Implications of Spot Price Models on the Valuation of Gas Storages

LEF, Energy & Finance
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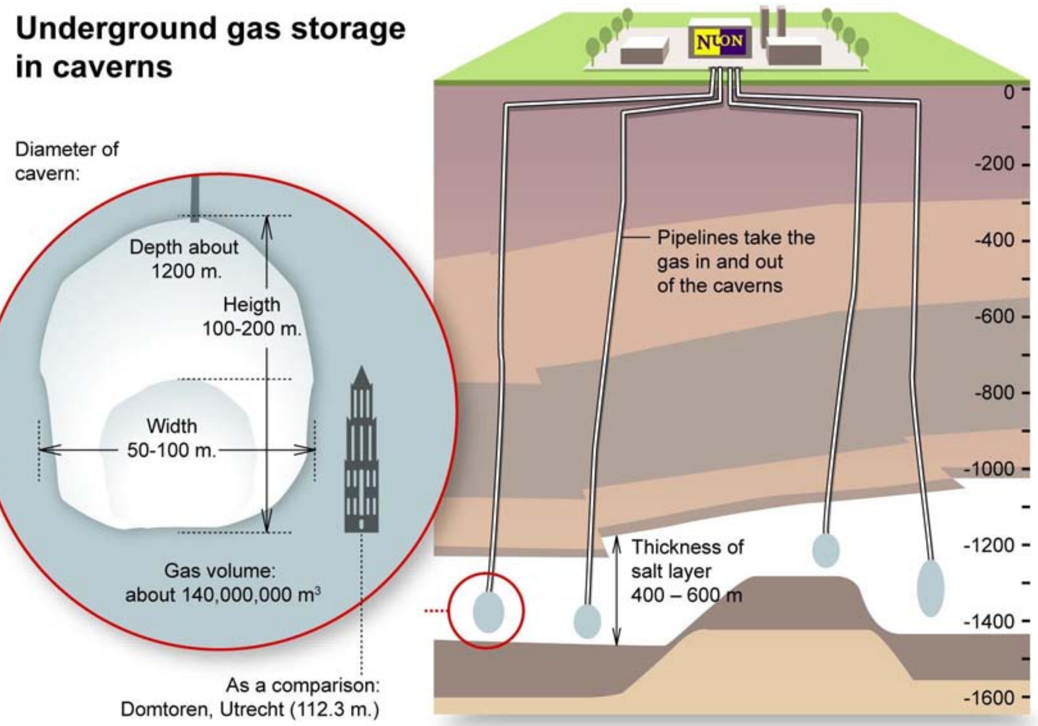
Agenda

- Gas storage
- Valuation of gas storages
- Spot price model
- Example: Valuation of gas storages
- Conclusions

Gas storage

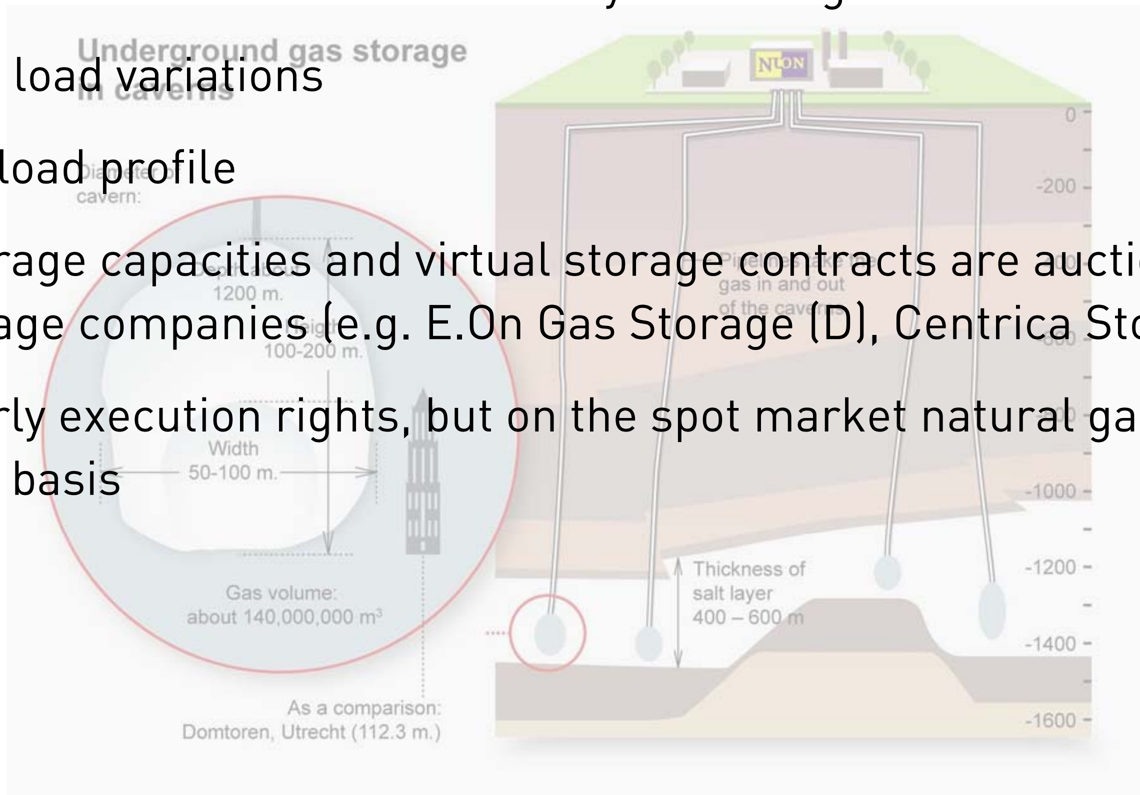
- Asset to inject or withdraw gas, e.g. depleted gas reservoir, salt cavern…



Source: NUON

Gas storage

- Asset to inject or withdraw gas, e.g. depleted gas reservoir, salt cavern…
- Natural gas is stored to structure delivery according to variations in demand
  - seasonal load variations
  - intraday load profile
- Physical storage capacities and virtual storage contracts are auctioned by several storage companies (e.g. E.On Gas Storage (D), Centrica Storage (UK))
- Daily or hourly execution rights, but on the spot market natural gas is traded only on daily basis



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Gas storage

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- Natural gas is stored to structure delivery according to variations in demand
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- Physical storage capacities and virtual storage contracts are auctioned by several storage companies (e.g. E.On Gas Storage (D), Centrica Storage (UK))
- Daily or hourly execution rights, but on the spot market natural gas is traded only on daily basis
- Valuation is done via Least Squares Monte Carlo
- References:
  - A. Boogert, C. de Jong: Gas Storage Valuation Using a Monte Carlo Method; Journal of Derivatives, Spring 2008

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Technical Conditions for Gas Storages

Storage volume.	V_d^{max}	maximum working gas volume on day *d*
	V_d^{min}	minimum working gas volume on day *d*
	V_d	actual working gas volume content on day *d* (positive variable)
Injection:	$Q_d^{I,max}(V)$	maximum injection rate on day d as a function of the working gas volume level
	Q_d^I	actual injection rate (positive variable)
	$C_d^I(V, Q_d^I)$	injection costs on day d as a function of the working gas volume level
Withdrawal:	$Q_d^{W,max}(V)$	maximum withdrawal rate on day d as a function of the working gas volume level
	Q_d^W	actual withdrawal rate (positive variable)
	$C_d^W(V, Q_d^W)$	withdrawal costs on day d as a function of the working gas volume level
Initial condition:	V_0	working gas volume at start of valuation period
Final condition:	V_{end}	working gas volume at the end of the valuation period

Valuation and Optimal Scheduling – Problem Statement

- storage balance

$$V_{d+1} = V_d + \left(Q_d^I - Q_d^W\right) \qquad \forall d$$

- Constraints

$$V_d^{min} \leq V_d \leq V_d^{max} \qquad \forall d$$

-

$$0 \leq Q_d^I \leq Q_d^{I,max}, \quad 0 \leq Q_d^W \leq Q_d^{W,max} \quad \forall d$$

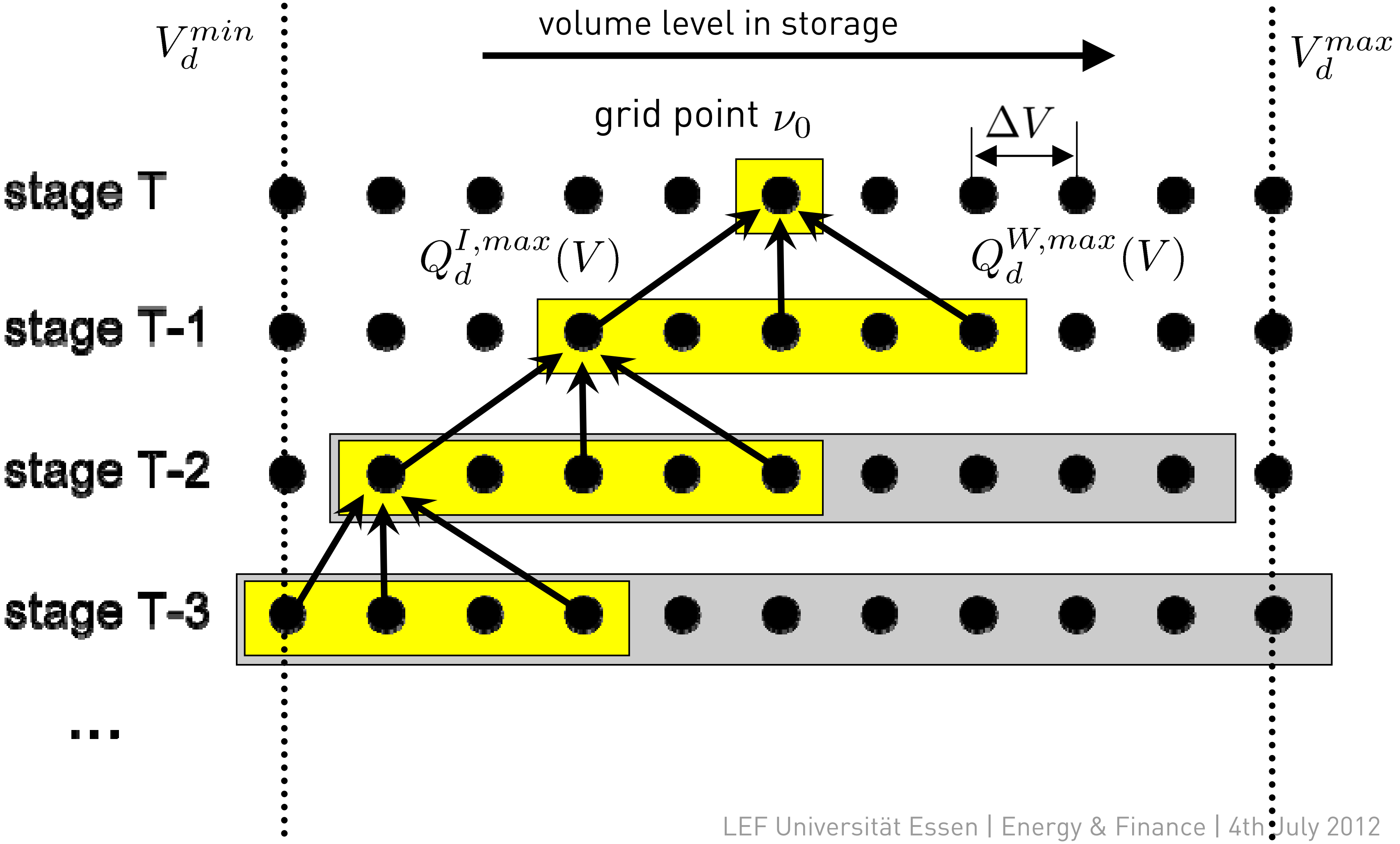
- Value function

$$M = \sum_d D_{d,d_0} \cdot \left[S_d \cdot \left(Q_d^W - Q_d^W\right) - C_d^I(V, Q_d^I) - C_d^W(V, Q_d^W)\right]$$

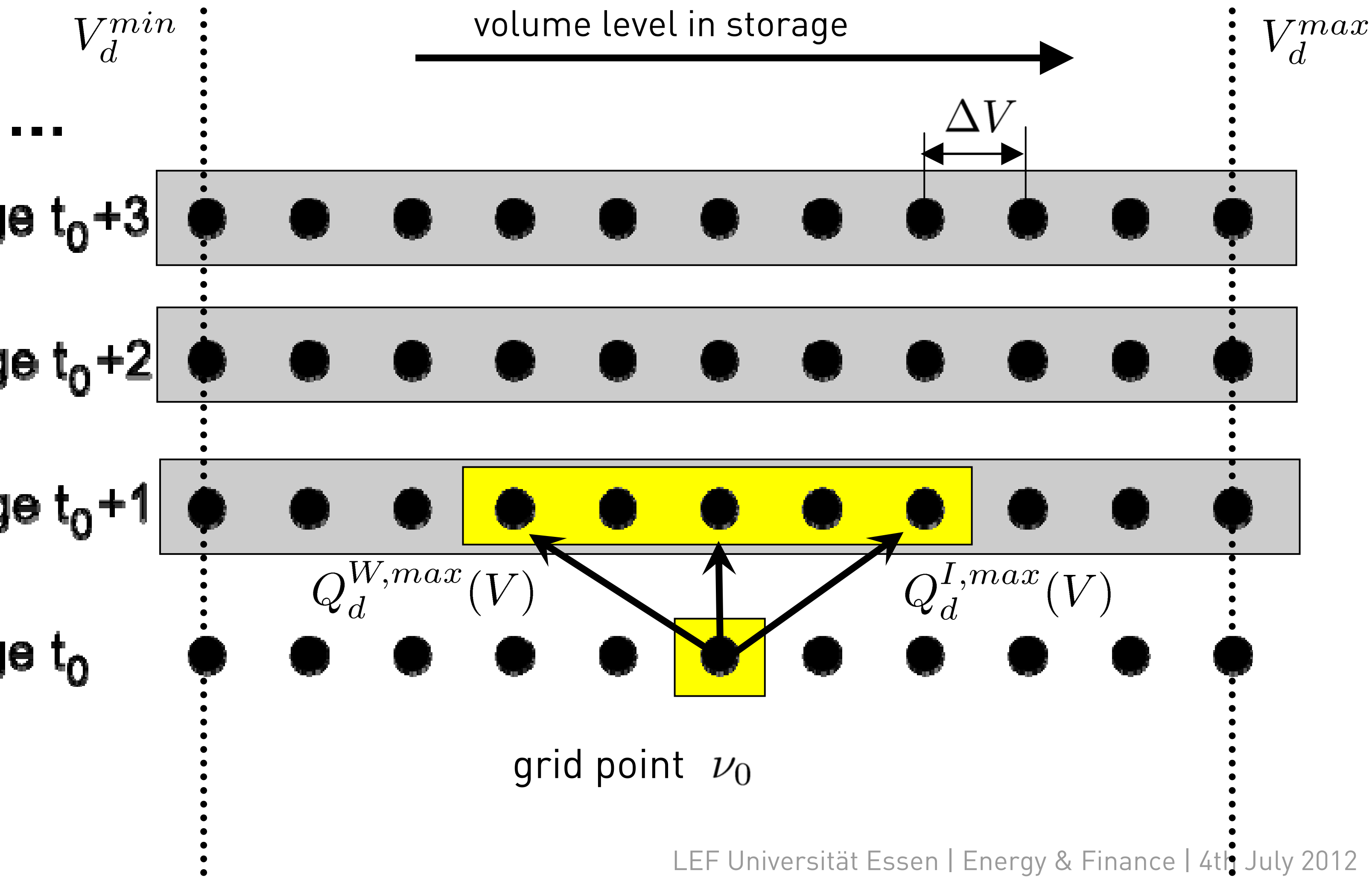
- Fair option value (risk neutral measure Q) at time d_0 :

$$V = \max_{Q_d^I, Q_d^W} \mathbb{E}_{d_0}^{Q}\left[M\right]$$

Dynamic Programming: Discretization (1)



Dynamic Programming: Discretization (2)

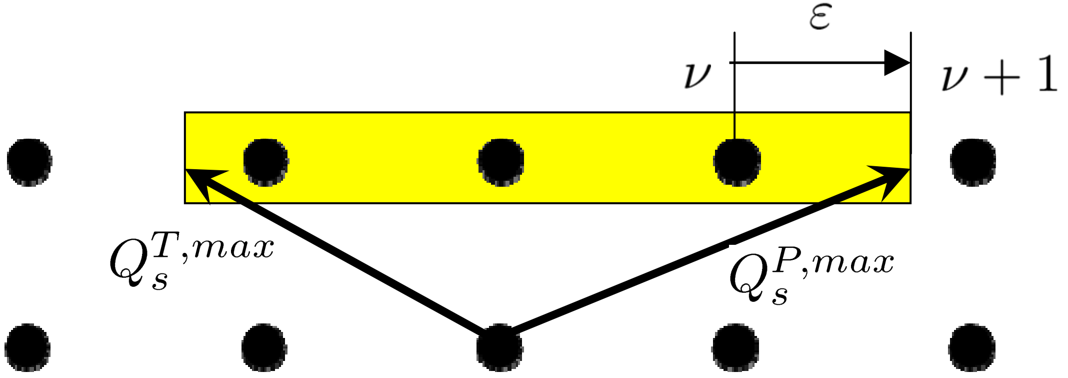


Dynamic Programming: Interpolation

- If injection and withdrawal rates are **not integer multiples** of the grid distance:
- Interpolate between continuation values for adjoint grid points

$$U(t,\omega,\nu+\varepsilon) = (1-\varepsilon)\cdot U(t,\omega,\nu) + \varepsilon \cdot U(t,\omega,\nu+1)$$

$$0 \leq \varepsilon \leq 1$$



Dynamic Program for Gas Storages

- Dynamic program:
- start with allowed grid points at time step T initialize continuation values with zeros (grid point ν, price scenario ω) $U(T, \omega, \nu) = 0$
- recursively step back in time
  1. discount continuation value to actual time for allowed grid points
  $$C(d_k, \omega, \nu) = D_{d_{k+1}, d_k} \cdot U(d_{k+1}, \omega, \nu)$$
  2. calculate reachable grid points ν and all allowed actions $\Delta\nu$
  3. maximise sum of immediate payoffs and future cashflows
  $$U(d_k, \omega, \nu) = \max_{\Delta\nu}[h(S_{d_k}, \Delta\nu) + C(d_k, \omega, \nu + \Delta\nu)$$

  here h is the immediate payoff from injection ($\Delta\nu > 0$) or withdrawal ($\Delta\nu < 0$)
  $$h(S_d, \Delta\nu) = -\Delta\nu \cdot \Delta V \cdot S_d$$
- Calculate option value as mean (starting volume ν_0):
  $$U = \frac{1}{N} \sum_{\omega=1}^{N} U(d_0, \omega, \nu_0)$$

What is the fair value?

Least Squares Monte Carlo

- Stochastic dynamic program (cf. Boogert and de Jong (2008)):
- start with allowed grid points at time step T initialize continuation values with zeros (grid point ν, price scenario ω) $U(T,\omega,\nu) = 0$
- recursively step back in time
  1. discount continuation value to actual time for allowed grid points
     $$C(d_k,\omega,\nu) = D_{d_{k+1},d_k} \cdot U(d_{k+1},\omega,\nu)$$
  2. calculate reachable grid points ν and all allowed actions $\Delta\nu$
  3. Approximate continuation value using a set of basis functions by regression
     $$\hat{C}(d_k,\omega,\nu) = \sum_{l=0}^{M} a_l^{\nu} B_l(S_{d_k}^{\omega})$$
  4. maximise sum of immediate payoffs and future cashflows
     $$U(d_k,\omega,\nu) = \max_{\Delta\nu}[h(S_{d_k},\Delta\nu) + \hat{C}(d_k,\omega,\nu+\Delta\nu)$$
     here h is the immediate payoff from injection of withdrawal
- Calculate option value as scenario mean (starting volume ν_0):
  $$U = \frac{1}{N}\sum_{\omega=1}^{N} U(d_0,\omega,\nu_0)$$

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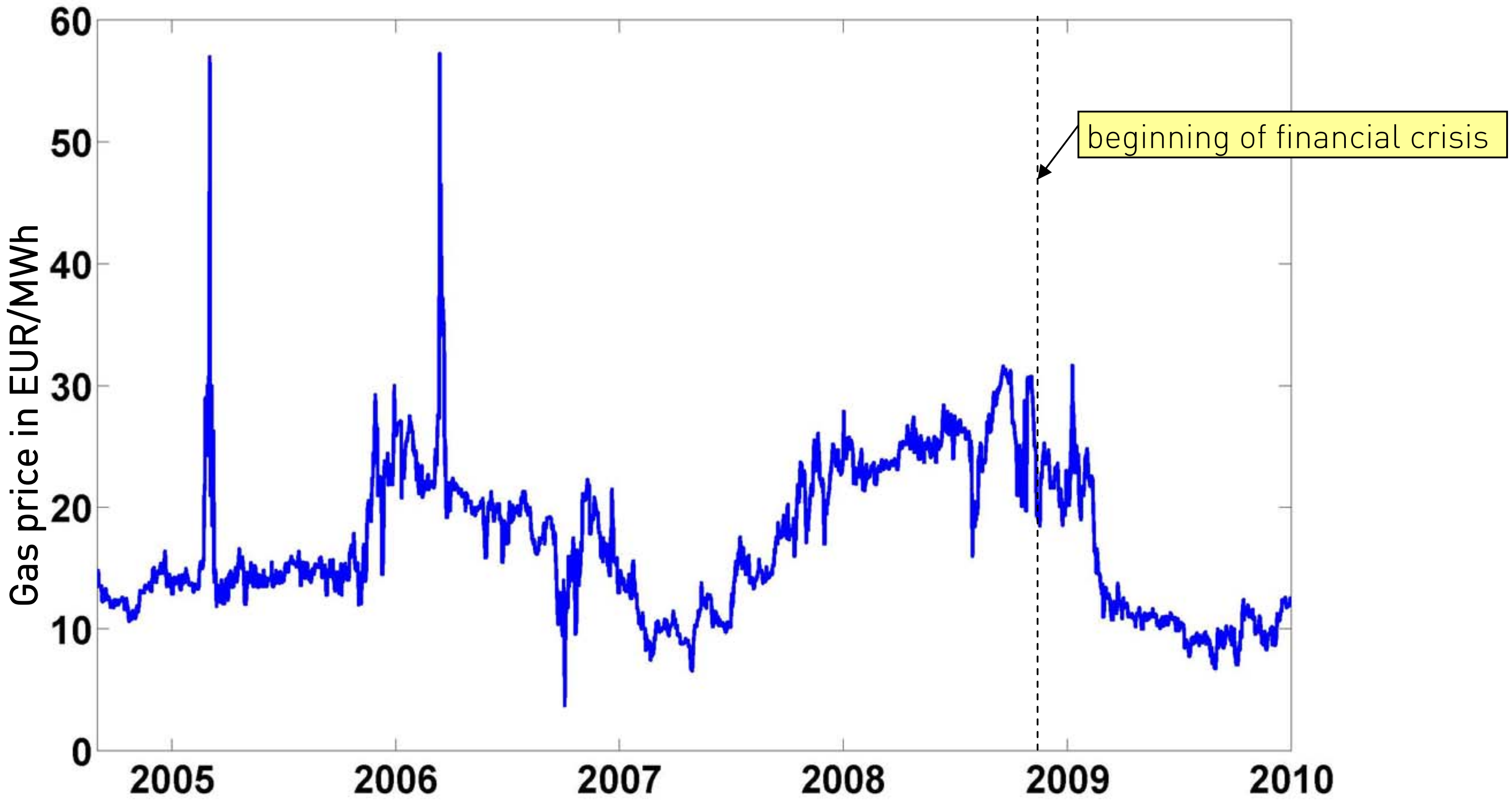
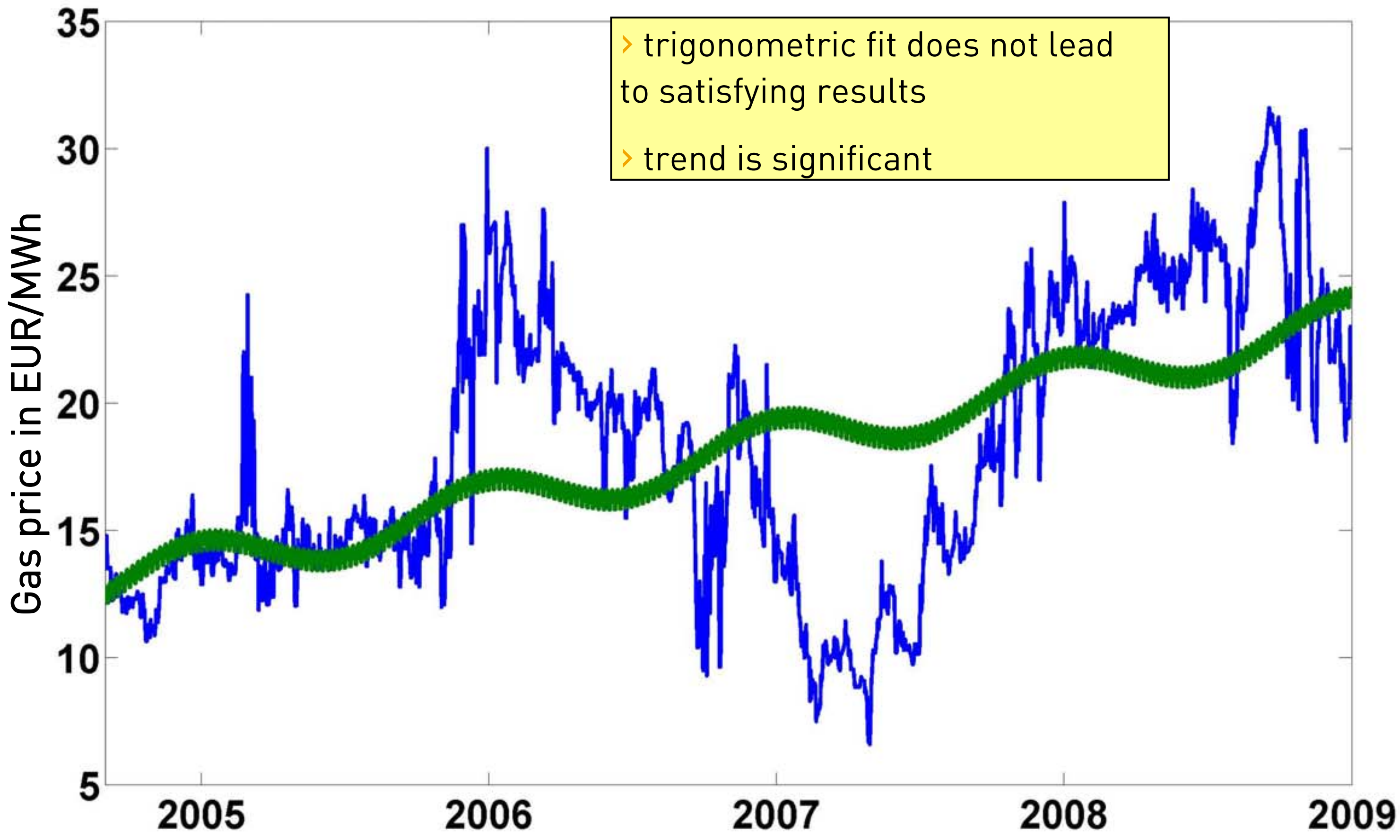
Natural Gas Prices
Properties of Spot Price Time Series



TTF Spot Prices

Natural Gas Prices
Is there a naive seasonality?



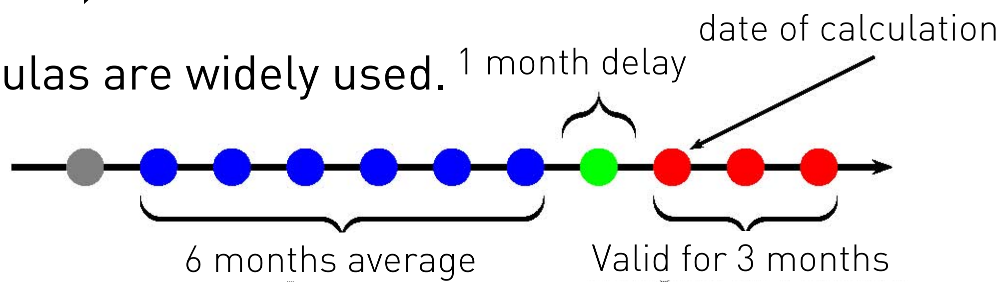
› trigonometric fit does not lead to satisfying results

› trend is significant

Natural Gas Prices

Are there any further influencing variables?

- Idea 1: In winter gas price is influenced by available storage volume.
  - Storage volume data is not sufficient.
  - Storage demand strongly depends on temperature.
  - Longer periods of cold weather lead to low storage volume and increasing spot market prices.
- Idea 2: Gas is imported by long term contracts which are indexed on oil price by formulas.
  - Typical formulas are 6-1-3, 6-3-3, 3-1-1 or 3-1-3.
  - Gas oil and fuel oil price formulas are widely used.



Influencing Variables
Heating Degree Days

- Heating Degree Days

  HDD = max(15-temperature;0)

- Cumulated Heating Degree Days (Winter)

  CHDD(t) = Sum of all HDDs in winter up to day t

- Cumulated Heating Degree Days for norm winter

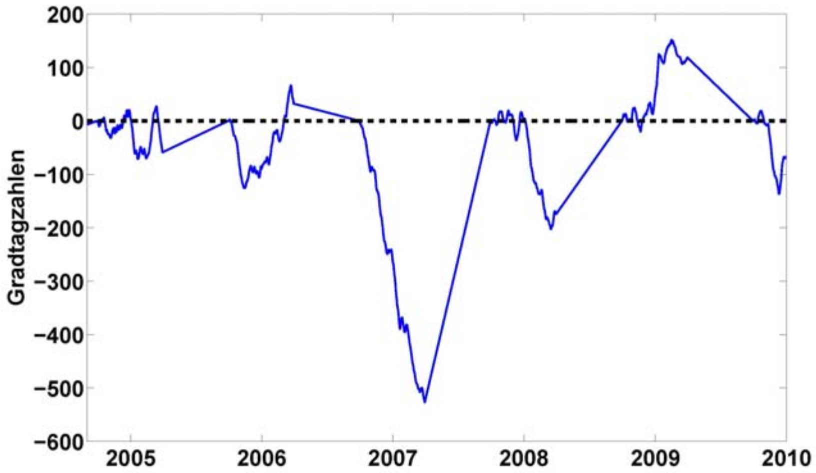
  MCHDD(t) = Mean of CHDD(t) for all historic winters

- Deviation of CHDD from norm winter:

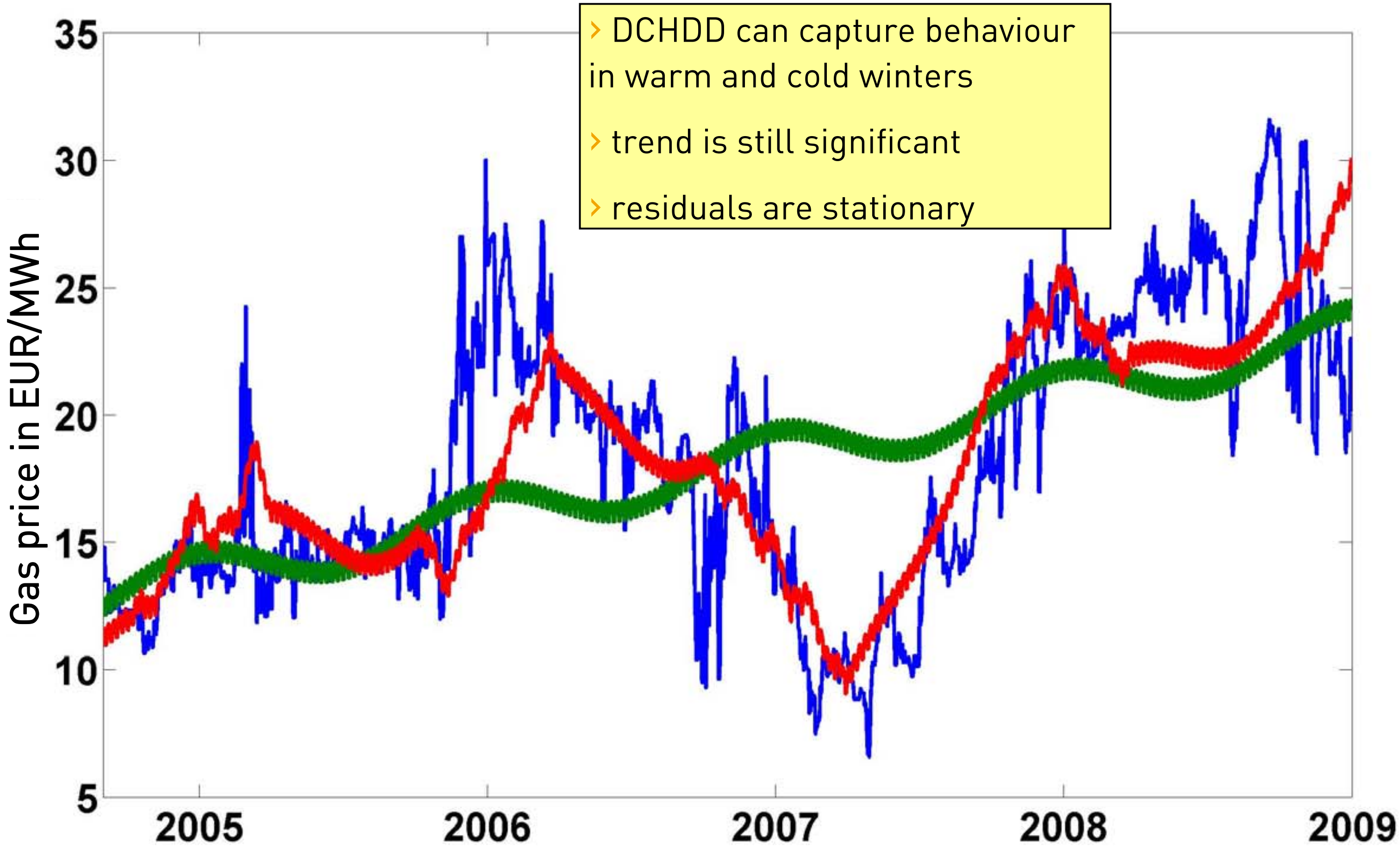
  DCHDD(t) = CHDD(t) – MCHDD(t)

- In summer linear interpolation down to 0

DCHDD for Eindhoven

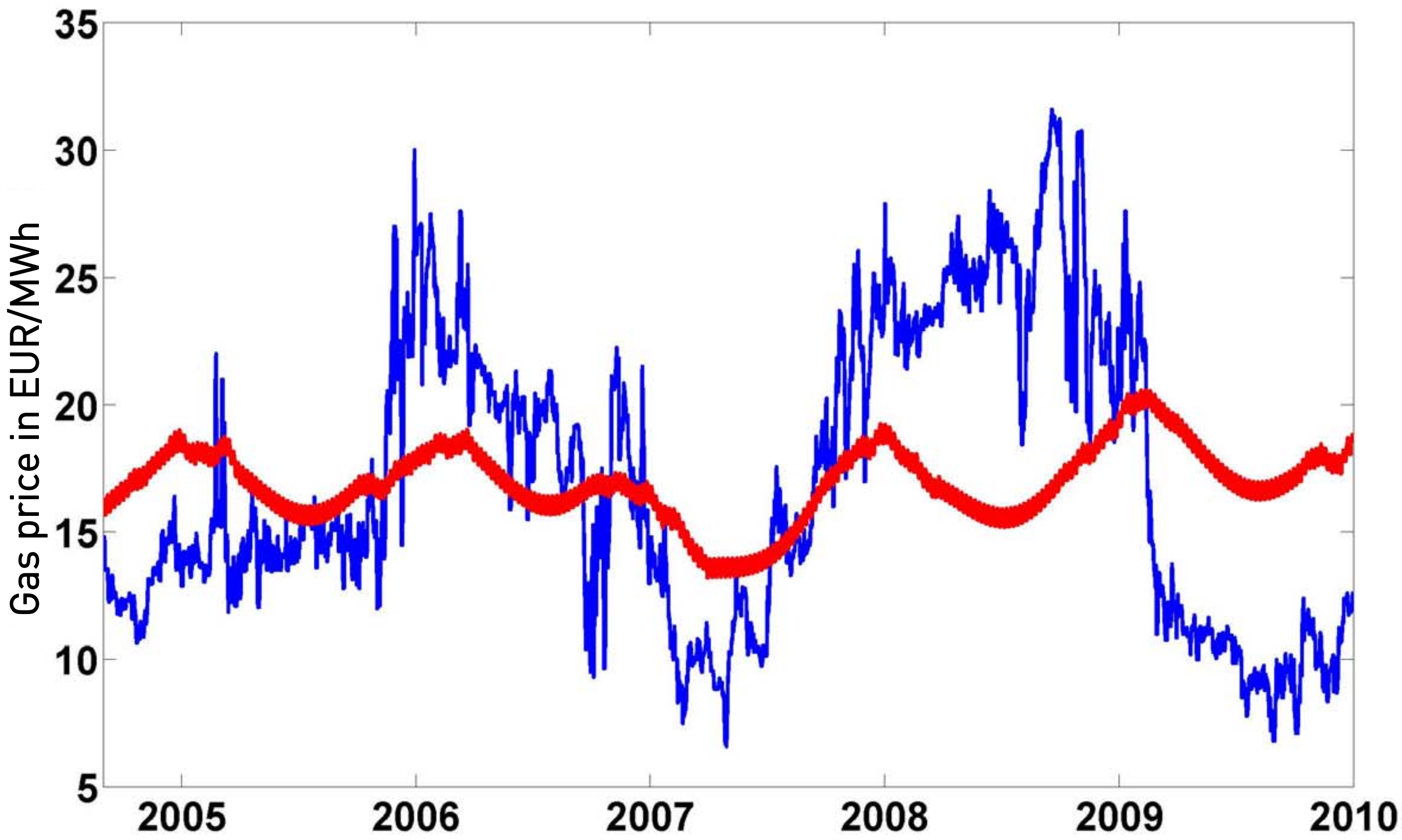


Seasonality with DCHDD



Seasonality with DCHDD

What happened during the financial crisis?

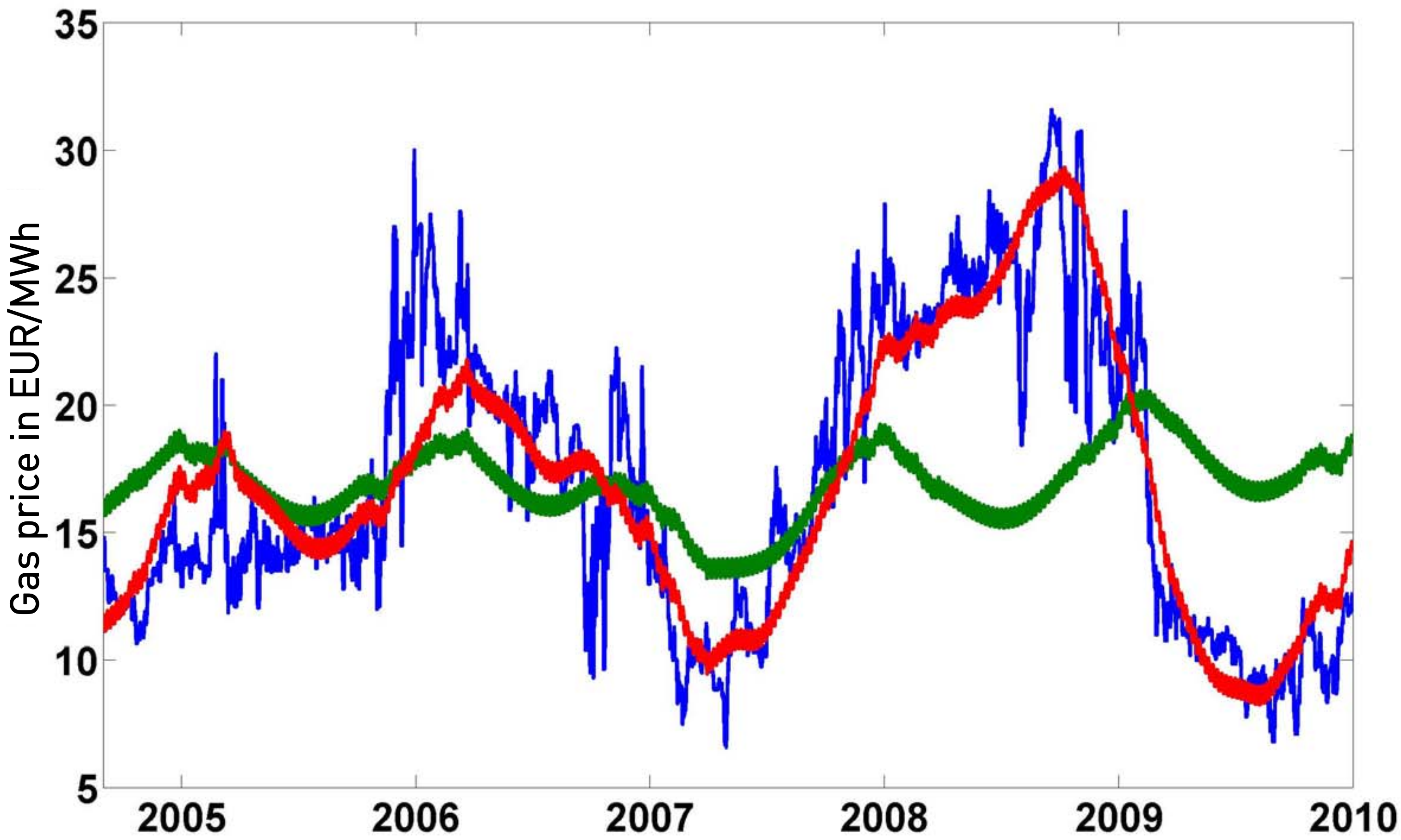


Influencing Variables
Oil price component

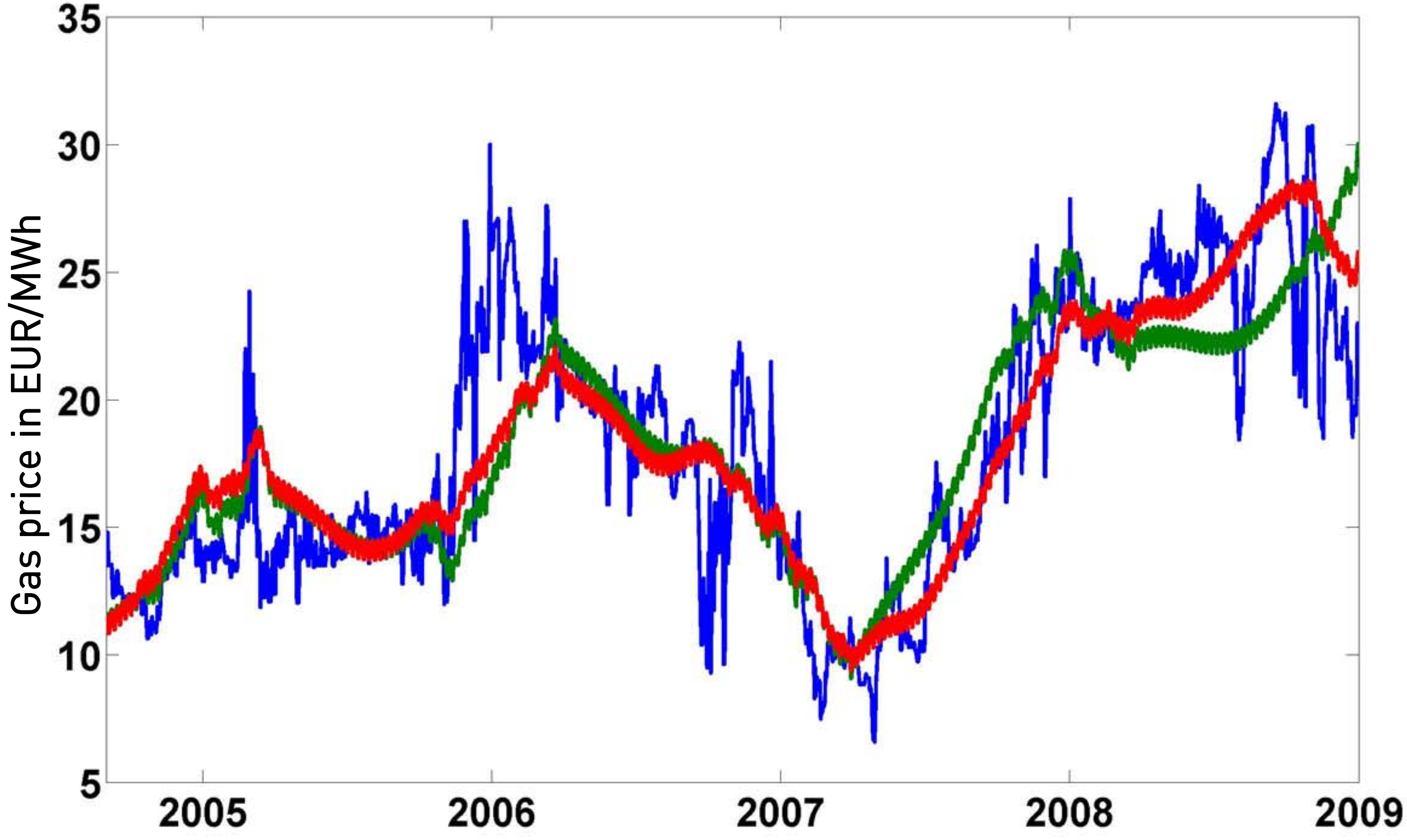
- Correlation between gas oil, fuel oil and Brent crude oil is 97% - 99%. Thus, choose Brent because of longer history and better quality of data.
- Use formulas to include smoothing and time lag.

Formula	R^2 of regression
5-0-1	0.7946
3-1-1	0.7812
3-1-3	0.7105
6-1-1	0.6995
6-1-3	0.5756
6-3-3	0.3047

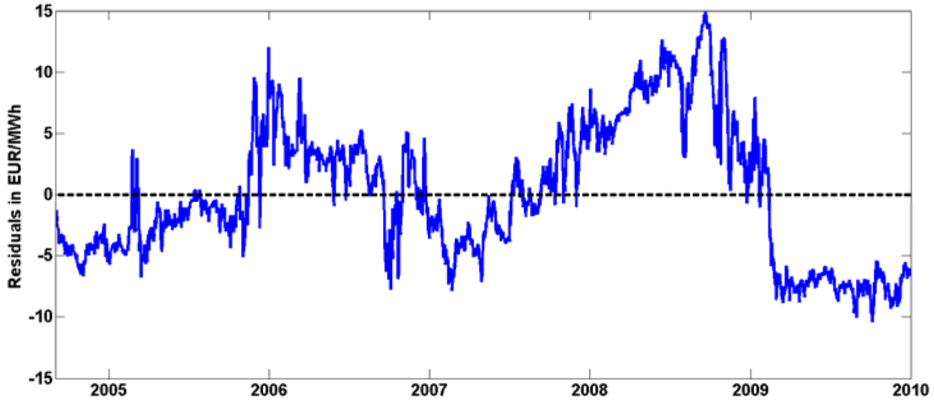
Seasonality with DCHDD and oil formula
Fit until end of 2009



Seasonality with DCHDD and oil formula
Fit until end of 2008

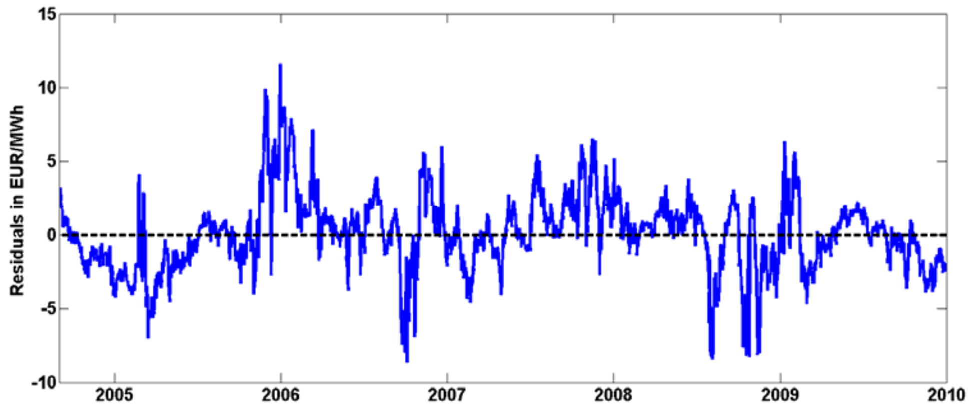


Residuals
Stationary or not?



modelled dependence on heating degree days

modelled dependence on heating degree days and oil price component

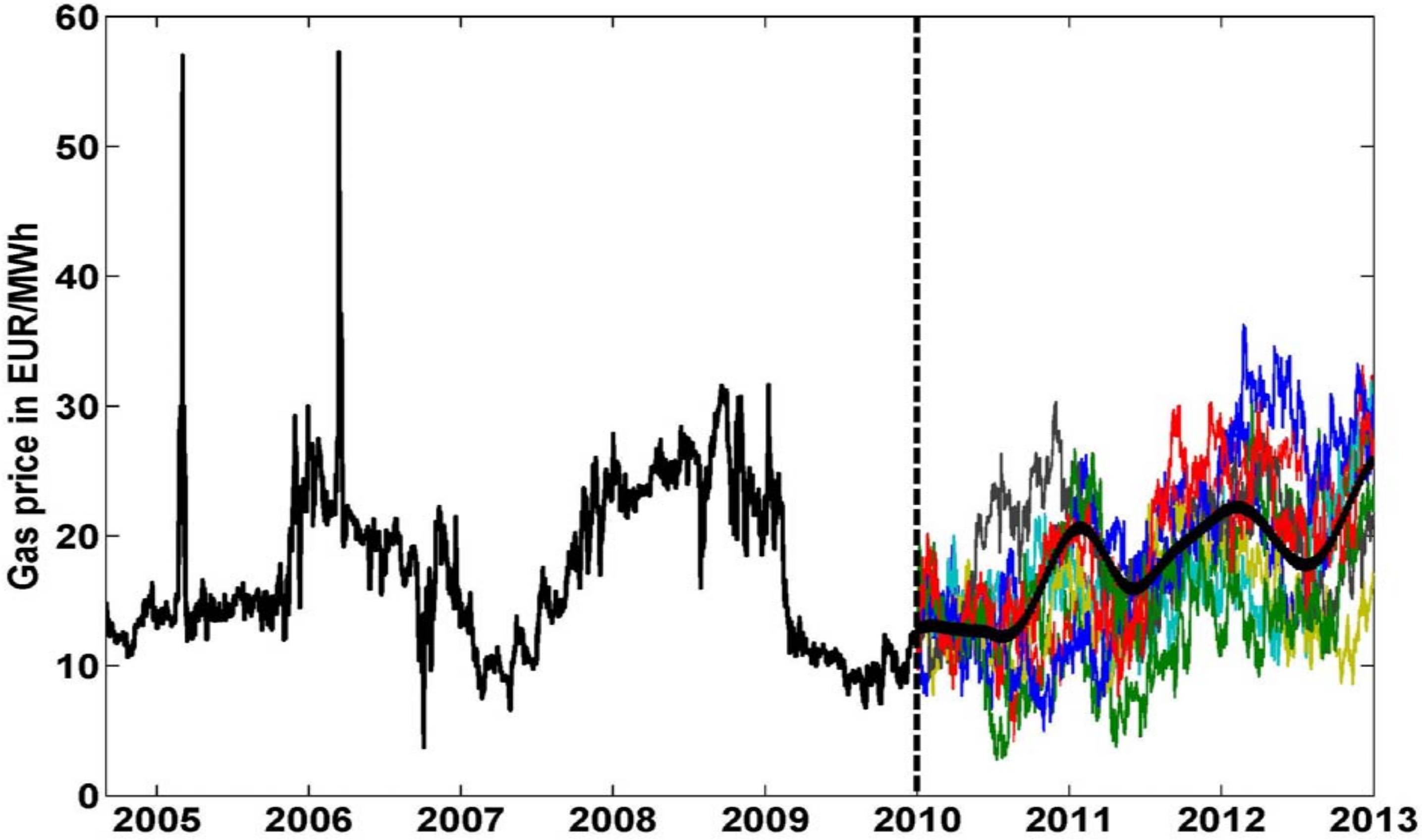


Stochastic Model

$$X_t = m_t + s_t + S_t + a_1 f(\Theta_t) + a_2 g(\Psi_t) + Y_t$$

m_t	linear trend
s_t	weekly seasonality
S_t	yearly seasonality
$f(\Theta_t)$	Normalised cumulative heating degree days with linear return to 0 during summer
$g(\Psi_t)$	5-0-1 oil formula for Brent crude oil
Y_t	stochastic component: ARMA(2,1) process with variance gamma innovations

Simulation paths



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Examples: Gas storage valuation

	Storage 1	Storage 2
Start date	05.01.2010	01.04.2010
End date	31.03.2010	31.03.2012
Max. volume (MWh)	216.000	324.000
Initial volume (MWh)	200.164	0
Injection rate (MW)	150	150
Withdrawal rate (MW)	150	300
Injections costs (€/MWh)	0	0,30
Withdrawal costs (€/MWh)	0	0
Valuation without oil component (€)	2.694.690	6.829.537
Valuation with oil component (€)	2.756.116	6.112.047

10% difference in valuation!

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Conclusion

- Significant parts of gas spot prices behaviour can be explained by using exogenous variables as regressors.
- Using NCHDD as fundamental component reduces volatility often overestimated by other models.
- The second fundamental component is oil which can explain behaviour during financial crisis 2009.
- Good models including fundamental components are important for valuation and trading decisions.
- References:

  - A. Boogert, C. de Jong: Gas Storage Valuation Using a Monte Carlo Method; Journal of Derivatives, Spring 2008
  - S.O. Stoll, K. Wiebauer: A Spot Price Model for Natural Gas Considering Temperature as Exogenous Factor and Applications; Journal of Energy Markets, 2010.
  - J. Müller: Ein gekoppeltes Spotmarktmodell für Öl- und Gaspreise; Master Thesis, University of Siegen, 2010.

Thank you for your attention!

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