Hedging with Electricity Futures: Evidence from the European Energy Exchange

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Outline

The European Energy Exchange I

Deregulation and Electricity Market Opening

	Opened	**Size**(TWh)		**Opened**	**Size**(TWh)
Austria	100%	55	Schweden	100%	135
Belgium	90%	60	UK	100%	335
Denmark	100%	3	Malta	0%	0
Finalnd	100%	80	Estonia	10%	1
France	70%	275	Latvia	76%	4
Germany	100%	500	Lithuania	–	–
Greece	62%	29	Poland	52%	50
Ireland	56%	12	Czech R.	47%	25
Italy	79%	225	Slovakia	66%	15
Luxembourg	57%	3	Hungary	67%	22
Netherlands	100%	100	Slovenia	75%	10
Portugal	100%	42	Cyprus	35%	1
Spain	100%	100	(Norway)	100%	110

*Source:*Technical annexes to the report from the Commission on the implementation of the gas and electricity internal market

Commission of the European communities, 2005.

The European Energy Exchange II

Country	Date	Name
England and Wales	1990-1999	Electricity Pool
	2001	UK Power Exchange (UKPX)
Norway	1993	Nord Pool Scandinavia
	1996	Nord Pool
Spain	1998	OMEL
Holland	1990	Amsterdam Power Exchange (APX)
Germany	2000	Leipzig Power Exchange (LPX)
	2000	European Power Exchange (EEX)
Poland	2000	Polish Power Exchange (PPX)
France	2001	Powernext
Austria	2002	EXAA
Italy	2004	Gestaro Mercato Electrico (GME)

The European Energy Exchange III

European Energy Exchange

- Founded in August 2000
- Financial derivatives on electricity since March 2002
- Supported by: Deutsche Börse, Swiss Stock Exchange
- Xetra, Eurex

Leipzig Power Exchange

- Founded in 2000
- Located in Leipzig
- Supported by: Nord Pool
- Sapri

European Energy Exchange

- Merger first March 2002
- Located in Leipzig
- Xetra, Eurex
- 160 trading members from 19 countries
- Spot market volume 2006: 89 TWh
- Derivatives market volume: 1.044 TWh (Euro 58.75 billion)

The spot and future market

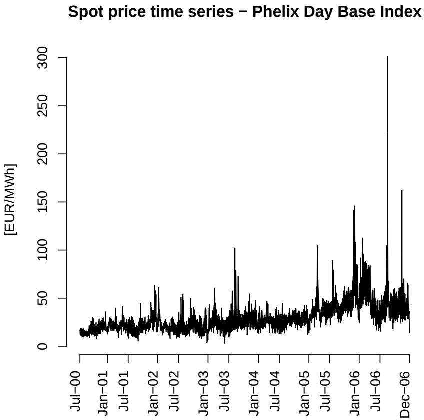
	Electricity	Gas
Spot market	hour contracts block contracts	Day ahead trading
Financial Futures	Phelix Base Futures Phelix Peak Futures	Gas futures
Physical Futures	German Power Futures French Power Futures Dutch Power Futures	
Options	Phelix Base Option Phelix Peak Option	

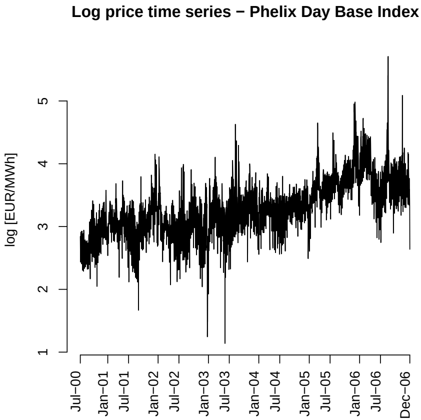
	Coal	CO_2 Emission allowances
Spot market		Eu emission allowances (Carbix)
Financial Futures	ARA coal futures RB Coal futures	First period EU carbon futures Second period EU carbon futures

Descriptive statistics I

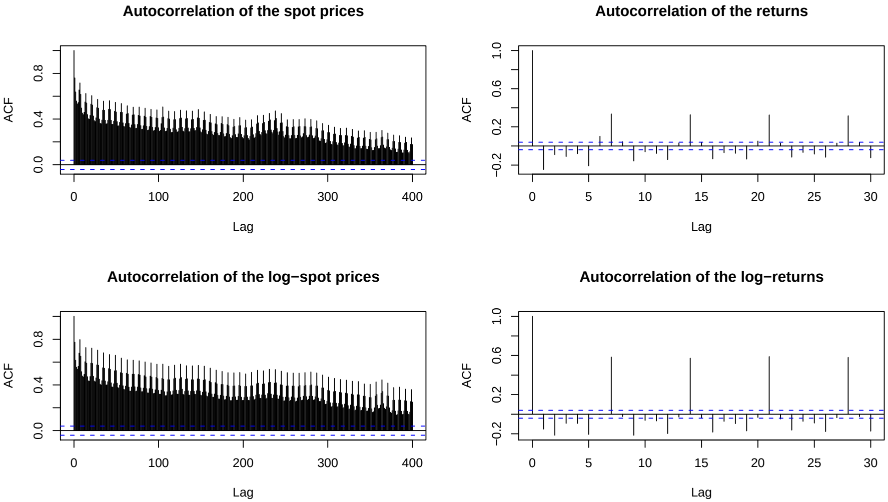
Phelix Day Base Index (June 2000 - December 2006)								
	N	Min	Median	Mean	Max	Sd	Skewn.	Kurtosis
All Season								
S_t	2390	3.12	28.61	32.12	301.50	17.81	3.54	32.10
ΔS_t	2389	-191.20	-1.08	0.00	200.80	12.34	0.69	66.35
$ln(S_t)$	2390	1.14	3.35	3.35	5.71	0.48	0.08	0.90
$\Delta ln(S_t)$	2389	-1.96	-0.04	0.00	1.74	0.32	0.66	1.97
Warm Season (May through September)								
S_t	1025	3.12	27.98	30.42	301.50	17.61	5.53	68.67
ΔS_t	1024	-191.20	-1.02	0.02	200.80	14.15	0.46	80.27
$ln(S_t)$	1025	1.14	3.33	3.30	5.71	0.48	0.00	0.92
$\Delta ln(S_t)$	1024	-2.21	-0.21	0.00	0.12	0.35	0.52	2.75
Cold Season (October through April)								
S_t	1365	3.47	28.91	33.39	162.20	17.86	2.16	7.69
ΔS_t	1364	-107.00	-1.05	0.00	101.70	10.86	0.97	19.36
$ln(S_t)$	1365	1.24	3.36	3.39	5.09	0.47	0.16	0.86
$\Delta ln(S_t)$	1364	-1.45	-0.04	0.00	1.12	0.30	0.66	1.32

Descriptive statistics II

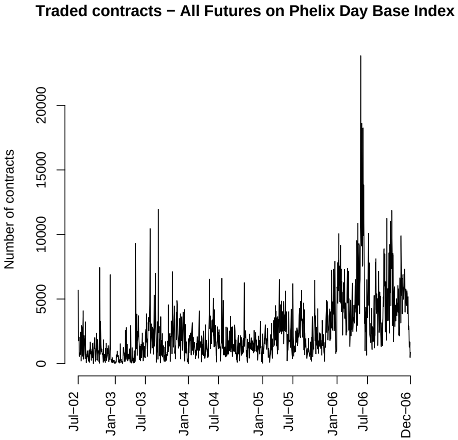


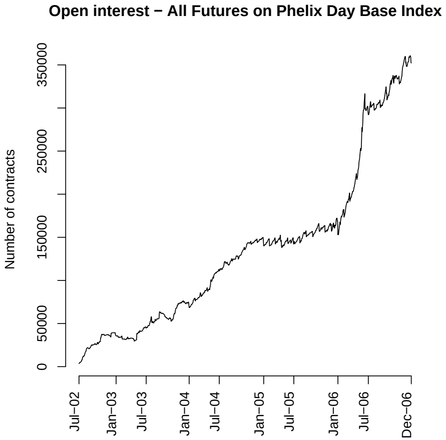


Descriptive statistics III



Descriptive statistics IV





Motivation - average holding period

- Average Holding Period analysis provides us with information about trading groups which are present at the EEX
- Immense volatility of the electricty prices (yearly volatility = 611 %) suggests high demand for hedging of the price risk
- Little or no possibility for arbitrage due to the specific characteristics of electricity points on increased share of hedgers in the participants portfolio
- Tools supporting this analysis are average holding period, smoothing-out ratio and relative holding period in comparison to the possible holding period

Methodology I

Smoothing-out ratio

$$SOR = \frac{\sum_{i=1}^{t_e} V_i - OI_{t_e}}{\sum_{i=1}^{t_e} V_i + OI_{t_e}}$$

Average holding period

$$AHP = \frac{2\sum_{i=1}^{t_e} OI_i}{\sum_{i=1}^{t_e} V_i + OI_{t_e}}$$

Relative average holding period

$$\text{relative } AHP = \frac{AHP}{\text{possible } AHP}$$

V_t = trading volume on day t $\quad$ OI_t = open interest in the future

Methodology II

Specific issues concerning the Phelix Futures Data

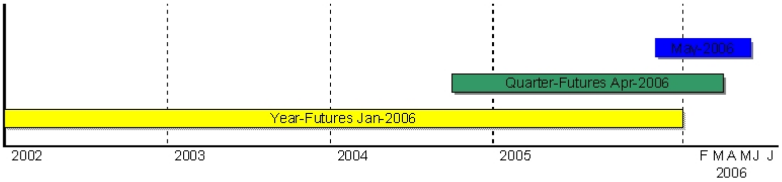
Open Interest Error:

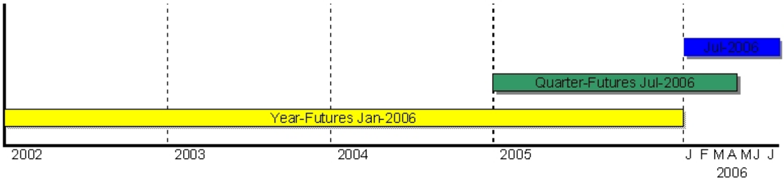
- Open interest contains errors due to settlement outside the exchange, which is being adjusted by the exchange
- The proper numbers can not be extracted, but a correction according to Dorfleitner(2004) may be applied

Cascading:

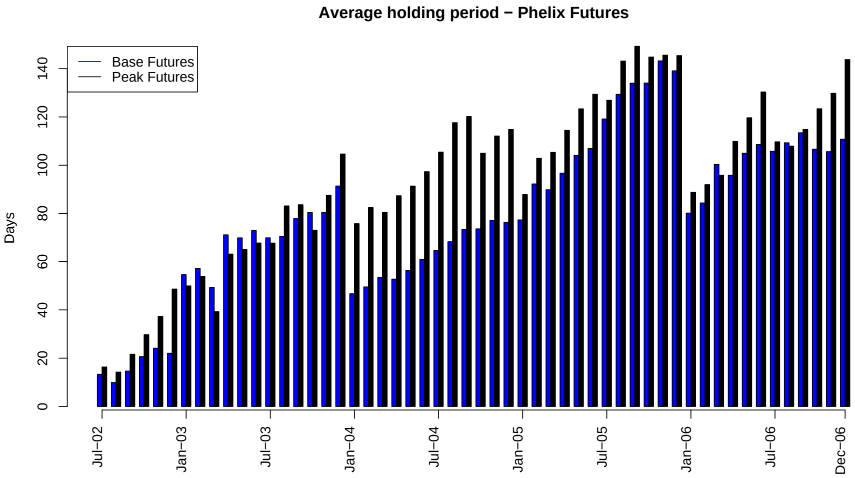
- Year and quarter futures are not settled by cash settlement, but at the beginning of the their delivery period allocated into shorter futures. This process is called cascading.

Methodology III

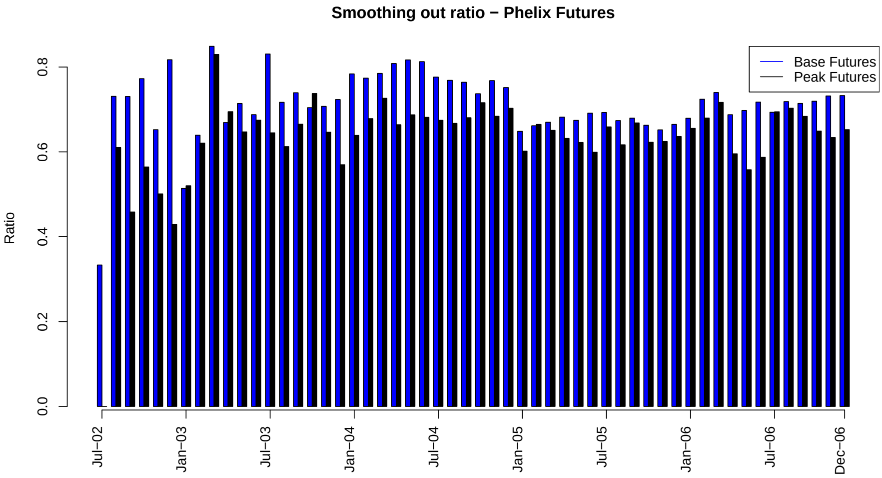




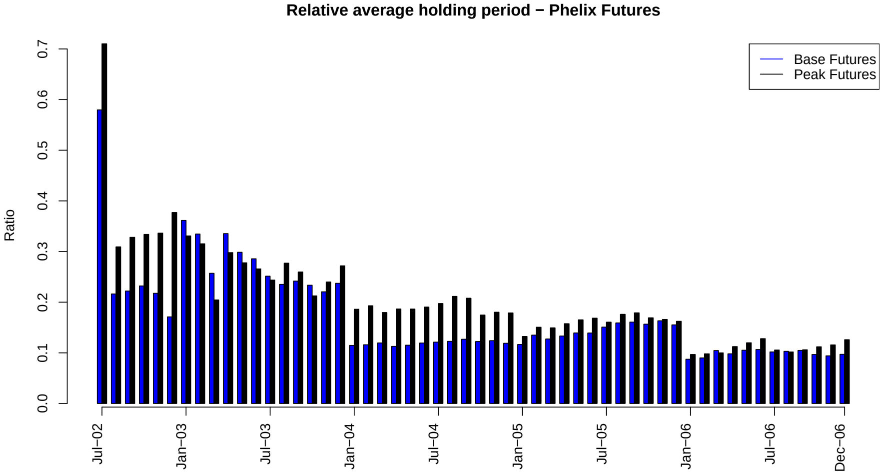
Average holding period



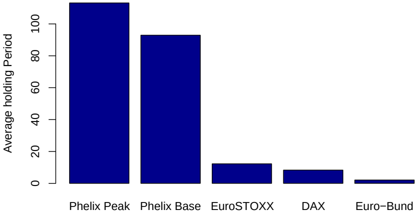
Smoothing-out ratio

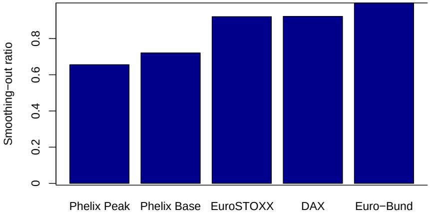


Relative average holding period



Comparison of different futures AHP and SOR





Hedging Problem

There is a certain month in the future (corresponding to a futures contract) in which some load l has to be bought.
Notation:

- f: today's price of the futures contract
- $\tilde{s}$: future settlement price (= average of the month's spot prices P)
- w: hedging ratio, i.e. number of futures
- $\tilde{c}$: future costs, i.e. spot price times load plus futures contract's pay off

$$\tilde{c} = -l \cdot \tilde{s} + (\tilde{s} - f) \cdot w$$

- U: utility function with $U(x) = -e^{-\lambda x}$

Hedging problem

$$\max_{w} \mathbb{E}\left[U(\tilde{c})\right]$$

Spot price model I

Lucia and Schwartz (2002) one factor spot price model

Model based on the price:

$$P_t = f(t) + X_t, \qquad (1)$$
$$dX_t = -\kappa X_t dt + \sigma dZ.$$

$$dP_t = \kappa(a(t) - P_t)dt + \sigma dZ$$
$$a(t) \equiv \frac{1}{\kappa}\frac{df}{dt}(t) + f(t).$$

Model based on the log price:

$$P_t = f(t) + Y_t, \qquad (3)$$
$$dY_t = -\kappa Y_t dt + \sigma dZ.$$

$$dP_t = \kappa(b(t) - lnP_t)P_t dt + \sigma P_t dZ,$$
$$b(t) \equiv \frac{1}{\kappa}\left(\frac{\sigma^2}{2} + \frac{df}{dt}(t)\right) + f(t).$$

$P_t \sim \mathbb{N}(\mu, \sigma^2)$:

$$\mathbb{E}_0[P_t] = f(t) + (P_0 - f(0))e^{-\kappa t},$$
$$\mathbb{V}_0[P_t] = \frac{\sigma^2}{2\kappa}(1 - e^{-2\kappa t}). \qquad (2)$$

$P_t \sim \mathbb{LN}(\mu_{LN}, \sigma_{LN}^2)$:

$$\mathbb{E}_0[lnP_t] = f(t) + (P_0 - f(0))e^{-\kappa t},$$
$$\mathbb{V}_0[lnP_t] = \frac{\sigma^2}{2\kappa}(1 - e^{-2\kappa t}). \qquad (4)$$

Spot price model II

Lucia and Schwartz (2002) one factor spot price model

The deterministic component $f(t)$:

$$f_1(t) = \alpha + \beta_{[1\times 12]} D_{t[12\times 1]}$$

$$D_t = \{d_{ti}\}$$

$$d_{ti} \in \{0,1\} \qquad i = 1\ldots 12$$

$$f_2(t) = \alpha + \beta H_t + \gamma \cos\left((t+\tau)\frac{2\pi}{365}\right)$$

$$H_t \in \{0,1\}$$

Estimation of the stochastic process:

$$z_t = \phi z_{t-1} + f(t) - \phi f(t-1) + u_t \qquad u_t \sim \mathbb{N}(0,\sigma^2) \tag{5}$$

Hedging procedure

1. Define hedging problem (hedging date h, strategy (load structure l))
2. Perform non-linear regression analysis using $P_t, lnP_t\ t \in [0, h]$ and derive $f_1(t), f_2(t)$ and ϕ
3. Use distribution assumption (equ. 2,4) to simulate the spot prices $\tilde{p}_i(i = 1...n)$
4. Use the autoregressive representation (equ. 5) of the stochastic process to calculate $p_{it}(t = 2 \ldots d)$
5. Calculte the settlement prices $\tilde{s}_i$
6. Perform optimisation:

$$\max_w \frac{1}{n} \sum_{i=1}^{n} U(\tilde{c}_i)$$

7. Calculate ex post performance ($\frac{1}{\#periods} \sum [U(s, f, l, w_{opt})]$) and compare with other strategies (no hedge ($w = 0$), naive hedge ($w = l/720$)).

Results - optimal hedging strategy I

Ex post performance July 2002 - June 2006:

load l in MWh	λ	month 1	2	3	4	5	6
500	0.01	Z	O	N	O	O	O
	0.002	O	O	N	N	N	N
	0.001	O	O	N	N	N	N
	0.0008	O	N	N	N	N	N
720	0.01	Z	O	N	O	O	O
	0.002	Z	O	N	N	O	O
	0.001	O	O	N	N	N	N
	0.0008	O	O	N	N	N	N
1000	0.01	–	–	–	–	–	–
	0.002	Z	O	N	N	O	O
	0.001	O	O	N	N	N	N
	0.0008	O	O	N	N	N	N

$O \ldots$ hedge with w_{opt} $\quad N \ldots$ naive hedge $w = l/720$ $\quad Z \ldots$ no hege $w = 0$

Results - optimal hedging strategy II

load l in MWh	λ	month 1	2	3	4	5	6
3000	0.01	–	–	–	–	–	–
	0.002	Z	O	N	O	O	O
	0.001	Z	O	N	N	O	O
	0.0008	Z	O	N	N	O	O
7000	0.01	–	–	–	–	–	–
	0.002	–	–	–	–	–	–
	0.001	Z	O	N	O	O	O
	0.0008	O	O	N	O	O	O
10000	0.01	–	–	–	–	–	–
	0.002	–	–	–	–	–	–
	0.001	–	O	N	N	O	O
	0.0008	Z	O	N	O	O	O

$O\ldots$ hedge with w_{opt} $N\ldots$ naive hedge $w = l/720$ $Z\ldots$ no hege $w = 0$

Further research

- Development of multiple hedging strategies
- Alternative objective functions (e.g. maximise expected payoff under a VaR constraint)
- Application of different spot price models (e.g. two factor models)

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The Journal of Futures Markets, Vol. 27,2007

Regression models

	Models based on the price				Models based on the log price			
	Model 1 (with $f_1(t)$)		Model 2 (with $f_2(t)$)		Model 3 (with $f_1(t)$)		Model 4 (with $f_2(t)$)	
Param.	Estim.	t-val.	Estim.	t-val.	Estim.	t-val.	Estim.	t-val.
α	37.9088	10.702***	35.6038	35.280***	37.9086	10.702***	3.4793	113.632***
β	−11.2500	−26.852***	−11.2557	−26.922***	−11.2500	−26.85***	−11.2557	−46.012***
γ			2.6878	1.915.			0.0804	1.885.
τ			10.9276	0.357			10.4397	0.336
β_2	1.1049	0.215			1.1051	0.2154		
β_3	−1.8062	−0.360			−1.8061	−0.360		
β_4	−4.4157	−0.8754			−4.4156	−0.875		
β_5	−7.4129	−1.480			−7.4128	−1.4804		
β_6	−3.8227	−0.771			−3.8226	−0.771		
β_7	−0.4610	−0.0964			−0.4608	−0.095		
β_8	−6.0758	−1.259			−6.0756	−1.259		
β_9	−1.6646	−0.342			−1.6645	−0.342		
β_{10}	−4.0156	−0.832			−4.0154	−0.832		
β_{11}	3.5366	0.727			3.5367	0.727		
β_{12}	−2.3633	−0.489			−2.3631	−0.489		
ϕ	0.7895	62.702***	0.7919	0.0125***	0.7895	62.701***	0.8515	79.141***
S.E.	10.16		10.15		0.221		0.2207	
RMSE	10.12975		10.14071		0.2203059		0.2204774	
RMSPE	0.2662922		0.2667118		0.07765395		0.07782557	

***,. = Significane at the $< 0.001, 0.05$ level.

The hedging problem I

Load structure matrix $\boldsymbol{L}$:

$$\boldsymbol{L}_{[n\times m]} = \{l_{ij}\} \qquad l_{ij} = l_{kj}\ \forall\ k = 1\ldots i\ldots n$$

$$j = \text{deliver period}(1\ldots m) \qquad n = \text{number of simulations}$$

Settlement price matrix $\tilde{S}$ and spot price matrix $\tilde{\boldsymbol{P}}$:

$$\tilde{\boldsymbol{S}}_{[n\times m]} = \{\tilde{s}_{ij}\} \qquad \tilde{s}_{ij} = \mathbb{E}\left[\tilde{\boldsymbol{P}}^{j}_{[1\times d]}\right] \qquad \tilde{\boldsymbol{P}}^{j}_{[1\times d]} = \{\tilde{p}^{j}_{t}\} \qquad t = 1\ldots d$$

$$d = \text{length of the delivery period}$$

Futures price matrix $\boldsymbol{F}$:

$$\boldsymbol{F}_{[n\times m]} = \{f_{ij}\} \qquad f_{ij} = f_{kj}\ \forall\ k = 1\ldots i\ldots n$$

The hedging problem II

Hedging ratio matrix $\boldsymbol{W}$:

$$\boldsymbol{W}_{[n\times m]} = \{w_{ij}\} \qquad w_{ij} = w_{kj} \ \forall\ k = 1\ldots i\ldots n$$

Cost matrix $\boldsymbol{C}$:

$$\boldsymbol{C}_{[n\times 1]} = \left(-\boldsymbol{L}_{[\boldsymbol{n}\times\boldsymbol{m}]} \cdot \tilde{\boldsymbol{S}}_{[n\times m]} + (\tilde{\boldsymbol{S}}_{[n\times m]} - \boldsymbol{F}_{[n\times m]}) \cdot \boldsymbol{W}_{[n\times m]} \right) \iota_{[m\times 1]}$$

Utility function $\boldsymbol{U}$:

$$\boldsymbol{U}_{[n\times 1]} = -e^{\left(-\lambda \boldsymbol{C}_{[n\times 1]}\right)}$$

Objective function:

$$\max_{\boldsymbol{W}} \left(\mathbb{E}\left[\boldsymbol{U}_{[n\times 1]} \right] \right)$$