market show quite a stable pattern. The tail index estimations vary throughout the day within a very small margin. The fattest tail is estimated on 8.828 (h1) while the least fattest tail is estimated on 20.030 (h19). Furthermore, the pattern of this market is quite remarkable. That is, it is the first pattern which shows a decrease of tail fatness at the start of the business day and during hours of a high electricity demand. It also displays an increase of tail fatness at the end of the business day, when electricity demand normally decreases.

The pattern of the Nord Pool market is furthermore noteworthy because, firstly, it is the opposite of the expectations of this thesis. Secondly, it is also the opposite of the patterns shown by the previous mentioned markets (APX, UKPX, Powernext and EEX). The only result showed by the Nord Pool pattern which does have some resemblance with the expectations of this thesis is the sudden increase of tail fatness around h17 and h18, representing a period with, generally, a high electricity demand. These hours do show a high degree of tail fatness, as was expected.

These statements are also shown by the graph visualizing the increase and decrease of tail fatness throughout the day (figure5.5). For a correct interpretation of this graph, note the difference in the scale of this graph compared to the scales of the graphs of the other markets.

5.6.2 Analysis of the change of tail fatness

The last table covering the Nord Pool market, table 5.10, indicates that very few changes of the tail index estimations turn out to be significant. This matches the pattern discussed in the previous paragraph. The few moments that the change of the tail index estimations does appear to be significant are almost all related to the one point the Nord Pool distribution does matches the assumptions of this thesis. With this statement I refer to the sudden increase of tail fatness on one of the peak-demand moments of a working day: around h19. But even then, the only significant changes of the tail index estimations are the differences between h19 and h1-h3 (three of the lowest demand hours of the day), h21 and h24.

An analysis of the results leads to the conclusion that the excess capacity of electricity significantly influences the electricity prices of the Scandinavian electricity market. It has to be noted however, that this relationship does not have the shape and quantity as was assumed in advance. In contrast, this significant relationship seems to be the exact other way around. However, even though this relationship is different and proves to be smaller than was assumed, it still is significant.

Table 5.10: Significance test of the change of tail fatness over the hours (Nord Pool)

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2	0,0023 (0,08)																							
3	0,0065 (0,23)	0,0042 -(0,15)																						
4	0,0150 (0,52)	0,0127 -(0,44)	0,0085 -(0,30)																					
5	0,0155 (0,54)	0,0132 -(0,46)	0,0090 -(0,32)	0,0005 -(0,02)																				
6	0,0134 (0,48)	0,0111 -(0,40)	0,0069 -(0,25)	-0,0016 (0,06)	-0,0021 (0,08)																			
7	0,0127 (0,43)	0,0104 -(0,35)	0,0062 -(0,21)	-0,0023 (0,08)	-0,0028 (0,09)	-0,0007 (0,02)																		
8	0,0377 (1,28)	0,0354 -(1,20)	0,0312 -(1,07)	0,0227 -(0,78)	0,0222 -(0,76)	0,0243 -(0,85)	0,0250 -(0,83)																	
9	0,0467 (1,68)	0,0444 -(1,61)	0,0402 -(1,46)	0,0317 -(1,16)	0,0312 -(1,14)	0,0333 -(1,25)	0,0340 -(1,20)	0,0090 -(0,32)																
10	0,0420 (1,21)	0,0397 -(1,15)	0,0355 -(1,03)	0,0270 -(0,79)	0,0265 -(0,77)	0,0286 -(0,85)	0,0293 -(0,83)	0,0043 -(0,12)	-0,0047 (0,14)															
11	0,0501 (1,64)	0,0478 -(1,57)	0,0436 -(1,44)	0,0351 -(1,16)	0,0346 -(1,14)	0,0367 -(1,24)	0,0374 -(1,20)	0,0124 -(0,40)	0,0034 -(0,12)	0,0081 -(0,23)														
12	0,0490 (1,73)	0,0467 -(1,66)	0,0425 -(1,52)	0,0340 -(1,22)	0,0335 -(1,20)	0,0356 -(1,31)	0,0363 -(1,25)	0,0113 -(0,39)	0,0023 -(0,09)	0,0070 -(0,21)	-0,0011 (0,04)													
13	0,0403 (1,42)	0,0380 -(1,35)	0,0338 -(1,20)	0,0253 -(0,91)	0,0248 -(0,88)	0,0269 -(0,99)	0,0276 -(0,95)	0,0026 -(0,09)	-0,0064 (0,24)	-0,0017 (0,05)	-0,0098 (0,33)	-0,0087 (0,32)												
14	0,0409 (1,43)	0,0386 -(1,36)	0,0344 -(1,22)	0,0259 -(0,92)	0,0254 -(0,90)	0,0275 -(1,00)	0,0282 -(0,97)	0,0032 -(0,11)	-0,0058 (0,21)	-0,0011 (0,03)	-0,0092 (0,31)	-0,0081 (0,29)	0,0006 -(0,02)											
15	0,0417 (1,42)	0,0394 -(1,35)	0,0352 -(1,21)	0,0267 -(0,93)	0,0262 -(0,90)	0,0283 -(1,00)	0,029 -(0,97)	0,004 -(0,13)	-0,005 (0,18)	-0,0003 (0,01)	-0,0084 (0,27)	-0,0073 (0,26)	0,0014 -(0,05)	0,0008 -(0,03)										
16	0,0488 (1,72)	0,0465 -(1,65)	0,0423 -(1,51)	0,0338 -(1,21)	0,0333 -(1,19)	0,0354 -(1,30)	0,0361 -(1,25)	0,0111 -(0,39)	0,0021 -(0,08)	0,0068 -(0,20)	-0,0013 (0,04)	-0,0002 (0,01)	0,0085 -(0,31)	0,0079 -(0,29)	0,0071 -(0,25)									
17	0,0320 (1,12)	0,0297 -(1,05)	0,0255 -(0,90)	0,017 -(0,61)	0,0165 -(0,58)	0,0186 -(0,68)	0,0193 -(0,66)	-0,0057 (0,20)	-0,0147 (0,54)	-0,01 (0,29)	-0,0181 (0,60)	-0,017 (0,61)	-0,0083 (0,30)	-0,0089 (0,32)	-0,0097 (0,34)	-0,0168 (0,61)								
18	0,0111 (0,38)	0,0088 -(0,31)	0,0046 -(0,16)	-0,0039 (0,14)	-0,0044 (0,15)	-0,0023 (0,08)	-0,0016 (0,05)	-0,0266 (0,91)	-0,0356 (1,30)	-0,0309 (0,90)	-0,039 (1,29)	-0,0379 (1,35)	-0,0292 (1,04)	-0,0298 (1,06)	-0,0306 (1,06)	-0,0377 (1,35)	-0,0209 (0,74)							
19	0,0634 (2,28)	0,0611 -(2,21)	0,0569 -(2,07)	0,0484 -(1,77)	0,0479 -(1,74)	0,05 -(1,88)	0,0507 -(1,78)	0,0257 -(0,91)	0,0167 -(0,63)	0,0214 -(0,64)	0,0133 -(0,45)	0,0144 -(0,53)	0,0231 -(0,86)	0,0225 -(0,83)	0,0217 -(0,78)	0,0146 -(0,54)	0,0314 -(1,16)	0,0523 -(1,90)						
20	0,0296 (0,93)	0,0273 -(0,86)	0,0231 -(0,73)	0,0146 -(0,47)	0,0141 -(0,45)	0,0162 -(0,53)	0,0169 -(0,52)	-0,0081 (0,25)	-0,0171 (0,56)	-0,0124 (0,34)	-0,0205 (0,62)	-0,0194 (0,63)	-0,0107 (0,34)	-0,0113 (0,36)	-0,0121 (0,38)	-0,0192 (0,62)	-0,0024 (0,08)	0,0185 -(0,59)	-0,0338 (1,11)					
21	0,0076 (0,26)	0,0053 -(0,18)	0,0011 -(0,04)	-0,0074 (0,26)	-0,0079 (0,28)	-0,0058 (0,21)	-0,0051 (0,17)	-0,0301 (1,02)	-0,0391 (1,42)	-0,0344 (1,00)	-0,0425 (1,40)	-0,0414 (1,47)	-0,0327 (1,16)	-0,0333 (1,17)	-0,0341 (1,17)	-0,0412 (1,46)	-0,0244 (0,86)	-0,0035 (0,12)	-0,0558 (2,02)	-0,022 (0,70)				
22	0,0144 (0,50)	0,0121 -(0,42)	0,0079 -(0,28)	-0,0006 (0,02)	-0,0011 (0,04)	0,001 -(0,04)	0,0017 -(0,06)	-0,0233 (0,80)	-0,0323 (1,19)	-0,0276 (0,81)	-0,0357 (1,19)	-0,0346 (1,24)	-0,0259 (0,93)	-0,0265 (0,95)	-0,0273 (0,95)	-0,0344 (1,24)	-0,0176 (0,63)	0,0033 -(0,12)	-0,049 (1,79)	-0,0152 (0,49)	0,0068 -(0,24)			
23	0,0204 (0,70)	0,0181 -(0,63)	0,0139 -(0,48)	0,0054 -(0,19)	0,0049 -(0,17)	0,007 -(0,25)	0,0077 -(0,26)	-0,0173 (0,59)	-0,0263 (0,95)	-0,0216 (0,63)	-0,0297 (0,98)	-0,0286 (1,02)	-0,0199 (0,71)	-0,0205 (0,72)	-0,0213 (0,73)	-0,0284 (1,01)	-0,0116 (0,41)	0,0093 -(0,32)	-0,043 (1,55)	-0,0092 (0,29)	0,0128 -(0,44)	0,006 -(0,21)		
24	0,0072 (0,25)	0,0049 -(0,17)	0,0007 -(0,02)	-0,0078 (0,27)	-0,0083 (0,29)	-0,0062 (0,22)	-0,0055 (0,19)	-0,0305 (1,04)	-0,0395 (1,43)	-0,0348 (1,01)	-0,0429 (1,41)	-0,0418 (1,49)	-0,0331 (1,18)	-0,0337 (1,19)	-0,0345 (1,19)	-0,0416 (1,48)	-0,0248 (0,88)	-0,0039 (0,14)	-0,0562 (2,04)	-0,0224 (0,71)	-0,0004 (0,01)	-0,0072 (0,25)	-0,0132 (0,46)	

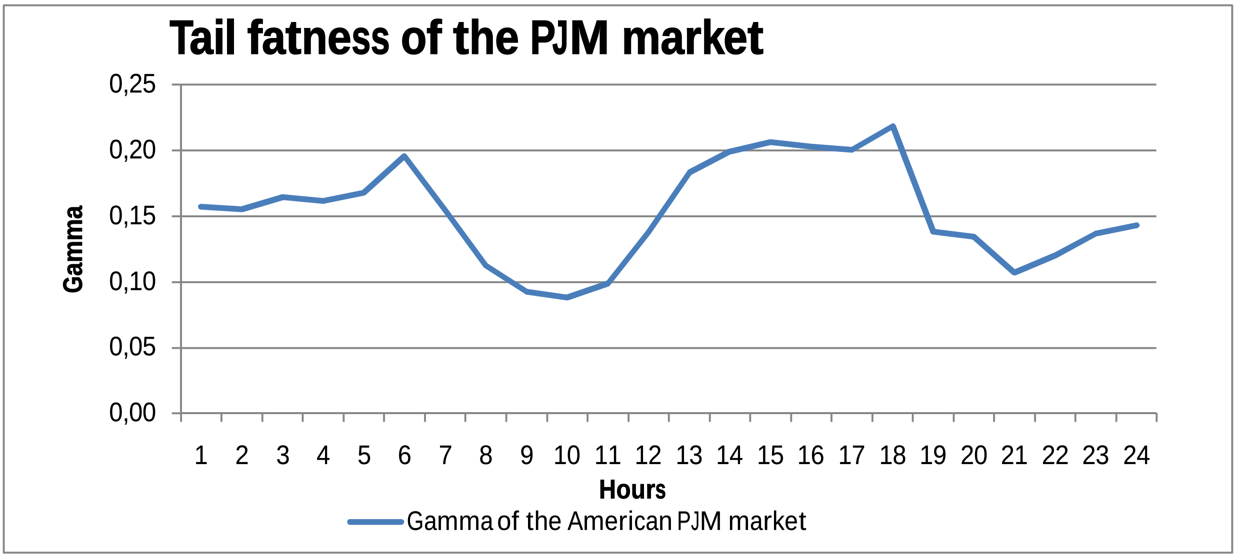
(Change in tail fatness (gamma) = $\gamma_X - \gamma_Y$)

5.7 Results of the PJM market (the United States)

Table 5.11: Tail fatness estimations of the PJM market

Hour	γ	s.e.	α	Hour	γ	s.e.	α
1.	0.1572	0.0152	6.3633	13.	0.1831	0.0345	5.4603
2.	0.1552	0.0229	6.4424	14.	0.1992	0.0169	5.0211
3.	0.1644	0.0246	6.0827	15.	0.2063	0.0414	4.8473
4.	0.1614	0.0204	6.1964	16.	0.2030	0.0176	4.9265
5.	0.168	0.0218	5.9523	17.	0.2003	0.0235	4.9919
6.	0.1955	0.0222	5.116	18.	0.2185	0.0189	4.5766
7.	0.1545	0.0214	6.4713	19.	0.1384	0.0237	7.2264
8.	0.1127	0.0202	8.872	20.	0.1346	0.0672	7.4268
9.	0.0928	0.0205	10.778	21.	0.1073	0.0202	9.3199
10.	0.0883	0.0208	11.326	22.	0.1201	0.0207	8.3252
11.	0.0991	0.0198	10.093	23.	0.1366	0.0208	7.3229
12.	0.1380	0.0224	7.2474	24.	0.1432	0.0344	6.9832

Figure 5.6: Tail fatness of the PJM market



5.7.1 Analysis of the tail index estimations

The pattern of the PJM electricity price distribution follows the pattern of the distribution of the Nord Pool market. That is, the PJM market is also characterized by a decrease of the tail fatness at the beginning of the working day (around h7). Tail fatness continues to decrease throughout the morning, reaching minimum tail fatness during h10. From that moment on, tail fatness starts to increase and, hereby, passes by the starting level of h1 (6.3633) during h13. At the end of the business day, normally a moment of increased electricity demand and generally a moment of increased tail fatness, the tail fatness of the PJM market nevertheless starts to decrease. This continues until h21. From that moment on, tail fatness increases slightly from 9.3199 on h21 to 6.9832 on h24. In summary, the PJM market finds its least fat tailed moment of the day during a period with a relative high electricity demand (h10) which contradicts the expectations of this thesis. However, the most fat tailed moment of the day (h18) does matches the expectations of this thesis.

5.7.2 Analysis of the change of tail fatness

The strange pattern of the PJM price distribution can also be seen in table 5.12. The table displays a 'block-pattern', just like the pattern of the changes of tail fatness of the UKPX market. However, the PJM shows 'strange' 'blocks'. That is, some of the 'blocks' the PJM market shows are the opposite of the UKPX market. This implies that the PJM sometimes shows 'blocks' of significant changes where the UKPX shows 'blocks' of non-significant changes and vice versa. However, there are also 'blocks' which are the same for both markets. This partly deviating pattern of the PJM market is probably the result of the price distribution of the PJM market which has also partly the opposite characteristics as, for example, the APX- and UKPX market.

Equally like the conclusion with respect to the Nord Pool market does the PJM market show a significant relationship between the excess capacity of electricity and tail fatness of its electricity prices. This conclusion does not need to be altered because of the differences between the shape of this relationship and the shape of the relationship as it was assumed to be in advance

Based on the results discussed in this chapter, a conclusion and some remarks regarding the applicability of this conclusion are stated in the following, final, chapter.

Table 5.12: Significance test of the change of tail fatness over the hours (PJM)

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2	0,0020 (0,07)																							
3	-0,0072 -(0,25)	-0,0092 (0,27)																						
4	-0,0042 -(0,17)	-0,0062 (0,20)	0,0030 -(0,09)																					
5	-0,0108 -(0,41)	-0,0128 (0,40)	-0,0036 (0,11)	-0,0066 (0,22)																				
6	-0,0383 -(1,42)	-0,0403 (1,26)	-0,0311 (0,94)	-0,0341 (1,13)	-0,0275 (0,88)																			
7	0,0027 (0,10)	0,0007 -(0,02)	0,0099 -(0,30)	0,0069 -(0,23)	0,0135 -(0,44)	0,0410 -(1,33)																		
8	0,0445 (1,76)	0,0425 -(1,39)	0,0517 -(1,62)	0,0487 -(1,70)	0,0553 -(1,86)	0,0828 -(2,76)	0,0418 -(1,42)																	
9	0,0644 (2,52)	0,0624 -(2,03)	0,0716 -(2,24)	0,0686 -(2,37)	0,0752 -(2,51)	0,1027 -(3,40)	0,0617 -(2,08)	0,0199 -(0,69)																
10	0,0689 (2,67)	0,0669 -(2,16)	0,0761 -(2,36)	0,0731 -(2,51)	0,0797 -(2,65)	0,1072 -(3,52)	0,0662 -(2,22)	0,0244 -(0,84)	0,0045 -(0,15)															
11	0,0581 (2,33)	0,0561 -(1,85)	0,0653 -(2,07)	0,0623 -(2,19)	0,0689 -(2,34)	0,0964 -(3,24)	0,0554 -(1,90)	0,0136 -(0,48)	-0,0063 (0,22)	-0,0108 (0,38)														
12	0,0192 (0,71)	0,0172 -(0,54)	0,0264 -(0,79)	0,0234 -(0,77)	0,0300 -(0,96)	0,0575 -(1,82)	0,0165 -(0,53)	-0,0253 (0,84)	-0,0452 (1,49)	-0,0497 (1,63)	-0,0389 (1,30)													
13	-0,0259 -(0,69)	-0,0279 (0,67)	-0,0187 (0,44)	-0,0217 (0,54)	-0,0151 (0,37)	0,0124 -(0,30)	-0,0286 (0,70)	-0,0704 (1,76)	-0,0903 (2,25)	-0,0948 (2,35)	-0,0840 (2,11)	-0,0451 (1,10)												
14	-0,0420 -(1,85)	-0,0440 (1,55)	-0,0348 (1,17)	-0,0378 (1,43)	-0,0312 (1,13)	-0,0037 (0,13)	-0,0447 (1,64)	-0,0865 (3,28)	-0,1064 (4,00)	-0,1109 (4,14)	-0,1001 (3,85)	-0,0612 (2,18)	-0,0161 (0,42)											
15	-0,0491 -(1,11)	-0,0511 (1,08)	-0,0419 (0,87)	-0,0449 (0,97)	-0,0383 (0,82)	-0,0108 (0,23)	-0,0518 (1,11)	-0,0936 (2,03)	-0,1135 (2,46)	-0,118 (2,55)	-0,1072 (2,34)	-0,0683 (1,45)	-0,0232 (0,43)	-0,0071 (0,16)										
16	-0,0458 -(1,97)	-0,0478 (1,66)	-0,0386 (1,28)	-0,0416 (1,54)	-0,035 (1,25)	-0,0075 (0,26)	-0,0485 (1,75)	-0,0903 (3,37)	-0,1102 (4,08)	-0,1147 (4,21)	-0,1039 (3,92)	-0,065 (2,28)	-0,0199 (0,51)	-0,0038 (0,16)	0,0033 -(0,07)									
17	-0,0431 -(1,54)	-0,0451 (1,37)	-0,0359 (1,06)	-0,0389 (1,25)	-0,0323 (1,01)	-0,0048 (0,15)	-0,0458 (1,44)	-0,0876 (2,83)	-0,1075 (3,45)	-0,112 (3,57)	-0,1012 (3,29)	-0,0623 (1,92)	-0,0172 (0,41)	-0,0011 (0,04)	0,006 -(0,13)	0,0027 -(0,09)								
18	-0,0613 -(2,53)	-0,0633 (2,13)	-0,0541 (1,74)	-0,0571 (2,05)	-0,0505 (1,75)	-0,023 (0,79)	-0,064 (2,24)	-0,1058 (3,82)	-0,1257 (4,51)	-0,1302 (4,63)	-0,1194 (4,36)	-0,0805 (2,75)	-0,0354 (0,90)	-0,0193 (0,76)	-0,0122 (0,27)	-0,0155 (0,60)	-0,0182 (0,60)							
19	0,0188 (0,67)	0,0168 -(0,51)	0,026 -(0,76)	0,023 -(0,74)	0,0296 -(0,92)	0,0571 -(1,76)	0,0161 -(0,50)	-0,0257 (0,83)	-0,0456 (1,46)	-0,0501 (1,59)	-0,0393 (1,27)	-0,0004 (0,01)	0,0447 -(1,07)	0,0608 -(2,09)	0,0679 -(1,42)	0,0646 -(2,19)	0,0619 -(1,85)	0,0801 -(2,64)						
20	0,0226 (0,33)	0,0206 -(0,29)	0,0298 -(0,42)	0,0268 -(0,38)	0,0334 -(0,47)	0,0609 -(0,86)	0,0199 -(0,28)	-0,0219 (0,31)	-0,0418 (0,59)	-0,0463 (0,66)	-0,0355 (0,51)	0,0034 -(0,05)	0,0485 -(0,64)	0,0646 -(0,93)	0,0717 -(0,91)	0,0684 -(0,98)	0,0657 -(0,92)	0,0839 -(1,20)	0,0038 -(0,05)					
21	0,0499 (1,97)	0,0479 -(1,57)	0,0571 -(1,79)	0,0541 -(1,88)	0,0607 -(2,04)	0,0882 -(2,94)	0,0472 -(1,60)	0,0054 -(0,19)	-0,0145 (0,50)	-0,019 (0,66)	-0,0082 (0,29)	0,0307 -(1,02)	0,0758 -(1,90)	0,0919 -(3,49)	0,099 -(2,15)	0,0957 -(3,57)	0,093 -(3,00)	0,1112 -(4,02)	0,0311 -(1,00)	0,0273 -(0,39)				
22	0,0371 (1,44)	0,0351 -(1,14)	0,0443 -(1,38)	0,0413 -(1,42)	0,0479 -(1,59)	0,0754 -(2,48)	0,0344 -(1,16)	-0,0074 (0,26)	-0,0273 (0,94)	-0,0318 (1,08)	-0,021 (0,73)	0,0179 -(0,59)	0,0630 -(1,57)	0,0791 -(2,96)	0,0862 -(1,86)	0,0829 -(3,05)	0,0802 -(2,56)	0,0984 -(3,51)	0,0183 -(0,58)	0,0145 -(0,21)	-0,0128 (0,44)			
23	0,0206 (0,80)	0,0186 -(0,60)	0,0278 -(0,86)	0,0248 -(0,85)	0,0314 -(1,04)	0,0589 -(1,94)	0,0179 -(0,60)	-0,0239 (0,82)	-0,0438 (1,50)	-0,0483 (1,64)	-0,0375 (1,31)	0,0014 -(0,05)	0,0465 -(1,15)	0,0626 -(2,34)	0,0697 -(1,50)	0,0664 -(2,44)	0,0637 -(2,03)	0,0819 -(2,91)	0,0018 -(0,06)	-0,002 (0,03)	-0,0293 (1,01)	-0,0165 (0,56)		
24	0,014 (0,37)	0,012 -(0,29)	0,0212 -(0,50)	0,0182 -(0,46)	0,0248 -(0,61)	0,0523 -(1,28)	0,0113 -(0,28)	-0,0305 (0,76)	-0,0504 (1,26)	-0,0549 (1,37)	-0,0441 (1,11)	-0,0052 (0,13)	0,0399 -(0,82)	0,056 -(1,46)	0,0631 -(1,17)	0,0598 -(1,55)	0,0571 -(1,37)	0,0753 -(1,92)	-0,0048 (0,11)	-0,0086 (0,11)	-0,0359 (0,90)	-0,0231 (0,58)	-0,0066 (0,16)	

(Change in tail fatness (gamma) = $\gamma_X - \gamma_Y$)

6. Conclusion

The final chapter of this thesis consists of 2 parts. First, concluding remarks regarding this research and its results are made. Secondly, the applicability of the thesis is discussed.

6.1 Concluding remarks

The goal of this thesis was to find out whether the excess capacity of electricity significantly influences the tail fatness of electricity prices. To test this, the 2008 hourly electricity prices of six electricity markets are used to estimate the tail fatness per hour. This is because the electricity prices are used to assess the excess capacity of electricity.

6.1.1 APX, UKPX, Powernext and EEX

The main expectation of this thesis was that the tail fatness of electricity is influenced by the excess capacity of electricity. More specifically, it was expected that the tail fatness would be higher during high-demand hours (e.g., 09:00 hours) when compared with low-demand hours (e.g., 02:00 hours). The results show that this is true for the APX-, UKPX-, Powernext- and EEX market, they all showed an increased tail fatness at the start of the business day. Furthermore, they all showed an increase of tail fatness during the high-demand hours and a decreasing tail fatness when the day was reaching its end. So for these markets, this thesis finds a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices.

6.1.2 Nord Pool

The pattern described above is in contrast with the pattern showed by the Nord Pool market. The Nord Pool market does show a significant increase and decrease of tail fatness throughout the day. However, the difference between the Nord Pool market and the previously mentioned four markets is that the Nord Pool market displays a pattern which is almost exactly the opposite of the other four markets. That is, the tail fatness of the Nord Pool market decreases during high-demand hours, and increases during periods with relatively little electricity demand. There is only one exception to this statement. That is, tail fatness does increase during the hour of generally the highest electricity demand of the day, h19.

The results of this research, regarding the Nord Pool market, imply that the excess capacity does have a significant effect on the tail fatness of the electricity price of the Nord Pool market, but that its relationship with the electricity prices is different from what was assumed. The shape of this relationship is not investigated by this thesis and remains left for further research. However, even though the relationship between the excess capacity and tail fatness on the Nord Pool market is not as was assumed in advance, a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices does exists.

6.1.3 PJM

The last market discussed in this thesis, the PJM market, also experiences a deviating pattern of tail fatness compared to the patterns of the APX-, UKPX-, Powernext- and EEX market. Or, at least, the PJM market partly deviates from these markets. That is, the PJM market experiences an increase in tail fatness during the first hours of the day, up to one of the peak-demand hours of the day, h8. However, from that moment on, tail fatness starts to decrease. The tail fatness even decreases far beyond the starting level of the day and thus far beyond the level of tail fatness of these low-demand hours. This period of little tail fatness continues for some hours. Then tail fatness starts to increase again and reaches its peak during a high-demand hour, h18. After h18, tail fatness decreases again and hereby follows the pattern of the previously discussed APX-, UKPX-, Powernext- and EEX markets. Therefore, the tail fatness of the PJM markets follows a pattern which looks like a combination of the group of the APK-, UKPX-, Powernext- and EEX-markets on the one side, and the Nord Pool market on the other side. Independent of the type of relationship the excess capacity of electricity has with the tail fatness of the electricity prices of the PJM market, this pattern proves that it significantly influences its tail fatness.

6.1.4 Hypotheses and main research question

After reviewing the results discussed in chapter 5 and the conclusions made in this chapter, this thesis finds enough evidence to reject H_0 and therefore does not reject H_A. For a clear overview, both hypotheses are restated below.

H_0: *There is no significant relationship between the excess capacity of electricity and the tail fatness of electricity prices.*

H_A: *There is a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices.*

After the rejection of H_0, the main research question of this thesis can be answered. This question, (which was also stated in the first chapter) is:

"Is there a significant relationship between the excess capacity of electricity and the probability of a price spike?"

The findings of this thesis clearly show that there is a significant relationship between the excess capacity of electricity and the probability of a price spike.

6.1.5 The necessity of further research

However, the results of this thesis do not answer all the questions regarding the tail fatness of electricity prices. Additional research remains necessary to gain a further insight into this phenomenon.

Differences between day-ahead data and spot data

The investigation of the consequences of the usage of two types of data could be a starting point for future research. That is, as is stated before, this thesis uses two types of electricity prices. For the APX-, the UKPX-, the Powernext- and the PJM market, the 2008 hourly day-ahead electricity prices are used. This is in contrast with the EEX- and the Nord Pool market, because for these markets, the spot prices are used. The question which has been raised by the usage of two types of data is whether or not this leads to different results and, consequently, a biased comparison.

Differences in the results, supply related effects

Additionally, to investigate the differences between the results of the six discussed electricity markets could also be a starting point for future research. A possible explanation for these differences could lie within the different production methods used by these markets. This thesis mainly focused on the effects of demand on the excess capacity. But the effects of supply variety on the excess capacity are not investigated and might therefore provide a good starting point for future research. That is, the fact that, e.g., the Nord Pool is mostly hydro-based, that the Powernext market relies heavily on nuclear energy and that the APX bases its generation on gas turbines might explain the differences in tail fatness of these markets. But this is only a hypothesis, future research could provide the answer.

Differences over time

One could also investigate the tail fatness of electricity prices further by investigating the differences of some markets over the years. Where this thesis only used 2008 electricity prices, it could be interesting to test if the tail fatness increased or decreased over the last years.

Because this thesis tests whether or not the tail fatness of electricity prices is significantly influenced by the excess capacity of electricity and thus tests the basic elements of the subject 'tail fatness of electricity prices', the findings of this thesis can be used as a basis for any future research on this subject.

6.2 Applicability of the findings

6.2.1 Theoretical applicability

The applicability of this thesis can be viewed from two opposite sides. On one side (as is discussed in chapter 2), a relationship between the excess capacity of electricity and the volatility of electricity prices is frequently assumed to be existing. Many different authors describe this relationship and use it for further research and new theories. So from that point of view, this research seems to provide little new knowledge. On the other side however, volatility and tail fatness are not the same. Furthermore, the relationship between tail fatness of electricity prices and the excess capacity of electricity was never previously empirically tested. Because this thesis did empirically test this relationship, the findings of this thesis can be used by other researchers to strengthen their theories and conclusions.

6.2.2 Practical applicability

The practical applicability of this thesis is, however, limited. Because the subject of this thesis is very specific, the findings of this thesis can only be used by a limited group of people.

Traders in electricity derivatives

The findings of this thesis could however be of value for, e.g., traders in electricity derivatives. That is because this thesis shows that a significant relationship exists between the excess capacity of electricity and the tail fatness of electricity prices. If such a relationship is not acknowledged by the formula used by traders for the pricing of electricity derivatives, this thesis indicates that they could be overestimating the probability of a price spike for low-demand hours, and underestimating the probability of a price spike for high-demand hours. As a result, the traders could be overestimating their expectations of the electricity price for low-demand hours, and underestimating their expectations of the electricity price for high-demand hours. Therefore, traders of electricity derivates could use the findings of this thesis to provide additional structure in their buy- and sell-policy and this thesis might therefore have an impact on, e.g., the formula used by these traders for determining the value of electricity derivatives.

Risk managers and accountants

Another example of the practical applicability of this thesis can be found in the newly created possibilities for risk managers and accountants. That is, the theory of the underestimation and overestimation of the probabilities of a price spike which holds for traders of electricity derivatives also holds for risk managers and accountants. The position of both risk managers and accountants require that, among others, business procedures are analyzed and that risks caused (or not excluded) by these procedures are located and diminished. Because this thesis finds a new and significant relationship between the excess capacity of electricity and the tail fatness of electricity prices, this thesis might help risk managers and accountants finding new and unidentified risks related to the purchase and sale of electricity and could also help them decrease those risks.

Those who find that too much market power is exercised

Furthermore, this thesis might also be of value for those who find that the deregulated electricity markets give generating companies too much market power. Assuming that generating companies find price spikes favorable because of the increased electricity price, they could decrease the excess capacity of electricity on certain moments to artificially generate price spikes. Because this thesis shows a significant relationship between the excess capacity of electricity and the tail fatness of electricity prices, it also indicates how price spikes might be prevented. That is, if a certain quantity of excess capacity is mandatory for the generating companies, the number of price spikes occurring during a certain period might be decreased. Therefore, this thesis could be used as an argument for the introduction of such rules/laws.

In short can be concluded that this thesis finds a significant relationship between the excess capacity of electricity and tail fatness of electricity prices. These findings have both a theoretical applicability and a practical applicability.

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