Intra-Day Risk Premia in European Electricity Forward Markets

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OVERVIEW

- Motivation for Estimating "Market Price of Risk" $\frac{\mu}{\sigma}$ for Energy Prices
- Expected Returns on Energy Futures — A Two-Factor Perspective
- Day-Ahead Electricity Returns: The U. S. Experience
- Unique Natural Experiment: Central Europe Day-Ahead Electricity Contracts
- Empirical Results

Definition and Motivation

- The "Market Price of Risk" (MPR) is
  - Compensation per unit standard deviation, so that $\mu_t = \lambda\sigma_t$
  - Assumption of MPR constancy motivated by behavioral attribute of constant compensation *per unit* standard deviation
- The MPR for electricity and natural-gas prices determines whether forward prices in energy are upward- or downward-biased predictors of future expected spot prices: Under the assumption of a constant MPR,

$$\begin{aligned} dF &= \mu_t F\,dt + \sigma_t F\,dz = \lambda\sigma_t F\,dt + \sigma_t F\,dz \\ \Longrightarrow \quad E(F_T) &= F_0 \exp\left\{\lambda \int_0^T \sigma_t\,dt\right\} \end{aligned}$$

- Implications:
  - Sign of λ determines $F_0 \neq E(F_T)$ relationship:

    $$\lambda > 0 \quad \Longrightarrow \quad F_0 < E(F_T) \qquad \text{and} \qquad \lambda < 0 \quad \Longrightarrow \quad F_0 > E(F_T)$$
  - Understanding the relationship between energy markets and other physical and financial markets
  - Incorporating risk premium in making informed hedging decisions
  - Relating futures prices to the forecast prices produced by industry

Expected Returns on Energy Futures Contracts — A Two-Factor Perspective

- Under the two-factor Schwartz-Smith model, each futures contract price F_T satisfies

$$d \ln F_T = \exp\{-\kappa T\}\, d\chi_t + d\xi_t \qquad (1)$$

  where returns are driven by *two* priced factors:

  1. A short-term, mean-reverting factor:
     - This is a factor that typically represents *supply-side* uncertainty, caused by either geopolitical, meteorological or facility-outage disruption
     - Risk is to the *up*-side (i.e., "spike")
  2. A long-term (non-mean reverting factor)
     - Driven primarily by economic growth
     - A "*positive*-beta" effect: Demand for oil, and consequently oil *prices*, expected to rise with world economic output
     - Risk is to the down-side (i.e., recession)

- Effect of the short-term factor decays with oil futures' maturities: More effect in the closer months, less in the longer months $\Longrightarrow$ First factor dominates in the earlier months

Selected Studies on Short-Term Risk Premia in Electricity Markets

- *Evidence for the Forward (Risk) Premium (RP):**
  - Positive RP between day-ahead forwards and real-time contracts for baseload at the PJM-market (e.g., Geman/Vasicek (2001), Pirrong/Jermakyan (2005))
  - Positive (negative) RP between day-ahead forwards for peakload (off-peak load) in the OTC market and at the EEX (Diko/Lawford/Limpens (2006))
  - Positive RP between week futures and day-ahead forwards for baseload at Nord Pool (Bühler/Müller-Merbach (2007), Lucia/Torro (2007))
- *Evidence for the Market Price of Risk (MPR):*
  - Negative MPR based on day-ahead forwards and real-time contracts for baseload at the PJM-market (Kolos/Ronn (2008))
  - Negative MPR based on monthly futures and day-ahead forwards for baseload at Nord Pool (Ollmar (2003), Weron (2008))
- Sign and magnitude of RP and MPR may vary across forward maturities depending on the hedging pressure from producers and consumers (Benth/Cartea/Kiesel (2008))

* Note that some studies use risk premium definitions different from ours; we adapt the results to make them comparable to our findings

Day-Ahead Electricity Returns:
The U. S. Experience

- Longstaff and Wang (2002) analyzed daily and hourly electricity-price data:

  "On average, the expected spot price is nearly 6.4% higher than the day-ahead forward price .... For most of the hours, the median premia are negative, and the overall median across hours is −6.3%. This suggests that the forward premium represents compensation for bearing the 'peso-problem' risk of rare but catastrophic shocks in electricity prices."

- Kolos and Ronn (2003): Using day-ahead prices,

$$\ln \frac{\mathrm{RT}_{tT}}{\mathrm{DA}_{tT}} = \left(\lambda \sigma_T - \frac{\sigma_T^2}{2} \right) \Delta t + \sigma_T \sqrt{\Delta t}\, \varepsilon_T$$

  where RT is real-time, and DA day-ahead, prices. Finding $\lambda = -1.82$, they conclude:

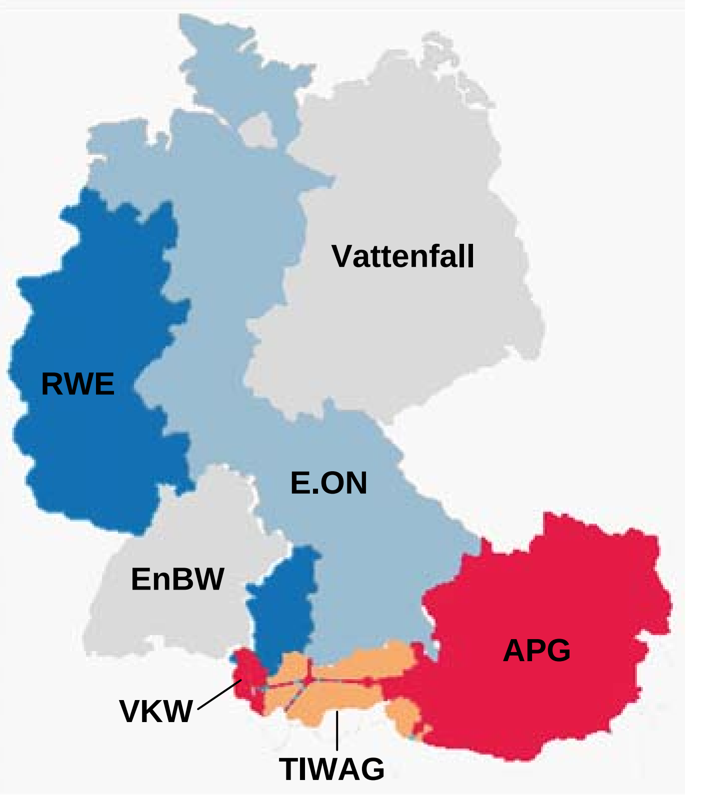
  "The MPR for Day-ahead PJM prices is significantly negative for all seasons but Spring. ... [T]he market appears to have ... priced average *daily* prices at a premium relative to the average [realized] hourly prices, compensating those giving up the price-spikiness of spot hourly electricity prices by selling a fixed-price in the day-ahead market."

German and Austrian Electricity Markets and Exchanges

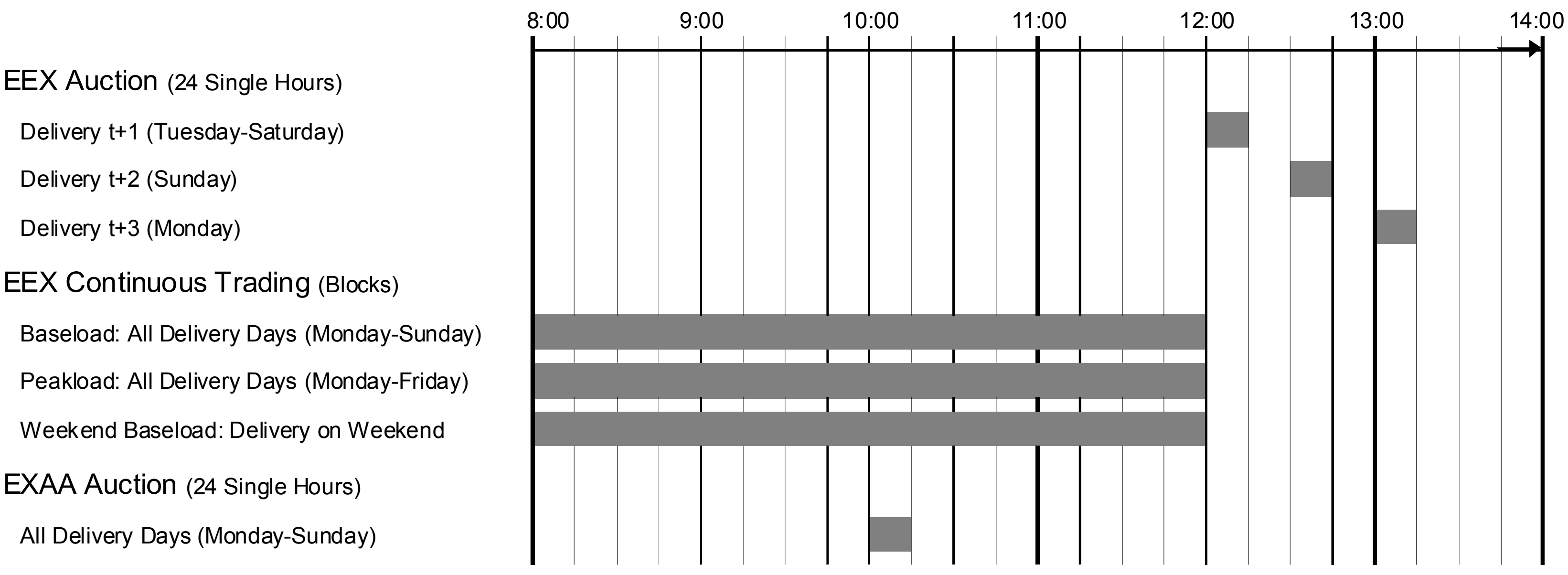
- Germany largest market in Europe in terms of electricity production and consumption; roughly ten times larger than Austrian market
- German, Austrian and Swiss market the hub for physical electricity exchange in Europe
- Both German and Austrian market 100% opened to competition according to European Commission, e.g., fair access to electricity networks
- High concentration in generation and transmission of electricity in both markets; generation in Germany balanced between fuels and in Austria mainly from hydropower
- High concentration in generation no suitable measure for market power potential in the day-ahead markets as only available capacity relevant; major generators typically sell most of their production in the forward market well in advance of delivery
- *European Energy Exchange (EEX)* founded in 1999 and merged with the Leipzig Power Exchange in 2001; day-ahead market since June 2000
- *Energy Exchange Austria (EXAA)* founded in 2001; day-ahead market since March 2002
- Trading volume of 86 TWh at the EEX in 2005 roughly 55 times larger than at the EXAA

Delivery Zones for Physical Delivery of EEX and EXAA Day-Ahead Forwards

- Deliver zones of EEX contracts:
  - All German TSO zones (EnBW, E.ON, RWE, Vattenfall)
  - Largest Austrian TSO zone (APG) since April 2005
- Delivery zones of EXAA contracts:
  - All Austrian TSO zones (APG, TIWAG, VKW)
  - Two largest German zones since June 2004 (E.ON) and May 2005 (RWE) re-spectively
- No transmission restrictions between these TSO zones in the high-voltage network



Trading of Day-Ahead Electricity Forwards at the EEX and EXAA



Day-Ahead Electricity Forwards at the EEX and EXAA

- Day-ahead forwards with physical delivery of electricity in the German or Austrian delivery zones on the next calendar day(s); time-to-maturity of one to three days
- Three different market segments for day-ahead forwards:
  - *EEX Continuous segment:* Baseload and peakload block contracts
  - *EEX Auction segment:* 24 single hours and combination of hours to blocks*
  - *EXAA Auction segment:* 24 single hours and combination of hours to blocks*
- Trading in continuous segment infrequent and volume fraction of EEX auction segment
- Transaction costs at the three segments virtually the same
- Prices of day-ahead forwards for base- and peakload employed for empirical analyses:
  - EEX data from August 2002 to September 2007 (in August 2002 switch to common trading system after merger)
  - EXAA data from June 2004 to September 2007 (in 2004 export fees abandoned, in June 2004 German delivery zone introduced)

* Block bids do not form separate products and their prices are based on the average of the respective single hours

Descriptive Statistics for Day-Ahead Forward Prices (1/2)

A. EEX Indices from August 2002 to September 2007*

Working Days	N	Mean	Min.	Max.	Std.dev.	Skewn.	Kurtosis
EEX Auction Base	1.304	41,17	12,40	301,54	19,24	4,19	36,65
EEX Auction Peak	1.304	52,12	15,86	543,72	30,15	6,31	73,71
EEX Continuous Base	801	42,08	12,00	179,33	20,10	2,55	10,29
EEX Continuous Peak	883	54,69	16,67	288,42	28,82	3,23	16,67
Non-Working Days							
EEX Auction Base	583	25,56	3,12	66,77	10,20	0,95	1,40
EEX Auction Peak	583	28,91	0,80	79,55	11,50	1,06	1,97
EEX Continuous Base	183	22,49	5,25	62,00	9,33	1,21	2,34
EEX Continuous Weekend Base*	127	25,38	10,68	56,25	9,97	1,45	1,61

* The time series for EEX Continuous Weekend Base starts in November 2002.

Estimating Ex-Post Risk Premia

- Forward (risk) premium = investor compensation for bearing risk of holding the asset
- The *ex-ante* risk premium is $F_t - E_t(S_T)$
- Under rational expectations the *ex-post* risk premium ($RP = F_t - S_T$) equals the *ex-ante* risk premium plus random noise
- The risk premium between the prices of two forwards with the same delivery period i, deliver day and other contract specifications but different trading times t_1 and t_2 (with $t_1 < t_2$) can be defined as

$$RP_{it} = E_t\left(F_{i,t_1} - F_{i,t_2}\right)$$

- An estimate of the *ex-post* risk premium is given by the sample mean of the differences

$$E\left(RP_{it}\right) = \frac{1}{T}\sum_{t=1}^{T}\left(F_{i,t_1} - F_{i,t_2}\right)$$

Risk Premia between Forward Prices in EUR (1/2)

A. Risk Premia between EEX Forward Prices from August 2002 to September 2007*

Working Days	N	Mean		Min.	Max.	Std.dev.	Skewn.	Kurtosis
EEX (Continuous - Auction) Base	801	0,65	+	-131,54	128,94	11,58	-2,27	70,92
Monday	127	1,98	+++	-34,26	36,01	6,36	0,25	14,43
Tuesday - Friday	674	0,40		-131,54	128,94	12,30	-2,21	65,58
EEX (Continuous - Auction) Peak	883	1,27	+	-255,30	190,45	20,75	-4,41	74,45
Monday	142	3,51	+++	-56,69	69,24	12,26	0,82	11,53
Tuesday - Friday	741	0,84		-255,30	190,45	21,99	-4,41	69,71

Non-Working Days	N	Mean	Min.	Max.	Std.dev.	Skewn.	Kurtosis
EEX (Continuous - Auction) Base	183	0,06	-6,56	8,37	2,69	0,31	0,13
Saturday	83	-0,15	-6,56	8,37	2,96	0,38	0,06
Sunday	80	-0,05	-5,56	5,84	2,15	0,04	0,24
EEX (Continuous Weekend - Auction) Base*	127	-0,01	-7,06	9,25	2,65	0,42	1,11

+++ (++, +) indicates significance at the 1% (5%, 10%) level according to t-statistics based on autocorrelation and heteroskedasticity consistent estimates of the variances.

* The time series for EEX Continuous Weekend Base starts in November 2002.

Risk Premia between Forward Prices in EUR (2/2)

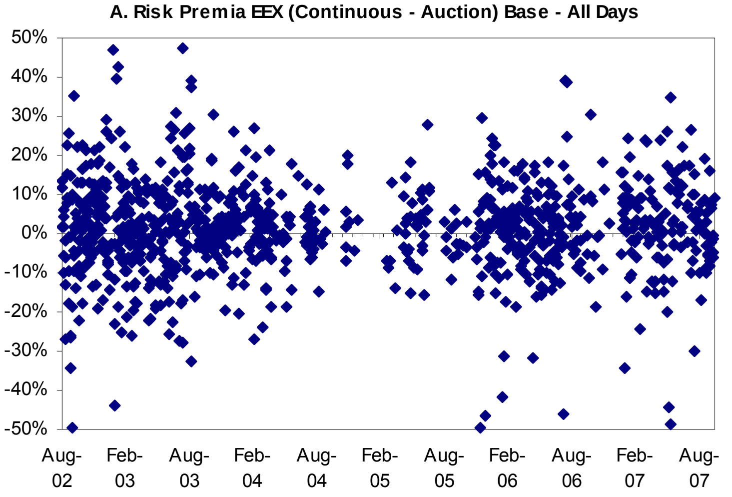
B. Risk Premia between EEX and EXAA Auction Forward Prices from June 2004 to September 2007

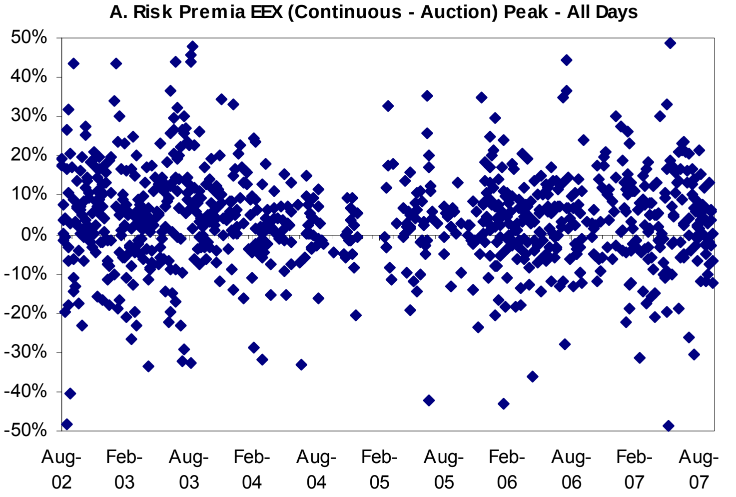
Working Days	N	Mean		Min.	Max.	Std.dev.	Skewn.	Kurtosis
(EXAA - EEX) Auction Base	829	0,24		-123,69	69,26	9,40	-5,61	75,78
Monday	160	1,00	+	-27,34	39,32	6,55	1,63	13,18
Tuesday - Friday	669	0,06		-123,69	69,26	9,96	-5,93	73,53
(EXAA - EEX) Auction Peak	829	0,28		-243,73	137,52	17,67	-6,46	92,77
Monday	160	1,20		-52,93	66,37	11,50	1,20	14,18
Tuesday - Friday	669	0,06		-243,73	137,52	18,85	-6,64	87,96

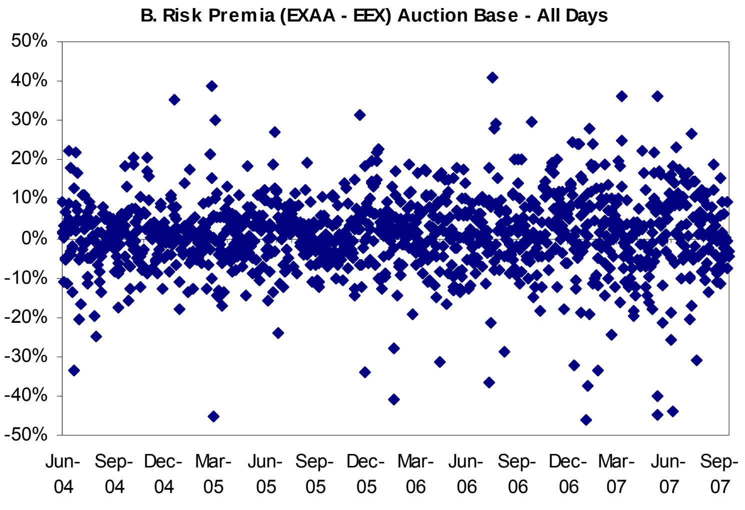
Non-Working Days	N	Mean		Min.	Max.	Std.dev.	Skewn.	Kurtosis
(EXAA - EEX) Auction Base	366	0,29		-10,93	9,83	2,95	0,16	0,57
Saturday	174	0,02		-10,93	9,83	3,32	0,11	0,42
Sunday	172	0,44	++	-5,10	7,39	2,41	0,37	0,11
(EXAA - EEX) Auction Peak	367	0,40	+	-14,22	12,64	3,45	0,20	1,70
Saturday	174	-0,11		-14,22	12,64	4,00	0,20	1,42
Sunday	173	0,77	+++	-5,13	9,24	2,66	0,74	0,47

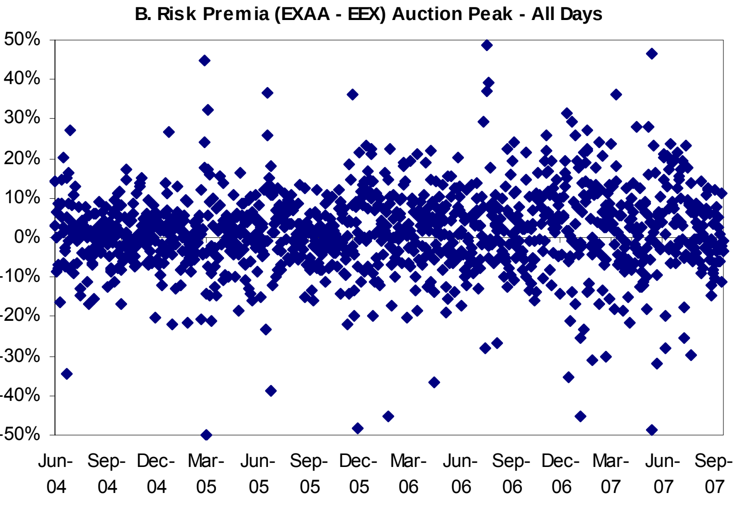
+++ (++, +) indicates significance at the 1% (5%, 10%) level according to t-statistics based on autocorrelation and heteroskedasticity consistent estimates of the variances.

Risk Premia in % of Forward Price









Estimating the Market Price of Risk (1/4)

- For a costless-to-enter forward contract the market price of risk is the expected rate-of-return compensation per unit standard deviation of returns [$\lambda_F = \mu_F / \sigma_F$]
- To account for the different time intervals between t_1 and t_2, we define the daily return as one-hour log return of forward price at t_2 divided by the one at t_1
- Four different estimators for the MPR employed to ensure robustness of result
- *Parametric Estimator (MPR_A):* Following Kolos and Ronn (2008) and assuming a constant* MPR, the evolution of the forward price is described by the following SDE

$$dF = \mu_t F dt + \sigma_t F dz = \lambda \sigma_t F dt + \sigma_t F dz$$

- In our case of no TSOV, discretizing the SDE gives

$$\ln \frac{F_{t_2}}{F_{t_1}} = \left(\lambda \sigma_T - \frac{\sigma_T^2}{2} \right) \Delta t + \sigma_T \sqrt{\Delta t}\, \varepsilon_T$$

* The assumption of a *constant* market price of risk is motivated by the plausible behavioral attribute of constant risk premium *per unit* standard deviation.

Estimating the Market Price of Risk (2/4)

- Under the assumption of a constant σ_t within a given season and no TSOV the maximum likelihood estimator of the MPR reduces to

$$\lambda = \frac{\mathrm{Ave}\left(\ln \frac{F_{t_2}}{F_{t_1}}\right)}{\Delta t\, \sigma} + \frac{\sigma}{2} \quad \text{with} \quad \sigma = \sqrt{\frac{\mathrm{Var}\left(\ln \frac{F_{t_2}}{F_{t_1}}\right)}{\Delta t}}$$

- *Non-Parametric Estimator (MPR_B)*: A good but not the best estimator for the MPR is

$$\lambda = \frac{\mu}{\sigma}$$

- *Non-Parametric Estimator (MPR_C)*: A less volatile measure for the MPR is

$$\lambda = \frac{1.34898 \cdot \mathrm{median}}{Q3 - Q1}$$

- For annualizing MPR_B and MPR_C, we multiply with $1/\sqrt{\Delta t}$ where Δt = 1/(24*365)
- Non-parametric bootstrapping is applied to estimate standard errors for the MPRs

Estimating the Market Price of Risk (3/4)

- *Non-Parametric Estimator (MPR_D)*: To account for the occasional price spikes in electricity markets and corresponding heavy-tailed return distribution, we estimate a jump-diffusion model using maximum likelihood methods. From

$$d\ln F = \mu\, dt + \sigma\, dz + J\, dq$$

we get conditional on no-jump

$$E\left(\ln F_{t_2} - \ln F_{t_1}\right) = \mu\,\Delta t$$
$$E\left(\ln F_{t_2} - \ln F_{t_1}\right) = \sigma^2 \Delta t$$

and further, conditional on a jump event occurring

$$E\left(\ln F_{t_2} - \ln F_{t_1}\right) = \mu\,\Delta t + \alpha$$
$$E\left(\ln F_{t_2} - \ln F_{t_1}\right) = \sigma^2 \Delta t + \gamma^2$$

- "Maximization of the log-likelihood function" $\sum_t \ln x_t$ where

$$x_t \equiv (1 - \kappa\,\Delta t)\, n\left[\ln \frac{F_{t_2}}{F_{t_1}}, \mu\,\Delta t, \sigma^2 \Delta t\right] + (\kappa\,\Delta t)\, n\left[\ln \frac{F_{t_2}}{F_{t_1}}, \mu\,\Delta t + \alpha, \gamma + \sigma^2 \Delta t\right]$$

Estimating the Market Price of Risk (4/4)

- An estimate of the MPR, where we ignore elements of order $(\Delta t)^2$, is given by

$$\lambda = \frac{\text{Expected Rate of Return}}{\text{Standard Deviation}} = \frac{(1-\kappa\,\Delta t)\mu\Delta t + \kappa\Delta t(\mu\Delta t + \alpha)}{\sqrt{\sigma^2\Delta t + \gamma^2}}$$

$$\cong \Delta t \frac{\mu + \kappa\alpha}{\sqrt{\sigma^2\Delta t + \gamma^2}}$$

- The annualized instantaneous MPR based on one-hour log-returns is then

$$\lambda = \frac{\mu + \kappa\alpha}{\sqrt{\sigma^2 + \gamma^2}}$$

- For computing standard errors we adopt the approach by Ball and Torous (1983, 1985)

Market Price of Risk for Electricity Forward Prices (1/2)

- Annualized MPR estimates based on parametric (MPR_A) and non-parametric (MPR_{B-D}) estimators
- Baseload (constant delivery of electricity on calendar day, 0:00-24:00 CET) and peakload (day between Monday and Friday, 8:00-20:00)

A. Market Price of Risk - EEX Indices from August 2002 to September 2007

Working Days	r_{Mean}	$r_{Std.dev.}$	MPR_A	MPR_B	MPR_C	MPR_D
EEX (In Auction - In Continuous) Base	-0.009 +++	0.065	-9.457	-12.490	-17.168	-22.187
Monday	-0.016 +++	0.038	-38.016 +++	-39.797	-38.901	-51.500
Tuesday - Friday	-0.007 +++	0.069	-6.648	-9.859	-13.230	-18.062
EEX (In Auction - In Continuous) Peak	-0.015 +++	0.078	-14.475 ++	-18.110	-29.848	-33.272
Monday	-0.020 +++	0.045	-39.282 +++	-41.407	-40.639	-61.228
Tuesday - Friday	-0.014 +++	0.082	-12.110	-15.967	-27.250	-30.157

Non-Working Days						
EEX (In Auction - In Continuous) Base	-0.006	0.075	-3.814	-7.344	6.935	-11.628
Saturday	0.000	0.053	2.896	0.430	17.921	0.821
Sunday	0.003	0.054	8.078	5.552	4.771	6.660

+++ (++, +) indicates significance of the one-hour ln returns and MPR_A at the 1% (5%, 10%) level according to classic t-statistics.

Market Price of Risk for Electricity Forward Prices (2/2)

- Annualized MPR estimates based on parametric (MPR_A) and non-parametric (MPR_{B-D}) estimators
- Baseload (constant delivery of electricity on calendar day, 0:00-24:00 CET) and peakload (day between Monday and Friday, 8:00-20:00)

B. Market Price of Risk - EEX and EXAA Auction Indices from June 2004 to September 2007

Working Days	r_{Mean}	$r_{Std.dev.}$	MPR_A	MPR_B	MPR_C	MPR_D
(ln EEX - ln EXAA) Auction Base	-0.005 +++	0.054	-6.906	-9.434	-17.269	-16.061
Monday	-0.007 ++	0.032	-17.658 +++	-19.173	-14.321	-28.931
Tuesday - Friday	-0.005 ++	0.058	-5.609	-8.324	-18.263	-13.815
(ln EEX - ln EXAA) Auction Peak	-0.008 +++	0.066	-8.038	-11.116	-22.309	-19.783
Monday	-0.006 +	0.039	-12.398 +++	-14.229	-17.948	-32.697
Tuesday - Friday	-0.008 +++	0.071	-7.625	-10.933	-26.030	-19.199

Non-Working Days						
(ln EEX - ln EXAA) Auction Base	-0.006 ++	0.051	-7.882 +	-10.276	-4.945	-12.810
Saturday	-0.001	0.054	0.988	-1.517	9.884	-3.533
Sunday	-0.007 ++	0.041	-14.300 +++	-16.210	-13.190	-36.357
(ln EEX - ln EXAA) Auction Peak	-0.006 ++	0.049	-9.732 ++	-12.032	-5.831	-16.295
Saturday	0.001	0.052	5.000	2.586	12.391	4.543
Sunday	-0.010 +++	0.038	-23.371 +++	-25.157	-13.956	-57.934

+++ (++, +) indicates significance of the one-hour ln returns and MPR_A at the 1% (5%, 10%) level according to classic t-statistics.

Summary

- Finance theory suggests futures prices are biased predictors of future spot prices
- In our case the day-ahead forward traded earlier in the day serves as “forward price” for the subsequently realized day-ahead (“spot”) price
- For both the intra-market and inter-market sample there is evidence for a positive risk premium, indicating that market participants are willing to pay a premium to secure day-ahead delivery of electricity earlier in a trading day
- Consistent with the positive risk premium there is evidence for a negative market price of risk
- Thus, the prices of short-term electricity forwards are upward-biased predictors of expected electricity spot prices