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On the Link between Spot and Forward Power Prices

A Comparative Analysis of German and Hungarian Power Market Efficiency

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

Prague, 15th of May 2015

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Signature

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ABSTRACT

This thesis examines the impact of shocks in spot prices on long-term forward contracts in power markets. A unique comparison of efficiency of German and Hungarian power markets is provided. The risk premium on week-ahead forward contract is scrutinized by both data inspection and by unbiased forward rate hypothesis (UFRH) testing. Additionally, the ex-post market's prediction error for this product is explained by main drivers of spot electricity price, which are presented in section devoted to introduction to power markets. Expectedly, Hungarian forwards with longer time-to-delivery are found to react heavily on spot market shocks after controlling for changes in short-run marginal costs of conventional power plants. Such outcome applies both to intra-day and weekly time horizons. However, this evidence was not found for German market. These results point out to immaturity and the presence of inefficiencies in Hungarian power market. However, Hungarian risk premia on week-ahead and day-ahead forward products turn out to be considerably lower than for Germany. This was confirmed by UFRH tests on week-ahead forward contracts, where a significant risk premium was found in Germany as opposed to Hungarian risk premium. This finding is surprising since Hungarian spot prices are more prone to upward spikes. Hence, the risk premium is supposed to be higher in Hungary to compensate for delivery risk.

JEL Classification: C32, C51, C52, D84. G14

Keywords: Risk Premium, Spot Power Market, Forward Power Market, Market Efficiency, Forward Rate Unbiasedness

ABSTRAKT

Tato diplomová práce se zabývá vlivem pohybů spotových cen elektřiny na ceny dlouhodobých forwardových kontraktů. Práce nabízí unikátní srovnání efektivity německého a maďarského velkoobchodního trhu s elektřinou. Riziková prémie forwardových kontraktů s dodávkou v příštím týdnu je zkoumána nejen analýzou dat, ale také testováním hypotézy nevychýlenosti forwardových cen. V následné analýze se věnujeme vysvětlení chyby odhadu forwardové ceny ex-post pomocí determinantů, které v době určování ceny byly nejisté nebo neznámé. Pomocí regresní analýzy, kde byly použity změny v krátkodobých mezních nákladech konvenčních elektráren jako kontrolní proměnné, bylo podle očekávání zjištěno, že maďarské forwardy s delší dobou splatnosti silně reagují na šoky na spotovém trhu, což bylo potvrzeno pro mezidenní i týdenní časový horizont. Pro německý trh tyto závěry ovšem neplatí. Tyto výsledky naznačují nevyspělost maďarského trhu s elektřinou a neefektivnost v tvorbě cen. Na druhou stranu, maďarská riziková prémie na forwardových produktech s dodávkou v následujícím dnu i týdnu vyšla významně nižší než německá. Test nevychýlenosti forwardových cen potvrdil tato pozorování, což není v souladu se stylizovaným faktem, že maďarské spotové ceny jsou náchylnější k nečekanému prudkému nárůstu ve srovnání s Německem. Riziková prémie by tedy měla být naopak vyšší, aby kompenzovala riziko plynoucí z dodávky elektřiny v exspiraci.

JEL klasifikace: C32, C51, C52, D84. G14

Klíčová slova: Riziková prémie, Spotový trh s elektřinou, Forwardový trh s elektřinou, Efektivita trhu, Nevychýlenost forwadové ceny

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List of Contents

List of Figures

LIST OF TABLES

ACRONYMS

API	All Publication Index
ATC	Available Transmission Capacity
CHP	Central Heating Plants
DE	Germany
EEX	European Energy Exchange
EMH	Efficient Market Hypothesis
EUA	European emission Allowances
EUR	the Euro
GW	Gigawatt
HU	Hungary
HUPEX	Hungarian Power Exchange
MW	Megawatt
OTC	Over-the-counter
PJM	Pennsylvania-New Jersey-Maryland
UFRH	Unbiased Forward Rate Hypothesis
SEE	South-Eastern Europe
TTF	Title Transfer Facility
TWh	Terawatt hour

INTRODUCTION

Power is a unique commodity for several reasons. Firstly, the supply curve is highly convex whose steepness depends on country-specific mix of generation sources. Secondly, demand is inelastic in the short term. Thirdly, a supply has to always meet demand (Böhm et al., 2008, p. 356). These factors together with non-storability of power as another feature bring about extreme price volatility of this product. Furthermore, there has been installed enormous capacity of renewable sources throughout Europe recently, predominantly in Germany. Since power production from such sources is usually weather-driven, the abovementioned price volatility is further amplified. Additionally, growing amount of renewables is pushing down prices (Nicolosi, 2010; Ketterer, 2014). This puts some conventional generation out-of-money, especially natural gas and hard coal power plants. However, these power plants serve as a tool to smoothen electricity prices. Hence, the volatility is exacerbated again.

Since the liberalization of German power market in 1990's, power has become a tradable asset in both forward and futures market. The term structure of futures ranges from day-ahead delivery up to delivery in 3 years (EEX, 2015). Even products with intra-day delivery or delivery in 5 years are traded on forward market. However, due to non-storability of power, we are not able to use a classic cost-of-carry model for pricing of forward contracts. Power forward contracts are in fact not derivatives because their value for a given delivery period is not derived from a reference product (Diko et al., 2006). As a result, the forward prices are just an expectation of future spot prices.

It is thus worthwhile to investigate to what extent a past development of volatile spot prices is extrapolated to forward prices. If market participants were found to be influenced by usually sudden and large swings of prices on the spot market or short time-to-delivery forward curve, it would signal adaptive expectations with certain inefficiencies and biased pricing of forward contracts with longer time-to-delivery.

This issue has been already investigated in various forms for mature markets (NordPool,[1] PJM,[2] Germany), see Böhm et al. (2008), Botterud et al. (2010), Diko et al.(2006) or Haugom & Ullrich (2012). However, to my knowledge, not a single study has focused on a new,

[1] Power exchange organizing spot and forward trading mainly in Northern European countries – Denmark,

[2] Pennsylvania-New Jersey-Maryland electricity market

developing power market of Hungary. Lower transparency, liquidity, continuity of prices and deepness in such a market suggest that Hungarian forwards with longer time-to-maturity react heavily on results of day-ahead power auctions as well as on price moves of short-time-to-maturity products. Since the spot price indicates a real power balance in a region, market players should put bigger emphasis on the result of spot auction in a market with limited set of fundamental information. Such hypothesis is empirically tested in this text.

Another major contribution of this thesis consists in inclusion of variables capturing a shock to the market. In most of the recent studies investigating relationship between spot and forward power prices, ex-post spot prices in various forms or their first as well as second moments are used as explanatory variables (e.g. Böhm et al., 2008; Botterud et a., 2010). However, a large share of significant deviations of spot price against its average value is known to the market and well priced-in. Hence, such moves of spot prices are not shocks to the market, but only significant deviations from normal, which poses no surprise to the market. The variables capturing these shocks on spot market used in this thesis are thus always confronted against the market prices to account for market expectations.

The thesis is organized as follows: I commence with basic theory of forward contract pricing and market efficiency. An overview of relevant academic literature is provided in first chapter as well. Subsequently, an introduction to German and Hungarian power markets is a topic of chapter 2. The determinants of both short time-to-maturity and long time-to-maturity power price are briefly discussed, too. Third section is devoted to a first hypothesis, which is the effect of a week-ahead modified risk premium on year-ahead forward contract. Chapter 4 is devoted to estimation of an intra-day effect of spot surprise on front-month contract. An unbiased forward rate hypothesis of forward contract with week-ahead delivery is tested, too. Additionally, I examine possible reasons for market’s prediction error of week-ahead contract. All of these hypotheses are applied both for Hungary and Germany.

1 THEORY & LITERATURE OVERVIEW

Power markets have drawn attention of researchers since the onset of their liberalization in 1990's. Power has become a tradable commodity at an increasingly transparent power market. Financial contracts gave rise to companies specialized for pure proprietary trading. Hence, a natural question has emerged – is the market efficient?

There are many definitions and forms of risk efficiency. According to Efficient Market Hypothesis (EMH) presented by Fama (1970), an efficient forward price should reflect all public and private relevant information. This is a strongest form of market efficiency. Obviously, such hypothesis is not testable in practice. That is why have researchers focused on a weak form, which states that market is efficient if past spot prices do not improve the prediction of future spot prices. If profit can be gained by taking position on forward market based on historic spot prices, it would signal weak form of market inefficiency.

Market efficiency is also assessed by an investigation of forward price unbiasedness. If there is a systematic deviation between forward price and future spot price, it usually signals inefficiency of the market. Such deviation is referred to as a premium. The premium $P_{t,T}$ at time t for T time delivery is thus denoted as follows:

$$P_{t,T} = F_{t,T} - S_T \tag{1}$$

Where $F_{t,T}$ is the forward price traded at time t for T time delivery. S_T is the realized spot price at time T unknown to the market at time t. As pointed out by Bessembinder & Lemmon (2002), a risk premium compensates market actors for spot price risk in electricity markets. However, sizeable risk premia would indicate market inefficiency. We test the existence and size of risk premia both in Germany and Hungary in chapter 5.

Before we present recent empirical findings on risk premia, and on a link between spot and forward prices in power markets, we briefly review theories on forward pricing. A classic approach for forward pricing, known from time of Kaldor (1939) dictates a following non-arbitrage condition.

$$F_{t,T} = S_t e^{(i+s)(T-t)} \tag{2}$$

Where $F_{t,T}$ is the forward price traded at time *t* for *T* time delivery. S_t is the spot price at time t, i stands for interest rate and s for storage costs. According to this formula, forward price should equal to spot price after accounting for costs of financing and storage. If forward was priced above this price, market players could exploit such opportunity and buy spot for borrowed money, sell forward simultaneously, and hold the commodity until expiration of forward contract. Assuming forward price is lower than right-hand side of the equation above, traders would short-sell spot letting proceeds from this sale yield interest i, and buy forward. These transactions would occur until both prices are pushed to its equilibrium and arbitrage opportunity seizes to exist.

However, this approach is not correct for electricity products due to their non-storability, although it has been used in some literature (see Clewlow & Strickland, 2000, Belden et al., 1998). Botterud et al. (2010) pointed out that a cost-of-carry model might be of some relevance only for power markets where hydrogenation dominates with ample water reservoirs, since they are effectively able to store electricity in a form of water ready to use for power production. However, this is not the case for our markets of interest, which is Hungary and Germany. We are thus left with expectation theory. This theory states that forward price is just a reflection of expectations on future spot prices.

$$F_{t,T} = E_t(S_T) \tag{3}$$

Allowing for risk-averse market actors, we add a risk premium, which compensates for holding a spot risk. This risk premium may be relatively sizeable due to large fluctuation of spot price. The equation is thus altered in the following way:

$$F_{t,T} = E_t(S_T) + P_{t,T} \tag{4}$$

The greatest difficulty for empirical estimation of the relationship (3) above is the inability to capture an unobservable expectation on future spot price. Some researchers have constructed models to arrive at expected spot price, which has been the case for Bessembinder & Lemmon (2002) equilibrium model or Bunn & Karakatsani (2005). The biggest drawback of this approach consists in potential ambiguous conclusion. Since we do not know if a model for expected spot prices is correct or not, we usually end up at 3 possible conclusions: 1) There is a (in)significant risk premium. 2) The model is wrong 3) Both first and second statement hold. That is why rather ex post risk premium is used, which is denoted as follows:

$$F_{t,T} = S_T + P_{t,T} \tag{5}$$

Bessembinder & Lemmon (2002) has also studied the ex-post risk premia for Pennsylvania-New Jersey-Maryland (PJM) electricity market concluding that risk premia on monthly contracts are highly seasonal and depend on forecasted mean as well as variance of demand. This risk premium is also positively related to skewness and variance of spot prices. Cartea & Villaplana (2010) concluded similarly that risk premium is seasonal and positively associated with variance of demand. These finding were confirmed also by Longstaff & Wang (2004). However, the study of Bessembinder & Lemmon (2002) assumed only generators and retailers to be active at the market, which is certainly not the case for the present. Cash settled contracts have evolved at PJM market, taking up a volume share of roughly 36% in 2012 in comparison to 5% in 2003 (Nodal Exchange, 2013), which has allowed companies with purely proprietary trading intentions to take their part as well. The presence of speculators should suppress the risk premia. Haugom & Ullrich (2012) provided empirical support for such hypothesis of efficiency improvement of PJM[3] power market, since they applied the same model as Bessembinder & Lemmon (2002) on recent data arriving at a conclusion of fairly priced market with no significant risk premia. Similarly, Diko et al. (2006) focusing on German, French as well as Dutch power markets argues that risk premium has been decreasing over their sample period. This declining trend in risk premium can be attributed both to liberalization of power markets which allowed speculators to step in as well, and a gradual learning of market actors. Diko et al. (2006) as well as Bessembinder & Lemmon (2002) find a diminishing risk premium with term structure. I.e. as time to delivery increases, the risk premium declines. This is in line with notion of the risk premium being a compensation for holding a spot price risk, since products which are close to expiration bear greater delivery risk.

Having discussed main conclusions on risk premia in electricity markets, we examine recent findings on the relationship between spot and forward in electricity markets. Böhm et al. (2008) have studied the impact of costs of fuels and spot prices on year-ahead baseload in

[3] However, as stressed by Botterud et al. (2010, p.967), the spot price refers to a real-time price in PJM market, which is in contrast to conventions in European power markets, where spot price is an outcome of day-ahead power auction. This spot price is then used as a reference price for futures market. The European convention is used in this thesis.

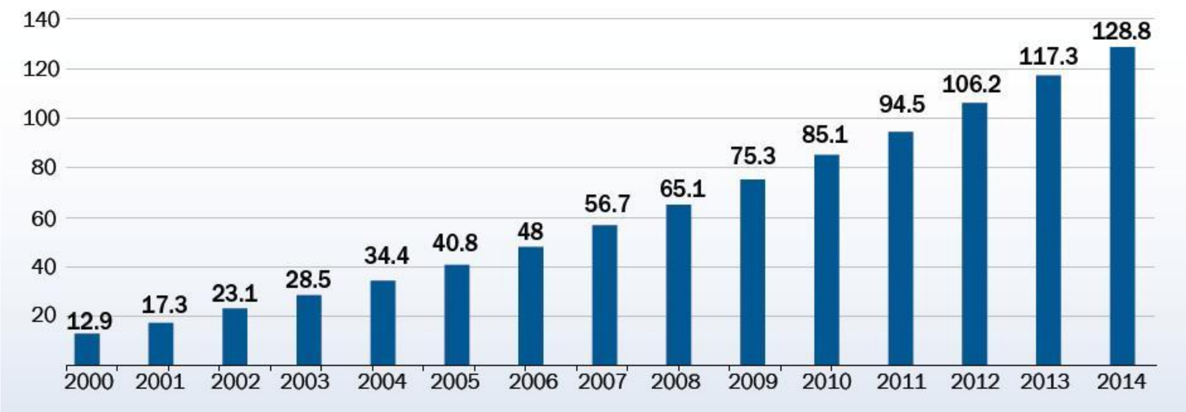
German market as well as in Nordpool. This paper has shown a significant effect of fuel and spot prices on year-ahead forward price (variables were changes of monthly averages). Botterud et al. (2010) inspect Nord Pool market, arguing that the relationship between spot and forward prices is linked to the physical state of the power system. Such findings indicate rather adaptive expectations and point to market inefficiencies, since a change in spot price should not have any significant impact on price of year-ahead power, ceteris paribus. In light of non-storability of power, spot and forward prices are in theory independent. In contrast to these findings, Haugom & Ullrich (2012) has not found any significant evidence that past spot prices or past demand characteristics are helpful for explanation of current spot prices. The forward prices captured most of their variability.

2 INTRODUCTION TO GERMAN AND HUNGARIAN POWER MARKETS

The liberalization of European power markets started in 1990's, which was fostered in 1996 by adoption of a directive regarding common rules for the internal power market (EC, 1997). Instead of cost-based regulated pricing, a market-oriented price formation has emerged. New market platforms both for short-term and long-term power were established, which brought about increasing competition. Trading volumes of power have risen sharply, especially in Germany, which has been established as a continental power hub with highest traded volume. To illustrate such sharp increase, the total volume traded both OTC and exchange-cleared amounted to 5344 TWh in 2014 (EEX, 2015). To provide a comparison to such figure, the total German power consumption was 610 TWh for year 2014 (BDEW, 2014), so the volume of power traded is roughly nine-times higher than consumed.

Additionally, a share of exchange-cleared transactions to overall volume traded has soared recently as well, from around 14% in 2012 to approximately 25% in 2014 (EEX, 2013, 2015). This signals opening of the power market to pure speculators with no asset-based trading activities. However, increasing share of cleared trading might also be attributed to credit deterioration of power generation companies, which is caused by declining electricity price.

Figure 2-1: Europe - cumulative installed wind capacity, 2000-2014 (in GW)



Source: EWEA, 2015

Along with the market evolution described above, a generation mix has completely changed as well. The whole Europe has turned to a more intensive generation from renewable sources in the last decade. As seen in Figure 2-1, a total wind power capacity installed in Europe has been rising sharply, almost to 130GW as of the end of 2014 (EWEA, 2015). The solar capacity grew enormously as well, close to 82GW in 2013 (EPIA, 2014).

Table 1: Europe - installed wind power capacity by country, 2006-2014 (in GW)

Country	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Austria	965	982	995	995	1 011	1 084	1 377	1 684	2 095
Belgium	194	287	415	563	911	1 078	1 375	1 651	1 959
Bulgaria	36	57	120	177	375	612	674	681	691
Denmark	3 136	3 125	3 163	3 465	3 752	3 871	4 162	4 772	4 845
France	1 567	2 454	3 404	4 492	5 660	6 800	7 623	8 254	9 285
Germany	**20 622**	**22 247**	**23 897**	**25 777**	**27 214**	**29 060**	**30 989**	**33 730**	**39 165**
Greece	746	871	985	1 087	1 208	1 629	1 749	1 865	1 980
Hungary	**61**	**65**	**127**	**201**	**295**	**329**	**329**	**329**	**329**
Italy	2 123	2 726	3 736	4 850	5 797	6 747	8 118	8 551	8 663
Netherlands	1 558	1 747	2 225	2 229	2 237	2 328	2 391	2 693	2 805
Poland	153	276	544	725	1 107	1 616	2 496	3 390	3 834
Portugal	1 716	2 150	2 862	3 535	3 898	4 083	4 529	4 724	4 914
Romania	**3**	**8**	**11**	**14**	**462**	**982**	**1 905**	**2 599**	**2 954**
Spain	11 623	15 131	16 689	19 149	20 676	21 674	22 784	22 959	22 987
UK	1 962	2 406	2 974	4 051	5 204	6 540	8 649	10 531	12 440

Source: Bundesnetzagentur

Germany has become a leader in building new wind and solar power plants with largest wind as well as solar power capacities in Europe. Table 1 provides us with a country breakdown of European installed capacity in wind generation. German total wind power capacity was above 39 GW by the end of 2014. Solar power capacity is also sizeable amounting to more than 38 GW (EPIA, 2014). Such figures are striking when comparing with average German consumption being around 69GW for an average hour in 2014. However, the utilisation of wind and solar power capacities is not high, since only 5.7% and 8.5% of total power generation was produced by solar and wind power plants in 2014, respectively (BDEW, 2014). Nevertheless, due to high solar and wind power generation, it is currently not an exception to see negative prices on German power spot auction, especially over weekends if low consumption is accompanied by high wind or solar power generation.

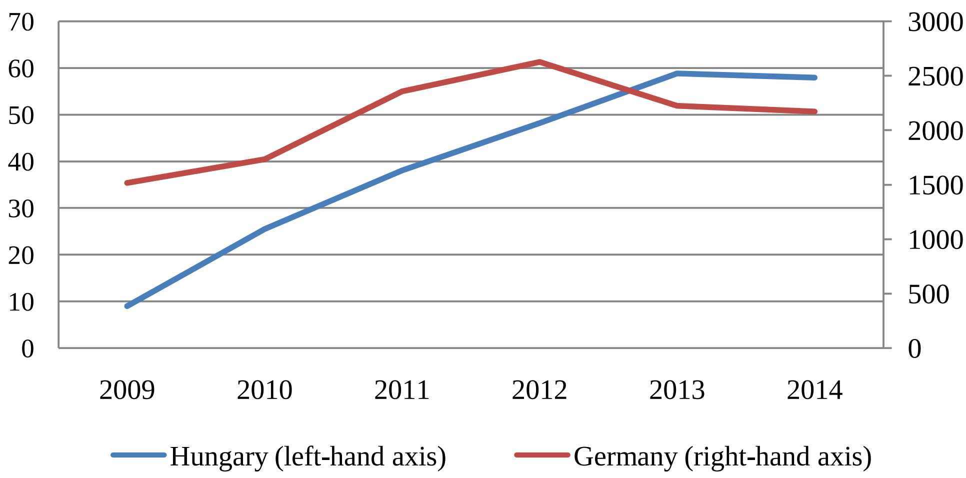
Table 2: Europe - installed solar power capacity, 2006-2014 (in GW)

Country	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Belgium	4	27	108	627	1 044	2 018	2 650	2 983	
Bulgaria	0	0	1	7	35	135	908	1 020	
Czech Rep.	1	3	64	462	1 952	1 959	2 084	2 175	
Denmark		3	3	4	6	16	394	548	
France	30	41	87	269	988	2 659	4 003	4 673	
Germany	**2 899**	**4 170**	**5 979**	**9 785**	**17 193**	**24 678**	**32 411**	**35 715**	**38 236**
Greece	7	8	18	55	205	631	1 536	2 579	
Hungary				1	2	4	4	22	
Italy	47	93	432	1 144	3 470	12 754	16 361	17 928	
Romania				1	2	3	30	1 151	
Spain	148	724	3 568	3 588	4 029	4 400	5 166	5 340	
UK	1	16	22	29	91	875	1 829	3 375	
TOTAL	3 137	5 085	10 282	15 972	29 017	50 132	67 376	77 509	

Source: Bundesnetzagentur

Overall, since variable costs of renewables are practically zero, such abundant output from solar and wind power plants dampen the overall power price level. This was also found in academic literature (Genoese, 2008; Horowitz et al, 2011; Nicolosi, 2010, Kemfert & Traber, 2011 or Ketterer, 2014). Furthermore, some German neighbours are building wind as well solar generation, too. Especially France, Denmark and Belgium have markedly increased their installed capacities of production from renewables (see Table 1 and Table 2). This magnifies both the volatility and downward pressure on power spot prices, since weather is well correlated within Central and Western Europe. The changes in cross-border flows thus cannot serve so well as a tool for German spot prices smoothening.

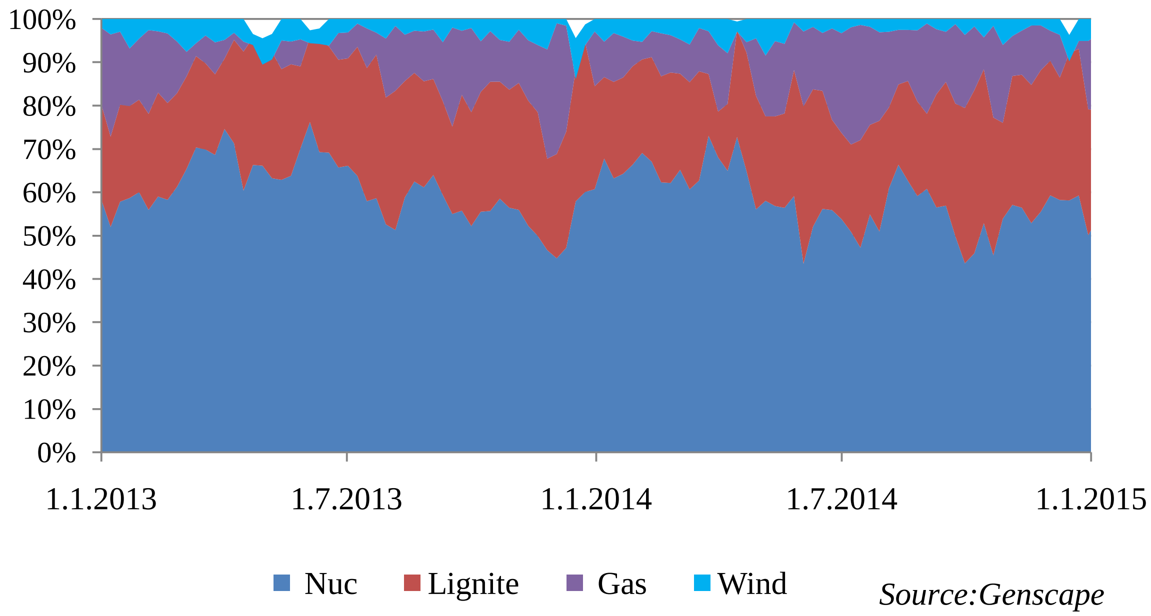
Figure 2-2: Germany, Hungary - OTC volume traded on front-year contract (in TWh)



Source: Trayport

As far as Hungarian market is concerned, trading activity on this market has been steadily increasing for the last two years. Hungarian power market has become a most liquid and deep market for South-Eastern Europe. Since Hungary is relatively well-connected through cross-border power capacities to SEE region, the electricity trading of the whole region is concentrated in Hungary. Although the total volume traded has been rising, it is definitely not comparable to German market. As you can see in Figure 2-2, the volume traded on front-year contract in Germany is almost forty-times bigger than in Hungary. Hungarian volume is roughly three-times lower even if we take into account smaller consumption of Hungary being only 42.5 TWh in 2014 (MAVIR, 2015). We might expect some catch up process towards Germany, in the relative terms at least.

Figure 2-3: Hungary - Breakdown of generation by power plant type (weekly averages)



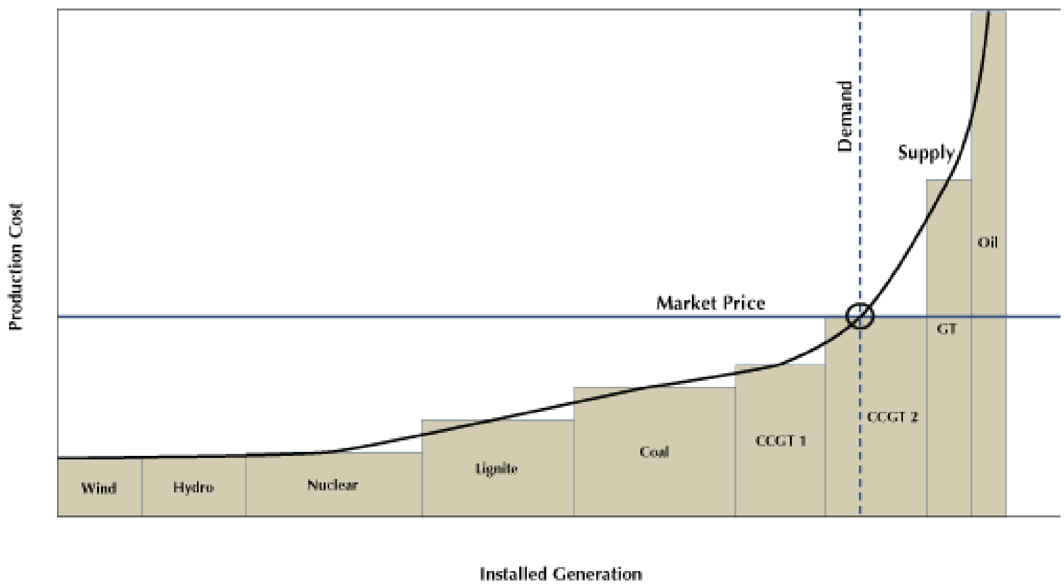
Source:Genscape

Regarding Hungarian generation mix, it is definitely not so much volatile as the German one, since it consists mainly of conventional generation, which is illustrated with Figure 2-3. Nuclear power dominates the Hungarian generation mix. Gas power plants take up quite a large share on the whole production as well. The installed wind power capacities in Hungary are tiny in comparison to Germany. However, Romania has built quite a large amount of wind capacities since 2010, having almost 3GW installed as of 2014 (see Table 1). This poses already a non-negligible effect for Hungarian power prices. Nevertheless, the impact of wind on Hungarian spot price is still not even comparable to German market.

2.1 DETERMINANTS OF SPOT AND SHORT TIME-TO-MATURITY POWER PRICE

This section offers a brief overview on the most important drivers of spot power price. We examine how the price is formed and investigate bidding curve of various participants of the spot auction. The spot price is set by an auction for each hour with day-ahead physical delivery. The result for each hour is thus obtained. The spot baseload price is then a simple average of these hours. Market participants send bids/offers for each hour, at what prices they are willing to buy/sell a given amount of electricity. Obviously, a market is cleared if supply equals demand. Since demand is inelastic in the short-term, the price is formed by a supply side. A large portion of consumption is put to the auction as an unlimited bid – the power has to be bought no matter what the price is. Generators, on the other hand, offer their production at marginal cost of corresponding power plant + a mark-up. Revenues from wind and solar production are not market-based, so they are considered a must-run generation. There are other price-independent electricity generation, for example central-heating power plants (CHP). Hydro-generation is treated almost as a must-run, since its variable costs are estimated to be close to zero. The price is thus set by net demand = demand + export – imports –hydro – wind - solar – (price independent generation), and a marginal production technology.

Figure 2-4: Stack curve example

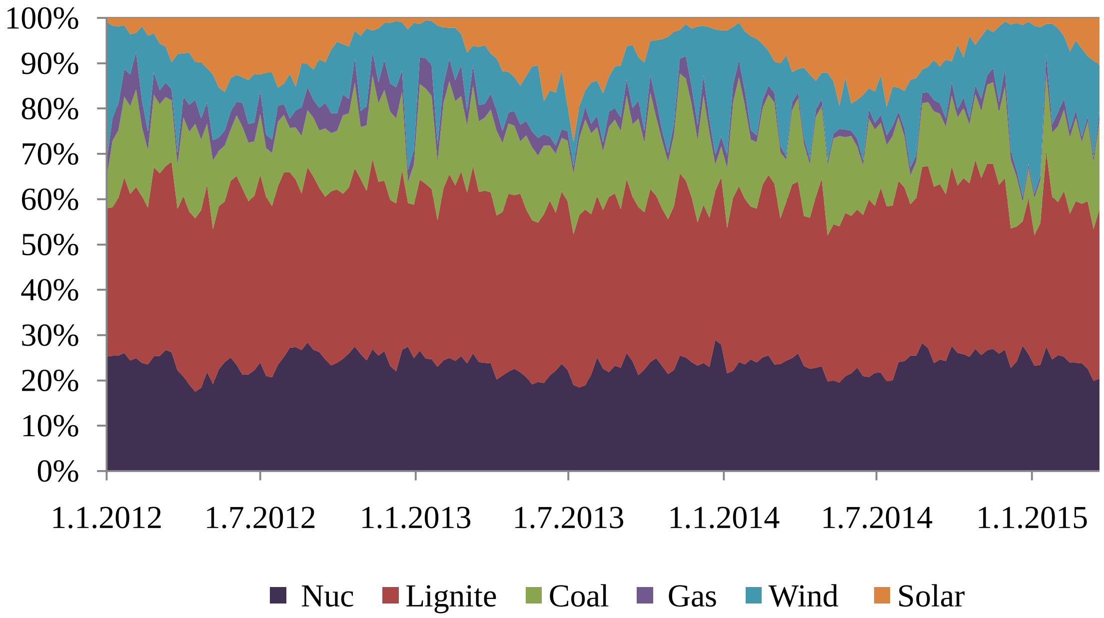


Source: Center for Climate and Energy Solutions

The marginal costs of each type of power plant are described by a stack curve, depicted in Figure 2-4 above. The supply curve is usually strongly convex. Hence, a price spikes occur if net demand is high, since very expensive generation sources has to be put online.

The growth in production from renewables, which has been discussed in previous section, is shifting the net demand to the left. This results in price decline. Consequently, such low prices make some conventional generation being out-of-money. Renewables thus crowd out other generation sources. Naturally, power plants with highest variable costs are hit most severely. Hence, real generation from gas power plants has been almost negligible relatively to the whole mix of German power production over last two years. This is well illustrated with Figure 2-5, which offers a breakdown of real generation according to type of power plants. We see that gas power production has been very poor since the second quarter of 2013. These plants are running usually only for selected hours during winter months if there is a shortage of output from renewables.

Figure 2-5: Germany - breakdown of generation by power plant type (weekly averages)

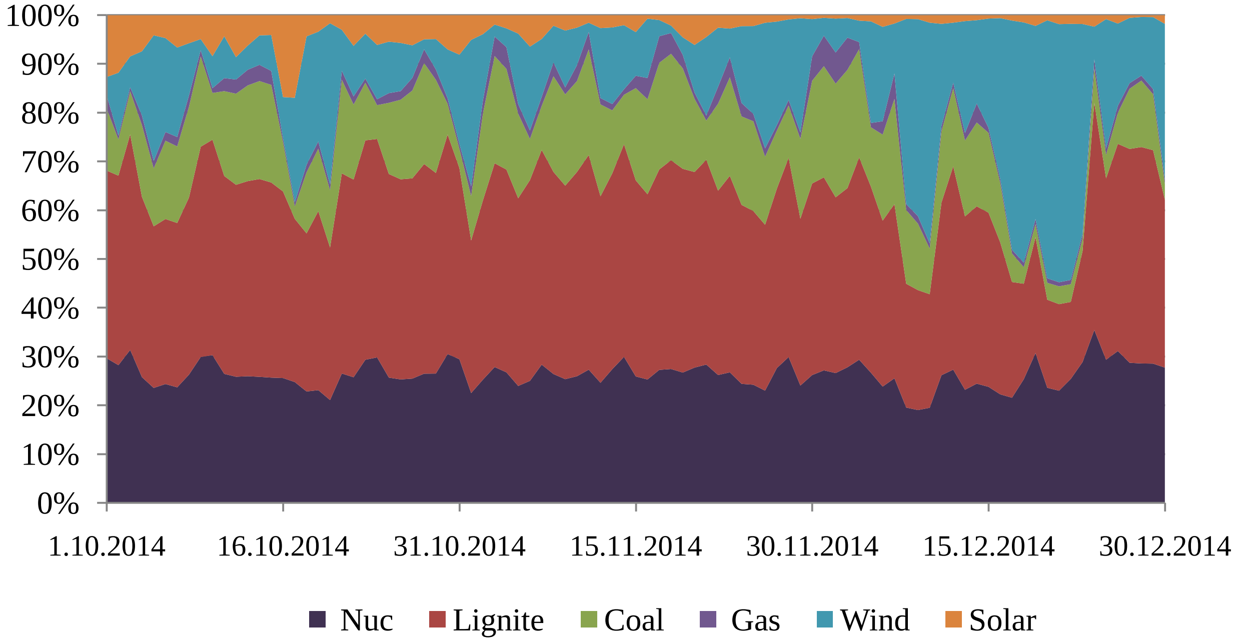


Source: EEX Transparency

Power plants fuelled by hard coal follow gas power plants in the stack curve as a second most expensive generation source, which makes them the second biggest sufferers. As observed in Figure 2-5, or Figure 2-6 to a more detail, hard coal power plants serve to partly smooth spot power price, because their output is negatively associated with wind and solar generation.

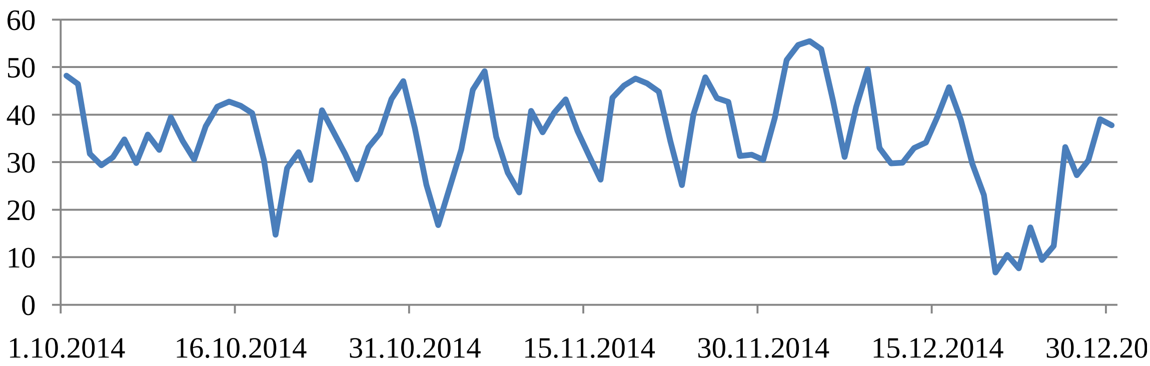
Since hard coal power plants are quite flexible, they are able to react on forecast of wind or solar output. Hence, if there is ample wind and solar generation, the spot prices are suppressed, which puts hard coal power production out-of-money. Renewable sources sometimes even crowd out lignite power plants whose production costs are generally significantly lower than for hard coal power plants. However, lignite power output is much more stable than for coal. Understandably, nuclear power plants are characterised by a rigid output, which depends solely on planned or unplanned outages.

Figure 2-6: Germany - breakdown of generation by power plant type, Q4 2014 (daily averages)



Source: EEX Transparency

Figure 2-7: Germany - spot prices, Q4 2014 (in EUR/MWh)

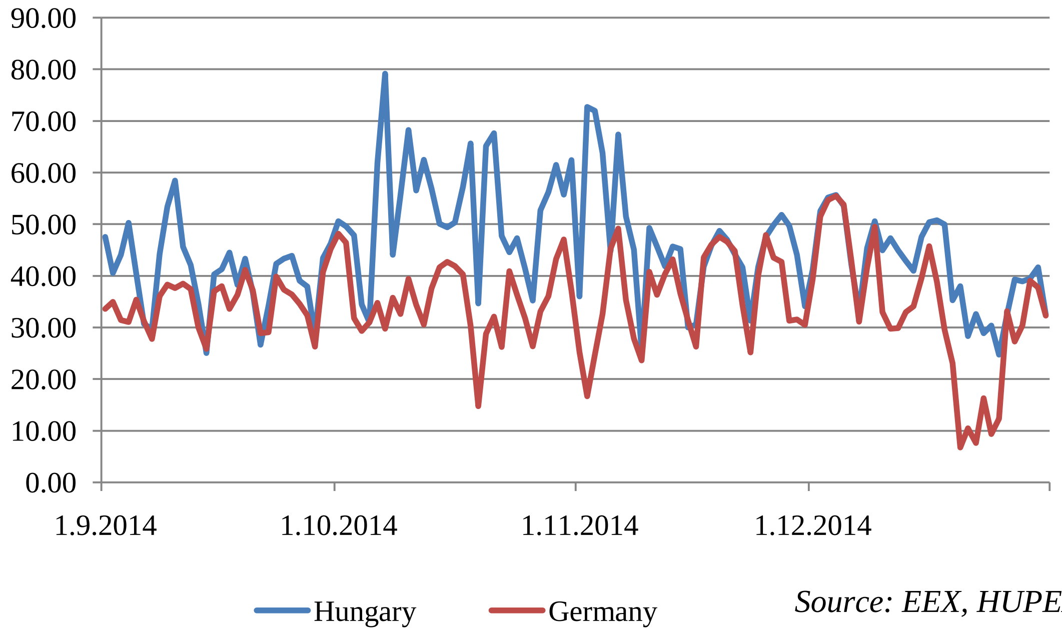


Source: EEX Phelix results

As seen in Figure 2-5 above, both wind and solar power output is highly seasonal. Obviously, solar production is the biggest during summer months peaking in August due to a specific incline of panels. However, the highest utilization of wind farms is over winter. Notice especially the end of years which is usually characterised by ample wind power production. This was also the case for December 2014, which is depicted to a more detail in Figure 2-6. Strong seasonality of power price comes also from the demand side, since consumption is heavily influenced by temperature and cloudiness. Consumption thus sharply rises in winter causing price spikes if there is a shortage of renewable generation (see Huisman et al., 2007; Kanamura & Ohashi, 2008; and Bunn & Karakatsani, 2008). Renewables actually contribute to overall volatility in winter, since there are weather patterns associated with either low temperatures and low wind-speed, or warm and windy weather at the same time. This makes winter spot prices extremely volatile in Germany. Such enormous price fluctuation is illustrated on following Figure 2-6, Figure 2-7, where the actual generation is compared with spot price for Q4 2014. Notice periods with strong wind and corresponding price crashes.

On the other hand, Hungarian spot prices are not so directly influenced by wind and solar power generation. The influence of renewables is rather imported from Germany and from Balkan, due to hydrogenation in the whole Balkan and wind farms in Romania.

Figure 2-8: Germany, Hungary - spot prices, Q4 2014 (in EUR/MWh)



Source: EEX, HUPEX

Observing Figure 2-8, Hungarian spot prices are clearly more prone to spikes than German prices. This is caused by a bipolar stack curve in Hungary (see Figure 2-3). There is either generation with low variable costs (lignite, hydro power plants) or expensive sources such as gas and oil power plants. The spot prices thus easily switch from low to high level if there is shortage of power in the system, since there is no tool for price moderation. A perfect example is October 2014, which is well depicted in Figure 2-8. A price spike is also brought about by a suboptimal power dispatch, which occurs especially over weekends and for Monday delivery.[4] Additionally, power flows are often inefficient, especially vis-à-vis Balkan countries,[5] which amplifies price volatility.

2.2 DETERMINANTS OF LONG TIME-TO-MATURITY FORWARD POWER PRICE

This section pinpoints main drivers and characteristics of forward power price. We concentrate on long part of forward curve, namely on year-ahead contract. Since the weather cannot be predicted for such contracts at all[6], the drivers of these long-time-to-delivery products are somewhat different from what has been discussed in previous part. Changes of long term power price are thus not so much weather-driven, but rather influenced by development of the whole projected stack curve. The stack curve of a certain country might be altered by generation mix modification or by changes of power plants' generation margin which can be caused by price fluctuations of fuel inputs or by imposing new regulatory framework.

While regulatory as well as production mix changes are usually one-off events, fuel prices move continuously, causing also power price fluctuations. Costs of power plants' inputs have been identified to play a major role for long-term power price formation in academic literature such as: Furió & Chuliá (2012), Joëts & Mignon (2011) or Böhm et al. (2008). Looking at Figure 2-5, gas prices might not be anticipated to be of paramount importance for power price given low utilization of gas power plants. However, marginal cost of gas power plants puts certain cap to spot prices, so especially peak forward prices are quite sensitive to development of gas prices. Germany is supplied mostly from Norway, Netherlands and Russia, so the Title

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[4]Power dispatch is not optimal because power plants (especially gas power plants) are sometimes not running although some blocks of hours end up well above variable costs of relevant power sources (observed from Genscape database).
[5] Since Hungary is not market-coupled with these countries. Only Romania joined in November 2014 the CZ-SK-HU market coupling area.
[6] Only with the exception of the last two to three weeks before delivery, this is the end of the year.

Transfer Facility (TTF) gas prices are most appropriate for calculation of gas power plants' marginal costs.

Hard coal price impacts German power heavily, as coal power plants still account for large portion of total electricity production. Europe imports mainly All Publication Index 2 or CIF ARA (Amsterdam, Rotterdam, and Antwerp) hard coal. To estimate marginal costs of lignite and nuclear power plants is a tough task. Generally, these costs are considered to be low (Kristiansen, 2011, p.47). Lignite is usually extracted from local opencast mines nearby the power plants, so the marginal production cost is highly individual for each power plant. All of the three power plants type might have to buy the right to release carbon emission as a by-product of their production. Thus, the price of European emission allowances (EUA) cannot be omitted. See the emission factor for various production technologies in Table 3 below.

Table 3: Emission factor for different power generation

	ton/MWh
Hard coal	0.96
Lignite	1.1
Natural gas steam turbine	0.48

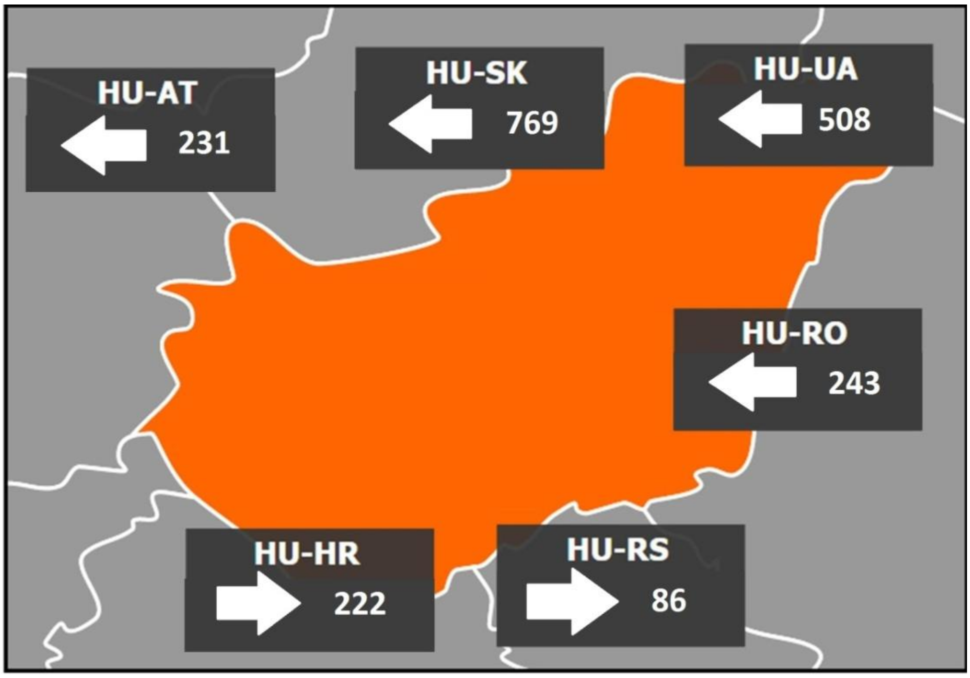
Source: Kristiansen (2011, p.48)

Determinants of Hungarian year-ahead forwards are similar to what has been discussed above, since these products are closely linked, and are traded as spreads intensively. Only the sensitivity of final spot prices on each fuel is not the same due to different production mix. However, recent findings in research papers indicate that besides fuels being decisive determinants of long-term forward power price, the current level of spot prices plays a role, too. This has been stated by Botterud et al. (2010), Böhm et al. (2008) or Pirrong & Jemakyan (2008). The effect of spot on forward prices with longer time to maturity both in Germany and Hungary is thus tested in chapter 3 and 4.

2.3 INTERCONNECTION OF HUNGARIAN AND GERMAN POWER MARKETS

German power market is considered a hub and a benchmark for most of smaller power markets in the continental Europe, including Central and Eastern parts. This applies also for Hungary. Hungarian market is connected to German one through various cross-border transmission lines. Since Hungary is a strong importer of power, which is illustrated in Figure 2-9,[7] where the power flow vis-à-vis neighbour countries for an average hour for 2013-2014 period is plotted. I focus mainly on the transmission capacities to Hungary. One is through Austrian grid APG[8] with maximum available transmission capacity of 800 MW for commercial flows. Another important interconnector is through Slovakia. The flow of power from Slovak grid (SEPS) to Hungary can be up to 1100 MW. Slovakia is heavily related to German grids via Czech Republic, since Czech grid (ČEPS) has ample transmission capacities with Germany, which results in lack of systematic price differentials between Germany and Czech Republic. Moreover, Slovakia, Czech Republic and Hungary comprise a single market coupling area since September 2012, which secures efficient utilization of transmission capacities.

Figure 2-9: Hungary - power flows, 2013-2014 hourly averages (in MW)



Source: MAVIR, own calculations

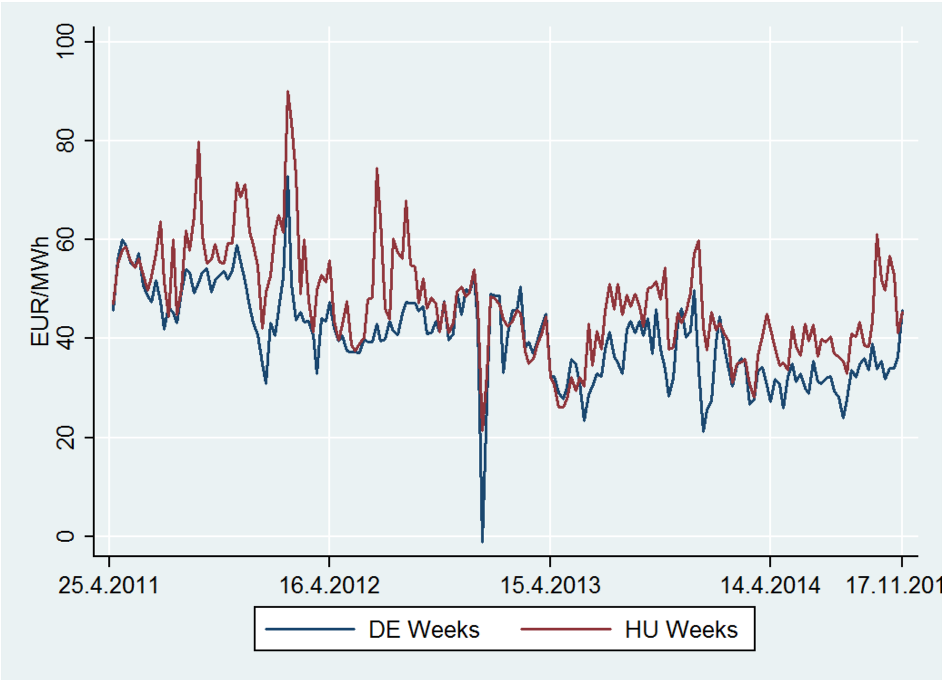
Hungarian power grid (MAVIR) is further indirectly related to APG grid through Slovenia (ELES grid), although Hungary does not have direct line with Slovenia. However, the power is transmitted through Croatia. The APG->ELES line's capacity is 950 MW. Considering the

[7] Note that the direction of the flows in Figure 2-9 is driven by the arrows in respect to its header. E.g. it means on HU-RO border that it was transmitted 243MW from Romania to Hungary for a 2013-2014 average hour.

[8] Austria has its own electricity grid but has the same exchange and there have been no price differentials with German market.

consumption in Hungary being around 4850 MW for average hour (MAVIR, 2015), these power flows via Austria and Slovakia are significant and sometimes price-setting. However, Hungarian price level has been usually above the German one over our period of interest, so the transmission lines are frequently congested in the direction towards MAVIR. This is illustrated with Figure 2-10, where the Hungarian and German settlement prices of weeks for the period from 25/4/2011 till 17/11/2014 are depicted. Although it might not seem that AGP-MAVIR or SEPS->MAVIR is congested due to real power flows being much lower than their limits, the congestion occurs usually only for selected block of hours, which bring about price differentials of the whole baseload.

Figure 2-10: Germany, Hungary - spot prices, 2011-2014 (weekly averages)

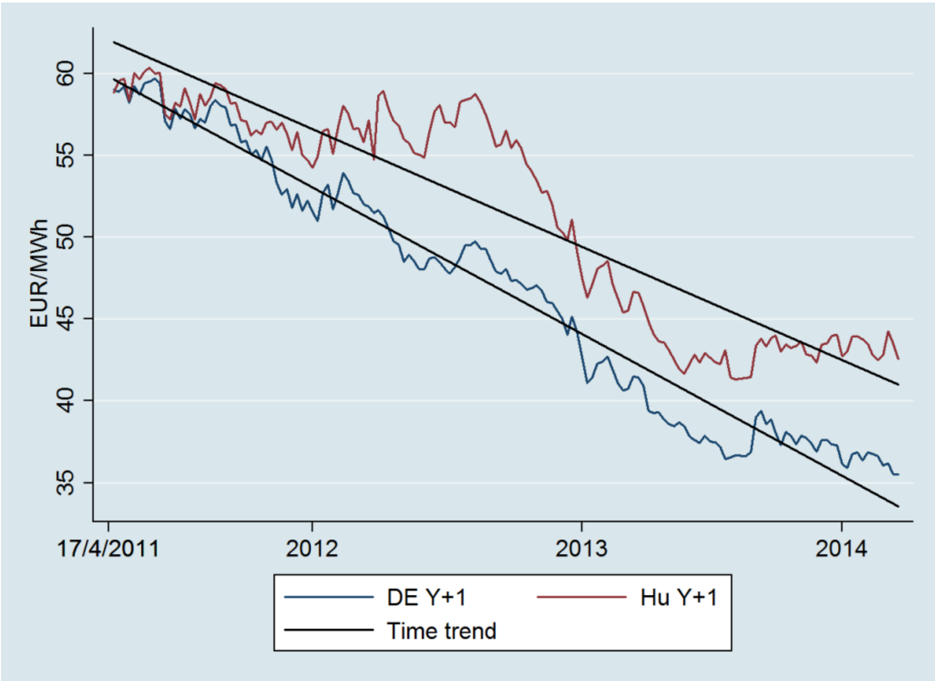


Source: HUPEX, EEX and own calculations

As outlined in previous sections, German prices crash sometimes even to a negative value, which is caused by abundant renewable generation sources. That is why the average German spot price for the period from 25/4/2011 to 17/11/2014 is 40.53 while the price in Hungary averages to 47.13 EUR/MWh.

As a result, there is often maximum flow of power from Austria or Slovakia to Hungary and the change in price level of Germany has limited impact on Hungary. German price serves rather as a floor to Hungarian prices. Merely occasionally Hungarian day-ahead baseload ends up systematically below German one. This occurred only for selected weeks in Q2 2013 if there is ample hydrogenation in Balkan, but usually an upward surprise in German day-ahead auction[9] is responsible for negative spread between Hungary and Germany. Since these markets are not market-coupled, the power flow might be inefficient, so transmitted from higher price zone to the grid with lower price. However, such situation is usually not systematic.

Figure 2-11: Germany, Hungary - front year forward prices, 2011-2014



Source: Trayport, own calculations

This fundamental situation in the market is reflected by year-ahead prices for both regions as seen in Figure 2-11. We have identified a divergence between Hungarian year-ahead contract in relation to its German counterpart since 2012. This is brought about mainly by sharp increase in German renewable capacity (Genoese et al., 2008; Horowitz et al., 2011) with only slow start of production from renewable sources in Hungary and Balkan countries. Having explained some basic fundaments of both German and Hungarian power markets, let us now turn to empirical part where specific hypotheses are presented and tested.

[9] Czech, Slovak as well as Hungarian spot auction results are published before deadline for bid submission to German exchange, so if there is no congestion at APG-> MAVIR or SEPS-> MAVIR borders, Hungarian price ends up roughly at the level of German OTC day-ahead market.

3 EFFECT OF WEEK'S SETTLEMENT ON YEAR-AHEAD POWER

The following two chapters are devoted to empirical analysis of links between spot and forward prices in Germany and Hungary. We investigate in this particular section whether a shock on the spot market is translated into price of electricity with year-ahead delivery. The shock on the spot market is captured by a difference between projected settlement of current week and the week's forward closing price traded in previous week. The expectation is that power price of year-ahead delivery is influenced by recent spot settlements both in Germany and in Hungary. However, the effect is assumed to be much stronger in Hungarian power market.

The reasoning is as follows: Let us assume that spot auction turn out to be repeatedly higher, increasing the projected settlement of current week, which in turn makes projected settlement of both current month and quarter higher as well. Market participants who are active for instance on front-month or front-quarter products compare these products with current or previous one and revise their price estimates accordingly. In our case, the prices of front-month or front-quarter products would increase. These effects make a projected settlement of current year significantly higher to which price expectations on year-ahead contract are revised. That is how seemingly insignificant outcomes of day-ahead auctions translate into forward curve. Such hypothesis thus assumes adaptive expectations in power markets, which is indirectly tested in this chapter.

3.1 MODEL

As outlined above, the explanatory variable of our interest is the difference between projected settlement of current week and its traded closing price. The projected Friday's settlement of current week is constructed as a weighted average of settled spot prices from Monday to Friday and forward closing price of weekend. We may look at this variable also as a prediction error of the market on the settlement of week-ahead working days and a change in forward price of its weekend. Using projected settlement of the week instead of the actual one, I avoid usual mistake of taking into consideration ex post information which was not available to market participants at the time when other explanatory variables were formed in the market.

Table 4: Notation of variables

Variable	Description
$pwr\_y_{de,t}$	front-year German power forward price
$wk^{pr}_{de,t} - wk^{tr}_{de,t}$	difference between projected settlement of current week in Germany and its traded closing price
$pwr\_y_{hu,t}$	front-year Hungarian power forward price
$wk^{pr}_{hu,t} - wk^{tr}_{hu,t}$	difference between projected settlement of current week in Hungary and its traded closing price
ttf^{y}_{t}	front-year natural gas forward price - Title Transfer Facility
api^{y}_{t}	front-year hard coal forward price -All Publication Index 2
eua^{y}_{t}	front-year price of European Emission Allowances futures

Lower index (t-1) stands for variable's first lag.

The dependent variable is thus weekly change of forward price of power with year-ahead delivery. The drivers of long time-to-maturity forward prices (see 2.2) are the costs of power plants' inputs, which are corresponding forward prices of emission allowances (EUA), hard coal (API 2) as well as natural gas (TTF). Weekly changes in these variables are included as control variables. First lags of abovementioned explanatory variables are incorporated into model as well to account for potential imperfect pass-through of fuel costs changes into power prices. Additionally, a shock on the spot market is suspected to have non-linear coefficient. Since the volatility of German spot prices is enormous due to renewables, the effect of spot prices on forward market is assumed to be less than proportional in Germany. Market actors usually know that current settlement of the week is different from its traded price because of change in forecast of output from wind farms and solar panels over weekend. That is why such change in week's settlement against its traded price is less translated into forward prices. The model for German year-ahead power is thus constructed as follows:

$$\Delta log\ pwr\_y_{de,t} = \beta_0 + \beta_1 (\log wk^{pr}_{de,t} - \log wk^{tr}_{de,t}) + \beta_2 (\log wk^{pr}_{de,t} - \log wk^{tr}_{de,t})^2 + + \beta_3 \Delta log\ ttf^{y}_{t} + \beta_4 \Delta log\ eua^{y}_{t} + \beta_5 \Delta log\ api^{y}_{t} + \beta_6 \Delta \log ttf^{y}_{t-1} + + \beta_7 \Delta log\ eua^{y}_{t-1} + \beta_8 \Delta log\ api^{y}_{t-1} + \beta_9 \Delta log\ pwr\_y_{de_{t-1}} + \varepsilon_{1_t} \tag{7}$$

Regarding the model for Hungary, the main explanatory variable of Hungarian year-ahead contract is its German counterpart, since German market is a benchmark for Hungary as explained in part 2.3. A sizeable portion of traded volume of Hungarian year-ahead power is even concluded as a spread with Germany. This illustrates the importance of German forward price for Hungarian price formation. German power price also reflects changes in fuel costs relevant for Hungarian market. We thus arrive at such a short model for Hungary:

$$\Delta log\, pwr\_y_{hu,t} = \gamma_0 + \gamma_1 (\log wk^{pr}_{hu,t} - \log wk^{tr}_{hu,t}) + \gamma_2 (\log wk^{pr}_{hu,t} - \log wk^{tr}_{hu,t})^2 + \\ + \gamma_3 \Delta log\, pwr\_y_{de,t} + \gamma_4 \Delta log\, pwr\_y_{hu,t-1} + \varepsilon_{2_t} \quad (8)$$

All data are log-differenced, so the variables are approximately weekly percentage changes of Fridays' closings. Only $(wk^{pr}_{de,t} - wk^{tr}_{de,t})$ is the percentage difference between projected settlement of current week from Friday and its closing price from Friday week before.

3.2 DATA DESCRIPTION

Data on forward prices are collected from a Trayport platform, which aggregates almost the screens of broker companies and energy exchanges. Data obtained from this source thus cover both financial and physical deals. There are even other forms of the contracts included, e.g. financial OTC deal or a cleared physical future. Results of daily power auctions are published by European Energy Exchange (EEX) for German market and Hungarian Power Exchange (HUPEX) for Hungarian one. Prices of natural gas traded at the Title Transfer Facility (TTF) and All Publication Index 2 (API 2) are used for price of hard coal. Carbon emission allowances futures of December delivery of current year are taken as another variable in the model.

The dataset consists of 139 observations covering weeks from 25.4.2011 to 28.9.2014. Some observation had to be dropped due to data unavailability. A reason for these missing data is usually poor liquidity in Hungarian market. Weeks including Christmas or New Year are excluded due to very low activity on the market before delivery of this product.[10]

[10]Proprietary traders are usually reluctant to put on positions before Christmas and just before the end of their business year. Hence, the risk premium for this period is sizeable and would cause bias in our results.

Observing summary statistics for our variables, we identify a clear downtrend for all energy commodities of our interests, since their mean is negative. Variables $(wk_{de,t}^{pr} - wk_{de,t}^{tr})$ as well as $(wk_{hu,t}^{pr} - wk_{hu,t}^{tr})$[11]are roughly expressing risk premium for German and Hungarian weeks, only with different sign. However, this premium is most probably underestimated, since we do not take into consideration actual spot results of the weekend, but its closing price. Given huge volatility of Hungarian weekends, this number understates especially Hungarian premium. Interestingly, Hungarian risk premium is even lower than German one, despite its higher volatility. This modified risk premium of both German and Hungarian weeks amounts to roughly 1.4%.

Table 5: Summary statistics

Variable	Mean	Std. Dev.	Min	Max
Δlog pwr_y_{de}	-0.0039	0.0134	-0.0395	0.0328
$\Delta log\ pwr\_y_{hu}$	-0.0022	0.0163	-0.0429	0.0688
$logwk_{de}^{pr} - logwk_{de}^{tr}$	-0.0141	0.0817	-0.2297	0.2420
$logwk_{hu}^{pr} - logwk_{hu}^{tr}$	-0.0138	0.1136	-0.3254	0.5105
$\Delta log\ ttf^{y}$	-0.0011	0.0143	-0.0437	0.0426
$\Delta log\ api^{y}$	-0.0043	0.0149	-0.0560	0.0411
$\Delta log\ eua^{y}$	-0.0072	0.0892	-0.4129	0.2013

A significant potential for spikes of Hungarian power spot prices is illustrated with a maximum value of projected settlement of Hungarian week being by more than 50% higher than its traded forward price. A certain stickiness of Hungarian prices, which results from traders' underestimation of such spike might be a reason for lower risk premium in Hungary in comparison to German market. Maximum risk premium is only 32.5%, which is comparable to German market, where risk premia are quite symmetric (-24 and 23%, note different sign of risk premia than our variable, again). We inspect Hungarian and German risk premia to a more detail in chapter 5.

A volatility of carbon emission allowances is also noteworthy. Such high percentage volatility is caused mainly by very small base, since EUA contract's nominal value is roughly six times

[11]These variables are defined as difference between projected settlement (which is close to actual spot price) and forward price. However, risk premium is usually understood to be a difference between forward price and spot price. Thus, there is just an opposite sign of our variable in comparison to traditional risk premium.

lower than for instance year-ahead power. Nevertheless, almost 9% weekly volatility with biggest drop of around 42% is sizeable.

Since our data are log-differenced, we should not encounter problems with data non-stationarity, which is confirmed by formal tests: Running both Augmented Dickey-Fuller and Phillips-Perron unit root tests, a null hypothesis of a unit root is rejected for all explanatory as well as explained variables. Results are robust to various time lags as well as inclusion of a time trend.

3.3 RESULTS

Before the results of the models above are presented, a fulfilment of classic OLS assumptions on residuals needs to be checked so that we can run a valid statistical inference. Breusch-Pagan/Cook-Weisberg test for heteroskedasticity had not revealed any violation of homoskedastic residuals. Since data are log-differenced there should not be a problem with serial correlation of residuals either, which is supported by Breusch-Godfrey LM test for autocorrelation. Using 12 lags of residuals, we cannot reject null hypothesis of no autocorrelation. Similar results are obtained also for Durbin's alternative test (see Appendix for details). RESET test has not found any flaws in model specification. Having compared normal density with Kernel density estimation, we observe only slight deviation from its normal counterpart. Residuals seem to be roughly normally distributed. To confirm our hypothesis, I run Shapiro-Wilk W test which is unable to reject a zero hypothesis of normally distributed residuals.

Regression results presented in Table 6 are in accordance with our expectations. The model is able to explain a large portion of dependent variable's volatility, since the R-squared is around 0.71. All coefficients have signs in line with theory. Increases in power plants' marginal costs represented by price of carbon emission allowances, natural gas and hard coal have thus positive impact on power price. Note that these are mere weekly changes of fuel costs which are priced into power with a delay. Adding coefficients of first lag, we arrive at higher long-term theoretical sensitivities of electricity price on price of fuels and EUA.

Table 6: Regression results - impact of week's settlement, Germany

Number of obs =139
R-squared =0.7106
Adj R-squared =0.6904

$\Delta log\ pwr\_y_{de}$	**Coefficient**	**Std. error**	**t-statistic**	**p-value**	**Std.coefficient**
$log\ wk_{de}^{pr} - logwk_{de}^{tr}$	0.0125	0.0088	1.42	0.1570	0.074
$(log\ wk_{de,t}^{pr} - logwk_{de,t}^{tr})^2$	-0.2123	0.0675	-3.15	0.0020	-0.151
$\Delta log\ ttf^y$	0.2284	0.0515	4.43	0.0000	0.242
$\Delta log\ eua^y$	0.0806	0.0078	10.34	0.0000	0.536
$\Delta log\ api^y$	0.2998	0.0475	6.31	0.0000	0.323
$\Delta \log ttf_{t-1}^y$	0.0854	0.0550	1.55	0.1230	0.088
$\Delta log\ api_{t-1}^y$	0.0947	0.0562	1.68	0.0950	0.102
$\Delta log\ eua_{t-1}^y$	0.0242	0.0101	2.40	0.0180	0.158
$\Delta log\ pwr\_y_{de_{t-1}}$	-0.2082	0.0852	-2.44	0.0160	-0.206
constant	-0.0003	0.0008	-0.36	0.7210	

At a first glance, emission allowances do not seem to have a significant economic impact on power, since our variables are expressed in logarithms and eua^y variable has low absolute value with average of 7.12 EUR/t, which causes the elasticity to be rather low. However, note the striking difference in standard deviation of the variables (see Table 5). Both $\Delta log\ eua^y$ and $(log\ wk_{de}^{pr} - logwk_{de}^{tr})$ variables have around six times higher volatility than the dependent variable. Therefore, the coefficients for these variables might look insignificant. However, we remove such difficulty by reporting standardized coefficients. Standardized coefficients tell us by how many standard deviations a dependent variable changes if an independent variable moves by one standard deviation. This technique makes comparison of economic significance of explanatory variables easier. Observing the standardized coefficients, the eua^y variable seems to be the most influential variable.

The variable capturing the shock on the spot market turned out to be rather insignificant. On the other hand, its economic impact is not negligible when looking at the standardized coefficient. However, its statistical significance is more than questionable, since we cannot reject the null hypothesis of a zero coefficient only at 80% level of confidence. This variable also seems to have a diminishing effect due to negative coefficient of its squared term. As stated above, such result was expected, since the cause for a large deviation of current week's projected settlement from its traded price is usually well known ex post (change of weather forecast, unplanned generation or transmission line outages, etc.).

This finding is rather in favour of German power market efficiency, so in line with conclusion of Haugom & Ullrich (2012). Since a fairly recent sample period is taken into account, our results is also in accordance with Diko et al. (2006) who argued that efficiency is improving over their time window. Understandably, the market transparency and availability of relevant data have improved rapidly over 10 years, so market participants do not overreact on a usually short-lived move of spot settlements.

Let us turn to Hungarian market and test the hypothesis described by equation (8) above. Before commenting on the results, we need to formally inspect our data. Running the same tests as for German model (7), we cannot reject the null hypothesis of a homoskedasticity and serially uncorrelated errors on 95% level of confidence, as seen in Appendix. Based on Shapiro-Wilk test and comparison of Kernel density estimate with normal density, we may conclude that error terms are approximately normally distributed. RESET test has not indicated wrong model specification either.

Table 7: Regression results - impact of week's settlement, Hungary

Number of obs =139
R-squared = 0.4720
Adj R-squared = 0.4607

$\Delta log\ pwr\_y_{hu}$	**Coefficient**	**Std. error**	**t-statistic**	**p-value**	**Std.coefficient**
$\Delta \log(wk^{pr}_{hu,t} - wk^{tr}_{hu,t})$	0.035	0.083	4.20	0.000	0.262
$\Delta log(wk^{pr}_{hu,t} - wk^{tr}_{hu,t})^2$	-0.024	0.038	-0.49	0.538	-0.301
$\Delta log\ pwr\_y_{de}$	0.731	0.067	10.89	0.000	0.658
$\Delta log\ pwr\_y_{hu_{t-1}}$	-0.074	0.077	-1.27	0.205	-0.078
constant	0.001	0.001	0.70	0.483	

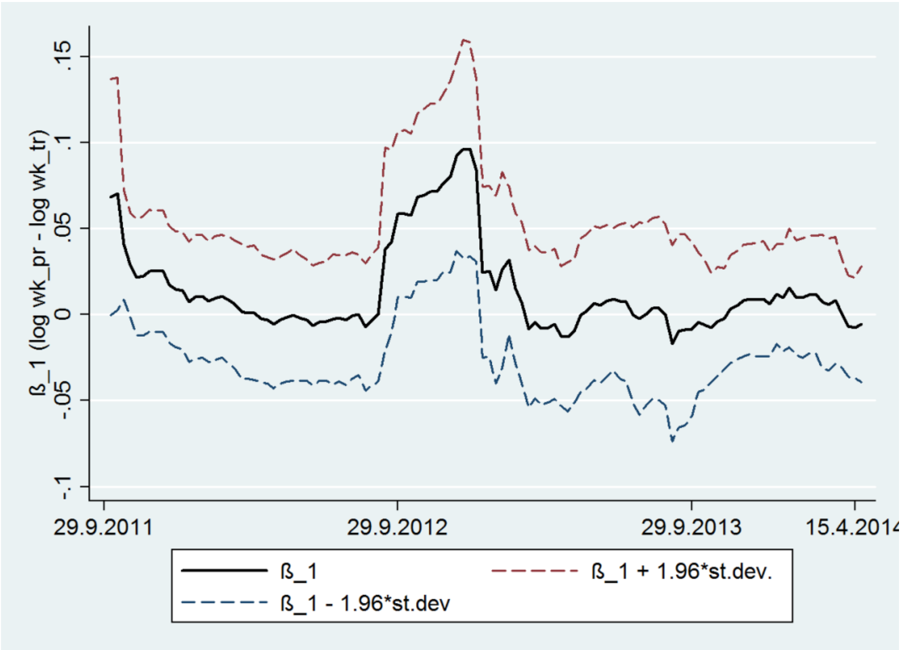
The R-squared is 0.47, which is lower than for Germany. However, this model still explains a significant portion of variability of dependent variable. Since the benchmark market for Hungary is Germany, a main explanatory variable for Hungarian year-ahead forward power price is its German counterpart. Expectedly, this fundamental interconnection is also reflected in empirical data by co-movement of forward prices. The estimated elasticity of Hungarian year-ahead forward price to German price is estimated to be around 73%.

However, the main focus lies on the variable describing the change of actual settlement of the week against its traded forward price. As assumed, this variable has already a great statistical as well as economic significance, whose standardized coefficient is more than three times higher than for Germany. Interestingly, its marginal effect is not diminishing with size of the difference between week's projected settlement and its traded price, since its squared term is not significant. This is in line with our theoretical explanation based on lower market transparency and data availability. Hence, market participants tend extrapolate current level of prices into forward prices with long time-to-maturity, which are far away to delivery.

3.4 Rolling Window Estimation

Estimation using rolling windows enables us to investigate the evolution of our above estimated parameters in time. Especially the effect of the shock on spot market is suspected to be time-varying. The significance of recent settlements is expected to be decreasing in time, since it indicates improving efficiency of the market. A time of window of 40 observations is used, which corresponds approximately to a 1-year period. Time index is set to be a window mid-point. Hence, the first window takes into account a sample from 25.4.2011 to 15.3.2012.

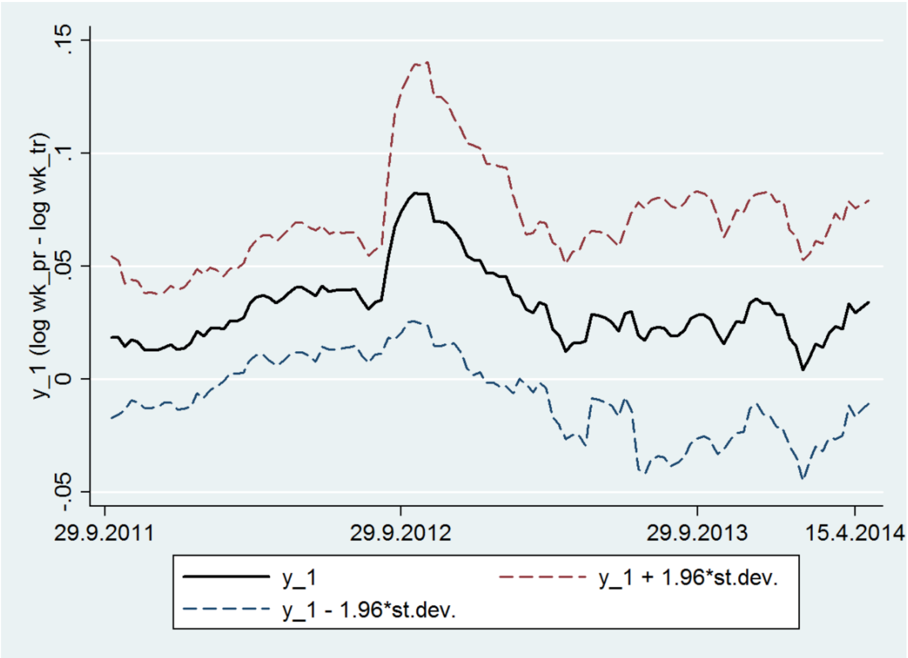
Figure 3-1: Estimation of β_1 parameter using rolling windows



Source: Author's own calculations

The residuals from regressions of models (7) and (8) were found to be normally distributed, so we can run a valid analysis even with only 40 observations. A $\beta_1$coefficient is first examined, which is a parameter from regression (7) explaining changes in front-year German power by difference between projected settlement of current week and its forward price. This estimate is proved to be rather instable, since it is significant only for a relatively short period of time. For the remainder of time windows, this parameter turns out to be close to zero as seen in Figure 3-1. On the other hand, other explanatory variables seem to be relatively stable over time as depicted in Appendix.

Figure 3-2: Estimation of γ_1 parameter using rolling windows

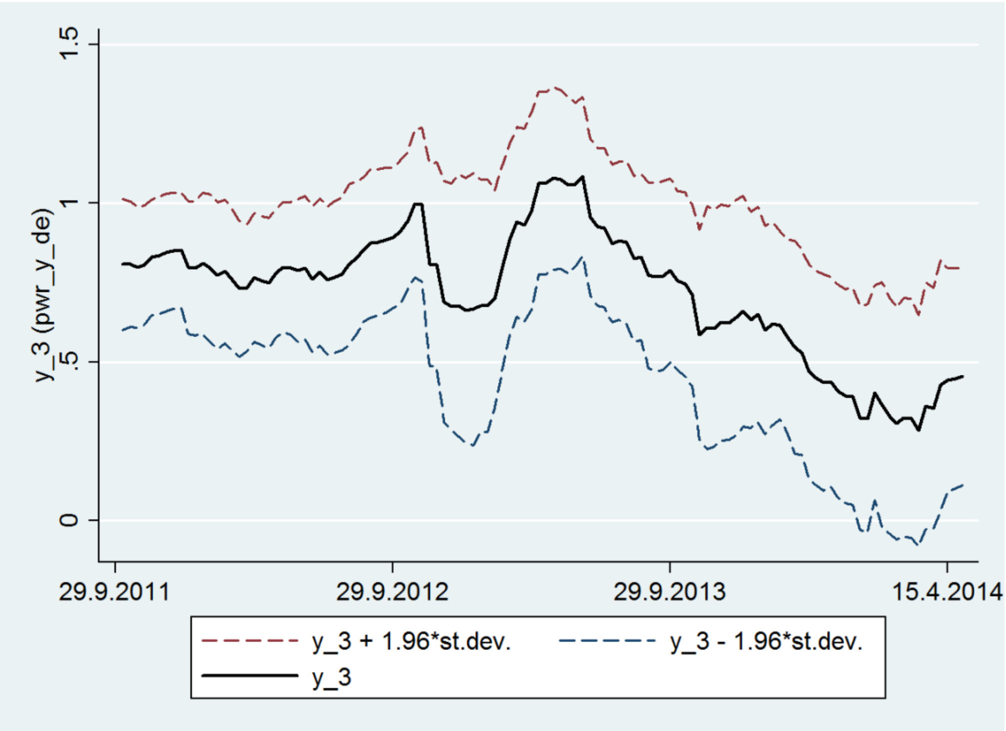


Source: Author's own calculations

Having examined time-variability of coefficient estimate for ($log\ wk_{de}^{pr} - logwk_{de}^{tr}$) variable, let us turn to its counterpart from the model (8) focused on Hungary, which explains front-year Hungarian power price. Observing Figure 3-2, a significance of weeks' premia is not confined to such a short sample period as for German power. However, the premium of Hungarian weeks seems to have effect especially before 2013. We thus identify a decreasing trend in variable's significance. This observation is in accordance with expectations, since it signals increasing efficiency of Hungarian power market.

A development of $\gamma_3$parameter, capturing the effect of change in German year-ahead price on its Hungarian counterpart, is also noteworthy. Interestingly, German year-ahead forward contract seems to have diminishing effect in time on Hungarian one as illustrated below. This approximately corresponds to a divergence in nominal values of these two contracts starting in mid-2013 (see Figure 2-11).As explained in introductory section, a high price spread between these two price zones, brought about by border congestion, makes price formation more independent in internal market. Such situation on spot market has been probably partially translated into forward market as well.

Figure 3-3: Estimation of γ_3 parameter using rolling windows



Source: Author's own calculations

3.5 CONCLUSION

In this section, we explained weekly changes of year-ahead forward power prices for both Germany and Hungary. As expected, they heavily depend on development of short-run marginal costs of power plants. Costs of inputs are a predominant portion of the operating costs of power plants. These are hard coal, natural gas and carbon emission allowances. Changes in corresponding forward price of these variables thus turn out to be highly significant. However, the aim was to test whether unexpected spot settlement shocks can affect year-ahead contract after accounting for changes in fuels and EUA. The spot settlements development is captured by a difference between projected settlement of current week and its closing price.

German power market seems not to react on these shocks much. The effect of spot settlement is small, statistically insignificant and diminishing with its size. As demonstrated by using rolling windows estimation, its non-zero coefficient is brought about only by a very significant short period at the end of 2012.

However, we obtained different results for Hungary. An unexpected settlement of the week has a significant impact on forward curve. Additionally, this impact seems to be linear with the size of the shock, not diminishing as for Germany. Changes in marginal costs of power plants are accounted for by inclusion of German front-year contract as a control variable.

These findings are in favour of rather efficient power market in Germany, since its price formation is probably not adaptive but based on fundamental expectations. This contradicts to conclusion of Böhm et al. (2008), but is in line with Haugom & Ullrich (2012). Such different results might be explained just by various sample used, since the market has been learning and becoming more efficient over time as shown by Haugom & Ullrich (2012). However, results for Hungary signals rather inefficient, adaptive price formation in this market, since changes in spot settlements affect front-year contract despite a theoretical irrelevancy between these products.

Such contradictory outcomes for Hungary and Germany are most probably connected to different stage of maturity in these markets. German market is relatively transparent, weather driven with sophisticated market players who are able to explain the settlement shocks. Hungarian market, on the other hand, apparently extrapolates current situation in spot market to forward products. The inefficiency consists in reaction of forward price on some unknown factor, which is most probably going to disappear soon.

4 INTRA-DAY EFFECT OF SPOT AUCTION ON MONTH-AHEAD POWER

In the previous chapter, we have found recent spot settlements to significantly affect the year-ahead contract in Hungary. As explained above, repeated higher/lower outcomes of spot auctions influence forward curve accordingly. However, the focus in this section is put on an immediate, intra-day effect of unexpected spot settlement on longer time-to-maturity forward contracts.

The shock on the spot market is now captured by a difference between an outcome of power spot auction published in the afternoon, and average of forward prices with day-ahead delivery. This day-ahead forward contract is traded only before the deadline of bid submission for spot auction. If the difference between result of day-ahead spot auction and its traded price is large, which means there is a significant spot surprise to power market, forward prices with longer time to delivery are suspected to react, especially as far as Hungarian market is concerned.

Front-month contract is selected to represent changes of forward curve, since it is a fairly liquid product with relatively shorter time to delivery than year-ahead product. This contract is thus included as a dependent variable. Product’s liquidity is needed since we compare averages of traded prices only for selected hours. A relatively short contract’s maturity ensures higher relevancy and sensitivity to our explanatory variable of interest.

A surprising spot settlement is thus assumed to affect front-month contract after accounting for changes in other drivers of power price, which are fuel costs and price of carbon emission allowances. Hence, the dependent variable as well as control variables are the differentials of average prices traded before and after publishing of day-ahead settlement prices, which is at 12:40 and 11:30 for Germany and Hungary, respectively. Similarly to previous section, spot settlement’s impact is expected to be more compelling for Hungary due to reasons explained therein. A much weaker though significant link is assumed to be found for German market as well.

4.1 MODEL

The model's dependent variable is a differential of month-ahead forward prices traded after and before the result of spot auction is known. The fuel costs are included as control variables. Intra-day changes of month-ahead forward prices of natural gas, hard coal as well as carbon emission allowances are supposed to be the most significant explanatory variables.

However, our variable of interest is the spot auction surprise – the differential between day-ahead auction price and its OTC traded average. Its squared term is added into equation (9) to account for non-linear response of our dependent variable to spot shocks.

$$\Delta log\; pwr\_m_{de,t} = \delta_0 + \delta_1 (\log\; spot_{de,t} - \log d_{de,t}) + \delta_2 (\log\; spot_{de,t} - \log d_{de,t})^2 +$$
$$+ \delta_3 \Delta log\; ttf_t^m + \delta_4 \Delta log\; eua_t^y + \delta_5\; \Delta log\; api_t^y +$$
$$+ \delta_6 \Delta log\; pwr\_m_{de,t-1} + \delta_7 \Delta log\;\; ttf_{t-1}^m + \delta_8 \Delta log\;\; eua_{t-1}^y +$$
$$+ \delta_9 \Delta log\;\; api_{t-1}^y + \varepsilon_{3_t} \qquad (9)$$

First lags of independent variables capture a certain sluggishness of response of front-month power to fuel changes. Variables are denoted as follows:

Table 8: Notation of variables

Variable	Description
$pwr_{m_{de}}$	front month German forward power price
$spot_{de,t}$	result of power spot auction at EEX
$d_{de,t}$	average of OTC day-ahead German power price
$pwr_{m_{hu}}$	front-month Hungarian forward power price
ttf_t^m	front-month natural gas forward contract - Title Transfer Facility
api_t^y	front-year hard coal price- All Publication Index 2
$spot_{hu,t}$	result of power spot auction at HUPEX
$d_{hu,t}$	average of OTC day-ahead Hungarian power price
eua_t^y	front-year emission allowances futures-EUA

Note that all data are intra-day changes as opposed to weekly deltas used for hypothesis 1.

Similarly to section 1, the main explanatory variable of intra-day changes of front-month Hungarian power is its German counterpart. Hence, we arrive at the following model for Hungarian power:

$$\Delta log\ pwr\_m_{hu,t} = \alpha_4 + \theta_1 (\log spot_{hu,t} - \log d_{hu,t}) + \theta_2 (\log spot_{hu,t} - \log d_{hu,t})^2 + + \theta_3 \Delta log\ pwr\_m_{de,t} + \theta_4 \Delta log\ pwr\_m_{hu,t-1} + \varepsilon_{4_t} \quad (10)$$

4.2 DATA DESCRIPTION

Front-month TTF is used to account for natural gas price, EUA futures with its closest delivery of December of current year for emission allowances. Due to lack of data, the API 2 contract of front-year delivery instead of front-month delivery had to be included to take into account the hard coal prices. However, the correlation between these products with different time to maturity is strong (0.73 in our dataset), so year-ahead coal price is a suitable proxy variable for month-ahead price of hard coal.

Since only hourly prices are available, we cannot use prices traded exactly after and before 12:40 or 11:30 for Hungary. The 12:00 a.m. and 11:00 a.m. are thus used as thresholds. More precisely, the time windows of 8:00-12:00am and 12:00am-5:00pm are used for Germany. For Hungary, we have 8:00-11:00am and 11:00am-5:00pm. Our sample period is from 21.7.2010 till 20.11.2014. Period's selection is solely based on data availability for Hungary. Data are daily excluding weekends.

Table 9: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
$\Delta log\ pwr\_m_{de,t}$	1062	0.0002	0.0055	-0.0287	0.0345
$\Delta log\ pwr\_m_{hu,t}$	577	0.0003	0.0083	-0.0250	0.0650
$(\log spot_{de,t} - \log d_{de,t})$	1123	-0.0026	0.0733	-0.4370	1.2700
$(\log spot_{hu,t} - \log d_{hu,t})$	1081	0.0132	0.1620	-1.1010	0.7090
$\Delta log\ eua_t^m$	1076	0.0003	0.0208	-0.3460	0.1320
$\Delta log\ ttf_t^m$	1093	0.0002	0.0061	-0.0420	0.0320
$\Delta log\ api_t^y$	820	0.0000	0.0041	-0.0206	0.0182

Observing summary statistics, month-ahead Hungarian power prices together with year-ahead hard coal prices pose a limitation to number of observations. Since we need to have all the variables present for a given date to arrive at a valid observation, the problem is further exacerbated. As seen in Table 11, only 346 observations are available for Hungary in comparison to 725 for Germany.

Interestingly, the mean is slightly positive for carbon emission allowances, gas price as well as month-ahead German and Hungarian power. This observation would indicate a profitable strategy of buying in the morning and selling in the afternoon. A possible explanation might be associated with a downtrend of these variables. Since these commodities open on average lower than last day, there is usually a tiny correction at the end of the day, which can cause a positive mean of the difference between average afternoon and morning prices. Coal prices did not exercise such clear trend in our sample period, which is in line with its zero mean.

A difference between spot and day-ahead price is in reality a day-ahead risk premium with opposite sign. Therefore, a positive value of our variable would mean a negative risk premium since our variables are defined as the difference between spot result and traded day-ahead prices. A comparison of German and Hungarian day-ahead risk premia provides us with a very unusual and interesting observation: German risk premium is relatively small and positive, which is in accordance with expectation. However, Hungarian risk premium is quite large and negative. Hence, buying day-ahead power and selling it at spot auction should bring a return of more than 1%.[12] Since Hungarian power market is more prone to sudden spikes, negative and sizeable risk premium is definitely not in line with financial theory, since market actors are supposed to earn a positive return for risking an outcome of day-ahead auction.

Expectedly, the standard deviation is enormous for our differentials between auction and day-ahead power price amounting to 7% for Germany and even 16% for Hungary. This illustrates a poor forecasting power for spot auction price even for Germany. There are still numerous factors which are either unknown[13] or whose effect cannot be properly estimated. A volatility of emission allowances is also noticeable, especially its highest intra-day drop by more than 34%.

[12]However, having brokerage, bid-offer spread and other costs included, all the profit would seize to exist and turn probably even to negative values.

[13] E.g. unplanned outages of significant generation units, power flows vis-à-vis non-coupled neighbour countries, what kind of forecast is used to estimate renewable production, etc.

4.3 RESULTS

Before the results of model described by equation (9) are presented, we check for heteroskedasticiy and autocorrelation in residuals. Breusch-Pagan/Cook-Weisberg test for heteroskedasticity could not reject null hypothesis of homoskedastic residuals. Autocorrelation has not been revealed by Breusch-Godfrey LM test either (see Appendix for further details).

As shown in Table 10, the R-squared is significantly lower compared to regression results for previous hypothesis. This is expected, since a bigger portion of intra-day price fluctuation is an unexplainable, random noise stemming from a large bid-offer spread, overreaction on newly released fundaments, lack of liquidity, etc.

Table 10: Regression results - intra-day impact, Germany

Number of obs =725
R-squared =0.2177
Adj R-squared =0.2111

$\Delta log\ pwr\_m_{de,t}$	**Coefficient**	**Std. error**	**t-statistic**	**p-value**	**Std.coeff.**
$(\log\ spot_{de,t} - \log d_{de,t})$	0.001	0.003	0.400	0.692	0.016
$(\log\ spot_{de,t} - \log d_{de,t})^2$	-0.003	0.003	-1.000	0.318	-0.039
$\Delta log\ ttf_t^m$	0.230	0.038	6.070	0.000	0.226
$\Delta log\ eua_t^m$	0.059	0.008	7.110	0.000	0.248
$\Delta log\ api_t^y$	0.311	0.053	5.920	0.000	0.221
$\Delta log\ pwr\_m_{de,t-1}$	0.012	0.011	1.110	0.267	0.038
$\Delta log\ ttf_{t-1}^m$	0.075	0.037	2.050	0.041	0.076
$\Delta log\ eua_{t-1}^m$	-0.005	0.008	-0.540	0.592	-0.019
$\Delta log\ api_{t-1}^y$	-0.055	0.050	-1.100	0.273	-0.041
constant	0.000	0.000	-0.120	0.904	

Variables capturing the changes in fuel prices turn out to be highly significant. These coefficients are very close to estimates for weekly change in previous hypothesis described in Table 6. However, the variable of interest being the difference between spot auction price and day-ahead forward price is not significant. It seems that the German market does not price the outcome of spot auction into forward prices at all. Such result would again indicate relative efficiency of German market. Let us investigate outcomes of regression for Hungarian power, which are described in Table 11 below.

Table 11: Regression results - intra-day impact, Hungary

Number of obs =346
R-squared =0.2391
Adj R-squared =0.2301

$\Delta logpwr\_m_{hu,t}$	**Coeff.**	**Std. error**	**t-statistic**	**p-value**	**Std.coeff.**
$(\log\ spot_{hu,t} - \log d_{hu,t})$	0.0125	0.0026	4.7900	0.000	0.234
$(\log\ spot_{hu,t} - \log d_{hu,t})^2$	0.0162	0.0080	2.0200	0.044	0.098
$\Delta log\ pwr\_m_{de,t}$	0.5043	0.0629	8.0200	0.000	0.380
$\Delta log\ pwr\_m_{hu,t-1}$	0.0783	0.0402	1.9500	0.052	0.094
constant	0.000	0.000	0.000	0.998	

The spot auction surprise is now highly significant with coefficient more than ten times higher than for Germany. Additionally, its squared term has positive sign and is significant as well. An effect of an extreme spot auction outcome is thus magnified.

The size of the coefficient might seem to be negligible. However, the standardized coefficient is very high. Its significance is comparable to variable capturing changes of German month-ahead forward price. Such difference between standard and standardized coefficients is brought about by a marked difference in volatility of the $(\log\ spot_{hu,t} - \log d_{hu,t})$ variable than the dependent variable (see Table 9). Hence, the spot auction is highly significant both in statistic and economic terms. Furthermore, accounting for the coefficient of its squared term, we arrive at even higher significance.

Interestingly, a coefficient of first lag of the dependent variable is positive and quite significant. The size of the coefficient is seven times higher than for Germany. In our model, this result can be interpreted as follows: Since we account for changes in German price and spot auction, a significance of first lag of Hungarian front month price means that it pays off to follow a trend in Hungarian-German spread on front-month contract after controlling for any surprises on the spot market.

4.4 CONCLUSION

This chapter focused on intra-day changes of power contract with month-ahead delivery as well as comparison of Hungarian and German market. The aim was to show to what extent an unexpected result of power spot auction influences front-month forward contract. We regressed changes between afternoon and morning prices of month-ahead power on change between final spot auction price and OTC traded day-ahead price. Similarly to previous section, fuels prices were used as control variables.

Having inspected our data, Hungarian day-ahead risk premium turned out to be negative, which is a finding not only non-intuitive but also in contradiction with financial theory. This was not the case for Germany, since its risk premium is slightly positive, as expected. A sizeable variance between traded day-ahead price and final auction price indicates poor forecasting ability of the market, which is heavily pronounced for Hungarian power market.

Regression results confirmed a strong dependence of front-month German power price on conventional power plants' costs, which are mainly fuels and carbon emission allowances. This is similar to previous hypotheses. However, we were not able to explain such large portion of dependent's variable variation as in previous chapter. A change of German month-ahead price is a control variable in model for Hungary.

The variable of interest, which is the day-ahead risk premium, appeared to be insignificant in Germany, but strongly significant for Hungary. Hungarian forward market is thus found to react heavily on a spot auction, in contrast to Germany. Additionally, the effect of spot surprise on forward is exponential in Hungary and rather diminishing in Germany. Therefore, it seems that the market actors strongly react on outcome of spot auction and translate current settlements into forward prices heavily. Both hypotheses thus indicate that a price formation of Hungarian forwards is rather backward-looking and based on adaptive expectations. Hence, the results signal relatively strong inefficiencies in the Hungarian power market.

5 UFRH AND EX-POST PREDICTION ERROR DRIVERS

A common and popular way how to inspect market efficiency is to check if the forward price is an unbiased predictor of future spot price. We simply test if there is any systematic bias in market prediction of spot price. The test is carried out on week-ahead forward prices. Afterwards, we examine what might be the cause of potential inaccuracy of market prediction of future spot price on week-ahead contract. The goal is not to come up with spot price forecast which would be better than prediction of the market, but to find out what relevant factors are either unknown to market participants at the time of forward price formation or what factors is the market not able to price in its forecast. We thus work with ex-post data which were not available to market participants at the time when forward price was created.

5.1 TESTING THE UNBIASED FORWARD RATE HYPOTHESIS

The model is very simple, we just regress the settlement of the week on its closing price both for Germany and Hungary.

$$wk_{de,t}^{set} = \lambda_0 + \lambda_1 wk_{de,t}^{tr} + \varepsilon_{5,t} \quad (11)$$

$$wk_{hu,t}^{set} = \eta_0 + \eta_1 wk_{hu,t}^{tr} + \varepsilon_{6,t} \quad (12)$$

For Germany, the settlements of the weeks are averages of spot auction results for corresponding periods. The average of spot results published by HUPEX is used for calculation of Hungarian settlement of the week. The average price traded at Trayport platform on Friday from 1pm till 4pm is used as a closing price for front-week.

Table 12: Notation of variables

Variable	Description
wk_{de}^{set}	Week's final settlement price
wk_{de}^{tr}	Week's closing price

Data are logarithmized due to high volatility of both variables. Table 13 below provides us with a summary statistics. It might seem that volatility of both settlements and closing prices of weeks do not differ significantly across these two countries. However, let us focus on the difference between volatility of weeks' settlement and volatility of weeks' closing prices in each country.

Table 13: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
$log\ wk_{de}^{set}$	213	3.719	0.2186	3.058	4.134
$log\ wk_{de}^{tr}$	213	3.730	0.236	2.618	4.161
$log\ wk_{hu}^{set}$	215	3.846	0.239	3.063	5.288
$log\ wk_{hu}^{tr}$	215	3.854	0.201	3.280	4.365

Given the nature of power markets, it is expected that the settlement volatility would be higher than volatility on the forward market, since there is a number of factors influencing the settlement price which are unknown to the market prior to delivery of this product. These factors may be the following: Unplanned generation outages, unplanned transmission lines outages, a significant change in weather forecast related to wind speed, temperature, cloudiness or precipitation, etc. Alternatively, the weather forecast is not fully priced-in, because it may change before delivery of the product. That is why we assume much higher volatility of weeks in settlement. However, this is only the case for Hungary. As seen in Table 13, standard deviation of week settlement is on average lower than for closing price in Germany while the opposite holds for Hungary.

Since German market is heavily weather-driven, an explanation for such a difference might be a slight overreaction of traders active in the German market on weather forecast for a front-week. Alternatively, the change in conventional generation based on renewable production forecast (see Figure 2-6) is imperfectly assumed or even not taken into account at all. On the other hand, price of Hungarian front-week tends to be stickier due to more stable generation mix and less information available for price formation.

Another interesting observation is the comparison of German and Hungarian risk premium on the front week contract. Unexpectedly, an average of Hungarian risk premium (defined as $\frac{log\ wk_{hu}^{tr} - log\ wk_{hu}^{set}}{log\ wk_{hu}^{tr}}$) is lower than a risk premium for Germany. Although the difference is not large, since Hungarian risk premium turns out to be 0.21% and 0.3% for Germany.

All data are stationary, based on both Augmented Dickey-Fuller and Phillips-Perron unit-root test. We can thus employ classic OLS. Regressing the model (11) above, we arrive at the following results:

Table 14: UFRH regression results, Germany

Number of obs =213
F(1,211)=222.75
Prob>F=0.000

$log\ wk_{de}^{set}$	**Coefficient**	**New.-West st.error**	**t-statistic**	**p-value**	**[95%**	**Conf. Int.]**
$log\ wk_{de}^{tr}$	0.841	0.056	14.920	0.000	0.730	0.952
_cons	0.583	0.213	2.740	0.007	0.163	1.001

After checking the residuals and running Breusch-Pagan/Cook-Weisberg test for heteroskedasticity as well Breusch-Godfrey autocorrelation test, the null hypothesis of no heteroskedasticity and no autocorrelation had to be rejected. To correct for violation of OLS classic assumptions so that our statistical inference is valid, the model is estimated using Newey-West standard errors, which are robust to both heteroskedasticity and autocorrelation.

The results are presented in Table 14. The slope coefficient is significantly below 1, which indicates that a week-ahead forward price is a biased predictor of its future spot settlement. The constant is also significantly positive, which signals positive risk premium. This finding is in line with our comments on summary statistics in Table 13, because we have noticed a significant risk premium therein already.

Table 15: UFRH regression results, Hungary

Number of obs =215
F(1,211)=249.85
Prob>F=0.000

$log\ wk_{hu}^{set}$	**Coefficient**	**New.-West st.error**	**t-statistic**	**p-value**	**[95%**	**Conf. Int.]**
$log\ wk_{hu}^{tr}$	0.901	0.057	15.81	0.000	0.789	1.013
_cons	0.372	0.225	1.66	0.099	-0.071	0.814

Moving to testing UFRH for Hungary, we have also encountered difficulties with heteroskedasticity and autocorrelation when estimating the model (12). Hence, the errors are corrected by Newey-West transformation as well.

The slope coefficient for $log\,wk_{hu}^{tr}$ turns out to be 0.901, however, it is not significantly different from 1.000 on a 95% confidence level. Furthermore, the constant term is not significantly different from zero either. These findings point out to close-to-zero risk premium on front-week contract in Hungary. This was already mentioned in section on data discussion, where Hungarian risk premium appeared to be lower than German one. Such outcome is striking, since financial theory would dictate the opposite result. One would expect bigger risk premium due to higher upward spike potential for Hungarian power, as illustrated with Figure 2-10. However, we have seen this surprising feature already when discussing risk premium on day-ahead contract in section 4.2.

5.2 EX-POST DRIVERS OF PREDICTION ERROR

Having tested whether week-ahead forward price is an unbiased predictor of future spot price, let us reveal possible reasons for market's imprecise pricing. Our dependent variable is an ex-post premium on week-ahead forward price, which is the difference between the forward closing price and the final settlement of the week. We can view this variable also as a market's prediction error. The most important factors influencing the settlement price are included as explanatory variables. These independent variables are in a log-differenced form, so we explain the prediction error by changes in the main drivers of short term power price.

As discussed in section 2.1, wind as well as solar power generation is nowadays a decisive factor for German spot prices. Real generation from wind farms and solar panels is thus present in our model described by equation (13). Since these variables put downward pressure on power spot price and our dependent variable is defined as $(log\,wk_{de}^{tr} - log\,wk_{de}^{set})$, their slope coefficients are expected to be positive, as both solar and wind is supposed to decrease the $log\,wk_{de}^{set}$ variable. Consumption is the most important driver of spot price from the demand side. The regression output is assumed to yield negative slope coefficients since higher consumption leads to higher spot prices, which decreases the premium. The total export/import balance of Germany has to be taken into account as well. This variable is defined as the sum of total export-imports, so its coefficient is expected to have negative sign, as higher exports out of Germany put upward pressure on power price which in turn diminishes risk premium. Variables have been log-differenced and denoted as below:

Table 16: Notation of variables

Variable	Description
$wind_{de}$	Week-average wind power production
$solar_{de}$	Week-average solar power production
$cons_{de}$	Week-average power consumption
$flow_{de}$	Week-average commercial power flow out of Germany
nuc_{de}	Week-average nuclear generation
lig_{de}	Week-average lignite generation
$coal_{de}$	Week-average coal generation

Note: Notation above is used for Hungary as well, only with hu in lower index.

Any changes in conventional generation need to be accounted for as well. The day-ahead availability forecasts of significant nuclear, lignite as well as coal power generation units are included as explanatory variables. The slope coefficients are expected to be positive, since higher generation obviously decreases spot price. A lag of week-ahead premium is considered as well, to account for autocorrelation in risk premia. The model for Germany is thus constructed as follows:

$$\begin{aligned} log\, pr_{de} \;=\; & \mu_0 + \mu_1 \Delta log\, wind_{de} + \mu_2 \Delta log\, solar_{de} + \mu_3 \Delta log\, cons_{de} \\ & + \mu_4 \Delta log\, flow_{de} + \mu_5 \Delta log\, nuc_{de} + \mu_8 \Delta log\, lig_{de} + \\ & + \mu_9 \Delta log\, coal_{de} + \mu_{10} log\, pr_{de,t-1} + \varepsilon_{7_t} \end{aligned} \tag{13}$$

Similar model to the above (13) used for Germany is assumed for Hungary as well. Only variables accounting for coal and solar power generation are omitted due to irrelevancy for Hungarian power. Solar as well as coal power generation is simply negligible relatively to the whole production mix (see Figure 2-3, Figure 2-6). We thus arrive at the following model for Hungary:

$$\begin{aligned} log\, pr_{hu} \;=\; & \varphi_0 + \varphi_1 \Delta log\, wind_{hu} + \varphi_2 \Delta log\, cons_{hu} + \varphi_3 \Delta log\, nuc_{hu} + \\ & + \varphi_4 \Delta log\, lig_{hu} + \varphi_5 \Delta log\, flow_{hu} + +\varphi_6 log\, pr_{hu,t-1} + \varepsilon_{8,t} \end{aligned} \tag{14}$$

The sign of coefficients is expected to be the same as for Germany. However, we might end up with insignificant coefficient or even opposite sign for flow variable (φ_5) than for its German counterpart. This variable denotes the export power balance out of Hungary. A difference sign of the coefficient is attributable to German position as a power hub in Europe with most liquid, deep as well as wide forward prices in Continental Europe.

Usually, neighbour countries adjust its demand or supply vis-à-vis Germany according to price traded on the forward market. If there is ample renewable generation, which dampens German power price, Germany becomes a strong power exporter, supplying neighbour countries. Hence, there is a negative correlation between price and flows, even though higher exports result in increase of domestic power price ceteris paribus. However, we account for the main price drivers in model (13), which is solar and wind power production, so the coefficient's sign for German flows should be in line with causality, not correlation.

Unfortunately, we need to apply slightly different reasoning for Hungarian power flows. The causality works often the other way around. This means that forward price reacts on future changes in power flows. Since Balkan and some Eastern European countries do not have any functioning national power markets, generation as well as sales companies hedge their production and demand in Hungary and buy cross-border capacity rights. Due to poor deepness and liquidity of Hungarian power market, such hedging activity is translated into forward prices. That is why the flow variable might turn out to be insignificant, because the changes in power flows vis-à-vis other countries are probably priced into forward price already. Since our dependent variable is the difference between traded price and settlement price, the export balance should not be as significant for Hungary as for Germany.

5.2.1 DATA DESCRIPTION

Data for Germany

A real wind as well as solar power generation provided by EEX transparency is used to account for generation from renewable sources. Unfortunately, a real German consumption was not available. Instead, a day-ahead consumption forecast provided by PointCarbon Continental Europe is taken into account. Due to short time series available for real generation from conventional sources provided by EEX transparency data, the EEX power plants' availability data are used instead. This should not pose any difficulty for nuclear power generation, since its variable costs are very low and availability of power plants thus almost corresponds to real generation. However, especially during summer months, this might not be the case for coal and to a lesser extent for lignite power plants. Since hard coal power plants' variable costs can be above current spot prices, the change in their availability does not have to bear an impact on spot prices, because this power plant is out-of-money anyway. This crowding-out of coal and partly lignite power plants is depicted in Figure 2-5 as well as Figure 2-6. The sample period is from 9.8.2010 till 23.11.2014.

Data for Hungary

Forward Hungarian prices on weeks come from the same source as for Germany. As written above, daily spot settlements are retrieved from HUPEX. However, data on power generation and consumption are somewhat different from what is used for Germany. Firstly, we include a real Hungarian consumption provided by transmission system operator (MAVIR). Secondly, due to lack of database providing historic data on significant generation units' availability, a real generation instead of generation availability of conventional power plants is taken into account. Data on real generation of lignite, nuclear as well as wind power plants are collected from Genscape. However, such data are available only starting 1.1.2013, which limits our sample for Hungary, which is thus covering only the period from 1.1.2013 till 23.11.2014.

Table 17: Summary statistics

Variable	Mean	Std. Dev.	Min	Max
$\Delta log\ wind_{de}$	0.0054	0.6218	-1.4356	2.0103
$\Delta log\ solar_{de}$	0.0041	0.3275	-0.9712	1.0949
$\Delta log\ cons_{de}$	0.0004	0.0531	-0.3106	0.2085
$\Delta log\ flow_{de}$	0.0059	0.2913	-1.0284	1.4836
$\Delta log\ nuc_{de}$	-0.0019	0.0797	-0.2839	0.3722
$\Delta log\ lig_{de}$	0.0007	0.0494	-0.1930	0.1791
$\Delta log\ coal_{de}$	0.0007	0.0619	-0.1818	0.1652
$\Delta log\ flow_{hu}$	-0.0018	0.1294	-0.7598	0.5108
$\Delta log\ cons_{hu}$	0.0002	0.0414	-0.1954	0.1364
$\Delta log\ nuc_{hu}$	0.0002	0.1037	-0.3872	0.3646
$\Delta log\ lig_{hu}$	0.0032	0.2048	-0.7558	0.5434
$\Delta log\ wind_{hu}$	0.0056	0.5867	-1.3661	1.6438

Table 17 above provides us with a summary statistics of variables used for the following two regression models. Note that data is log-differenced, so they roughly express weekly deltas in percentage points. The volatility of renewable generation is striking. Standard deviation of especially wind power generation is enormous, amounting to around 62% with very strong extremes. This reflects sudden changes in weather patterns in Europe affecting wind speed.

Positive mean both for solar and wind power generation mirrors their increasing installed capacity in Germany. Note lower volatility of solar generation. On the other hand, a demand side represented by consumption in our model is much more stable with standard deviation of only 5%. This nicely illustrates the drivers of such strong price volatility, which is highly variable power supply coming from renewable sources. A flow variable describes a total export power balance out of Germany.[14] It is adjusted in a way it takes positive values only so that it can be logarithmized. The export/import balance is also very volatile as it is highly correlated with renewable production.

Gas power plants' availability is excluded from the model, since it is only rarely in-the-money. Hence, any changes in availability do not affect the spot power price, since these power plants are usually not running anyway. Since data are log-differenced, we should not encounter any problems with unit-root in the data, which confirm both Augmented Dickey-Fuller and Phillips-Perron tests both for German and Hungarian variables.

5.2.2 RESULTS

Results of model (13) are shown in Table 18. Heteroskedasticity was detected in residuals, so robust standard errors are used. Assumption of no autocorrelation in residuals has not been violated based on both Breusch-Godfrey and Durbin-Watson alternative test and is robust to different lags chosen (see Appendix for details). RESET test has not found any violation in model specification.

Observing our results, the coefficients of variables capturing output from renewable sources, which are $\Delta log\, wind_{de}$ and $\Delta log\, solar_{de}$, have signs as expected. Wind output is characterised by a very strong statistical as well as economic significance with high standardized coefficient, which is not entirely the case for solar power production. This might be attributable to a more unpredictable nature of wind power production than for solar output, which would cause the solar power output to be priced into week-ahead price already.

[14]So positive sign means that Germany is net electricity exporter

Table 18: Regression results for DE

Number of obs =212
R-squared=0.3135
Prob> F = 0.000

$log\ pr_{de}$	**Coefficient**	**Robust St.Er.**	**t**	**p-value**	**Std.coeff.**
$\Delta log\ wind_{de}$	0.078	0.012	6.29	0.000	0.486
$\Delta log\ solar_{de}$	0.046	0.019	2.48	0.014	0.153
$\Delta log\ cons_{de}$	0.757	0257	2.95	0.004	0.405
$\Delta log\ flow_{de}$	-0.067	0.024	-2.83	0.005	-0.196
$\Delta log\ nuc_{de}$	0.157	0.066	2.39	0.018	0.126
$\Delta log\ lig_{de}$	0.216	0.101	2.15	0.033	0.108
$\Delta log\ coal_{de}$	-0.105	0.152	-0.69	0.489	-0.066
$log\ pr_{de,t-1}$	0.228	0.046	4.93	0.000	0.228
cons	0.007	0.005	1.27	0.205	

Source: Own estimation

However, coefficient for consumption delta is in contradiction to our expectations, since the regression outcome yield significantly positive value of the consumption coefficient. Obviously, higher consumption should increase the settlement price and decrease in turn the risk premium. On the other hand, the overall consumption is well correlated with temperature, whose forecast is quite reliable for week-ahead contract. Especially for winter months, a drop in temperature forecast for front-week is well translated into forward power prices. These forward prices grow, since the probability for spike in settlement rises heavily with higher consumption. For such situation, the risk premium should be sizeable, which is confirmed by numerous research papers, e.g. Bessembinder & Lemmon (2002), Botterud et al.(2010), Lucia & Torró (2011) or Pirrong & Jemakyan (2008) find that risk premium is highly seasonal and large over times with strong demand. The forward price thus slightly overreacts on soaring demand and turns out to be on average higher than spot price. This most probably explains a counterintuitive sign of consumption coefficient we obtained.

Variables denoting availabilities of nuclear as well as lignite power plants have coefficient signs as expected and are significant on a 10% level of confidence. Nuclear availability is usually well-known at the time when week-ahead forward price has been formed, only unplanned outages are assumed to cause this variable to be significant. On the other hand, lignite power plants availability was expected to yield more compelling result as these generation sources are much more flexible and are able to react on day-ahead prices. Their output can thus vary markedly according to its margin on day-ahead basis in the week's settlement which is mostly not foreseen before the delivery of the week-ahead contract.

Changes in availability of German coal power plants turn out to be insignificant. As outlined in section 5.2, the power prices might be below variable costs of coal generation for some period of time, especially over summer months, so the availability of coal power plants should not have any effect. Furthermore, the variation of coal power plants' availability is very low during winter, since most of the planned outages are scheduled for summer. This might contribute to overall insignificance of the variable in the model.

Interestingly, a first lag of the dependent variable is strongly significant with positive coefficient. This finding would dictate to follow a trend of spot prices. It should thus be a profitable strategy to buy/sell the week-ahead contract and sell/buy power on daily basis in spot auction if current week is settling higher/lower than its closing price from last Friday. However, omitting other explanatory variables and just regressing the dependent variable on its first lag does not yield a significant slope coefficient anymore. Hence, we would have to know all the explanatory variables used in model (13), which is the future wind, solar power generation, together with changes in flows, consumption as well as availability of conventional power plants, to be able to exploit such autocorrelation.

Having described and analyzed estimation outcomes for Germany, let us move to the model for Hungary. Table 19 shows the results of model (14) estimation using OLS with heteroskedasticity-robust standard errors. Both Breusch-Godfrey and Durbin's alternative test did not reject the null hypothesis of no serial correlation (see Appendix). RESET test has not found any flaws in model specification either.

Results are not as compelling as for Germany. R-squared is much lower than was the case for Germany. As mentioned in previous section on data description, we suffer from smaller sample size of only 90 observations. Nevertheless, changes in wind power generation seem to help explain a difference between week-ahead forward and spot price. Consumption coefficient's sign is now more intuitive, since it is negative, as opposed to significant positive value for Germany. Since we have found lower premium in Hungary than for Germany in previous section, negative Hungarian consumption slope coefficient is in line with our explanation above that German risk premium rises significantly during high demand periods which is probably not the case for Hungary.

Table 19: Regression results for HU

Number of obs =90
R-squared = 0.1748
Prob> F = 0.0007

$log\ pr_{hu}$	**Coefficient**	**Robust St.Er.**	**t**	**p-value**	**Std.coeff.**
$\Delta log\ wind_{hu}$	0.037	0.019	1.90	0.061	0.225
$\Delta log\ cons_{hu}$	-0.380	0.377	-1.01	0.368	-0.134
$\Delta log\ nuc_{hu}$	-0.050	0.050	-1.00	0.321	-0.340
$\Delta log\ lig_{hu}$	0.061	0.061	1.02	0.313	0.358
$\Delta log\ flow_{hu}$	-0.002	0.068	-0.03	0.980	-0.003
$log\ pr_{hu,t-1}$	0.394	0.102	3.87	0.000	0.402
$cons$	0.007	0.012	0.55	0.582	

Source: Own estimation

First lag of our dependent variable is strongly significant as well, even more than its German counterpart. Even if we omit other explanatory variables and use the whole sample for estimation, we arrive at slightly significant first lag of week-ahead premium, which is described in Table 20 below. Neither heteroskedasticity nor autocorrelation was found in residuals. Such finding is in accordance with our hypothesis of sticky week-ahead contract which was discussed in section 3.2. It thus seems that front-week in Hungary lags slightly behind development of recent spot settlements. There should thus be some money gained if we buy/sell front week based on higher/lower settlements than closing price of current week and bring it to delivery. However, the coefficient is not greatly significant and R-squared is only 2%, which are not compelling numbers.

Table 20: Autocorrelation of premium on week-ahead forwards, Hungary

Number of obs =213
R-squared = 0.0206
Prob> F = 0.0361

$log\ pr_{hu}$	**Coefficient**	**Robust St.Er.**	**t**	**p-value**	**Beta**
$log\ pr_{hu,t-1}$	0.104	0.0494	2.11	0.036	0.144
$cons$	0.015	0.0078	1.86	0.064	

5.3 CONCLUSION

The risk premium on week-ahead contracts both in Germany and Hungary was examined in this chapter. The unbiased forward rate hypothesis in its simplest form was tested in section 5.1, where a sizeable risk premium in Germany was found. Surprisingly, this was not the case for Hungarian power, since we could not reject a hypothesis of unbiased week-ahead forward price. The risk premium was significantly lower than for Germany, which is an interesting observation, since the probability for upward price spike in settlement is higher for Hungarian power due to different generation mix as described in section 2.1.

The aim in next part was to identify potential sources of market players' inaccuracy of week-ahead contract pricing. Additional explanatory variable were thus included into the UFRH equation. Note that such data is not available to market participants at time when a forward price is formed. For Germany, generation from renewable sources, especially wind, has been pinpointed to affect the final prediction error heavily. Additionally, flow vis-á-vis other neighbour countries as well as day-ahead availabilities of lignite and nuclear power plants play a role, too. Our model yield counterintuitive coefficient for consumption, but this is most likely connected to sizeable risk premium during high demand periods.

However, cautiousness is advocated when drawing a clear conclusion out of the results presented above, since absolute deltas in explanatory variables instead of forecast changes are used. Based on the analysis above, we can thus arrive at the following conclusions: Firstly, variables which have been found significant are unpredictable and vary markedly even after closing price is formed when we get to delivery. Secondly, market is not able to price-in known fundaments. Thirdly, both can be true. If Friday's forecasts of explanatory variables in equations (13) and (14) were collected, we would be able to rule out some possibilities. Nevertheless, given general unpredictability of output from renewable generation and their highest significance in the model (13), I would prefer the first option that the known fundaments are priced-in correctly, but as we go to the delivery of the product, these fundaments change, especially weather forecast, which further influences both flows and generation availability.

CONCLUSION

This thesis investigated an effect of unexpected moves in power spot prices on forwards and discusses potential differences between results estimated for German and Hungarian power market. The efficiency of the market is connected with this issue as well. Hence, I also tested the unbiased forward rate hypothesis of week-ahead time-to-maturity forward contract. Additionally, the realized market's prediction error for this product is subsequently explained by main drivers of spot electricity price.

A substantial emphasis was put in this thesis on construction of variables which capture a certain shock to the market, as opposed to shock in absolute level of some variable which is often used in literature. A large portion of sizeable deviations is known to the market and poses no surprise. However, this might not be the case for a researcher examining data ex-post. This is a reason why the explanatory variables of the main interest were differenced against the market price instead of levels or data differenced against its past values.

For the first hypothesis, the impact of a risk premium of current week on weekly changes of year-ahead forward contract is tested. Instead of using ex-post risk premium, which is usual practice in research papers, I constructed a projected settlement price of current week based on Friday closing prices. The explanatory variable of interest is thus the difference between week-ahead forward closing price and the projected settlement of current week. By construction of this modified risk premium, only such information is taken into account which was available to market participant at the time when forward prices were formed. Since forward prices traded on Friday are included in the model as explained and explanatory variables, the final settlement price of the week would not be known yet. The weekly changes in drivers of marginal costs of power plants are included as control variables. These variables are prices of hard coal, natural gas and carbon emission allowances. The German year-ahead contract is used as a control variable for Hungarian year-ahead.

German front-year contract does not seem to react on shocks of spot settlements in current week. If there is any effect, it would be rather diminishing with the size of shock. The changes in prices of fuels and EUA turn out to be highly significant, as expected. On the other hand, Hungarian front-year forward has proved to be significantly driven by deviation of current week's settlement from its traded price. Additionally, the impact of the unexpected settlement is linear, as opposed to findings for Germany. Expectedly, German year-ahead forward has found to have a large explanatory power, too.

The second hypothesis is similar to previous one; however, it examines intra-day impact of spot auction surprise on front-month forward contract. The spot auction surprise is defined as a difference between OTC traded day-ahead contract and the result of spot auction. The dependent variable is a change of front-month price after and before the result of spot auction is published. As for the first hypothesis, I control for any intra-day changes in fuels and EUA in Germany. For Hungary, the German front-month contract serves as a control variable. Results have confirmed the evidence from the first hypothesis, since Hungarian spot surprise variable turned out to be strongly significant, which is not the case for Germany. Furthermore, this variable appears to have an exponential effect in Hungary.

However, during data description both for first and second hypothesis, the modified premium on week-ahead contracts was found to be much lower in Hungary than in Germany. Even negative premium was revealed on day-ahead contract in Hungary. Such observation is remarkable, especially if we take into account different structure and production mix of Hungarian power market. This market is in general more prone to sudden upward spike than German one, so the compensation for taking delivery risk is supposed to be significantly higher. I also tested the unbiased forward rate hypothesis for week-ahead contracts. The results indicate smaller ex-post risk premium in Hungary as well. The hypothesis of no premium could not be even rejected. However, a significant risk premium was detected in Germany.

Additionally, possible reasons for prediction error of the market on the week-ahead forward were presented and estimated. The ex-post risk premium was explained by main drivers of short-term power price as discussed in section 2.1. The weekly changes of production from renewables, day-ahead reported availabilities of significant generation units, consumption and power flows were thus included as explanatory variables. A wind and to a lesser extent solar power generation appeared to play a crucial role for risk premium explanation. German power flow with nuclear and lignite availabilities were significant, too. However, a counterintuitive coefficient sign for consumption was obtained. Such result is most probably attributed to large risk premium for periods with strong demand, as stated by Bessembinder & Lemmon (2002), Botterud et al.(2010), Lucia & Torró (2011) or Pirrong & Jemakyan (2008). Except for wind power generation, results for Hungary were rather inconclusive due to limited dataset available. However, we cannot draw a clear conclusion based on the findings from this model, since absolute deltas in explanatory variables instead of forecast changes are used. We can thus arrive at the following conclusions: Firstly, variables which have been found significant are unpredictable and vary markedly even after closing price is formed. Secondly, market is not able to price-in known fundaments. Thirdly, both statements are true. The analysis including prediction of fundaments from Friday might be a subject of next research.

In general, the findings in this thesis indicate that Hungarian forwards with longer time-to-maturity react on unexpected fluctuations of spot prices. Such evidence has not been found for German power market. These results thus point out to price formation based on adaptive expectations in Hungary. A development of short time-to-maturity contracts is heavily extrapolated to contracts with longer time-to-delivery. Hence, a better-than-market estimation of future Hungarian spot prices for day-ahead and week-ahead delivery are useful for trading front-month and front-year German-Hungarian spread, respectively.

Such outcomes of the analyses above are in line with limited transparency and data availability needed to build fundamental forecasting models for Hungarian forward price with longer time-to-delivery, which would eliminate this dependency on spot prices. Since spot and forward power prices are in theory independent, this impact of spot price on forward signal inefficiency of Hungarian power market, as opposed to German market. However, the surprising findings on Hungarian risk premia both for week-ahead and day-ahead delivery, which turned out to be close to zero or even negative are in contradiction to the conclusion above and deserve further research.

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APPENDIX

3.3

Germany

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
chi2(1) = 0.75
Prob>chi2 = 0.3868

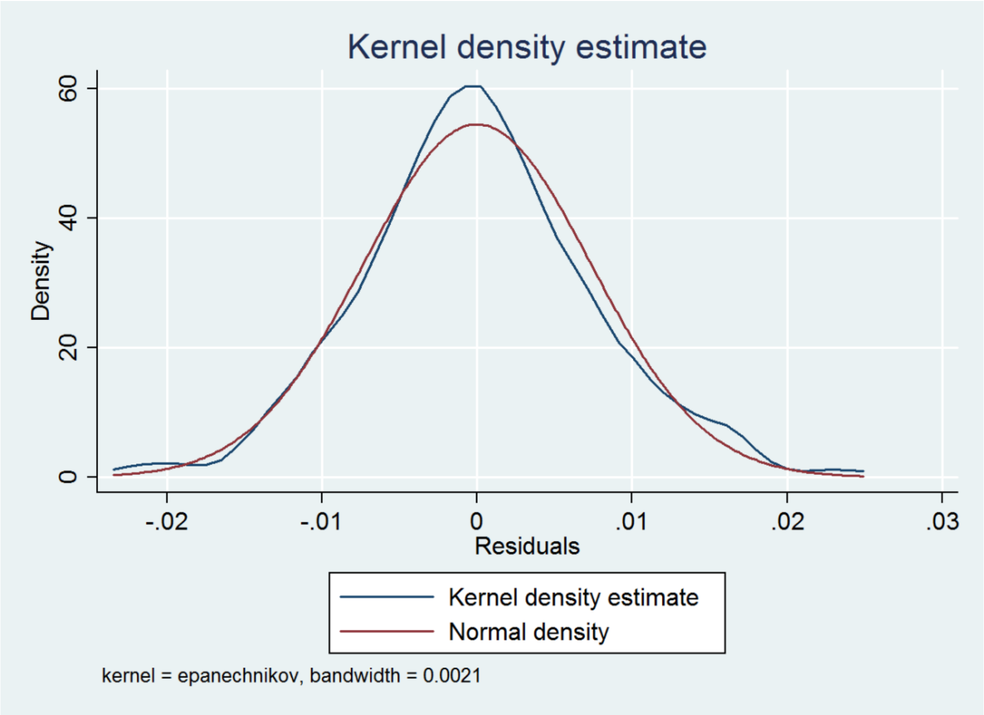
Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	3.9920	12.0000	0.2393

Shapiro-Wilk W test for normal data

Variable	W	V	z	Prob>z
resde	0.9918	0.8910	-0.2620	0.6032

Figure 0-1 Kernel Density Estimate vs. Norm. Distribution



Hungary

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
chi2(1) = 0.07
Prob>chi2 = 0.797

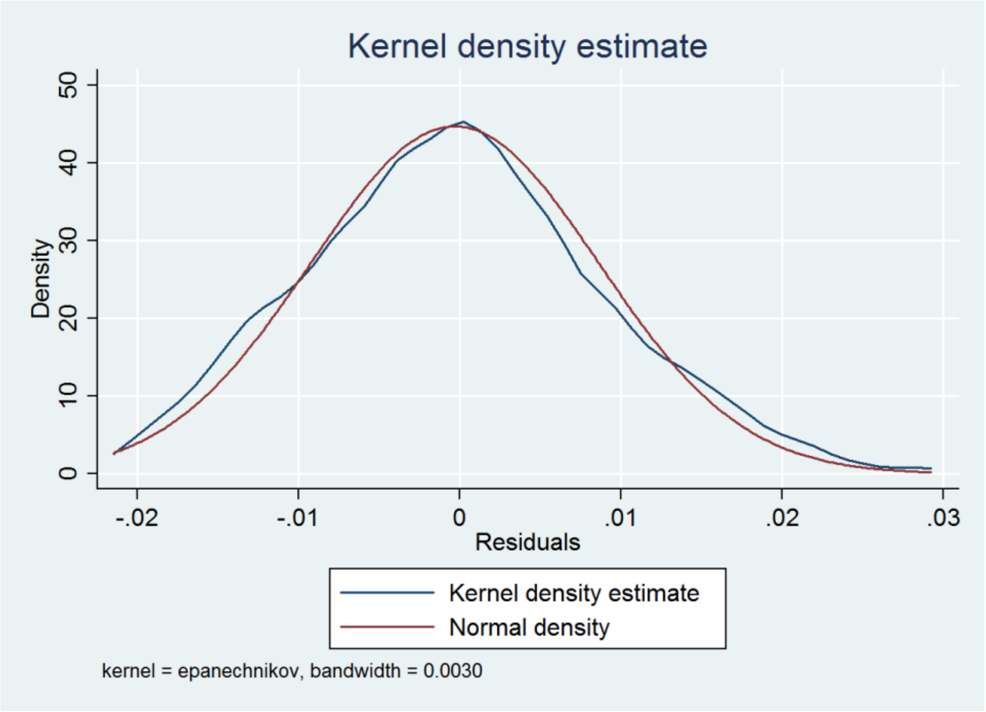
Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	5.137	12.0000	0.5196

Shapiro-Wilk W test for normal data

Variable	W	V	z	Prob>z
reshu	0.9900	1.1510	0.3180	0.37526

Figure 0-2: Kernel Density Estimate vs. Norm. Distribution



3.4 Rolling Window Estimation

Figure 0-3: Estimation of β_3 parameter using rolling windows

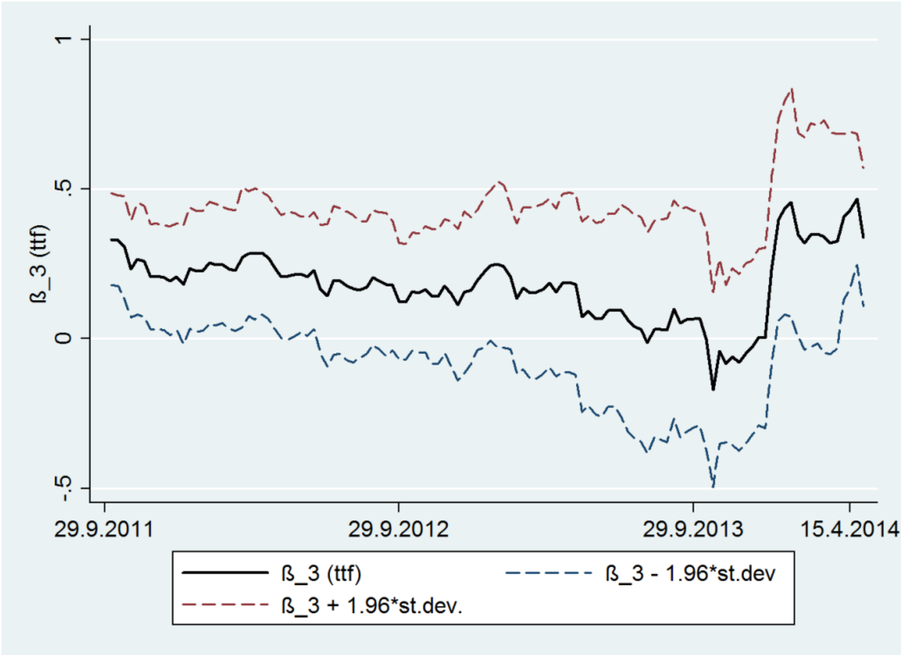


Figure 0-4: Estimation of β_4 parameter using rolling windows

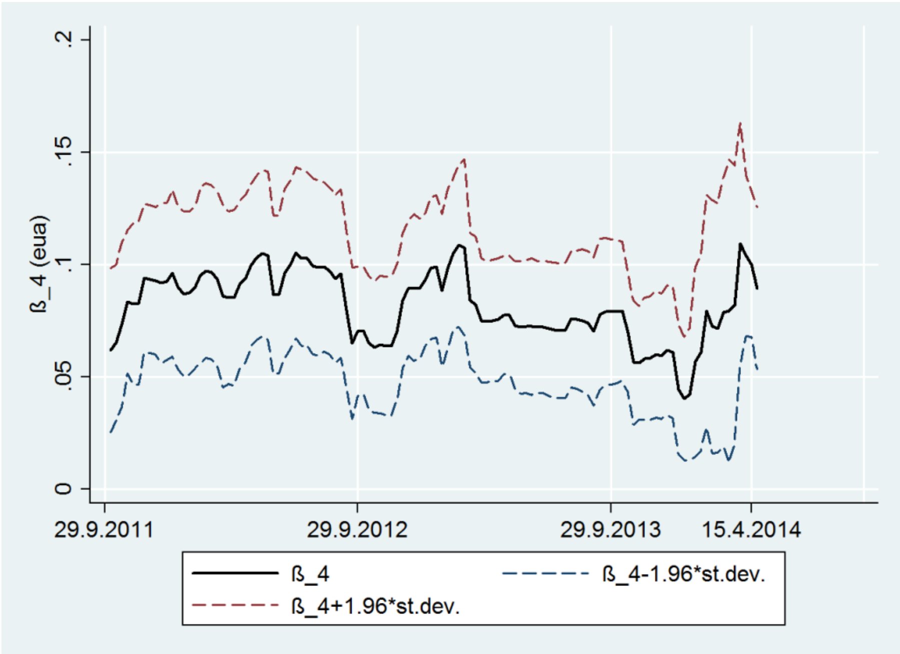
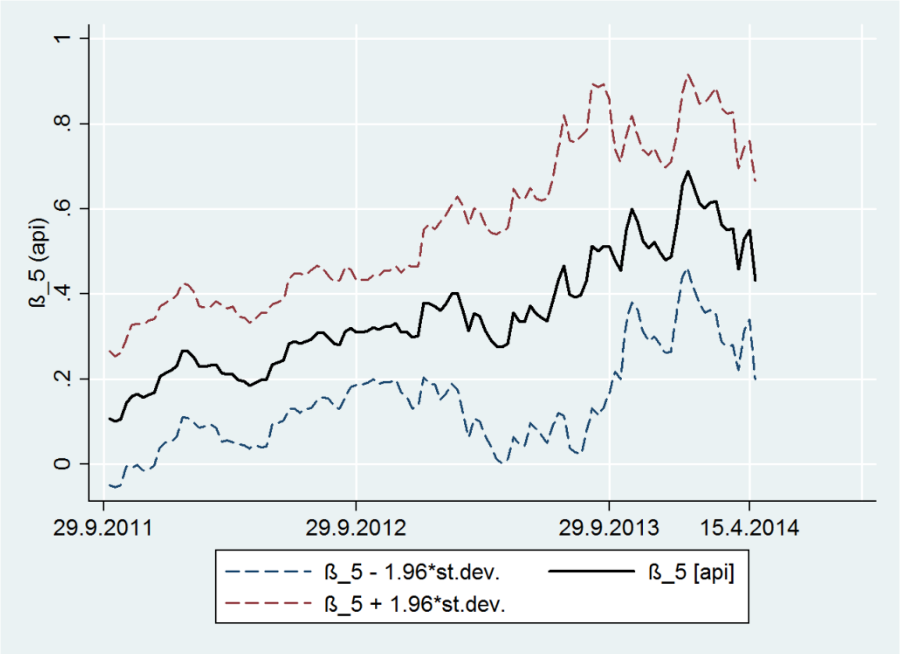


Figure 0-5: Estimation of β_5 parameter using rolling windows



4.3

Germany

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
chi2(1) = 0.51
Prob> chi2 = 0.4756

Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	9.77	12	0.6361

Hungary

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
chi2(1) = 0.01
Prob> chi2 = 0.9372

Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	9.54	12	0.2364

5.2.2

Germany

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

chi2(1) = 17.15
Prob> chi2 = 0.0000

Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	16.145	12.00	0.1847

Durbin's alternative test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	15.745	12	0.2032

Hungary

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

chi2(1) = 4.64
Prob> chi2 = 0.0304

Breusch-Godfrey LM test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	16.441	12.00	0.1719

Durbin's alternative test for autocorrelation

lags(p)	chi2	df	Prob> chi2
12	15.868	12	0.1973

MASTER'S THESIS PROPOSAL

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Proposed Topic:

On the Link between Spot and Forward Prices in Hungarian Power Market

Motivation:

Power is an unique commodity due to its non-storability. That is why the cost-of-carry model for pricing of forward contracts cannot be used. Power forwards are in fact not derivatives because the value for a specific delivery period is independent on other time of delivery. As a result, the forward prices are just an expectation of future spot prices.

It is thus worthwhile to investigate to what extent a past development of spot prices forms expectations on future prices. This issue has been already investigated at mature markets (NordPool, PJM, Germany). E.g. Böhm et al. (2008) as well as Erdmann &Zweifel (2008) finds positive relation of monthly averages of year-ahead price and spot prices after accounting for costs of fuels and emission allowances. Bessembinder& Lemon (2002) states that risk premium of forward price is positively associated with skewness of spot prices and negatively with variance. However, not a single study has focused on a new, developing power market of Hungary. Given lower transparency, liquidity, continuity of prices and deepness in such a market, my expectation and anecdotal evidence suggest that the Hungarian forward should react much more on results of day-ahead power auctions. Since the spot price indicates the real power balance in a region, market players should put more emphasis on the result of this spot auction in a market with limited fundamental information.

Hypotheses:

1) Year-ahead forward power prices are influenced by recent spot settlements both in Germany and to a bigger extent in Hungary. To model the year-ahead contract, I incorporate natural drivers of this product's price which are fuels and emission allowances. The EUR/USD exchange rate is generally viewed to play a role as well, since hard coal prices are denominated in USD, but Continental as well as Hungarian power is traded in EUR. After controlling for these effects, I assume that the situation at the short part of forward curve has a significant impact on long end, which is the front year delivery period. As stated above, I expect this variable to produce more compelling result in Hungary.

2) Both Hungarian and German month-ahead forward prices react on result of spot auction immediately. However, impact on German price is short-lived and fades away even during the day.

This hypotheses states that a differential between day-ahead price and actual spot auction outcome has an impact on forward prices. The main explanatory variable will be the surprise of spot auction (difference between traded day-ahead price and price settled).This variable should have impact on the difference between the month-ahead price traded before the auction result and after the outcome of the exchange is published, which is at 11:30 am. Since there are usually no important new fundaments released after 11:30, there should not be an omitted variable bias.

3) Risk premia of weekly contracts are negatively autocorrelated.

This hypothesis arises from similar reasoning, which is the overreaction on recent settlement prices. Hence, a certain stickiness of forward prices is assumed. Since I use the price of front week traded on Friday, the calculation of projected settlement of the current week needs to be done. This is going to be made up of settled prices of working days and forward price of weekend. The difference between the projected settlement and closing forward price of current week on Friday is expected to have an impact on the risk premium of week to follow. I will control for any change in fundaments, which include the flows from neighbour countries, Hungarian consumption as well as generation and change in German prices.

4) Risk premium is decreasing over time both in Hungary and Germany. However, German risk premium is substantially lower. Efficiency of the market is improving and errors in spot price predictions are being reduced.

In this section, we simply compare the ex post risk premia in both markets. The focus will be both on week and month-ahead delivery. Subsequently, the unbiased forward rate hypothesis (UFH) is to be tested. The methodology will be similar as suggested by Haugom & Ullrich (2013). The estimation with rolling window will be used to reveal the evolution of parameters in the UFH equation in time. The intuition is that overall volatility of forward prices and risk premia slowly decrease in time as the market is developing. This is probably caused by increasing presence of proprietary traders, by better ability of generators to dispatch power in a more efficient way and flow from other countries is expected to be more efficient as well due to market coupling and more sophisticated market actors active at cross-border trading.

Methodology:

1) For the first hypothesis, log-differenced weekly averages will be used for fuel, emission allowances and price of front-year power. To capture the effect of recent spot settlements, I construct a projected settlement of current week which will be compared to its average traded price from previous week. The projected settlement will be made on Friday, so it consists of already settled working days and weekend forward price.

Data on forward prices will be collected from brokers and power exchanges aggregated at a Trayport platform, which covers practically the entire volume traded. TTF natural gas and API 2 index will be used for change in gas price and hard coal, respectively.

2) Similar control variables will be used as for 1st hypothesis – changes in fuels and emission allowances. However, I take into account intraday changes as opposed to weekly deltas for hypothesis 1.

Expected Contribution:

As far as I know, the inclusion of Hungarian power market into an econometric analysis is already a significant contribution. Hungarian market has not drawn an attention of researchers yet. First reason for this absence of research is that this market is fairly new - I will have to use only data 2010 onwards due to absence of enough trades. Secondly, data on forward prices are not publicly available since almost entire volume traded is done at OTC market.

Similar hypotheses as hypothesis 1 and 4 have been already tested at German market, so I apply them in a modified form in Hungary. However, I account for market's ex ante expectation on settlement of current week by incorporation of projected settlement to calculate risk premia.

The 2nd and 3rd hypothesis is unique – to my knowledge, the immediate effect of spot auction has not been studied yet.

This analysis can significantly help reveal a difference in behaviour of market participants at Hungarian and German power market.

Outline:

1) Introduction

2) Literature overview

3) Data description and summary.

4) Hypothesis 1

5) Hypothesis 2

6) Hypothesis 3

7) Conclusion

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