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Rational Expectations in Electricity Futures Markets? Empirical Insights from the Interaction between EEX Spot and Forward Prices

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Abstract

Non-storability of a commodity implies the independence of corresponding spot and futures prices. We investigate empirically the case of electricity and show that a relation does emerge between spots and forwards. This is because of the links in storable fuels used for production and behavioural biases in power trading. The latter cause a significant influence of the electricity spot price on the futures price. We observe that futures pricing is a compound function of rational (fuel and carbon prices, wind feed-in and demand) and behavioural (electricity prices) components. The results question the predictive power of forwards and, hence, market efficiency. The interaction between spot and futures prices entails the spillover of spot market power effects unfolding market monitoring issues.

JEL classification

Q40; C10; G13

Keywords

Electricity, spot market, futures market, price formation, interaction, behavioural pricing, spillover, efficiency.

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1. Introduction

Breaking up the regulated monopoly of electricity supply in the European Union (EU) in 1997[2] into the potentially competitive segments of generation and supply and the regulated natural monopoly businesses of transmission and distribution has led to an unprecedented transformation of the industrial organisation of the power sector. Final customers and suppliers can, since liberalisation, freely source their electricity, generators may and actually do enter new business fields, electricity has become a tradable commodity and, accordingly, organised market places have emerged. As with any market, the sources of risk – and market participants' demands for compensation – are manifold.

Theories of industrial organisation, regulation and financial markets have proposed various treatments of these risks. This paper assesses the price formation in one potential cure: The forward market, which should contribute to market completeness and the facilitation of risk management and risk transfer (Newbery and Stieglitz, 1981). Specifically, the analysis focuses on the empirical assessment of the biggest European electricity market: The Central/Western European power market with its leading exchange, the European Energy Exchange (EEX)[3].

The attractiveness of futures markets, in turn, is reflected in high trading volumes – eventually exceeding physical demand. High trading volumes and, correspondingly, high market liquidity are generally considered as indications of mature and well-functioning markets. Yet it is crucial to gain deeper insight into the futures price formation process – not at least because of the special characteristics of the physical commodity electricity, associated consequences for the market structure, and its importance for the overall economy. These insights enable an efficient and effective design of the markets and its regulatory and legislative provisions.

[2] European Commission (1997).
[3] http://www.eex.com/en

Hence, the analyses below will specifically address the following questions:

- What are the links between current spot and futures prices?[4]
- Are there common drivers of these links?
- Which exogenous parameters effect the components of the electricity price system?
- What are the implications for the performance of electricity futures markets?

The paper proceeds as follows: Section 2 frames the conducted research, postulates hypothesis on relations between electricity spot and futures prices and summarises related theories and empirical research. Section 3 presents the data, section 4 studies the links between spots and forwards and presents a VAR model including exogenous drivers. Finally, section 5 concludes.

2. Research background and hypothesis

In a competitive power market the spot price of electricity on the wholesale spot market is determined by the generation costs of the marginal technology; that is the short run marginal costs of the most expensive plant needed to meet demand. In futures markets, where delivery is deferred, price formation gets more complex.[5] Given the non-storability of electricity even more so in power markets.

Economic theory provides two main approaches for pricing futures contracts. The first is dating back to Kaldor (1939) where current spot prices, interest rates, storage costs and a convenience yield are used to determine a no-arbitrage condition between spot and futures prices:

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[4] The terms futures and forward prices are used interchangeably in this paper.

[5] Assuming risk neutral market actors forming rational expectations in a competitive environment yields, theoretically, an equal price (formation) on short and long term markets.

$$F_{t,T} = S_t e^{(r+s-cy)(T-t)} \tag{1}$$

where $F_{t,T}$ is the futures price at time t for delivery in T, S_t is the spot price at time t, r is a constant interest rate, s are storage costs and cy is the convenience yield obtained from holding the physical commodity.[6] Keynes (1930) considers equilibrium in expectations and risk aversion amongst agents with heterogeneous needs for hedging spot price uncertainty. The forward price $F_{t,T}$ quoted at time t for delivery at time T is thereby viewed as being determined as the expected spot price $E(S_T)$ plus an ex ante forward premium $FP_{t,T}$ (Redl and Bunn, 2010):

$$F_{t,T} = E(S_T) + FP_{t,T} \tag{2}$$

Expected spot prices reflect market participants' expectations of fundamental supply and demand conditions during the delivery period of the forward contract. The forward premium is considered the net hedging cost of risk averse producers, retailers or other market participants and compensates for bearing price risks (Bessembinder 1992, Bessembinder and Lemmon 2002, Longstaff and Wang 2004). Hence, assuming rational expectations and risk-neutral market actors, future spot prices should, in turn, only deviate from forward prices in case of unexpected shocks. Therefore, under these stringent assumptions, spot prices in the delivery period S_T should equal forward prices $F_{t,T}$ plus a white noise error term ε_t with zero mean (Redl et al., 2009):

$$F_{t,T} = E_t(S_T | \Omega_t) \Rightarrow S_T = F_{t,T} + \varepsilon_t \tag{3}$$

A traditional approach to test hypothesis (3) is to run a regression where the spot price is regressed against a constant and the futures price. If the forward price were an unbiased predictor of the future spot price the regression coefficients of the constant term and the futures price

[6] See e.g. Telser (1958) for the concept of convenience yield for futures pricing.

should not be statistically different from zero and one respectively. This approach necessitates a clear distinction between exogenous and endogenous variables. Interestingly, for electricity spot and forward markets the distinction is not as clear cut as commonly recognised.

A link between current spot and current forward prices might not be anticipated due to the fact that electricity is not storable. Finding a corresponding relationship may, accordingly, suggest a behavioural pricing component prevailing in the markets. Fundamentally, power prices are affected by production costs, demand, and market power (Bunn, 2004, Weron, 2006). The inputs to electricity production (gas, coal and CO2 permits)[7] are, however, storable. Hence, links between electricity spots and forwards can emerge from the fact that electricity is a derived commodity.[8] This necessitates a careful variable selection for an empirical analysis of prices (and corresponding links).

Still, the relations between electricity spots and forwards may not only emerge from links in storable fuels. Also, counter to the implications of rational pricing models, behavioural biases (e.g. caused by employing heuristics or anchoring) are reasonably to be expected to prevail in electricity markets.[9] We argue that spot price forecasts for a delivery period comprising at least one month ahead prove to be elusive (for research aiming to model expectation behaviour and market participants alike). Hence, given an adaptive (behavioural) adjustment, a link between current long and short term prices appears not surprising. We aim to give insights on the relevance of this topic below.

[7] Fossil fuelled power plants are price setting in the EEX market.

[8] Douglas and Popova (2008) show that gas inventory levels can affect electricity day-ahead forward premia by influencing the moments of electricity prices. We aim to analyse the effect of storable fuels on the futures prices themselves.

[9] See Ricciardi (2008) for a review of behavioural decision theory and Redl and Bunn (2010) for consequences of behaviorual biases on the risk assessment of electricity market participants.

Interestingly, despite rich literature on explicit stochastic spot and forward price models and empirical analyses of the properties of risk premia, few studies specifically dealt with (high-frequency and short-term) interactions of electricity spot and futures prices. Bunn and Gianfreda (2009) estimate the integration of different regional European spot and futures electricity markets using Granger, cointegration and impulse response tests and find significant interactions among European spot markets and also among European futures markets. Similarly, Bunn and Fezzi (2008) and Fell (2010) study in detail the interactions between carbon, fuel and electricity spot prices. However, the above studies do not assess interactions between electricity spots and forwards in the same regional market. We specifically seek to address this issue in the following. Shawky et al. (2003) constitutes a first exception for electricity. They estimate an EGARCH and a VAR model and find that conditional volatility and shocks to spot returns determine the relation between spots and forwards. Most of the empirical literature available on price interactions studies, obviously, oil prices. Ng and Pirrong (1996) provide an early analysis for petroleum products using non-linear error correction models and find (current) futures prices leading (current) spot prices. Newer work on oil includes Kaufmann and Ullman (2009) and Bekiros and Diks (2008).[10] Depending on the sample and applied methodology results differ – generally, they suggest mixed lead/lag relation between spots and forwards. Finally, Gronwald et al. (2010) apply Granger causality tests on European CO2 spot and futures prices finding a bi-directional relationship.

[10] See also the references therein.

3. Data analysis

Figure 1 depicts the evolution of daily EEX spot and forward (month-ahead, quarter-ahead and year-ahead) prices. Generally, stable market periods can be distinguished from trending market periods whereas a similar behaviour between spot and futures prices can be observed. Given the existence of potential links as argued above, a natural question arising concerns the information flows (causal relation) between the current spot and forward prices. Does the spot follow the forward? Is it vice versa? Is one series (at least weakly) exogenous? Evidence from the literature (mainly available on oil price analyses only) suggests mixed evidence on lead/lag relationships.[11] Therefore, Granger causality tests and a vector autoregression (VAR) model will be applied in the following to assess these questions. Furthermore, the VAR model will be expanded by exogenous variables driving the electricity price series (and its links).

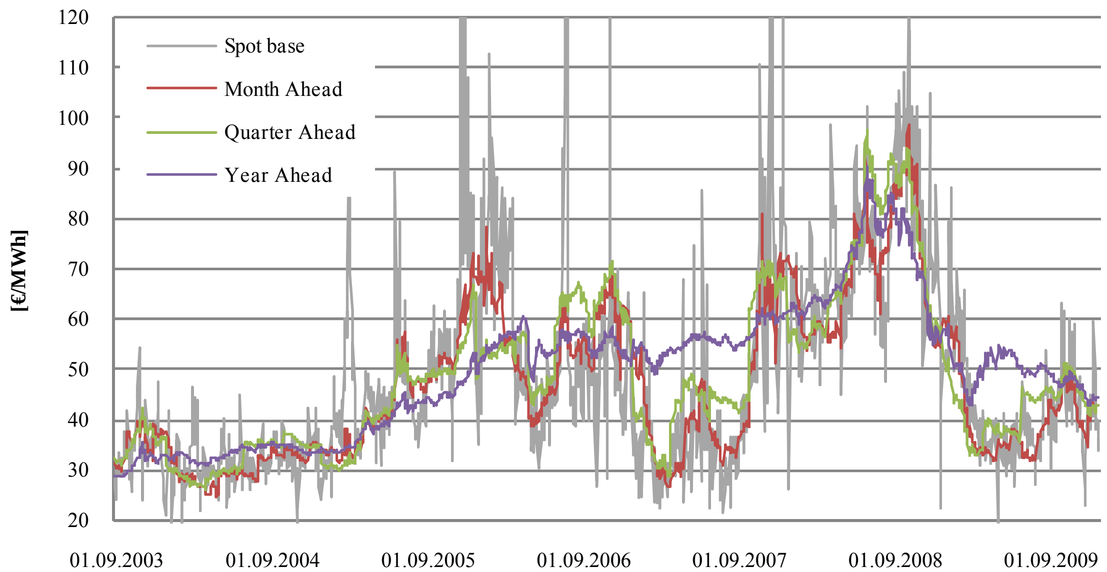

Figure 1. Comparison of daily spot prices (grey line) and daily forward settlement prices for the next month, quarter and year (coloured lines). Note that the y-axis is restricted to values ranging from 20 to 120 €/MWh. Source: EEX

[11] See section 2.

Several issues have to be considered before judging too quickly on generalisable patterns in the links between spots and forwards. Trading is thin for contracts with maturities more distant in the future. Hence, a model representation including all currently traded products may not touch upon the relevant relations which were governed by actual trading and corresponding "fundamental" market liquidities. A related fact concerns that due to arbitrage prices of several contracts can be determined by the other products on the market which brings about problems of endogeneity. For prices observed in January, for example, the price of the second quarter contract must be the average of the prices for monthly futures for April, May and June updated by transaction cost. Hence, in order to avoid these problems the empirical analysis presented below focuses on spot and one month-, quarter-, and year-ahead prices only. The employed empirical methodology depends on the properties of the analysed daily price time series. All time series depicted in Figure 1 are non-normally distributed and are highly correlated with correlation coefficients exceeding a minimum value of 0.58 (between current year-ahead and spot prices) and ranging up to 0.92 (between month and quarter-ahead prices)[12]. Table 1 summarises the correlation coefficients and shows descriptive statistics of the individual distributions. To filter out the relationship only working days are used for the price time series since futures contracts are not traded on weekends and public holidays.

[12] These correlations may appear surprisingly high given a non-storable commodity.

Table 1. Correlation coefficients between daily EEX spot, month-ahead, quarter-ahead and year-ahead base load prices noted on working days (top panel) from September 2003 to December 2009 and summary statistics (bottom panel).

	S_t	Month-ahead$_{t,T}$	Quarter-ahead$_{t,T}$	Year-ahead$_{t,T}$
S_t	1.00			
Month-ahead$_{t,T}$	0.76	1.00		
Quarter-ahead$_{t,T}$	0.69	0.92	1.00	
Year-ahead$_{t,T}$	0.58	0.79	0.87	1.00
Mean	49.20	46.88	48.55	49.77
Median	43.08	42.32	45.21	51.15
Maximum	301.54	98.41	97.50	90.15
Minimum	17.06	24.85	26.28	28.62
Std. Dev.	21.49	15.42	15.40	12.99
Skewness	2.51	0.81	0.90	0.46
Kurtosis	19.02	2.98	3.35	2.99
Jarque-Bera	18757.27	175.01	225.29	56.77
Observations	1598	1598	1598	1598

All time series except the spot prices contain a unit root. Hence, an analysis in levels could be performed for the forwards only if the respective time series were cointegrated.[13] Since the analysis also comprises stationary spot prices an unrestricted VAR model is tested for the returns (i.e. the logarithmic differences) of the original price series instead. This transformation has to be kept in mind when interpreting the model results. As shown in Figure 2 the return series are clearly stationary (which is confirmed by unit root tests). Table 2 summarises the correlation coefficients and shows descriptive statistics of the returns data set.

[13] The futures price series are non-stationary when including an intercept as well as a linear trend in the test equation.

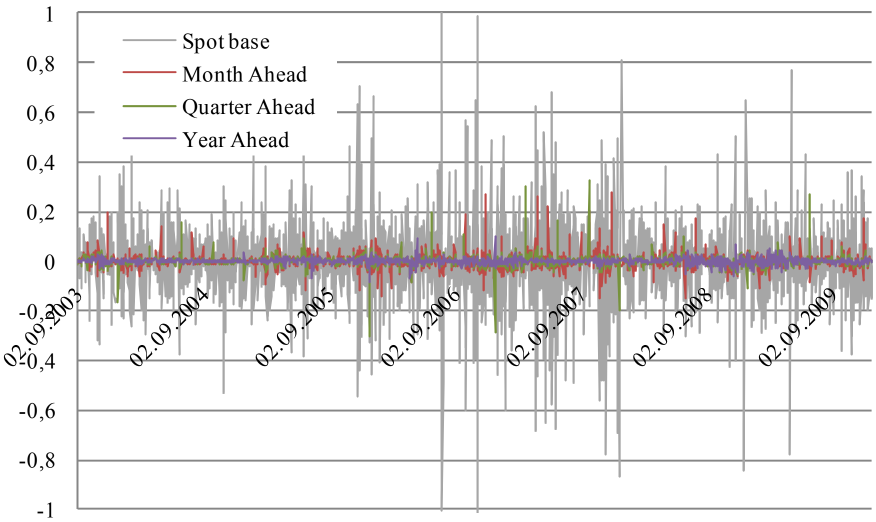

Figure 2. Daily spot price and forward price (month, quarter and year-ahead) returns. Source: EEX, own calculations

In a first step, the lead/lag relationship in the electricity price system will be assessed according to Granger causality. This will be followed by a VAR modelling approach.

4. The link between current spot and futures prices

The interrelation between spot and futures prices is first tested by Granger non-causality tests. The null hypothesis that spot returns do not Granger cause forward price returns must be rejected for yearly contracts. Similarly, the null hypothesis that quarter-ahead and year-ahead forward price returns do not Granger cause month-ahead and quarter-ahead forward returns respectively can be rejected. Therefore, according to the definition of Granger causality, lagged values of the price returns can be used for forecasting the other return series which confirms the interrelatedness of the spot and futures time series. Table 3 and Figure 3 summarise these results.

Table 2. Correlation coefficients between daily EEX spot and futures returns (top panel) from September 2003 to December 2009 and summary statistics (bottom panel).

	S_t	$\Delta LogMonthAhead_{t,T}$	$\Delta LogQuarterAhead_{t,T}$	$\Delta LogYearAhead_{t,T}$
$\Delta LogS_t$	1.00			
$\Delta LogMonthAhead_{t,T}$	-0.031	1.00		
$\Delta LogQuarterAhead_{t,T}$	-0.003	0.339	1.00	
$\Delta LogYearAhead_{t,T}$	-0.059	0.386	0.438	1.00
Mean	0.000	0.000	0.000	0.000
Median	0.003	-0.001	0.000	0.000
Maximum	1.096	0.276	0.328	0.102
Minimum	-1.076	-0.150	-0.304	-0.087
Std. Dev.	0.178	0.032	0.026	0.012
Skewness	-0.096	1.953	1.291	-0.008
Kurtosis	8.733	18.747	67.311	11.988
Jarque-Bera	2189.145	17515.330	275653.900	5375.611
Observations	1597	1597	1597	1597

Table 3. Results of Granger non-causality tests for daily spot and forward returns of EEX from September 2003 to December 2009.

		EEX		
Variable	H0	Variable	F-statistic	p-value
$\Delta log(S_{t)}$	$\nrightarrow$	$\Delta log(F_{t,t+1M)}$	1.58	0.21
	$\nrightarrow$	$\Delta log(F_{t,t+1Q)}$	0.27	0.76
	$\nrightarrow$	$\Delta log(F_{t,t+1Y)}$	4.25	0.01
$\Delta log(F_{t,t+1M)}$	$\nrightarrow$	$\Delta log(S_{t)}$	0.73	0.48
	$\nrightarrow$	$\Delta log(F_{t,t+1Q)}$	1.76	0.17
	$\nrightarrow$	$\Delta log(F_{t,t+1Y)}$	0.69	0.50
$\Delta log(F_{t,t+1Q)}$	$\nrightarrow$	$\Delta log(S_{t)}$	0.39	0.67
	$\nrightarrow$	$\Delta log(F_{t,t+1M)}$	4.68	0.01
	$\nrightarrow$	$\Delta log(F_{t,t+1Y)}$	1.02	0.36
$\Delta log(F_{t,t+1Y)}$	$\nrightarrow$	$\Delta log(S_{t)}$	0.18	0.84
	$\nrightarrow$	$\Delta log(F_{t,t+1M)}$	2.17	0.11
	$\nrightarrow$	$\Delta log(F_{t,t+1Q)}$	3.03	0.05

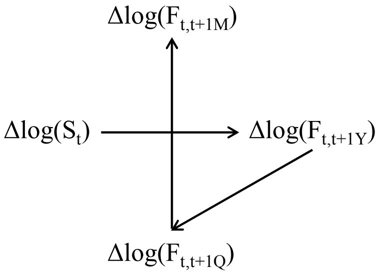

Figure 3. Pair wise Granger causality for daily electricity spot and futures price returns at the EEX.

Benth et al. (2009) contend that the lacking storability of electricity implies that spot prices are not affected by available information about future price changes (i.e. price changes in the forward contract market). In reverse, futures prices should not be affected by spot price changes. However, the results of the Granger tests suggest the opposite. In fact, the prevalence of behavioural components in the electricity markets' price formation is discernible since different product types (i.e. spots and various forwards) mutually influence each other.

Clearly, this system of (endogenous) electricity prices is not only driven by its interrelation but also by common exogenous parameters. To assess the interrelation between spot and forward prices and exogenous drivers an unrestricted vector autoregression (VAR) model is estimated. The model considers electricity spot and forward prices to be endogenous. These endogenous variables mutually influence each other. Furthermore, exogenous parameters (input prices, electricity demand and wind generation) are included to additionally explain the evolution of the endogenous variables (and their interactions).

As discussed in section 2 power prices are influenced by electricity demand, fuel costs and carbon prices. Hence, these parameters are treated as exogenous in the model.[14] Demand, however, is influenced by prices. As the elasticity of demand with respect to prices is very low in the short-run, this analysis nevertheless considers system wide demand to be exogenous (Karakatsani and Bunn, 2008). As regards CO2 prices, carbon permits in the EU-ETS must be surrendered on an annual basis. For this reason carbon futures are traded with an annual maturity only. Similarly, there exists no coal spot market which explains the absence of coal spot price returns in model (4). Finally, wind power generation is another exogenous variable in model (4). German wind power generation is subject to a support scheme where the transmission system operator has to purchase wind power at a guaranteed feed in tariff. This production is, in turn, sold on the EEX as an unlimited offer and therefore influences the price formation.[15] The demand and wind power time series consist of realised daily values. Given the short forecasting horizon (day-ahead) the quality of the prognosis can be considered very high (e.g. 95% for wind power with respect to the installed capacity, Sperling, 2009) and the inclusion of published forecasts would not have altered the results. Alternatively, the inclusion of lagged demand and wind power series in (4) could be interpreted as a test for the adaptive adjustment of market participants. In fact, testing this alternative specification did not affect the results presented in Table 4. Given the existence of strong serial correlation in the (daily) demand and wind power time series this appears not surprising. The following model is tested:

$$y_t = A_0 + A_1 y_{t-1} + A_2 y_{t-2} + ... + A_p y_{t-p} + A_x x_t + \varepsilon_t \qquad (4)$$

[14] The results of Redl et al. (2009) suggested a non-linear effect of CCGT plants' generation costs in a monthly model of EEX futures prices. It would be reasonable to expect a similar non-linear effect also in a daily representation of the time-series. However, no significant non-linear effect (though regression coefficients were negative as expected) could be detected for gas prices in model (4). This might be due to the daily granularity of the data suggesting no immediate short-term effect of rising gas prices on power plant dispatch.

[15] See e.g. Obersteiner (2010) for a detailed analysis.

where $y_t = \begin{bmatrix} \Delta Log(S_{t,t+1}) \\ \Delta Log(F_{t,t+1M}) \\ \Delta Log(F_{t,t+1Q}) \\ \Delta Log(F_{t,t+1Y}) \end{bmatrix}$ is a vector of spot and forward price returns,

$x_t^T=[\Delta Log(S_{Gas,t,t+1}), \Delta Log(F_{Gas,t,t+1M}), \Delta Log(F_{Gas,t,t+1Q}), \Delta Log(F_{Gas,t,t+1Y}), \Delta Log(S_{CO2,t,t+1}), \Delta Log(F_{CO2,t,t+1Y}), \Delta Log(F_{Coal,t,t+1M}), \Delta Log(F_{Coal,t,t+1Y}), \Delta Log(Demand_{t,t+1}), \Delta Log(Wind_{t,t+1})]$ is a vector of exogenous variables, $\underline{A_0}$ is a vector of constants and $\underline{A_1}$, etc., are the coefficient matrices. $\Delta Log(S_{t,t+1})$ is the daily return in the day-ahead spot market, $\Delta Log(F_{t,t+1M})$, $\Delta Log(F_{t,t+1Q})$, and $\Delta Log(F_{t,t+1Y})$ are the month-, quarter-, and year-ahead futures price returns. Similarly, $\Delta Log(S_{Gas,t,t+1})$, $\Delta Log(F_{Gas,t,t+1M})$, $\Delta Log(F_{Gas,t,t+1Q})$ and $\Delta Log(F_{Gas,t,t+1Y})$ are the daily returns of spot, month-, quarter-, and year-ahead gas prices[16], $\Delta Log(S_{CO2,t,t+1})$ and $\Delta Log(F_{CO2,t,t+1Y})$ are the daily returns of spot and year-ahead CO_2 prices, $\Delta Log(F_{Coal,t,t+1M})$ and $\Delta Log(F_{Coal,t,t+1Y})$ are the daily returns of month- and year-ahead coal prices at the EEX, $\Delta Log(Demand_{t,t+1})$ are German electricity demand returns[17] and $\Delta Log(Wind_{t,t+1})$ are returns of the daily German wind generation. Lag length criteria suggest a lag length of 1 (AIC and HQ). Table 4 shows the results of the VAR model (4).

[16] Spot and month-ahead gas prices are from the Zeebrugge hub and quarter- and year-ahead gas prices are taken from EEX.

[17] https://www.entsoe.eu/

Table 4. Results of the unrestricted VAR model (4) for daily electricity spot and forward price returns at the EEX from July 2007 to December 2009 (t-statistics in brackets). *, **, *** denotes significance on the 10%, 5% and 1%-level.

Variable	EEX			
	$\Delta\log(S_{t,t+1})$	$\Delta\log(F_{t,t+1M})$	$\Delta\log(F_{t,t+1Q})$	$\Delta\log(F_{t,t+1Y})$
Constant	0.00 (0.08)	0.00 (0.34)	-0.00 (-0.00)	-0.00 (-0.51)
$\Delta\log(S_{t-1})$	-0.22 (-6.70)***	-0.01 (-1.74)*	0.00 (0.50)	-0.00 (-1.80)*
$\Delta\log(F_{t-1,t+1M})$	0.00 (0.00)	0.04 (1.07)	0.03 (1.18)	0.02 (1.65)*
$\Delta\log(F_{t-1,t+1Q})$	-0.19 (-0.77)	0.09 (1.54)	0.03 (0.80)	0.02 (1.33)
$\Delta\log(F_{t-1,t+1Y})$	0.58 (1.22)	-0.06 (-0.56)	0.02 (0.37)	-0.03 (-0.99)
$\Delta\log(S_{Gas,t,t+1})$	0.21 (2.44)**	0.00 (0.21)	-0.01 (-1.14)	-0.01 (-1.08)
$\Delta\log(F_{Gas,t,t+1M})$	0.19 (1.25)	0.18 (5.29)***	-0.05 (-2.52) **	-0.00 (-0.37)
$\Delta\log(F_{Gas,t,t+1Q})$	0.34 (1.66)*	-0.02 (-0.39)	0.45 (17.22)***	-0.01 (-0.98)
$\Delta\log(F_{Gas,t,t+1Y})$	-0.33 (-0.76)	0.15 (1.49)	-0.41 (-7.31)***	0.20 (8.28)***
$\Delta\log(S_{CO2,t,t+1})$	-0.01 (-0.56)	-0.01 (-1.35)	-0.00 (-0.46)	-0.00 (-0.45)
$\Delta\log(F_{CO2,t,t+1Y})$	0.33 (1.32)	0.14 (2.49)**	0.15 (4.74)***	0.17 (12.41)***
$\Delta\log(F_{Coal,t,t+1M})$	-0.46 (-0.78)	-0.17 (-1.28)	-0.27 (-3.49)***	0.10 (3.05)***
$\Delta\log(F_{Coal,t,t+1Q})$	-0.53 (-0.68)	0.29 (1.66)*	0.32 (3.22)***	0.08 (1.88)*
$\Delta\log(F_{Coal,t,t+1Y})$	0.83 (1.19)	-0.02 (-0.11)	0.32 (3.57)***	0.11 (2.82)***
$\Delta\log(Demand_{t,t+1})$	1.28 (6.78)***	0.02 (0.57)	-0.03 (-1.38)	-0.04 (-3.39)***
$\Delta\log(Wind_{t,t+1})$	-0.11 (-16.02)***	0.00 (0.05)	0.00 (0.12)	0.00 (0.25)
R^2 (R^2_{corr})	0.35 (0.34)	0.14 (0.12)	0.52 (0.51)	0.71 (0.70)
Serial correlation (5 lags)		χ^2_{16DOF} (p-value)	0.725	
Observations		625		

Electricity spot price returns are significantly negatively influenced by its lagged value which is consistent with mean reversion properties of the stationary spot price series. As expected gas spot price returns (significantly) positively influence electricity spot returns. However, also returns of quarterly gas futures influence electricity spot returns on a 10% significance level. This result might be a consequence of the cost of carry in the storable fuel gas. The fundamental supply and demand variables significantly influence the spot price returns and show the expected signs (i.e. positive for demand and negative for wind power). Interestingly, carbon spot price returns do not affect electricity returns. This seems puzzling. CO2 certificate prices represent opportunity costs and are therefore part of electricity prices. Still, the results of model (4) suggest that on a high(er) frequency basis (i.e. daily) carbon spot price returns do not affect the electricity price return system. However, electricity spot returns are positively influenced by carbon futures returns on a (weak) 15% significance level. Apart from the year 2007 (i.e. the last year of the first period of the EU-ETS) carbon spot and futures prices are highly correlated due to the storability of carbon permits.[18] Hence, carbon year-ahead futures returns capture the CO2-related movement of the electricity price return system for all maturities of the latter (from spot to year-ahead) as will be seen in the following.[19]

Returns of month-ahead futures are negatively influenced by spot price returns on a 10% level whereas lagged values of month-ahead returns do not influence the former. As expected gas month-ahead price returns (significantly) positively influence electricity month-ahead returns. Year-ahead carbon returns do positively affect the month-ahead electricity returns which, at first sight, appears counterintuitive but can be explained by the fact that CO2 allowances must be surrendered annually and, moreover, the storability of carbon permits implies a strong link between year-ahead prices and those of spot prices (and "virtual" maturities in between). Coal month-ahead futures returns do, interestingly, not influence the corresponding electricity returns whereas coal quarter-ahead returns do. Similar to CO2, this can be explained by the storability of coal which implies a high correlation of coal month- and quarter-ahead futures prices.

Returns of quarter-ahead electricity futures are not influenced by the electricity return system which seems to contradict the results of the Granger non-causality tests presented in Table 3 indicating Granger causality running from year-ahead to quarter-ahead returns. However, model (4) has to rely on a shorter sample size and the movement of the endogenous variables in this

[18] Including a dummy variable for the first trading period of the EU-ETS did not alter the results.

[19] Bunn and Fezzi (2008) show that UK and German spot electricity prices are not affected by carbon spot prices. However, they do not consider carbon futures in their model.

model is largely driven by exogenous variables. Gas quarter-ahead price returns (significantly) positively influence electricity quarter-ahead returns whereas there is also a negative effect of gas month- and year-ahead returns.

Returns of year-ahead electricity futures are influenced by electricity spot returns (in accordance with the Granger non-causality tests presented in Table 3 indicating Granger causality running from spot to year-ahead returns) and month-ahead returns. Gas, coal and carbon year-ahead price returns (significantly) positively influence electricity year-ahead returns which is to be expected whereas returns of coal month- and quarter-ahead futures also positively influence year-ahead electricity returns. There might be an interaction affect between the coal futures returns causing this result. Reinforcing the interpretation of behavioural pricing components, a small negative (but significant) affect of the day-ahead demand returns on the year-ahead electricity futures return can be detected.[20]

In general, a link between electricity spot and futures prices may emerge not only from a behavioural bias. Given storable fuels as production inputs (coal, gas and CO2 permits) a link in electricity may possibly follow from the cost of carry in those inputs. Still, both exogenous variables and endogenous electricity (spot) prices are significant in (4). Moreover, the correlation between inputs and spots in (4) is low ruling out multicollinearity concerns. This indicates an important influence of the spot price on the futures price itself.[21]

[20] In terms of behavioural pricing components Redl and Bunn (2010) have argued that oil market volatility spills over to the price of risk in electricity markets. Accordingly, it might be reasonable to expect a similar effect when assessing the price formation itself. Still, regression coefficients for oil prices turned out insignificant when included in model (4). This suggests that oil markets are especially relevant for the *risk* assessment of electricity wholesale market participants.

[21] Performed regressions on the electricity basis (the difference between current futures and spot prices) on the basis prevailing in the gas, coal and CO2 markets indeed yielded significant effects. This result implies the spill over of the cost of carry of input fuels to the non-storable commodity electricity. Nevertheless, these regressions also yielded significant influences of lags of the electricity basis (In fact, the regressions are misspecified if only the carrying costs are included). This, again, indicates a behavioural bias. Results are available upon request.

5. Conclusions

The analysis on links between spot and futures electricity prices has disclosed several interesting results. First, Granger-non causality tests have revealed significant interactions among spot price returns and month-, quarter-, and year-ahead futures price returns casting doubt on a clear distinction between short- and long-term markets. This suggests the existence of behavioural pricing components and rejects claims on a supposedly exogeneity of spot prices on the one hand and forward prices on the other.

Second, these results were confirmed by VAR regression models. Although the modelled time series are returns (i.e. logarithmic differences) the coefficient of determination R^2 is satisfactorily high in the above presented models. More specifically, the movement of the electricity price system can, to a large extent, be explained by exogenous supply and demand side variables driving the electricity prices. Still, there are strong interactions between the electricity price series confirmed by significant regression coefficients in the VAR models. The results of the regression models implies the prevalence of behavioural pricing components in the markets which, in turn, casts doubts on the predictive power of forward prices and, in turn, on market efficiency.[22]

What are the implications of this potentially lacking informational function of the futures prices? The results appear particularly surprising given the non-storability of electricity and are counter to the implications of a rational pricing model of non-storable commodities. In fact, the results suggest that the pricing of futures is a compound function of rational[23] and behavioural components. Additionally, the tie in storable fuels implies the corresponding cost of carry also effecting the non-storable commodity electricity. Consequently, this complicates the price

[22] Even when taking into account the systematic bias arising from risk aversion. See Redl and Bunn (2010).
[23] In the neo-classical sense.

formation. The risk assessment of market participants might be affected increasing the cost of hedging spot price uncertainty.[24]

Links between spots and forwards also imply the spill over of spot market power effects into forward prices. This unfolds market monitoring issues.[25] Analyses concerning market power effects in electricity markets typically focus on spot markets only. Whereas these studies do confirm the crucial role of excess supply capacities and of strategic withholding on spot market results the effect of spillovers is not considered.

The analysis in this paper has revealed that the electricity price formation and, correspondingly, the expectation formation of the market participants are a compound mix of rational and several behavioural components. As market equilibrium is linked to equilibrium in expectations the existence of behavioural effects applies for all groups of market participants. Future research could build a formal model of different groups of market actors detailing psychological biases. This could shed light on the specific short and long positions taken in the forward markets. Moreover, this would allow testing for expectations induced trend (herding) effects.

Publications of the USA based Commodity Futures Trading Commission (CFTC) list long and short open interests of different types of traders.[26] If such market transparency programmes were implemented in the European electricity futures markets this would decrease asymmetries and increase the data base for new descriptive analysis and new theories on decision making of market participants.[27] In fact, publication on aggregated trader category levels would take into

[24] Indeed, Redl and Bunn (2010) find behavioural assessments and dynamic links influencing the forward premium.
[25] Forward markets are typically considered to be pro-competitive.
[26] Commitment of Traders reports available at http://www.cftc.gov/MarketReports/CommitmentsofTraders/index.htm
[27] In fact, European Commission (2010) proposes draft rules on regulative oversight of trading in wholesale power markets. This proposal includes data collection on transactions and corresponding orders.

account the trade-off between reducing asymmetries and releasing sensitive business related information.

The performed analyses have relied on aggregated market data – basically settlement prices of different commodities. The insights could be enlarged by the inclusion of data related to the positions taken, at least on aggregate, by hedgers and speculators and market concentrations. The robustness of the results could be increased by assessing additional forward contract maturities and taking into account higher granularities of intra-daily price time series and testing ARCH specifications and non-symmetric adjustments. Still, much of this would necessitate higher transparency levels.

New empirical insights can frame new theories of decision making under risk. This paper provided empirical insights into the price formation on electricity wholesale markets. They suggest expanding existing equilibrium models considering oligopolistic market environments, psychologically based behavioural concepts and different information levels.

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References

Bekiros, S.D., Diks, C.G.H., 2008. The relationship between crude oil spot and futures prices: Cointegration, linear and nonlinear causality. Energy Economics 30, 2673-2685.

Benth, F.E., Meyer-Brandis, T., 2009. The information premium for non-storable commodities. The Journal of Energy Markets 2(3), 111-140.

Bessembinder, H., 1992. Systematic Risk, Hedging Pressure, and Risk Premiums in Futures Markets. The Review of Financial Studies 5(4), 637-667.

Bessembinder, H., Lemmon, M.L., 2002. Equilibrium Pricing and Optimal Hedging in Electricity Forward Markets. The Journal of Finance 57(3), 1347-1382.

Bunn, D.W., 2004. Modelling Prices in Competitive Electricity Markets. Wiley.

Bunn D., Fezzi C., 2008. A vector error correction model of the interactions among gas, electricity and carbon prices: an application to the cases of Germany and United Kingdom, in (Editor: F. Gulli): Markets for carbon and power pricing in Europe: theoretical issues and empirical analyses, Edward Elgar Publishing, pp. 145-159.

Bunn, D.W., Gianfreda, A., 2009. Integration and shock transmissions across European electricity forward markets. Energy Economics 32(2), 278-291.

Douglas, S., Popova, J., 2008. Storage and the electricity forward premium. Energy Economics 30, 1712-1727.

European Commission, 1997. Directive 96/92/EC of the European Parliament and of the Council concerning common rules for the internal market in electricity. L027, Brussels.

Fell, H., 2010. EU-ETS and Nordic Electricity: A CVAR Analysis. The Energy Journal 31(2), 1-26.

Gronwald, M., Ketterer, J., Trück, S., 2010. On the Origins of Emission Allowance Price Fluctuations. Unpublished working paper.

Kaldor, N., 1939. Speculation and economic stability. The Review of Economic Studies 7, 1-27.

Karakatsani, N.V., Bunn, D.W., 2008. Intra-day and regime-switching dynamics in electricity price formation. Energy Economics 30(4), 1776-1797.

Kaufmann, R.K., Ullman, B., 2009. Oil prices, speculation, and fundamentals: Interpreting causal relations among spot and futures prices. Energy Economics 31, 550-558.

Keynes, J. M., 1930. A Treatise on Money. London: Macmillan.

Longstaff, F.A., Wang, A., 2004. Electricity Forward Prices: A High-Frequency Empirical Analysis. The Journal of Finance 59(4), 1877-1900.

Newbery, D.M., Stiglitz, J.E., 1981. The Theory of Commodity Price Stabilization. A Study in the Economics of Risk. Clarendon Press, Oxford.

Ng, V.K., Pirrong, S., C., 1996. Price dynamics in refined petroleum spot and futures markets. Journal of Empirical Finance 2, 359-388.

Obersteiner, C., 2010. The market value of wind power from a generator's perspective – An analysis of influencing parameters, PhD thesis, Vienna University of Technology.

Redl, C., Haas, R., Huber, C., Böhm, B. Price formation in electricity forward markets and the relevance of systematic forecast errors. Energy Economics 31(2009) 356-364, 2009.

Redl, C., Bunn, D.W., 2010. Components of the Forward Market Premium in Electricity. Working Paper.

Ricciardi, V., 2008. The Psychology of Risk: The Behavioral Finance Perspective. In: Frank J. Fabozzi, ed., Handbook Of Finance: Volume 2: Investment Management And Financial Management, Wiley, pp. 85–111.

Shawky, H.A., Marathe, A., Barret, C.L., 2003. A First Look at the Empirical Relation Between Spot and Futures Electricity Prices in the United States. The Journal of Futures Markets 23(10), 931-955.

Telser, L.G., 1958. Futures Trading and the Storage of Cotton and Wheat. The Journal of Political Economy 66(3), 233-255.

Weron, R., 2006. Modeling and forecasting electricity loads and prices: a statistical approach. Wiley, Chichester, ISBN 047005753X.