The European CO_2 emissions trading system (EU-ETS)

The good, the bad and the interesting

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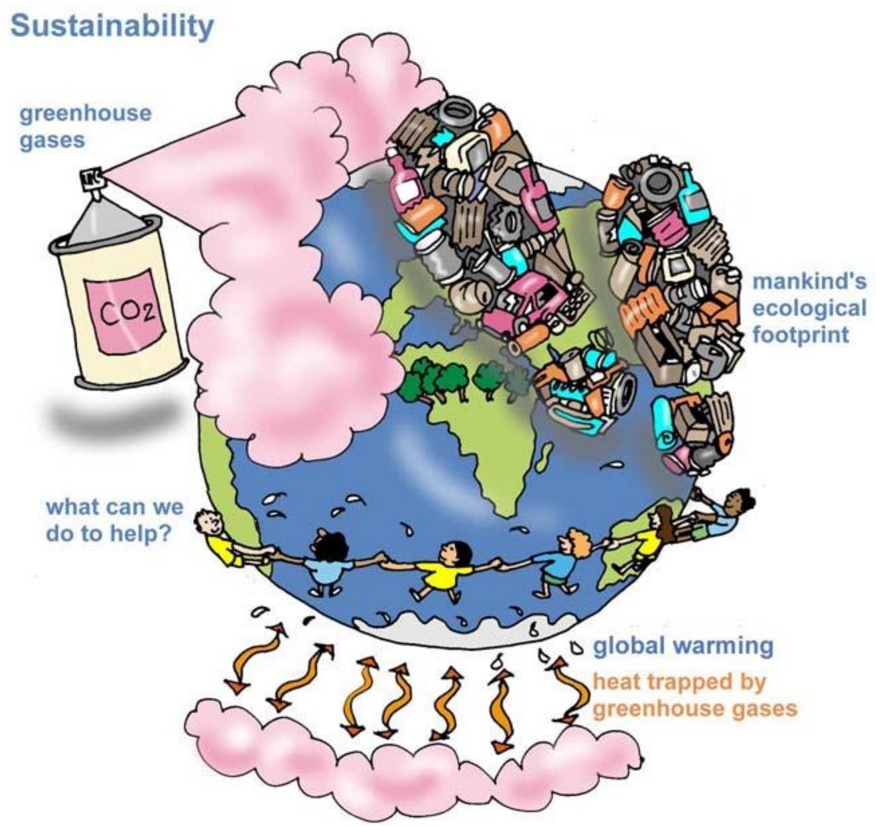
Agenda

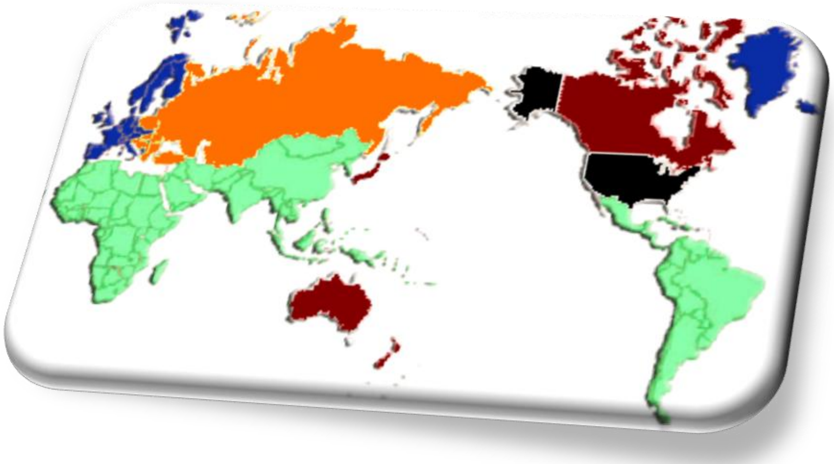
- The good
  - The Kyoto Protocol
  - The EU-ETS
- The bad
  - Political manipulation
  - Corruption
- The interesting
  - Spot-futures carbon price relationships
  - Convenience yields and term structure



The good: The Kyoto Protocol

- Aimed at fighting global warming
  - A protocol to the *United Nations Framework Convention on Climate Change* (UNFCCC)
- Negotiated in Kyoto in **Dec 1997**
- **2 x 55 rule**: min. 55 countries, min. 55% of emissions
  - The ratification by Russia satisfied the ‘55%’ clause and 3 months later **brought the treaty into force** on 16 Feb 2005
  - Rumors have it that the decisive argument was the prospect of the benefits of participation in emissions trading …

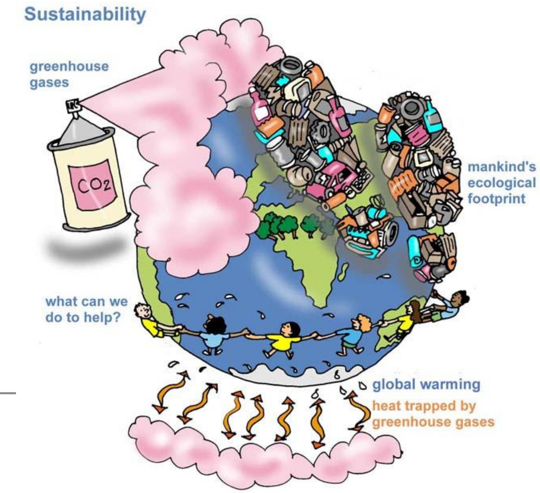
Participation in the Kyoto Protocol

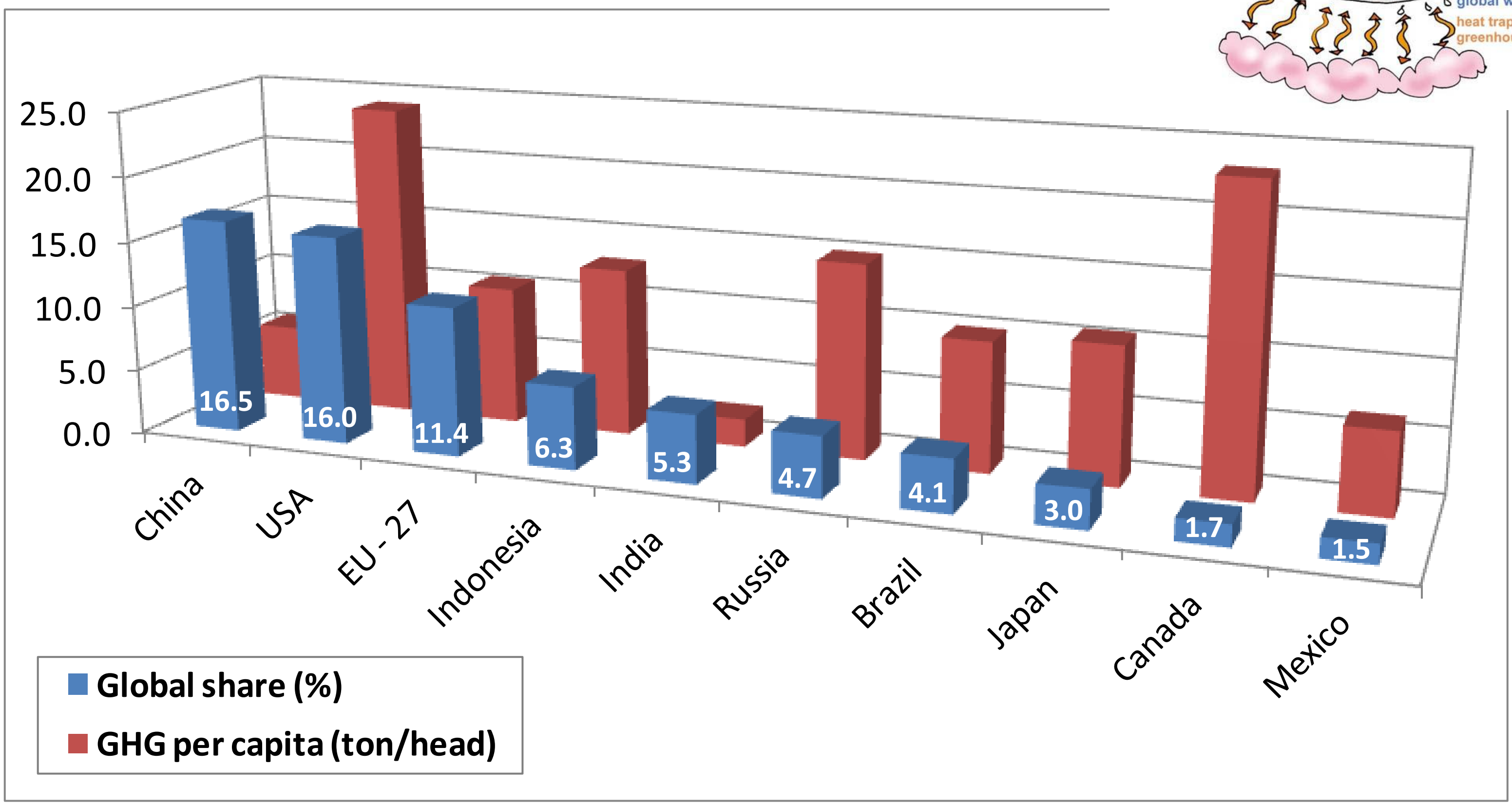


- EU-15
- 'European' transition economies
  - Have emission caps and are usually net sellers in the carbon market
  - Joint Implementation (JI) projects are hosted in some of these countries
- Annex II non-EU countries that ratified the Kyoto Protocol
  - Have compliance targets, but are not part of the EU
- Annex I parties that have not ratified (… USA)
  - USA: KP is too liberal on China
- Non-Annex I countries having ratified the Kyoto Protocol
  - No emission caps, potential host countries of Clean Development Mechanism (CDM) projects

Top ten polluters

Greenhouse gas (GHG) emissions in 2005



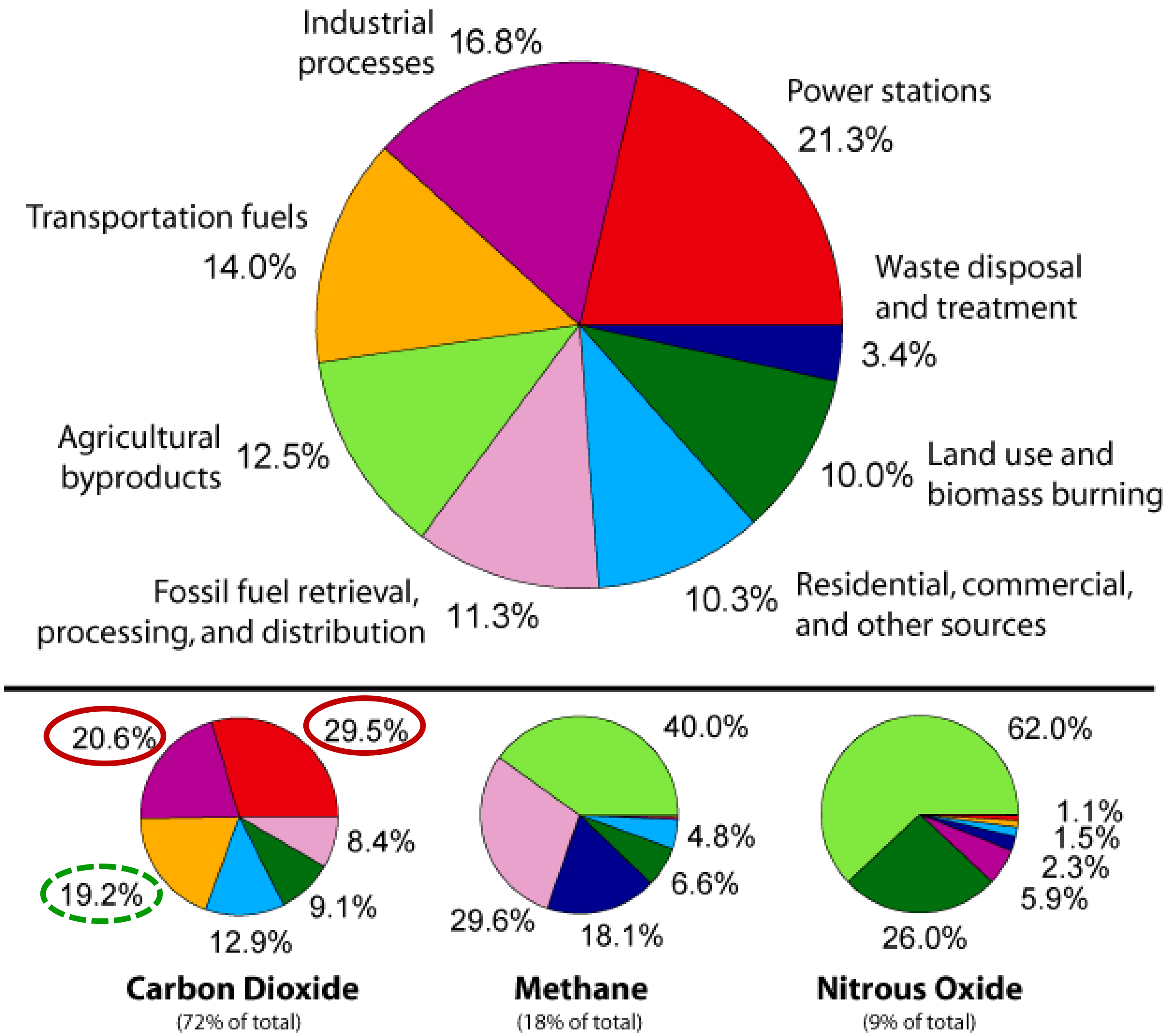


Data: IEA 2007

Annual GHG emissions in 2000

By sector

- **Initially**: focus on the energy and industrial sectors
- **Near future**: cover the 3rd largest CO_2 polluting sector - transportation



Source: Emission Database for Global Atmospheric Research 2010

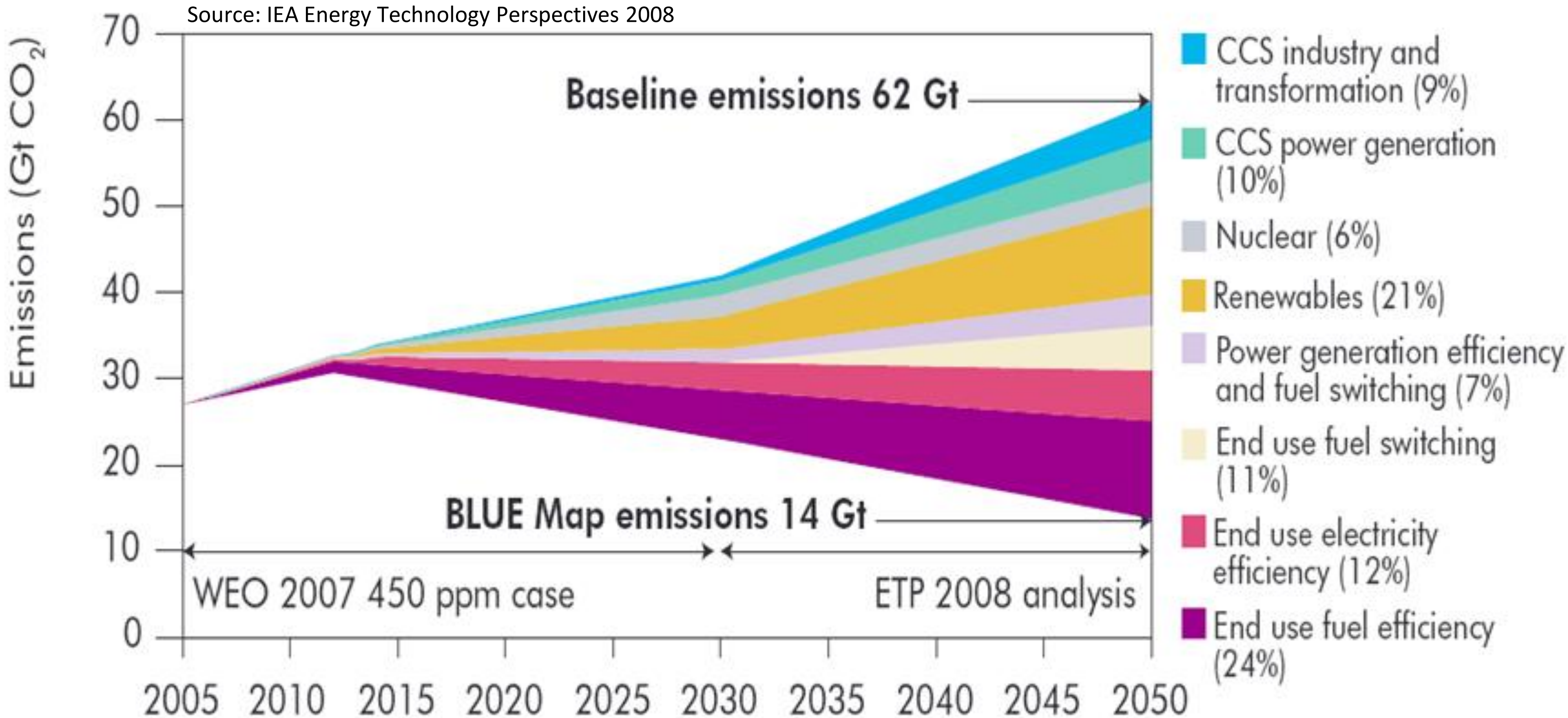
The bad: Liberalization or re-regulation?

- Government climate policy is subject to
  - scientific evidence (discoveries and … hypotheses)
  - **social attitudes** and
  - **geopolitical self-interests**
- Implemented through a mixture of regulations & incentives
  - The cap & trade markets are expanding (like the EU-ETS)
  - … but interact with other mitigation mechanisms
  - … and link to the energy commodities
- Carbon price formation is a complex and evolving mix of **fundamentals** and **policy risk**

Emission reduction options

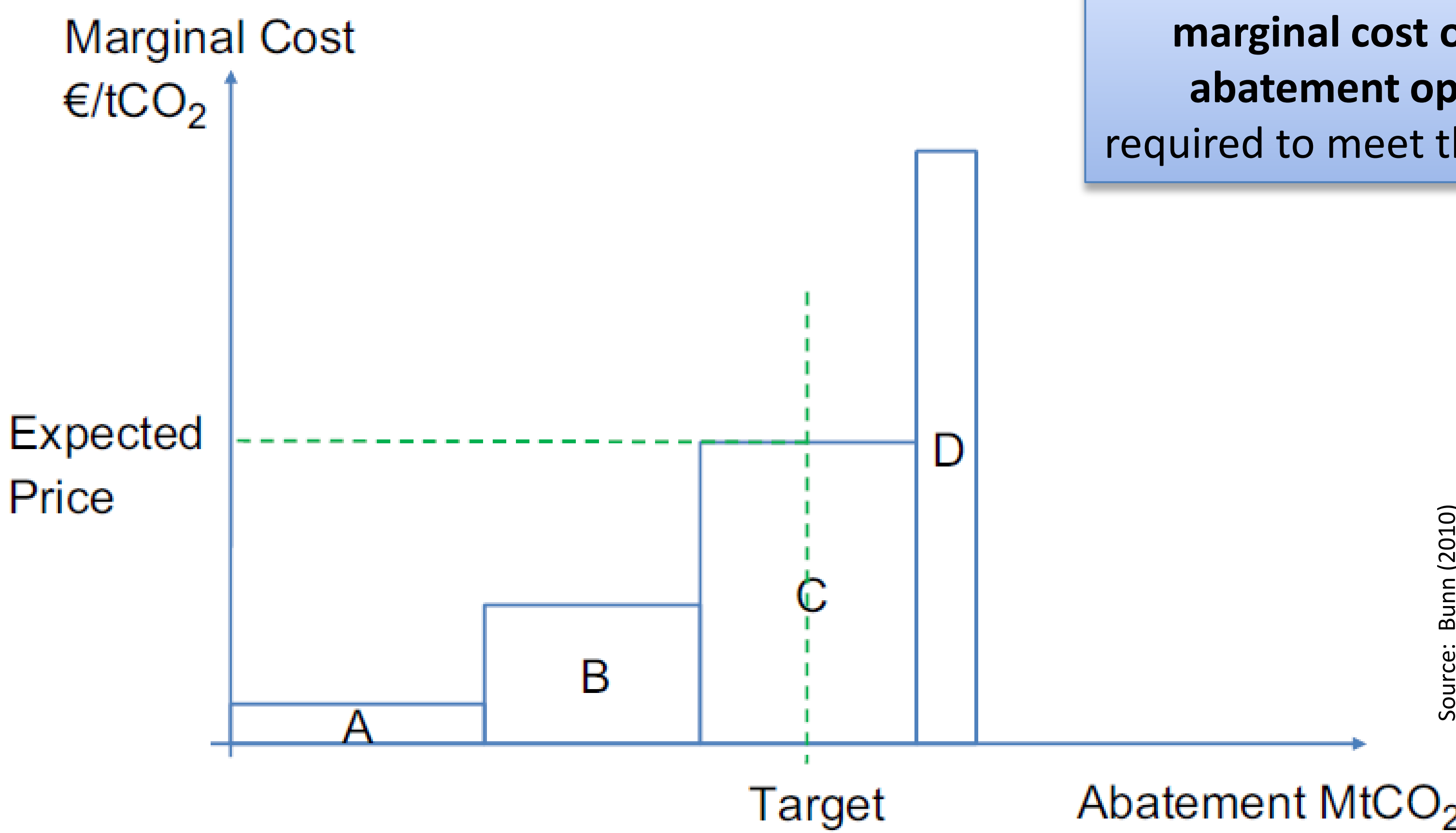
- Policy analyses start by projecting baseline emissions
- … then consider the costs of **abatement** (reductions)

Source: IEA Energy Technology Perspectives 2008



In the long-term …

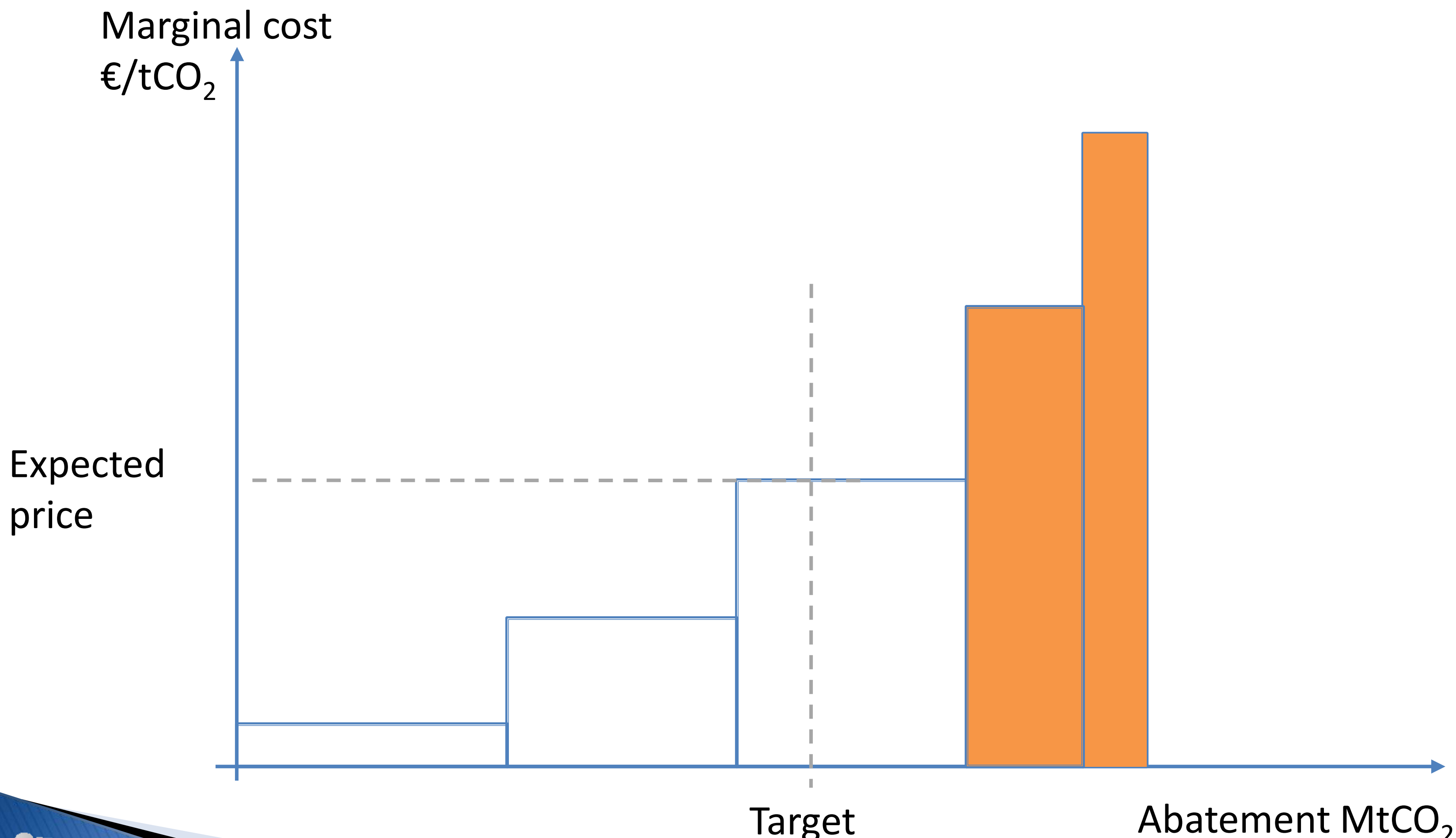
... the expected carbon price is determined by the **marginal cost of the abatement option** required to meet the target



Source: Bunn (2010)

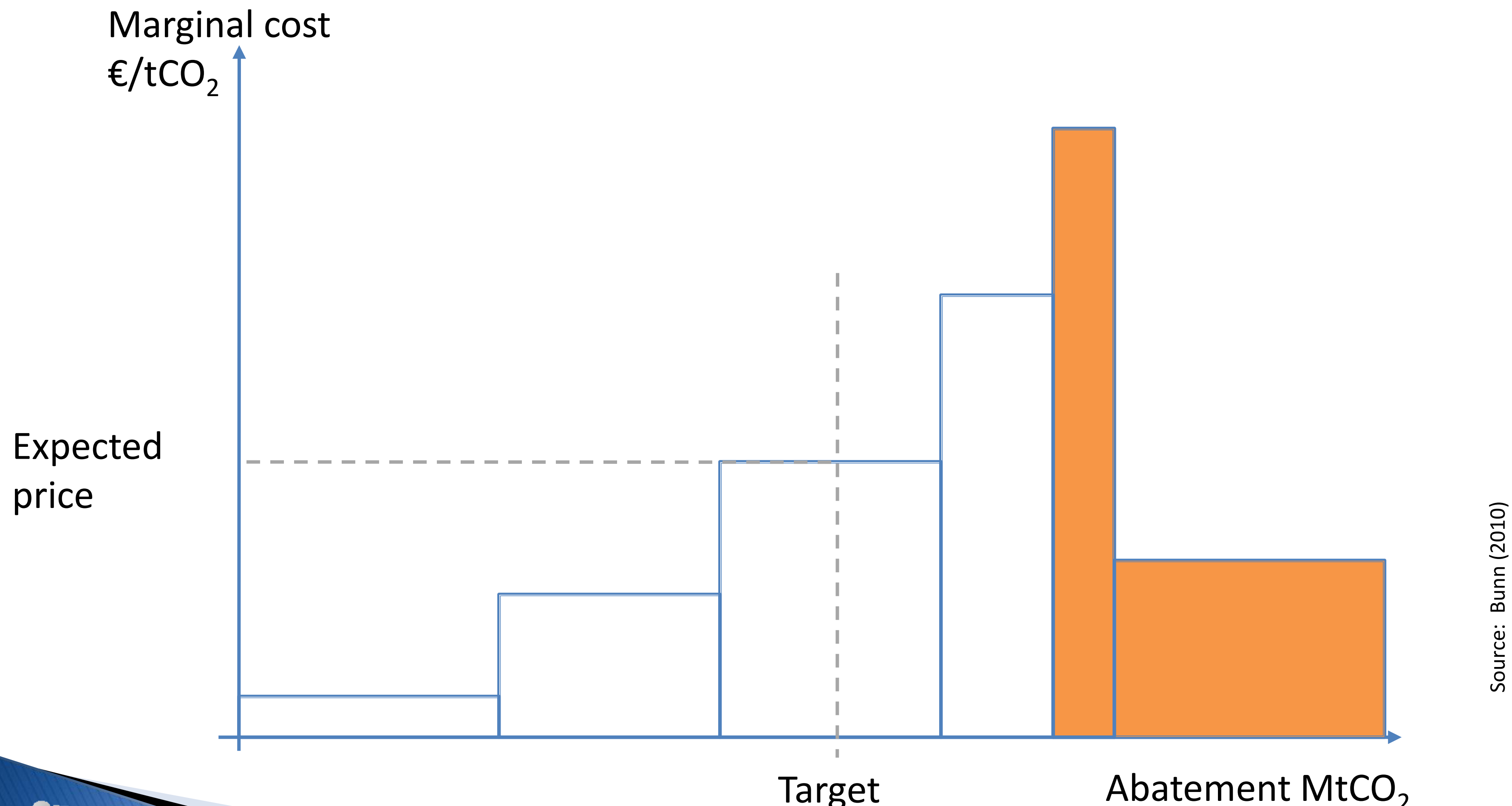
Fig. 1. Standard representation of an increasing marginal abatement curve.

Some technologies may receive policy support



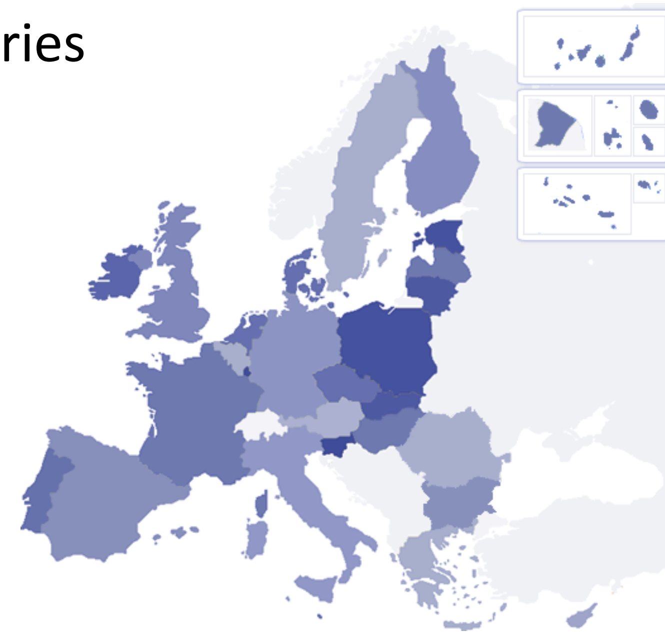
Source: Bunn (2010)

... and some technologies need help in their learning curves



The good: EU Emission Trading Scheme (EU-ETS)

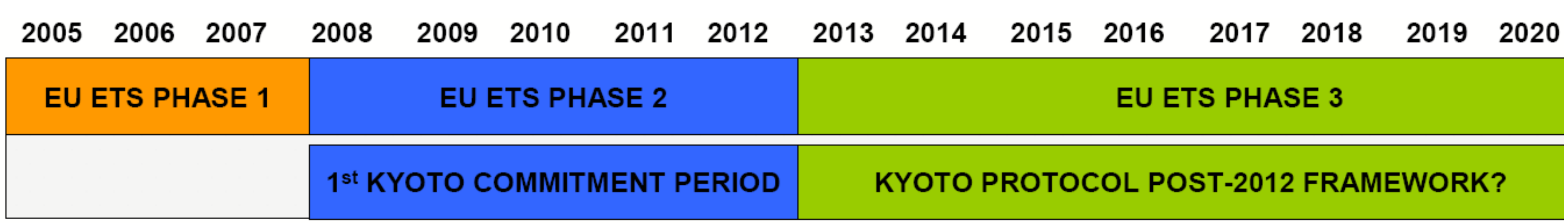
- ‘Cap & trade’ system
  - Obligations imposed on the polluters … for whom it is easier to reduce emissions (→ direct approach)
- Unit: European Union Allowance
  - Can be traded freely between EU countries
  - 1 EUA = 1 metric ton of CO_2
    - emitted e.g. by driving an average car for approximately 4500 km
- Financial penalties
  - 40 EUR/ton until 2007
  - 100 EUR/ton until 2012



EU-ETS

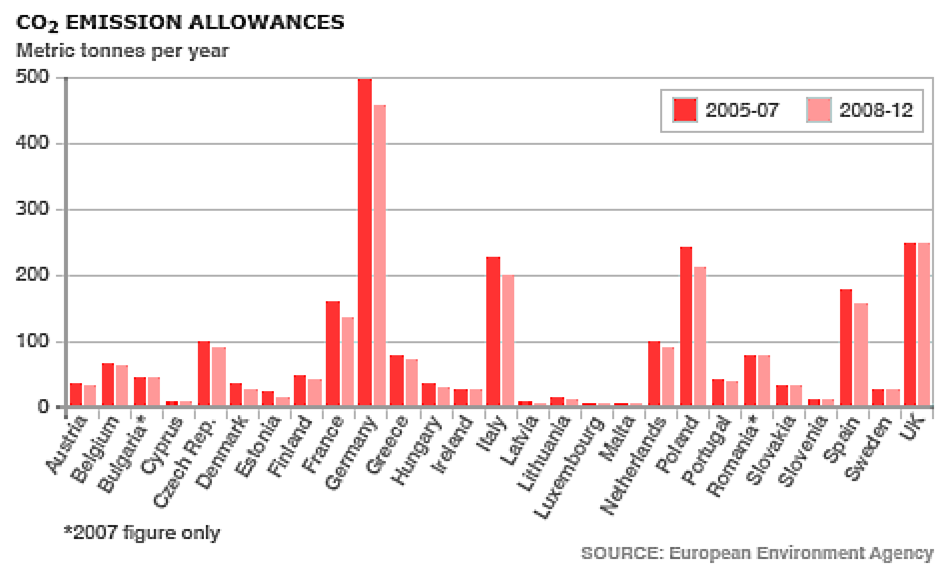
- Covers over 12,000 installations with a net heat excess of 20 MW in the energy and industrial sectors
  - Power plants, refineries, cement plants, steel, glass and paper mills, civil aviation (to be included from 2012)
  - Collectively responsible for ca. 50% of the EU's CO_2 emissions and 40% of its total GHG emissions
- System phases:
  - Phase I 'pilot' (2005-2007), Phase II (2008-2012)
  - Phase III, … ?

Source: defra

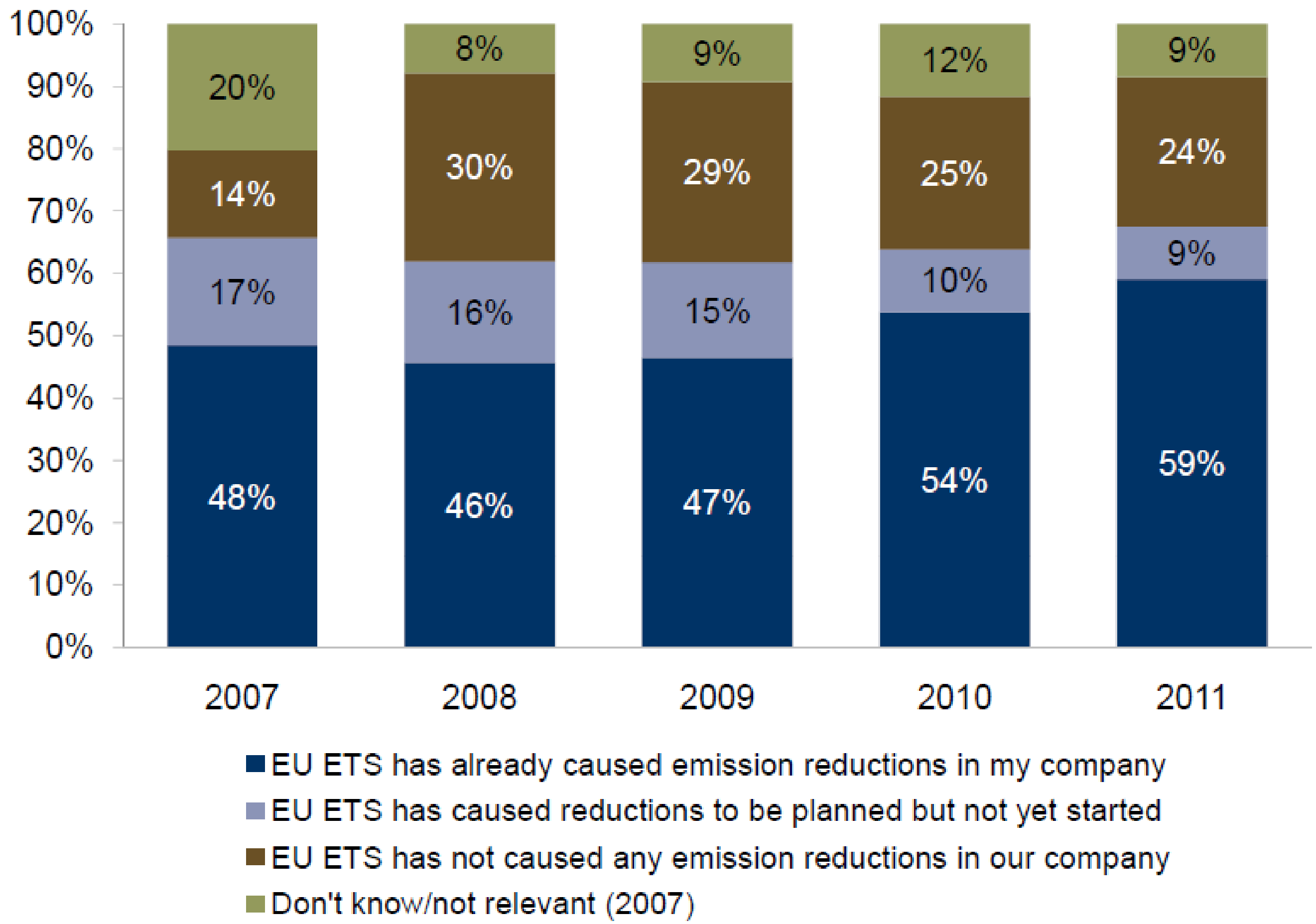


The bad: National Allocation Plans (NAPs)

- Define the distribution of EUAs in the member states
  - Poland: 239.1 tons/year (10.4% EU) in Phase I
  - 208.5 tons/year (10% EU) in Phase II
  - Plans must be accepted by the European Commission (EC)
  - Conrad et al. (2011)
    - The decisions of the EC on NAPs have a strong and immediate impact on EUA prices

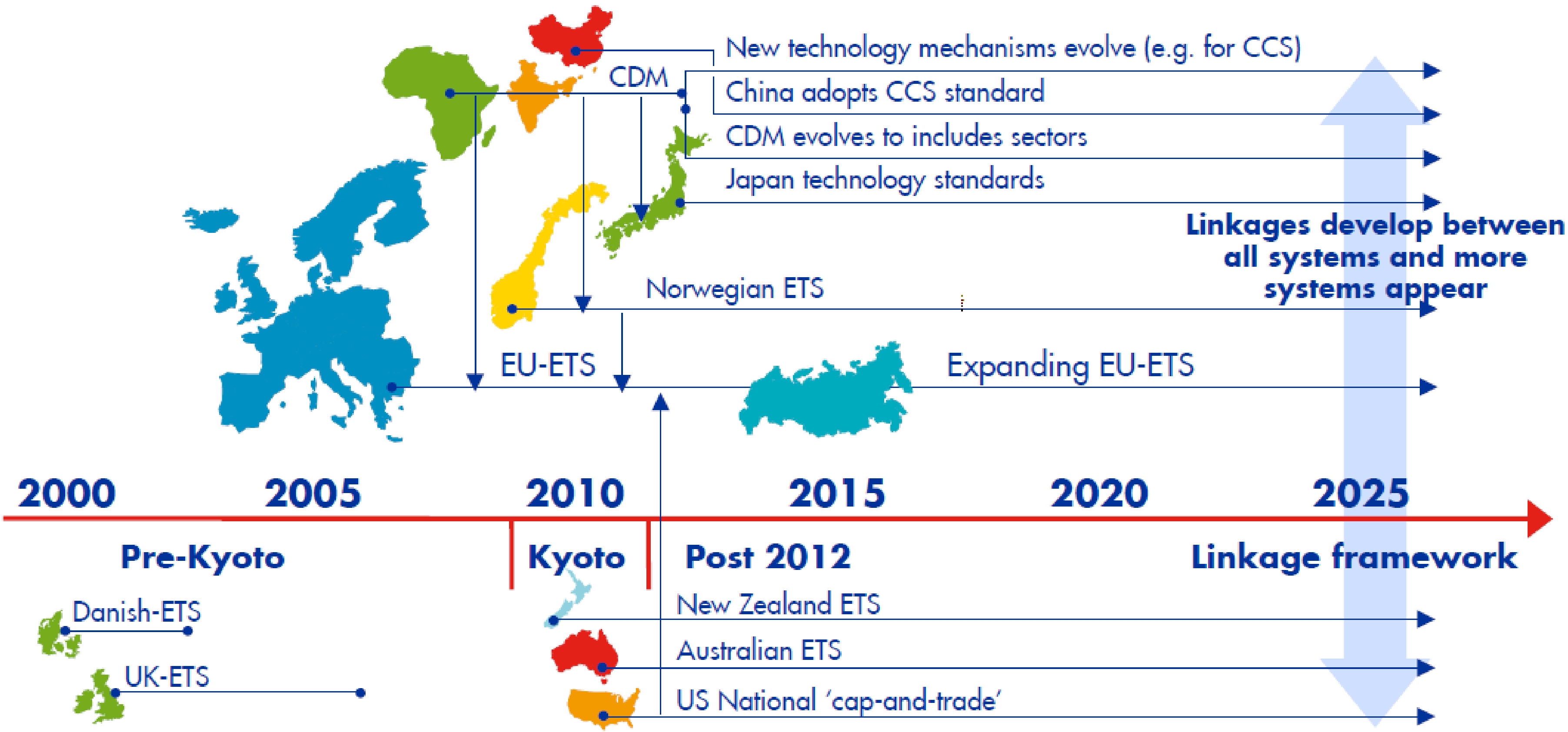


The good: EU ETS and internal abatement



Source: Point Carbon

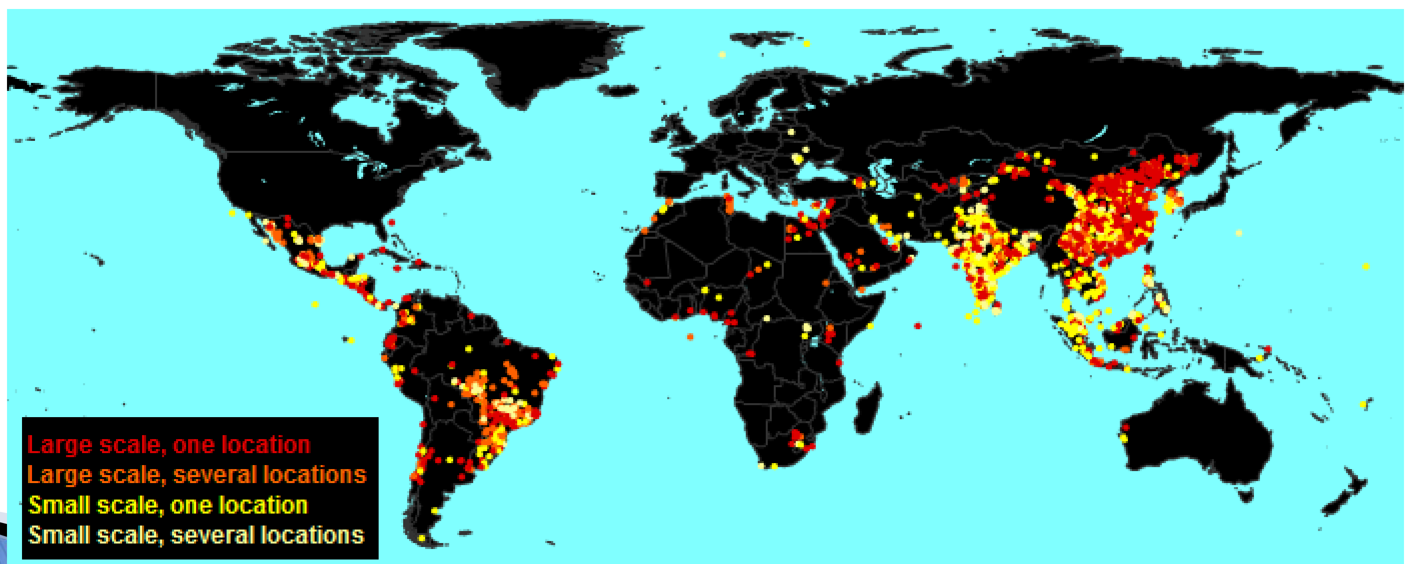
Linkages to other systems



Source: Shell International Ltd.

The good: Clean Development Mechanism (CDM)

- CDM is a mechanism for project-based emission reduction activities in developing countries
  - **Certified Emission Reductions** (1 CER = 1 EUA) are generated from CDM projects that lead to emissions reductions that would otherwise not occur

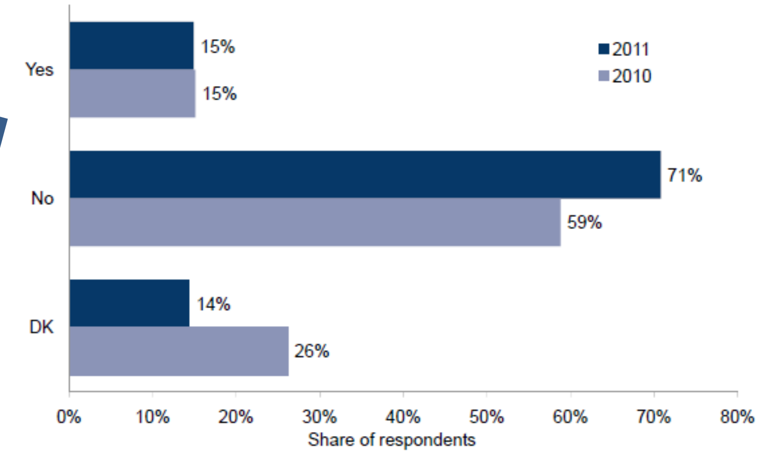


Source: UNFCCC 2011, http://unfccc.int

The bad: CDM/JI fraud

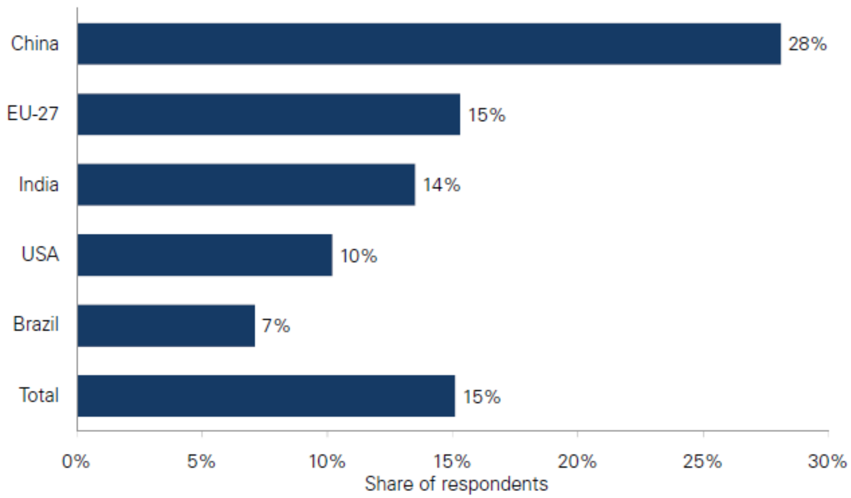
- **15%** of respondents had seen incidences of fraud/ corruption in connection with a CDM/JI project
  - This does not apply to the mechanisms in general, but only to specific projects where the respondent's company is involved

Figure 3.2: CDM/JI fraud?
"Have you ever witnessed fraud, embezzlement or corruption in connection with a CDM or JI project?" N=571



Source: Point Carbon

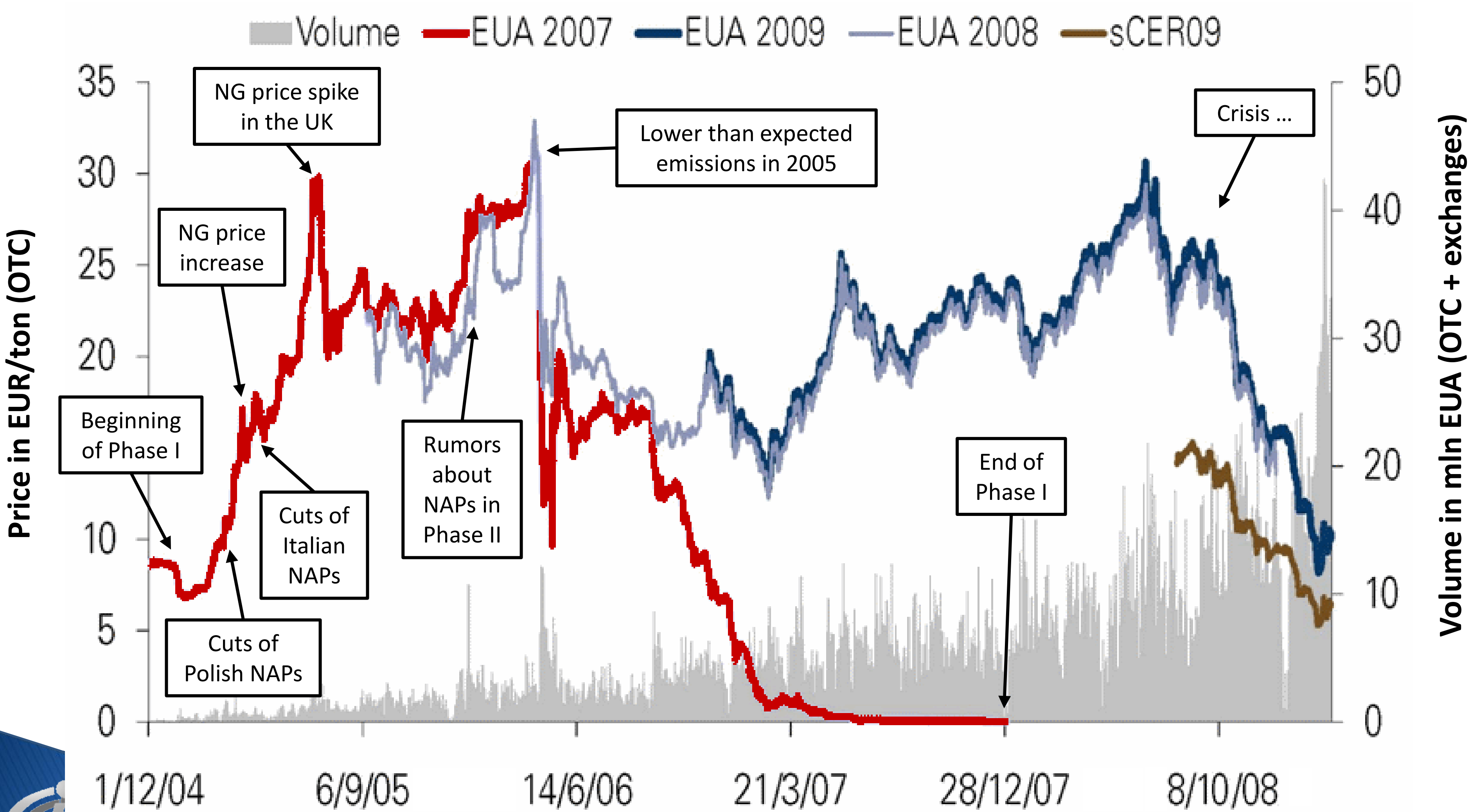
Figure 2.12b: CDM/JI fraud, by country
CDM/JI fraud, embezzlement and corruption reported by respondents based in selected countries. N=890 (2010)



Phase III: Proposals

- An expansion to other
  - Large polluters (e.g. the chemical and aluminum industries)
  - And GHG (N2O – fertilizers, perfluorocarbons – PFC)
- The setting of an overall EU cap, with allowances then allocated to 27 EU members
  - Linear decrease to 2020 (and beyond)
  - On average 14% wrt 2005, ETS installations by 25%
- A move from allowances to auctioning
  - 20% (in 2013) up to 70% (in 2020); recommendation to auction 100% of EUAs for the power sector from 2013
- Carbon capture and storage (CCS)

EUA prices (12/2004 – 3/2009)



Data: PointCarbon

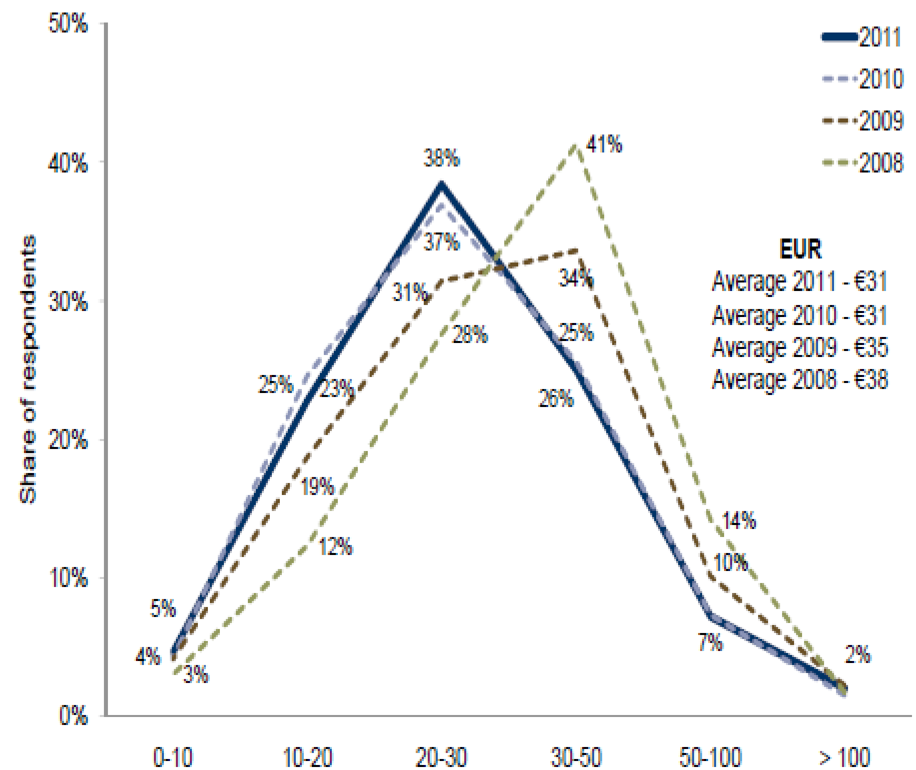
Post crisis evolution and 2020 price expectations in 2008-2011 surveys

Source: PointCarbon

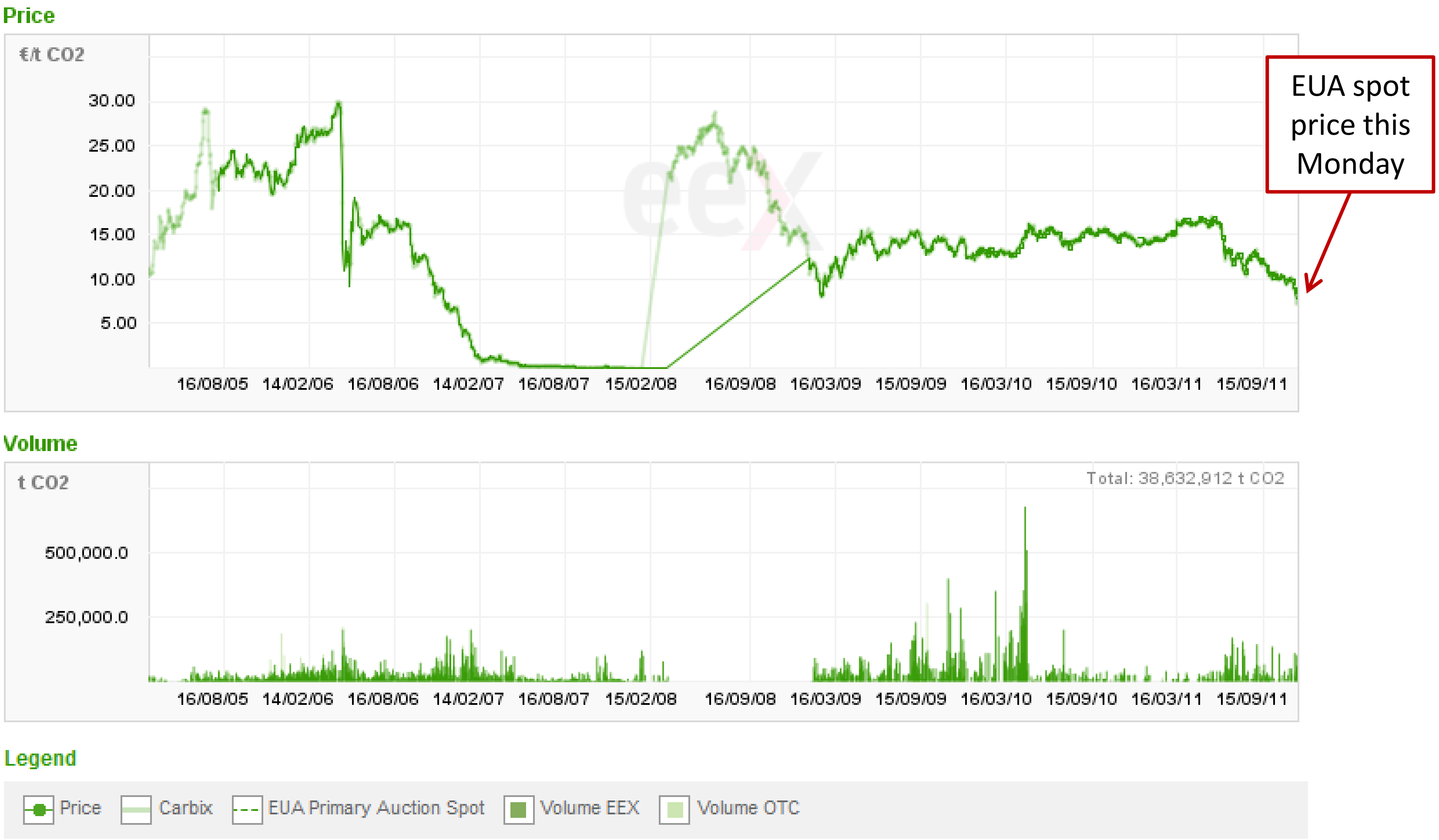
Figure 5.6: Price expectations for 2020

Expectations for global CO2 price level in 2020, in EUR

N=1,300 (973 for EUR and 639 for USD)..



Where is the EUA spot price today?



The interesting: What drives EUA prices?

- Montgomery (1972)
  - Allowance price (e.g. EUA) is a consequence of the **substitution principle**: $S_t = MC_t$
    - For $t \in [0,T]$, where S_t – allowance price, MC_t – marginal cost of reducing emissions by 1 ton of CO_2 at time t
- In the mid-term **fuel switching** is the cheapest technology that can be easily implemented
  - E.g. replacing the cheap but 'dirty' coal by a more expensive but 'clean' NG

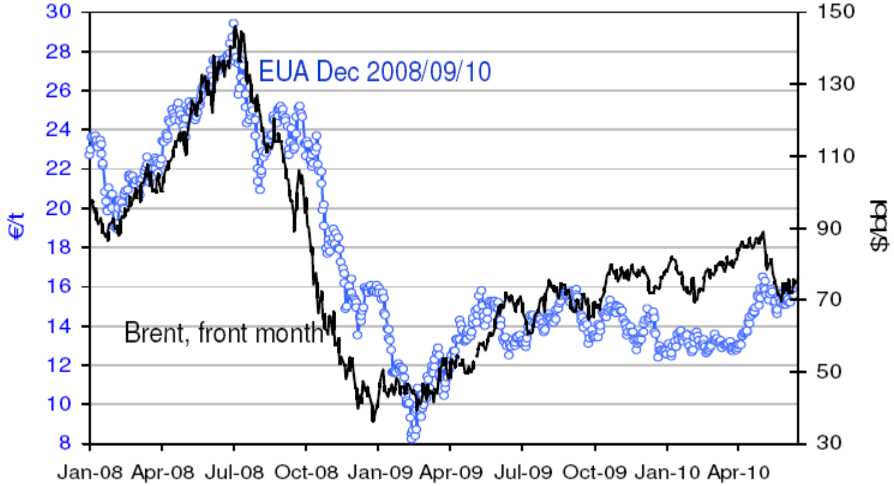
Fuel switching does not explain EUA prices …

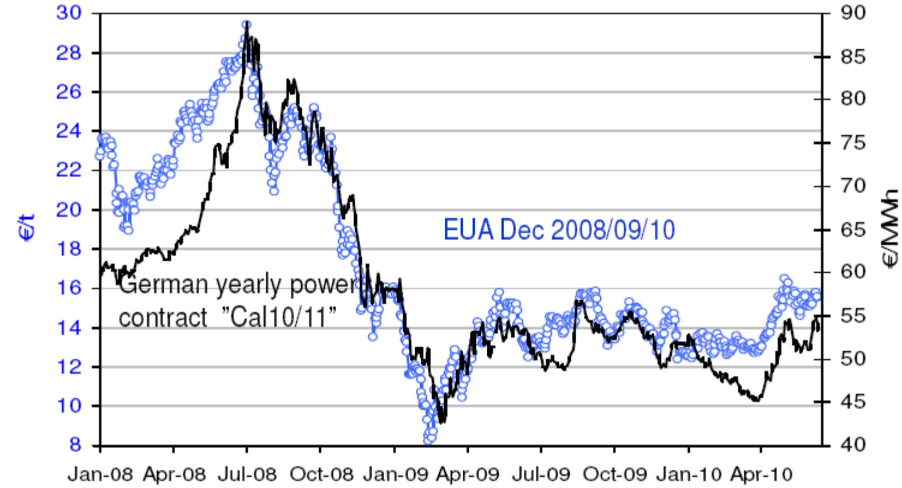
Carbon Market Monitor, page 10, 4 December 2009

… but oil, power and equities do

(at least in the short-term)

Source: Bunn (2010)

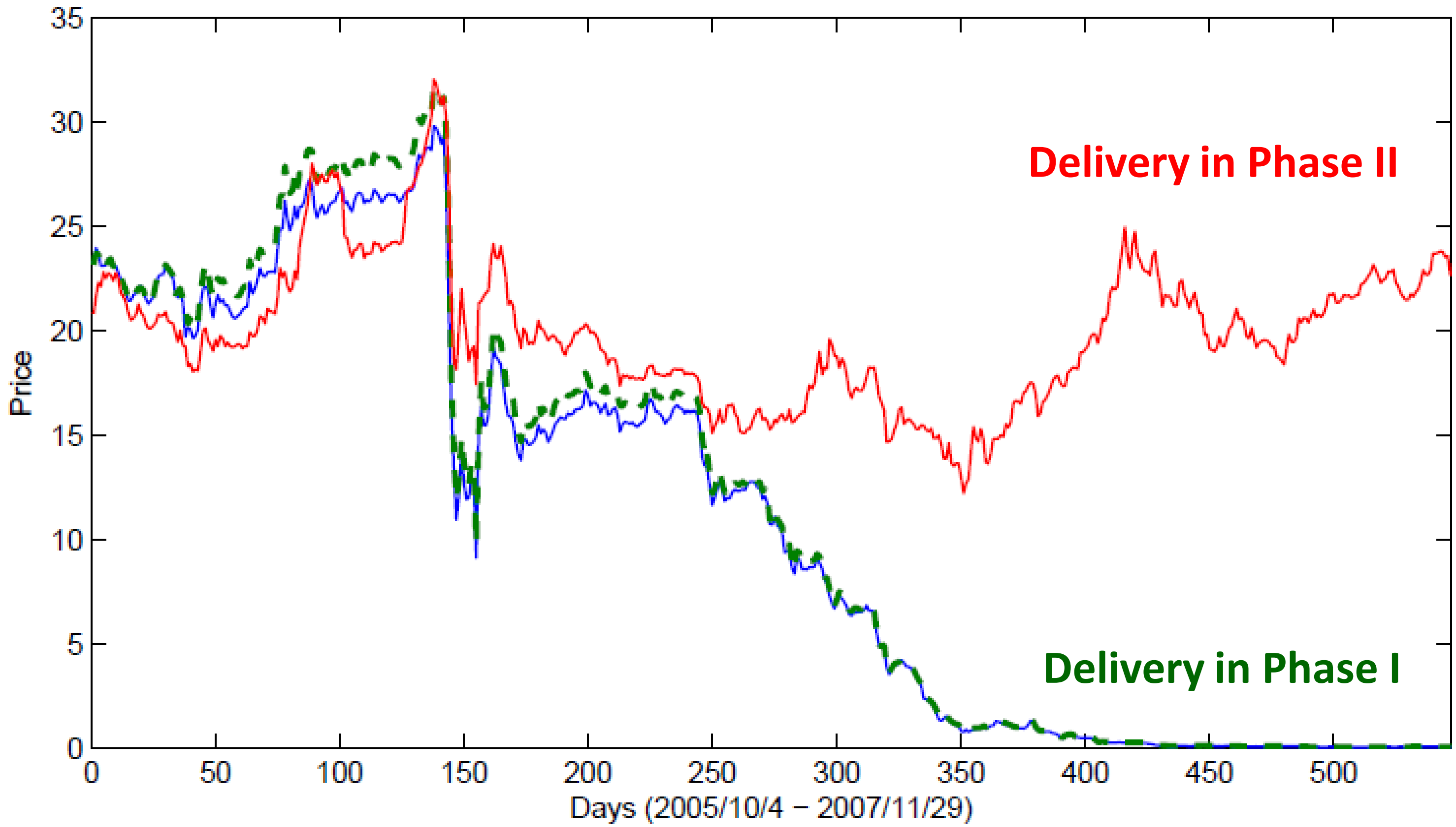




- Chevallier (2009): CO_2 futures returns may be weakly predicted on the basis of **equity dividend yields** and the **'junk bond' premium**
- Conrad et al. (2011): EUA prices increase in response to better than expected **news on the future economic development**

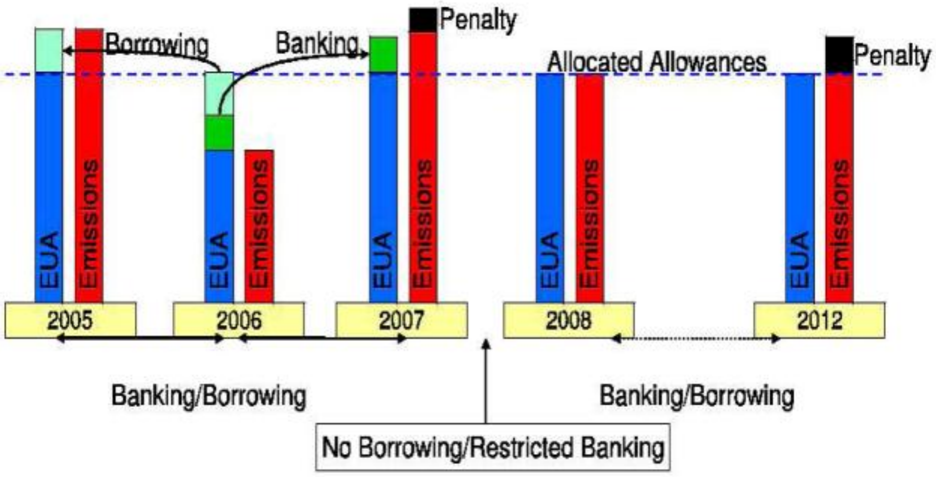
What about the spot-futures price relationship?

- **EUA spot price** and futures price for delivery in **2007** and **2008** for the period Oct 10, 2005 to Nov 29, 2007



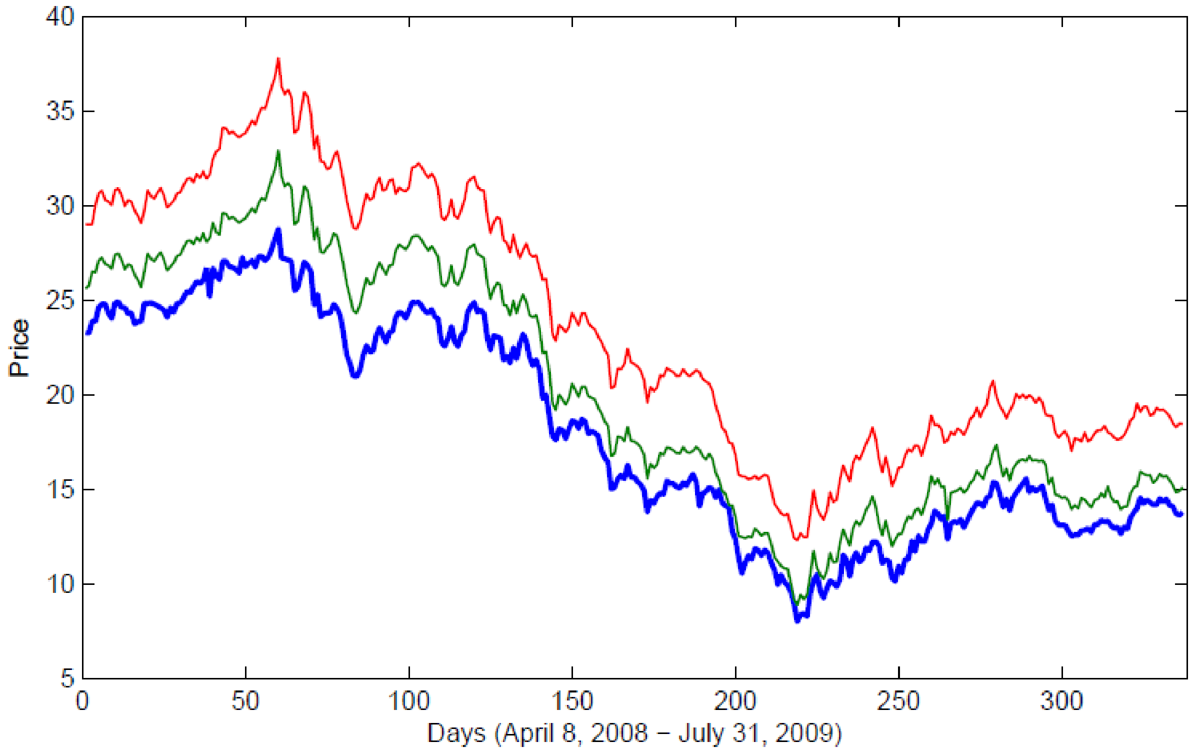
Banking and borrowing

- Banking and borrowing within pilot trading period (Phase I) was permitted
  - 2006 EUA could be used in 2007 (banking) or in 2005 (borrowing)
- Banking from pilot period to Kyoto-commitment period (Phase II) was (basically) banned
- Banking from Phase II to Phase III is allowed, but not borrowing



The spot-futures price relationship in Phase II

- **EUA spot price** and futures price for delivery in **2011** and **2014** for the period Apr 8, 2008 to Jul 31, 2009



The interesting: Questions

- What is the relationship between spot and futures prices for different phases?
- Are EUA convenience yields similar to other commodity markets?
- Are these backwardation or contango markets?
- What is the term structure dynamics?

Typical price behavior of commodities

- Downward sloping (i.e. *inverted*) forward curve, also called **backwardation** (Litzenberger and Rabinowitz, 1995)

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	$F_{t,T} > e^{r\tau} S_t$

- 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, called the **Samuelson effect** (Samuelson, 1965)

Backwardation and contango in commodity markets

- Backwardation was introduced by Keynes (1930)
  - Arises naturally as producers of commodities are more prone to hedge their price risk (falling prices) than consumers
- Contango was first mentioned in 1853 by Liverpool stockbrokers
  - Consumers buying insurance against raising prices
  - Suggests currently available supply but medium-to-long-term shortages of a commodity

Relating spot and futures prices

- Fama and French (1987) identify two groups of approaches:
  - The first suggests a **risk premium** to derive a model for the spot-futures price relationship
  - The second is closely linked to the **cost and convenience of holding inventories**

Risk premium

- The reward for holding a risky investment rather than a risk-free one, i.e. **the difference between the expected spot price and the forward price**
  - Normal backwardation is equivalent to a **positive risk premium** – the risk is transferred to the long position in the futures contract
  - Normal contango is equivalent to a **negative risk premium**
- Electricity prices generally exhibit negative risk premiums
  - A reasonable explanation for contango is a higher incentive for hedging on the demand side relative to the supply side
  - … because of the non-storability of electricity as compared to the limited and costly but still existent storage capabilities of fuel
  - Bierbrauer et al. (2007), Botterud et al. (2010), Weron (2008)

Convenience yield

- In a no arbitrage setting spot and forward prices can be related (Geman, 2005; Pindyck, 2001)

$$\gamma_{(T-t)} = S_t e^{r(T-t)} - F_{t,T}$$

- Differences between spot and futures prices are explained by
  - Interest foregone in storing a commodity, warehousing costs and the **convenience yield** (γ) on inventory
  - γ represents the privilege of holding a unit of inventory, for instance, to be able to meet unexpected demand

The data: EEX futures for EUA's

- EUA futures contracts
  - An agreement to deliver a specified quantity of allowances at a specified future date
  - Delivery on the last trading day in November (for EEX) or mid December (for ECX/ICE) of a particular year
    - Phase I futures with delivery in Nov/Dec 2006, 2007
    - Phase II futures with delivery in December 2008-2012
    - Phase III futures with delivery in December 2013, 2014, …
- Two datasets (spot and futures) used in this study
  - Phase I: Oct 4, 2005 - Nov 29, 2007 → Phase I/II futures
  - Phase II: April 8, 2008 - July 31, 2009 → Phase II/III futures

Convenience yields: Phase I

The market was initially in **backwardation**

After the news of **overallocation**, allowance prices and convenience yields approached zero

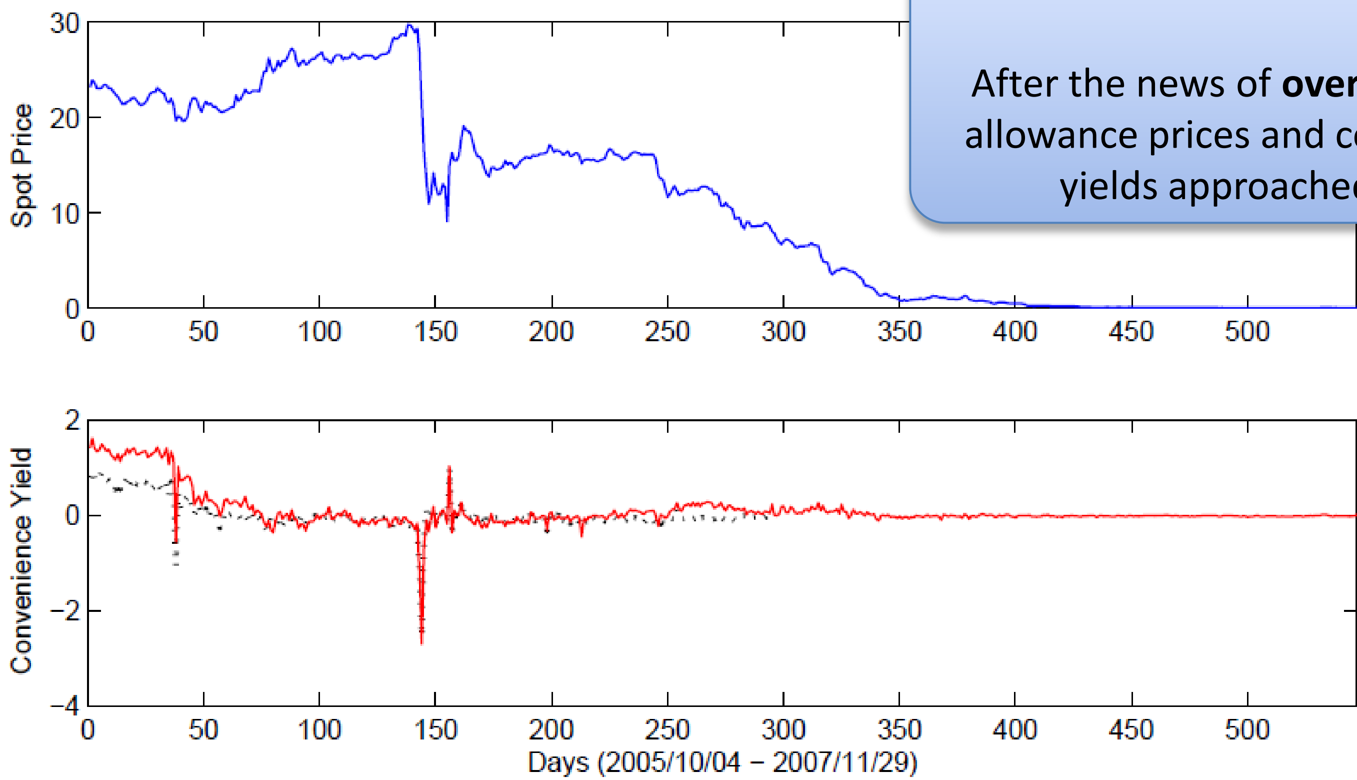


Figure 4: *Upper panel:* Spot prices (EUR/ton) from October 4, 2005 to November 29, 2007. *Lower panel:* Convenience yields (EUR/ton) for 2006 (dotted black) and 2007 (solid red) EUA futures.

Market inefficiencies in Phase I

- Due to borrowing and banking within Phase I, there is no benefit of holding an asset now in comparison to December futures contract
  - Products are basically interchangeable
- As a consequence convenience yields would be expected to be close to zero
  - Initially market exhibits inefficiencies with significant convenience yield
  - During 2nd and 3rd year convenience approaches zero

‘Convenience yields’: Phase I → II

- Banking of EUAs was essentially banned
- Basically two different products are compared

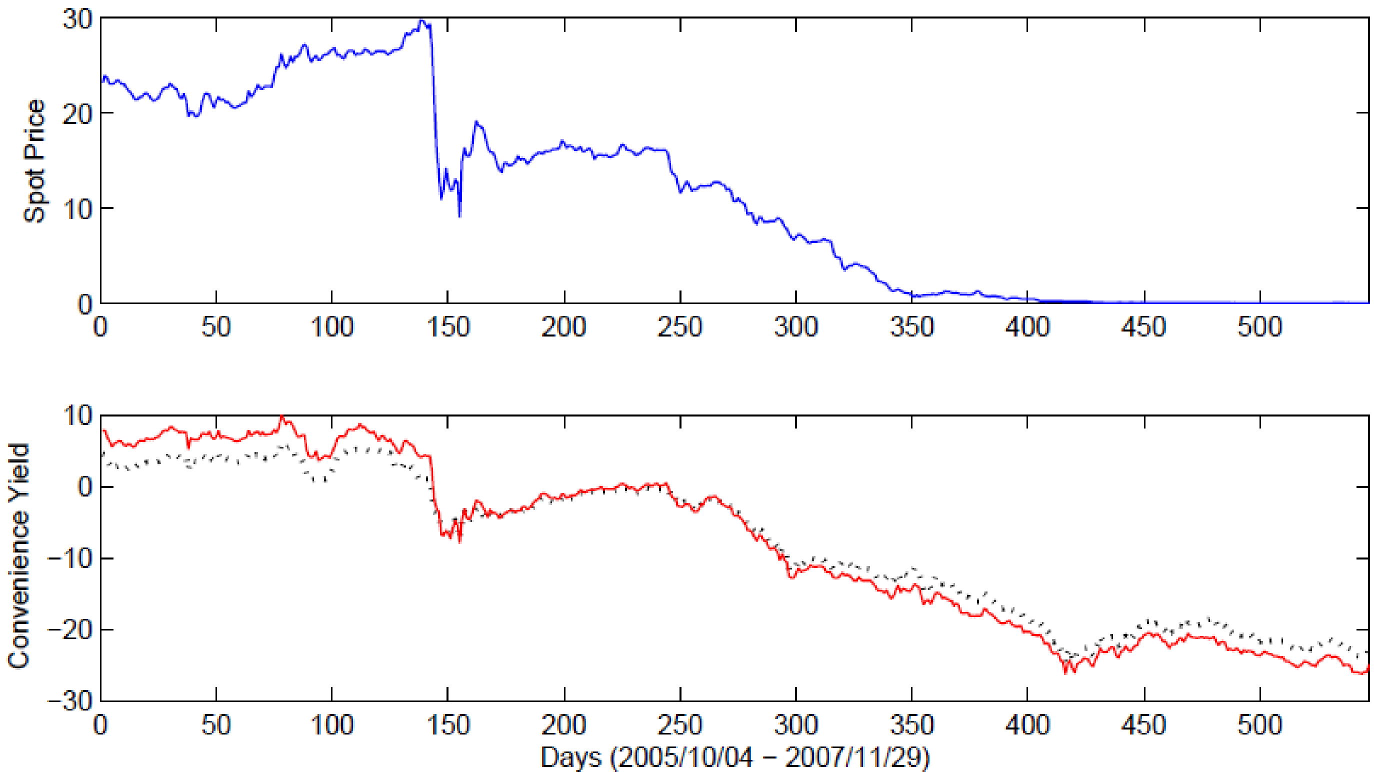
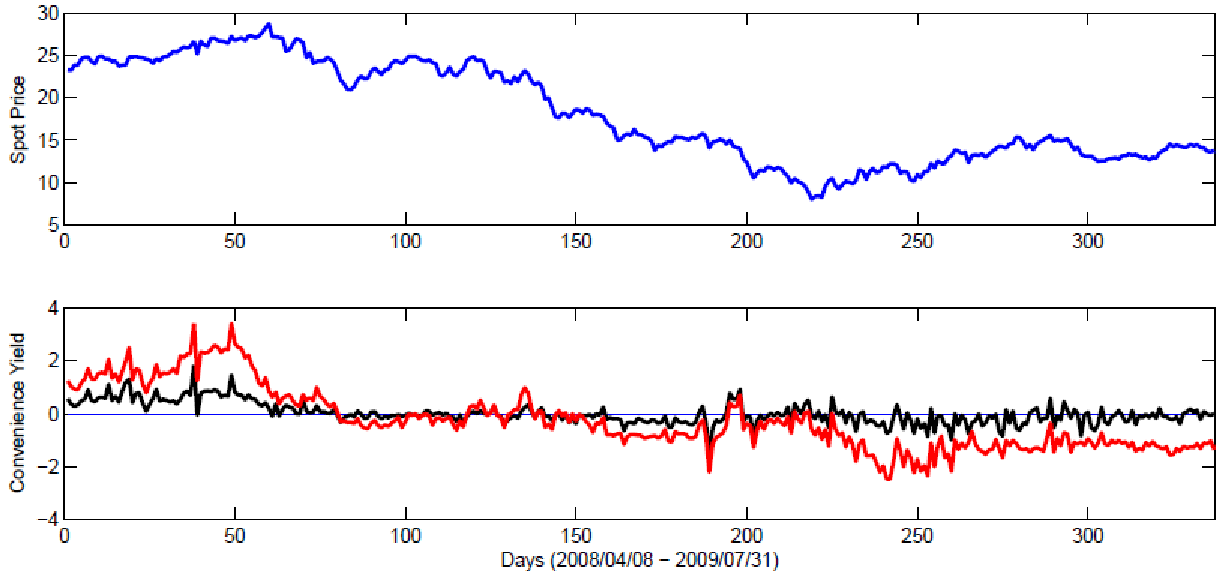


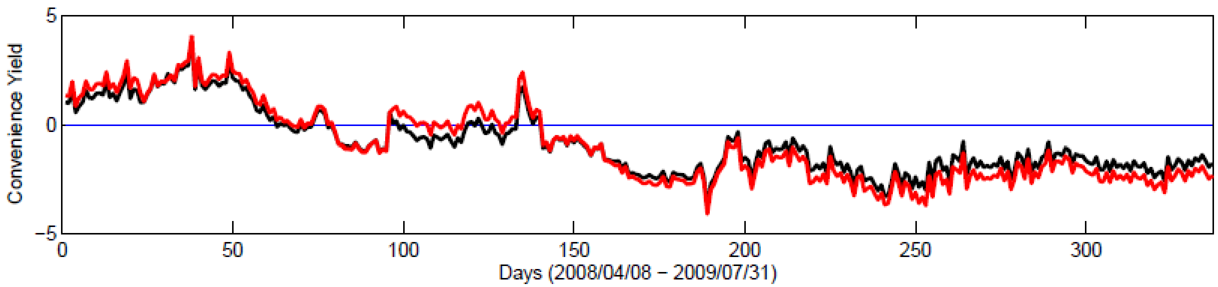
Figure 5: *Upper panel:* Spot prices (EUR/ton) from October 4, 2005 to November 29, 2007. *Lower panel:* ‘Convenience yields’ (EUR/ton) for 2008 (dotted black) and 2012 (solid red) EUA futures.

Convenience yields: Phase II → II & III



The market changed from **backwardation** to **contango** indicating available sufficient short-term supply but **long-term scarcity** due to reduced allocations in Phase III

Figure 11: *Upper Panel:* Spot prices (EUR/ton) from April 8, 2008 - July 31, 2009. *Lower Panel:* Convenience yield (EUR/ton) for Dec 2009 (black) and Dec 2012 (red)



Lower Panel: Convenience yield (EUR/ton) for Dec 2013 (black) and Dec 2014 (red)

Arbitrage opportunities?

- Unless **regulatory risk** is considered, market offers arbitrage possibilities
- Consider the following example on Apr 20, 2009:
  - EEX spot price: 12.80 EUR/tCO2
  - ECX 2012 futures price: 16.14 EUR/tCO2
  - Eurozone risk-free interest rate for 45 months: 2.35%
- Riskless profit is possible by borrowing money to buy e.g. 1000 spot EUAs and sell 2012 futures

$$16140 - 12800 * e^{0.0235*3.75} = 16140 - 13980 = 2160$$

Conclusions

- **News of over-allocation** had significant impact on allowance prices and the relationship between spot and Phase II futures prices
- **Significant convenience yields** can be observed during initial trading period of Phase I and during Phase II
- Phase II offers arbitrage opportunities unless an additional ‘**regulatory risk**’ is considered

The DSFM approach

- The **Dynamic Semiparametric Factor Model (DSFM)** is a principal component (PCA) type approach
  - Originally introduced for modeling implied volatility surfaces (Fengler et al., 2007)
  - Primary application → dimension reduction which may lead to more parsimonious and efficient risk management tools
  - Observed variables are assumed to be linear combinations of unobserved factors
- Compared to PCA
  - DSFM minimizes the squared residua (or maximizes the in-sample fit with respect to some score function)
  - While PCA maximizes the expected variance

A standard factor model vs. DSFM

- In a standard model, a J-dimensional vector of observations $Y_t = (Y_{t,1}, \ldots, Y_{t,J})$ is represented as an L-factor model (L < J):

$$Y_{t,j} = m_{0,j} + Z_{t,1} m_{1,j} + \ldots + Z_{t,L} m_{L,j} + \varepsilon_{t,j}$$

  - $Z_{t,l}$ are common factors and the coefficients $m_{l,j}$ are factor loadings
- The DSFM modifies the standard model by
  - Incorporating observable covariates $X_{t,j}$ (e.g. maturities) and
  - Generalizing factor loadings to nonparametric functions $m_{l,j}(\cdot)$

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

  - Can be regarded as a regression model with embedded time evolution
  - However, the model is different from varying-coefficient models, since the series $Z_{t,l}$ is actually unobservable

Term structure Phase I → II

Backwardation or contango?

For Phase I the term structure of futures prices is non-uniform with a **significant kink** between 2007 (Phase I) and 2008 (Phase II)

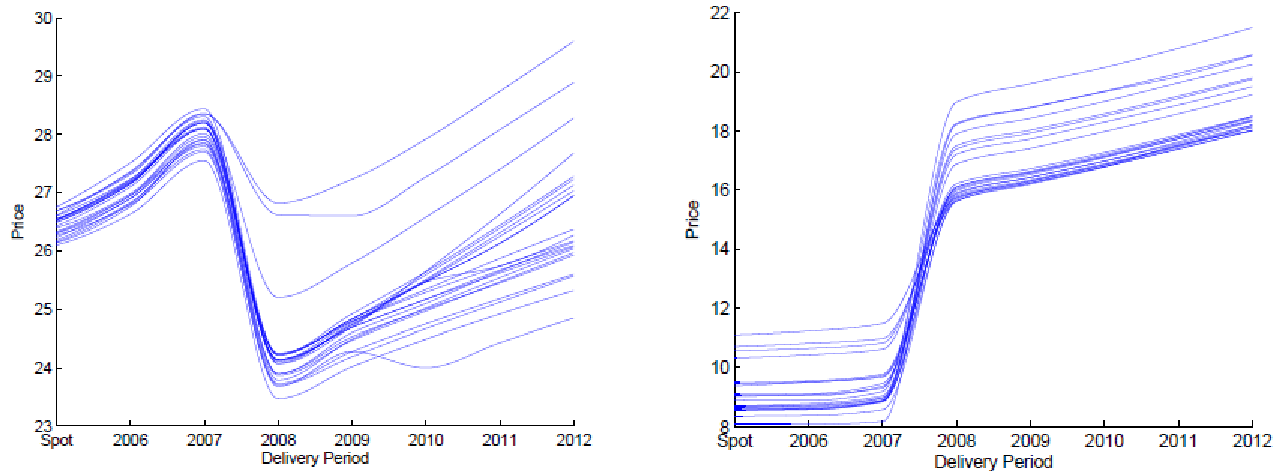


Figure 6: Term structure for spot and futures prices for each day, initial trading period March 1 - 31, 2006. (*left panel*) and Nov 1 - 29, 2006 (*right panel*).

Model calibration

- In our study we observe J_t=6 or 7 contracts
- The term structure dynamics is then explained by the time propagation of the L=1,2,… factors
- Contrary to a parametric approach both $m_{l,j}$ and $Z_{t,l}$ have to be estimated from the data
  - Fengler et al. (2007) use of a nonparametric kernel estimator
  - Following Borak and Weron (2008) and Park et al. (2009) we implement a series based estimator of the form

$$Z_t^T m(X) = \sum_{l=0}^{L} Z_{t,l} \sum_{k=1}^{K} a_{l,k} \psi_k(X) = Z_t^T A \psi(X)$$

  - where $\psi(X) = (\psi_1, \ldots, \psi_K)^T(X)$ is a vector of known basis functions

Model calibration cont.

- The least-squares estimators are given by

$$(\hat{Z}_t, \hat{A}) = min_{Z_t, A} \sum_{t=1}^{T} \sum_{j=1}^{J_t} \{Y_{t,j} - Z_t^T A \psi(X_{t,j})\}^2$$

  - *K* is the number of series expansion functions
  - ψ is the type of the basis function (here tensor B-splines)
- For the choice of **dimension L**, the proportion of the variation explained by the model is compared to the estimate given by the overall mean (i.e. total variation)

$$1 - RV(L) = 1 - \frac{\sum_t^T \sum_j^{J_t} \{Y_{t,j} - \sum_{l=0}^{L} \widehat{Z}_{t,l} \widehat{m}_l(X_{t,j})\}^2}{\sum_t^T \sum_j^{J_t} (Y_{t,j} - \bar{Y})^2}$$

DSFM results

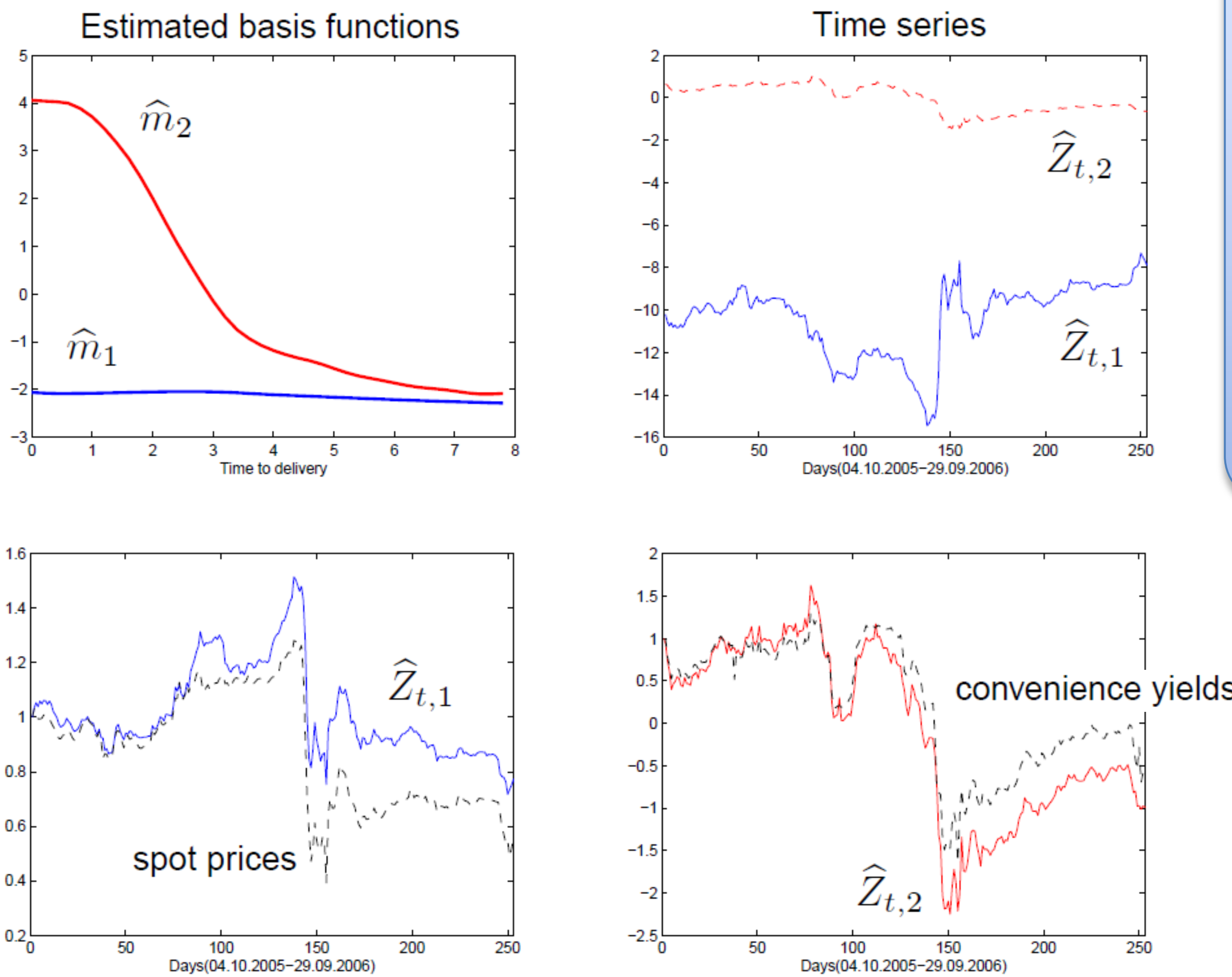
- Explained variance for models with L=1,…,3 dynamic factors:
  - Oct 4, 2005 - Nov 29, 2007
    Phase I spot, Phase I/II futures
  - Apr 8, 2008 - Jul 31, 2009
    Phase II spot, Phase II/III futures
- **Two factors** explain a high 'enough' percentage of the variance for both trading periods

No. Factors	$1 - RV(L)$
L=1	0.9167
L=2	0.9890
L=3	0.9896

No. Factors	$1 - RV(L)$
L=1	0.9638
L=2	0.9914
L=3	0.9922

DSFM results

(Phase I spot → Phase I/II futures)

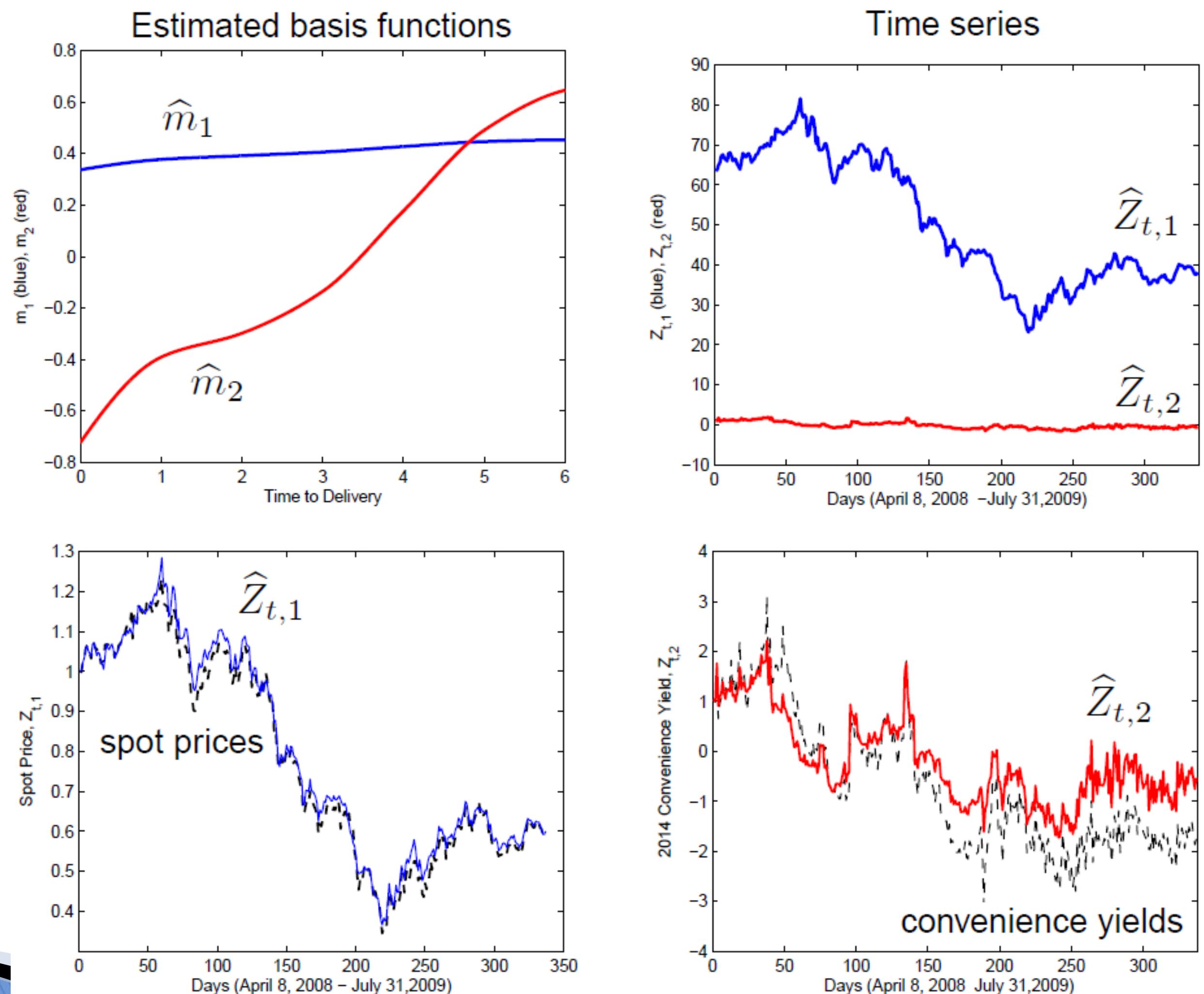


These results can be related to the classic model for pricing contingent claims in commodity markets

Gibson and Schwartz (1990) present a two-factor model using the **spot price** and the **convenience yield** as factors

DSFM results

(Phase II spot → Phase II/III futures)

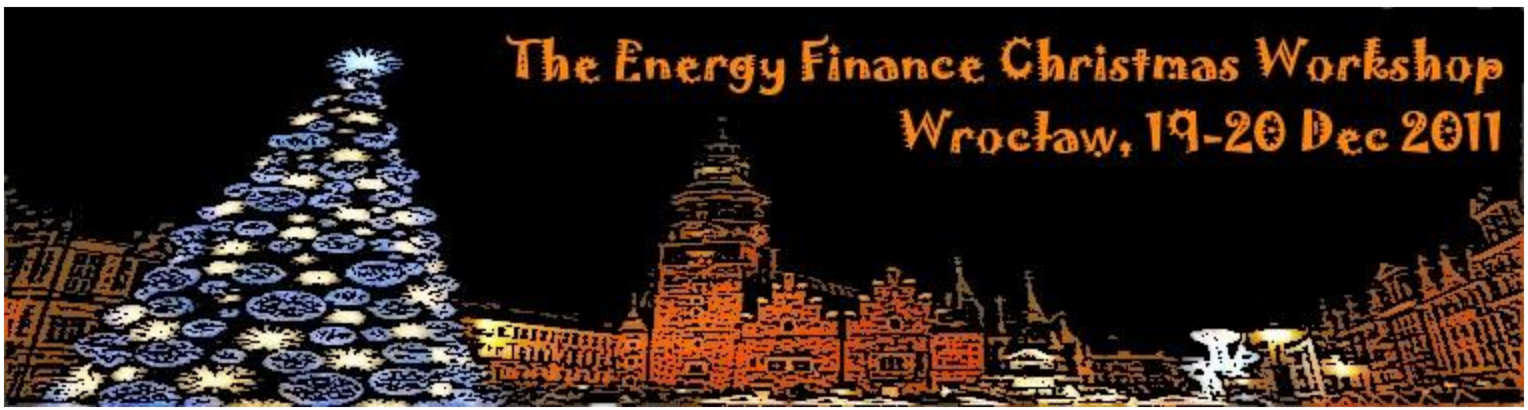


Conclusions

- Banking helps to **smooth out** price differences between the different phases and makes term structure less volatile
  - See Phase I → II and Phase II → III term structures
- DSFM model with **two factors** explains a high ‘enough’ percentage of the variance for both trading periods
  - The first factor shows high correlation with **spot price**
  - The second factor with **convenience yield** of futures contracts with longer maturity
  - The same two factors drive the Gibson and Schwartz (1990) model for pricing contingent claims in commodity markets

Conclusions cont.

- There are still many open questions in Energy Economics
- Hopefully some of them will get answered during:



- You are cordially invited ☺

The Energy Finance Christmas Workshop 2011 - Mozilla Firefox

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www.ioz.pwr.wroc.pl/pracownicy/weron/EFC11.htm

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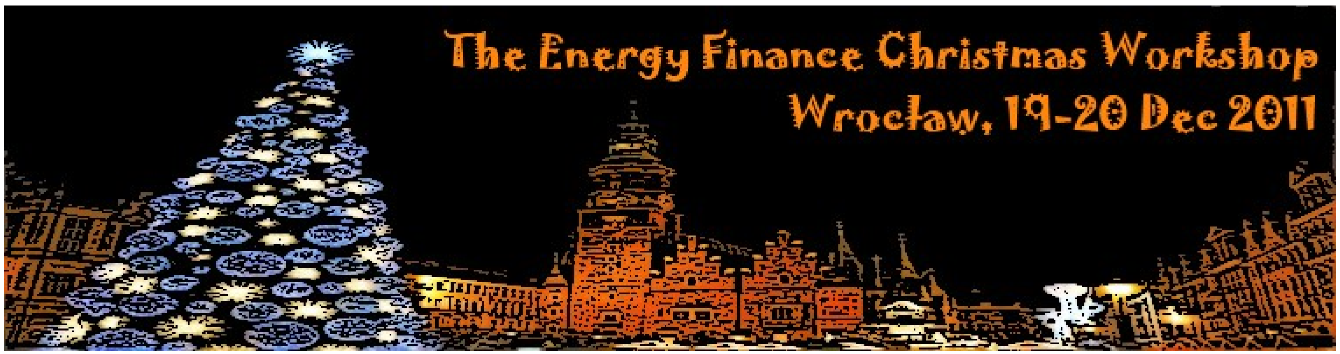

The Energy Finance Christmas Workshop (EFC11) *is a cozy, informal workshop devoted to the latest developments in Energy Finance. The topics include, but are not limited to CO_2 emissions trading, electricity price spike forecasting, modeling with regime switching models, quantile regression applications, power market data filtering and deseasonalizing, weather derivatives and wind power.*

Invited speakers:

- Brenda Lopez Cabrera (HUB, Berlin, D)
- Angelica Gianfreda (EUI, Florence, I)
- Stephane Goutte (CNRS, Paris, F)
- Joanna Janczura (WUT, Wrocław, PL)
- Valery Kholodnyi (Verbund, Vienna, A) *
- Tomasz Kludka (Redpoint Energy, London, GB) *
- Tarjei Kristiansen (SN Power, Oslo, N)
- Katarzyna Maciejowska (WUT, Wrocław, PL)
- Sandro Sapio (U.Parthenope, Naples, I)
- Anannit Sumawong (ICMA, Reading, GB)
- Stefan Trueck (MQ, Sydney, AUS)
- Sjur Westgaard (NTNU, Trondheim, N)

Hosted by: Rafał Weron

Time and venue:

December 19-20, 2011
Wrocław University of Technology (WUT), Poland
Institute of Organization and Management
Room 447, building B4
(campus map: JPG, 345KB)

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