Risk Premiums for CO_2 Emission Allowances in the EEX Market

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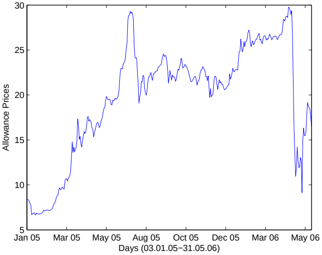
History of Emission Trading in Europe

- 1997: Kyoto Protocol
- 2002: EU Common Agreement on Emission Trading Scheme.
- 2005: EU-wide CO_2 emissions trading system entered into operation
- 2005-2007: pilot trading period
- 2008-2012: first Kyoto commitment period

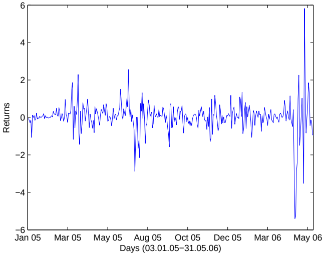
The European Energy Exchange (EEX) in Leipzig

- 1996: EU Directive Guidelines for Liberalisation of Power Markets
- 1998: Deregulation of German Power Market
- 2000: Energy Exchanges EEX in Frankfurt and LPX in Leipzig
- 2002: Merge of LPX and EEX results in EEX in Leipzig

Spot Price Behavior



(a) Spot Prices



(b) Returns

Figure 1: Allowance prices and returns for trading period Jan 3, 2005 - May 31, 2006.

Spot and Futures prices

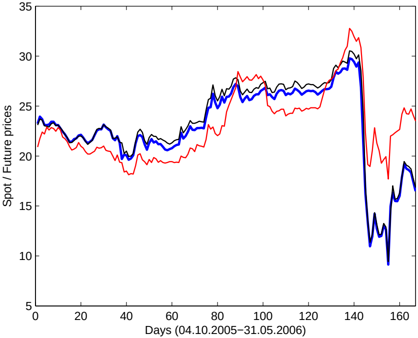


Figure 2: Spot price (blue) and futures prices for delivery in November 2006 (black) and November 2009 (red).

Emission Allowance Price Behavior (cont.)

Similar to other commodities, emission allowance spot and futures prices show features like:

- High Volatility
- Excess Kurtosis and Heavy Tails
- Price Shocks
- Dynamic Term Structure of Futures Prices
- Stochastic Behavior of Risk Premiums

General Questions

- Relationship between spot and futures prices
- Similarity of convenience yields to other commodity markets
- Effects of price shocks on the risk premiums
- Backwardation or contango market
- Term structure dynamics
- Dynamic models for risk premiums and convenience yields

Outline

Market Participants and Sanctions

- All combustion installations exceeding 20 MW will be affected by the trading scheme
- Allowance equals emission of 1 ton of CO_2.
- Emission allowances can be regarded as a factor of production.
- Banking of Emissions from pilot period to Kyoto-commitment period is left up to individual member states.
- Sanction Payment per missing ton of CO_2 allowances:
  - 40 Euro during pilot period
  - 100 Euro during commitment period

The EEX Futures Market for Allowances

- futures contract: agreement to deliver a specified quantity of allowances at a specified future date
- delivery at last trading day in November of the particular year
- marked-to-market at each trading day
- futures traded for pilot period 2006, 2007 and for Kyoto period 2008-2012

Price Behavior of Commodities

- tendency to decline in futures prices with time-to-delivery, also called backwardation (Litzenberger and Rabinowitz, 1995)
- seasonality and mean-reversion (Schwartz, 1997)
- heteroscedasticity (Duffie and Gray, 1995)
- price volatility positively correlated with the degree of backwardation (Ng and Pirrong, 1994)
- declining term structure of commodity forward price volatility (Samuelson, 1965)

Backwardation and Contango

$F_{t,T}$ - futures price at time t for delivery at time T
S_t - current spot price in t
$e^{r\tau}S_t$ - the expected spot price in T with $\tau = T - t$
Distinction between the following situations:

Market Situation	Relation: Spot and Future
Backwardation	$F_{t,T} \leq S_t$
Normal Backwardation	$F_{t,T} \leq e^{r\tau}S_t$
Contango	$F_{t,T} > S_t$
Normal Contango	$F_{t,T} > e^{r\tau}S_t$

Backwardation

Backwardation (Keynes, 1930):

- immediate ownership of the commodity entails some benefit or convenience which a long forward position does not
- hedgers tend to hold short positions in futures as insurance against their cash position
- they must pay speculators a return to hold long positions in order to offset their risk
- normal backwardation is equivalent to a positive risk premium since the risk is transferred to the long position in futures

Contango

Contango (Oxford Dict. *arbitrary or fortuitous formation from continue.*), first mentioned in 1853 by Liverpool stockbrokers:

- can be interpreted as consumers buying insurance against raising prices
- suggests currently available supply but medium-to-long-term shortages of a commodity
- speculators must be rewarded for holding short positions in futures to offset their risk

Samuelson Effect

The term structure of commodity **forward price volatility** typically declines with contract horizon (Samuelson, 1965).

Violations of this pattern occur when inventory is high (Fama and French, 1988).

In particular, forward price volatilities can initially increase with contract horizon.

Convenience Yields

Assume that there are no possibilities for arbitrage between the spot and futures market. Then the following relation between S_t and $F_{t,T}$ can be derived (Pindyck, 2001):

$$\psi_\tau = S_t e^{r_\tau (T-t)} - F_{t,T} \tag{1}$$

with
r_τ: the risk-free interest rate for the period $T - t$
ψ_τ: the so-called **convenience yield** for the period $T - t$

Convenience Yields

- The convenience yield obtained from holding a commodity can be regarded as being similar to the dividend obtained from holding a company's stock.
- It represents the privilege of holding a unit of inventory, for instance to be able to meet unexpected demand.
- As the price of a stock can be regarded as the present value of the expected future flow of dividends, the price of a commodity is the present value of the expected future flow of convenience yields.

The Data

The data comprises emission allowance spot and futures prices traded at EEX in Leipzig:

- considered period: Oct 4, 2005 - May 31, 2006
- spot price, futures prices for delivery periods Nov 2006, 2007,...,2012
- riskless yields for matching time periods
  - long term: swap based zero coupon yields
  - short term: zero coupon yields of European Index
  - use linear interpolation to match time horizons

Price Correlations

Delivery	Spot	2006	2007	2008	2009	2010	2011	2012
Spot	1	0.996	0.991	0.709	0.678	0.647	0.618	0.588
2006		1	0.998	0.722	0.693	0.664	0.635	0.606
2007			1	0.749	0.723	0.697	0.671	0.644
2008				1	0.998	0.992	0.984	0.974
2009					1	0.998	0.993	0.986
2010						1	0.998	0.994
2011							1	0.999

Correlations between daily spot and futures prices.

Contango or Backwardation?

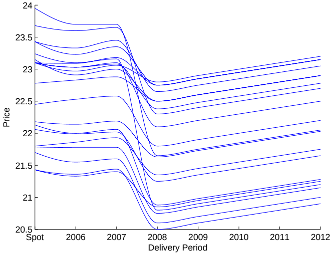


Figure 3: Term structure for spot and futures prices for each day, initial trading period Oct 4 - 31, 2005. (*left panel*) and January 1 - 31, 2006 (*right panel*).

Contango or Backwardation?

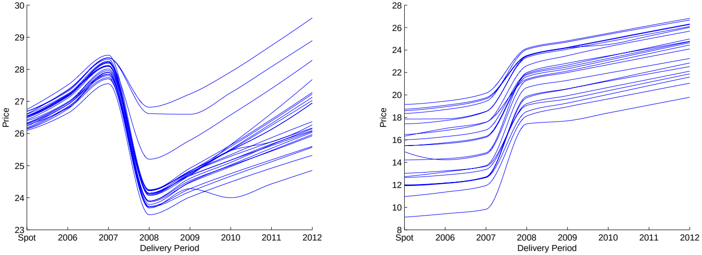


Figure 4: Term structure for spot and futures prices for each day, initial trading period March 1 - 31, 2006. (*left panel*) and May 1 - 31, 2006 (*right panel*).

Samuelson Effect?

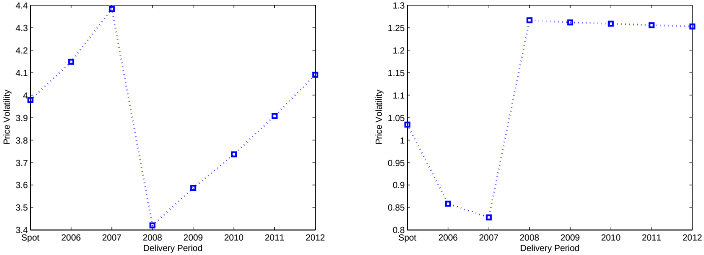


Figure 5: Volatility for spot and futures prices from Oct 4, 2005 - May 31, 2005 (*left panel*) and Oct 4, 2005 - Dec 31, 2005 (*right panel*).

Samuelson Effect?

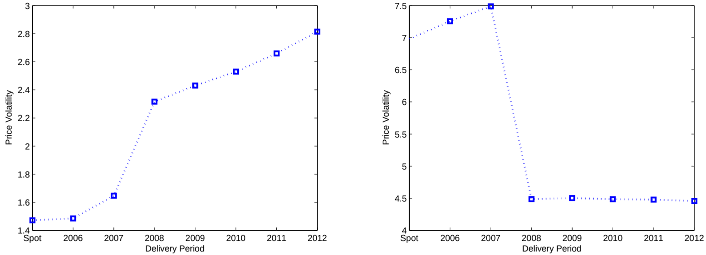


Figure 6: Volatility for spot and futures prices from January 2, 2006 - March 31, 2006 (*left panel*) and April 3, 2006 - May 31, 2006. (*right panel*).

Convenience Yields

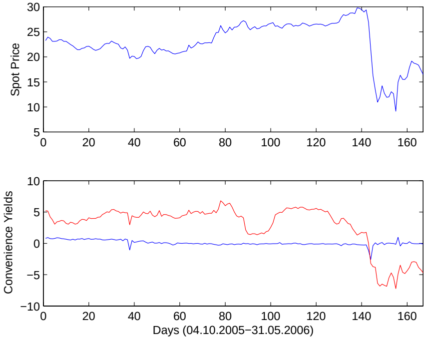


Figure 7: *Upper Panel:* Spot prices (EUR/ton) from Oct 4, 2005 - May 31, 2006. *Lower Panel:* Convenience yields (EUR/ton) in futures prices for delivery on Nov 2006 (red) and Nov 2009 (blue).

Convenience Yields

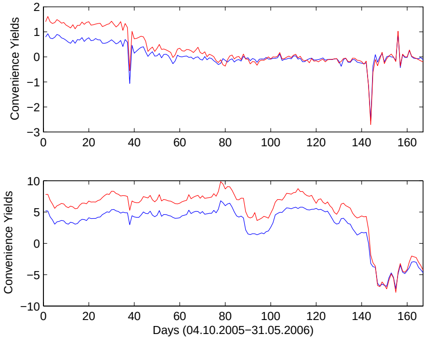


Figure 8: *Upper Panel:* Convenience yields (EUR/ton) for futures with delivery in Nov 2006 (blue) and Nov 2007 (red). *Lower Panel:* Convenience yields for futures with delivery in Nov 2009 (blue) and Nov 2012 (red)

Significance of Convenience Yields

Maturity	Mean	Std.	p-value	Min	Max	Skew	Kurt
2006	0.0807	0.4162	0.0132	-2.5501	0.9577	-1.1465	11.7567
2007	0.2897	0.6435	0.0000	-2.7060	1.6088	0.0906	4.6938
2008	2.3426	3.1899	0.0000	-7.3871	5.9008	-1.5954	4.4374
2009	2.9008	3.4159	0.0000	-7.2254	6.7947	-1.6509	4.5487
2010	3.5490	3.6505	0.0000	-7.4642	7.7495	-1.7111	4.7195
2011	4.2562	3.8953	0.0000	-7.6728	8.7584	-1.7559	4.8550
2012	5.0364	4.1561	0.0000	-7.8370	9.8560	-1.7915	4.9627

Table 1: Descriptive Statistics and p-value for t-test with $H_0 : \psi = 0$.

Explaining Convenience Yields

Pindyck (2001) suggests that the convenience yield depends on:

- the current price level
- the price volatility
- the level of storage

We test the following simple model:

$$\psi_t = \beta_0 + \beta_1 S_t + \beta_2 v_{S_t} + \varepsilon_t \qquad (2)$$

where v_{S_t} denotes a variable measuring the volatility of the emission allowance spot price.

Explaining Convenience Yields

Spot price volatility in t is modeled using the following approaches:

- Model A: volatility of period t measured by:

$$v_{S_t} = r_t^2$$

- Model B: moving average of length m:

$$v_{S_t} = \frac{1}{m} \sum_{j=0}^{m-1} r_{t-j}^2$$

We test: $m = 5$ (one week), $m = 20$ (one month) and $m = 60$ (three months). Best results were obtained for $m = 20$.

Explaining Convenience Yields

Pilot Period - Model A					
Year	β_0	β_1	β_2	R^2	F_{model}
2006	0.9664	-0.0337	-0.2090	0.1776	17.7111
	(0.1914)	(0.0078)	(0.0377)		
2007	1.5926	-0.0493	-0.3165	0.1672	16.4668
	(0.2978)	(0.0122)	(0.0587)		

Table 2: Coefficients, standard errors and model summary for the estimated regression models for the pilot trading period (Model A).

Explaining Convenience Yields

Pilot Period - Model B					
Year	β_0	β_1	β_2	R^2	F_{model}
2006	1.8141	-0.0635	-0.4040	0.1917	19.4521
	(0.2877)	(0.0108)	(0.0692)		
2007	3.6093	-0.1200	-0.8265	0.3138	37.4930
	(0.4098)	(0.0154)	(0.0986)		

Table 3: Coefficients, standard errors and model summary for the estimated regression models for the pilot trading period (Model B).

Explaining Convenience Yields

Kyoto Period - Model A					
Year	β_0	β_1	β_2	R^2	F_{model}
2008	-7.1445	0.4396	-1.0412	0.5383	95.6138
	(1.0990)	(0.0450)	(0.2167)		
2009	-7.3153	0.4731	-1.1114	0.5414	96.8102
	(1.1729)	(0.0481)	(0.2313)		
2010	-7.5877	0.5148	-1.1694	0.5513	100.7472
	(1.2399)	(0.0508)	(0.2445)		
2011	-7.8341	0.5576	-1.2174	0.5567	102.9739
	(1.3151)	(0.0539)	(0.2593)		
2012	-8.0186	0.6014	-1.2884	0.5637	105.9278
	(1.3920)	(0.0571)	(0.2745)		

Table 4: Coefficients, standard errors and model summary for the estimated regression models for the Kyoto commitment period (Model A).

Explaining Convenience Yields

Kyoto Period - Model B					
Year	β_0	β_1	β_2	R^2	F_{model}
2008	4.5606	*0.0308*	-4.2042	0.7831	296.0476
	(1.1421)	*(0.0430)*	(0.2747)		
2009	5.4407	*0.0277*	-4.5643	0.7952	318.4519
	(1.1883)	*(0.0448)*	(0.2858)		
2010	6.0230	*0.0395*	-4.8578	0.8045	337.4197
	(1.2409)	*(0.0467)*	(0.2985)		
2011	6.7315	*0.0490*	-5.1733	0.8117	353.3647
	(1.2997)	*(0.0490)*	(0.3126)		
2012	7.4561	*0.0611*	-5.4924	0.8165	364.8537
	(1.3687)	*(0.0516)*	(0.3292)		

Table 5: Coefficients, standard errors and model summary for the estimated regression models for the Kyoto commitment period (Model B). *Italic letters indicate non-significant coefficients at* 5% *level*.

Explaining Convenience Yields

- Simple regression model with current price level the price volatility as exogenous variable gives significant coefficients.
- Measuring the volatility by a 20-day moving average gives the best results for all periods. Negative relationship between volatility in spot prices and convenience yields.
- Explanatory power for Kyoto period is significantly higher with R^2 between 0.78 and 0.82.
- Negative (significant) relationship between spot price and convenience yields for the pilot, positive (not significant) relationship for Kyoto period.

Dynamics of Convenience Yields

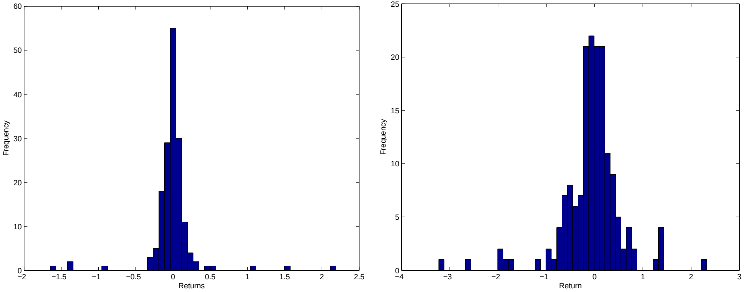


Figure 9: Histogram of Convenience Yields' Daily Returns; Maturity of Futures in 2006 (*left panel*) and 2006 (*right panel*).

Dynamics of Convenience Yields

Fit of AR-GARCH(1,1) to daily changes in convenience yields:

$$\Delta\psi_t = c + \phi\Delta\psi_{t-1} + \varepsilon_t, \tag{3}$$

$$\varepsilon_t = u_t\sigma_t, \quad \text{with} \quad \sigma_t^2 = k + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2, \tag{4}$$

where u_t is i.i.d. with zero mean and finite variance.

Dynamics of Convenience Yields

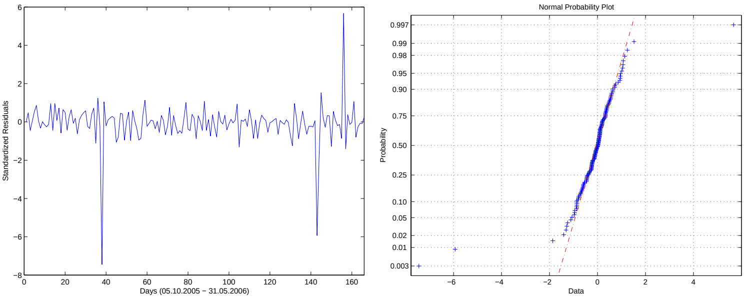


Figure 10: Standardized Residuals and normal probability plot of the standardized residuals after fit of AR(1)-GARCH(1,1) model for convenience yields' daily changes (pilot period).

Dynamic Semiparametric Factor Models (DSFM)

Model futures prices $Y_{t,j}$ by a DSFM (Fengler et al., 2005) with time-varying coefficients:

$$Y_{t,j} = m_0(X_{t,j}) + \sum_{l=1}^{L} Z_{t,l}\ m_l(X_{t,j}) + \varepsilon_{t,j}\ , \tag{5}$$

where the m_l are time invariant functions, $X_t = 0, 1, 2, ..$ is the maturity, $Z_t = (Z_{t,1}, ..., Z_{t,L})$ is the L-dimensional time series.

Explanatory Power of Factor Models

Factors	R(L)
L=1	0.8579
L=2	0.9967
L=3	0.9993

where R(L) denotes the explanatory power of the model in relation to the most simple model:

$$R(L) = 1 - \frac{\sum_t \sum_j (y_{tj} - \sum_{l=0}^{L} z_{lt} m(X_{tj}))^2}{\sum_t \sum_j (y_{tj} - \bar{y})^2}$$

Results for a Two-Factor Model Setting

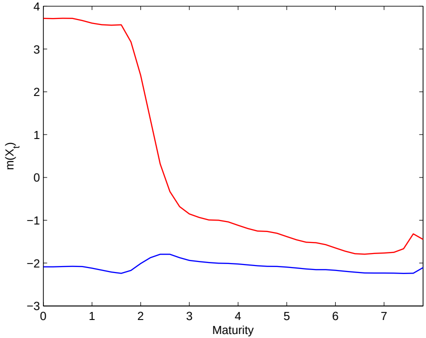


Figure 11: Basis Functions.

Results for a Two-Factor Model

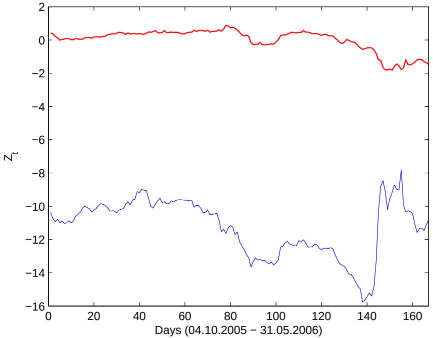


Figure 12: Factor Loadings.

Summary

- CO_2 Emission Allowances prices show different behavior than purely financial assets (high volatility, heavy tails, price shocks)
- Nonuniform term structure of Future Prices with a significant jump between 2007 (pilot period) and 2008 (Kyoto commitment period)
- Substantial changes in spot and futures price volatility and term structure of the volatility
- High correlation for spot and futures prices of the pilot period, correlation decreases for Kyoto
- In total an increasing futures price volatility for pilot and Kyoto period can be observed (contradicts Samuelson effect)

Summary (continued)

- Convenience Yields are significant, stochastic and show strong reaction to volatility and price shocks
- Simple regression model Kyoto period convenience yields with spot price level and volatility as exogenous variables gives high explanatory power
- Market changed from initial backwardation to contango due to available short-term supply but long-term insecurity about new allocation for Kyoto period
- Dynamics of future prices may be modeled by a dynamic semiparametric factor model with two factors

Outlook

- Investigate stochastic models for risk premiums and convenience yields!
- Can CO_2 emission allowance spot and future dynamics be explained by inclusion of additional macroeconomic variables, prices of other commodities?
- What are the effects of CO_2 emission allowance prices on other commodities like electricity?
- Investigate stochastic models for Emission Allowance spot and future prices!
- Provide hedging and risk management strategies for market participants!
- Determine optimal production processes for power generators and industries!

For Further Reading

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