The Systemic Risk of Energy Markets

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Systemic Risk

Systemic risk: the risk of the financial sector as a whole being in distress and its spillover to the economy at large

Systemic risk is related to

1. dependence, causality, externality, interconnectedness, spillover effects
2. market integration, contagion, commonality
3. shocks, crises, extreme events

Does this exist in energy markets?
How to measure it?
How does this affect the rest of the economy?

Energy Systemic Risk

Energy Systemic Risk: the risk of an energy crisis raising the prices of all energy commodities with negative consequences for the real economy.

- increased dependence of the economy on energy
- increased energy market integration
- extreme energy market shock from the supply side
- negative consequences for the energy sector and the rest of the economy

Energy Security: "the uninterrupted availability of energy sources at an affordable price." (IEA)

Related literature

This project relates to the literature on

- Past energy crises and the impact of energy prices on the economy (Hamilton, 1983)
- Systemic Risk
  - Network (Nier et al. (2007), Battiston et al. (2009), Billio et al. (2010), Hautsch et al. (2011), Diebold and Yilmaz (2011))
  - Co-movements (Billio et al. (2010), Kritzman et al. (2011), Acharya et al. (2010), Brownlees and Engle (2011))
- Energy prices co-movements
  - Cointegration and causality in the mean (Bunn and Fezzi (2008))
  - Multivariate Volatility (Chevallier (2012), Bauwens et al. (2012))
  - Copulae (Benth and Kettler (2010), Boerger et al. (2009), Gronwald et al. (2011))

Outline

1. The Energy Systemic Risk Measure: EnSysRISK
2. Econometric methodology and application
   - Causility in means and variances
   - Factor model and tail expectations
3. EnSysRISK and the impact on the economy

Outline

EnSysRISK

The conditional MES of an energy asset (Acharya et al. (2010), Brownlees and Engle (2011)) is given by

$$MES_{it} = \mathrm{E}_{t-1}\left(r_{it} | energy\ crisis\right)$$

Corresponding systemic prices are derived from past price levels

$$sysprice_{it} = p_{it-1} * \exp(MES_{it})$$

EnSysRISK: the total cost of an energy asset to the non-energy sector during an energy crisis

$$EnSysRISK_{it} = \max(0, sysprice_{it} * w_{it}),$$

where w_{it} is the quantity exposure of the economy to asset i at time t.

For an energy contract with maturity and delivery period ν, the exposure at time t is

$$w_{it}(\nu) = \varsigma_i \mathrm{E}_{t-1}\left(fincons_\tau - inv_\tau\right) \text{ for } \tau \in [t+\nu; t+2\nu-1]$$

The MES of energy markets (1/2)

Energy crisis: an extreme positive energy market shock from the supply side

$$MES_{it}(C) = \mathrm{E}_{t-1}\left(r_{it} | r_{EnM,t} > C, r_{M,t} < 0\right),$$

where $r_{EnM,t}$ is the energy market return, $r_{M,t}$ is the return of the non-energy sector, and C represents the VaR of the energy market at $(1-\alpha)\%$.

An extreme increase in energy prices...

- Not only oil prices: "While the security of oil supplies remains important, contemporary energy security policies must address all energy sources" (IEA 2011)
- Integration dimensions: underlying energy (oil, coal, natural gas, electricity, carbon), maturity/delivery, region
- Futures prices

The MES of energy markets (2/2)

Methodology: the conditional MES as a function of mean, volatility and tail expectation

$$\begin{aligned} MES_{it}(C) &= \mathrm{E}_{t-1}\left(\mu_{it} + \sigma_{it} u_{it} | r_{EnMt} > C, r_{Mt} < 0\right) \\ &= \mu_{it} + \sigma_{it} \mathrm{E}_{t-1}\left(u_{it} | r_{EnMt} > C, r_{Mt} < 0\right) \end{aligned}$$

where μ_{it} and σ_{it}^2 are the conditional mean and variance of asset return i and $u_{it} = (r_{it} - \mu_{it})/\sigma_{it}$ are the standardized residuals.

Separate causality from common factor exposure:

- Causality in μ_{it} and σ_{it}

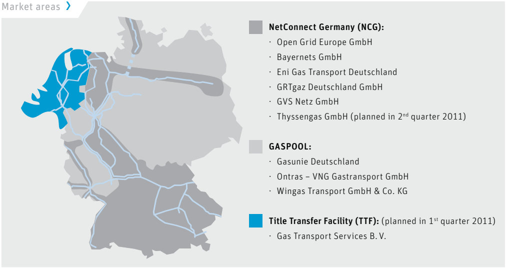
  Heteroskedasticity and causality are removed to concentrate on the 'pure' commonality or contagion phenomenon (Forbes and Rigobon (2002), Billio and Caporin (2010))

- Common factors in standardized residuals: $u_{it} = f(\mathrm{y}_t, \zeta_{it})$

Outline

EEX futures, energy spot and DAX industrial indices

- 10 EEX futures
  - Electricity: Phelix financial futures (M, Q, Y maturity)
  - Natural gas: Gaspool physical futures (M, Q, Y maturity)
  - Coal: ARA financial futures (M, Q, Y maturity)
  - EU emission allowances: EUA financial futures (Y maturity)
- 3 energy spot indices highly correlated to EEX futures returns
  - Brent crude oil
  - European coal
  - EUA
- 1 DAX industrial index (energy consumers) = non-energy index



Source: EEX

Outline

Cointegration and Granger-causality in the mean

Augmented Vector Error Correction Model (VECM) for the joint mean of the $(n \times T)$ matrix of returns r_t capturing cointegration, autocorrelation, causality, and seasonality

$$r_{it} = \pi_i \eta' \ln(\mathrm{p}_{t-1}) + \sum_{k=1}^{K} \delta'_{ik} \mathrm{r}_{t-k} + \sum_{m=1}^{M} \theta'_{im} \mathrm{x}_{t-m} + \varphi'_i \mathrm{q}_t + \varepsilon_{it}$$

where η are the cointegrating vectors,
π_i are error-correction parameters,
δ_{ik} is a $(n \times 1)$ vector of autocorrelation and Granger-causal parameters of order k,
x_{t-m} are exogenous variables lagged by m days and
q_t are deterministic (seasonal) factors.

Similar to Bunn and Fezzi (2008), except that all energy products are here considered to be endogenous variables (as part of the 'system').

Multiplicative Causality GARCH model

Multiplicative Causality GARCH model for the variance with a GARCH component and an interaction component

$$\varepsilon_{it} = \sigma_{it} u_{it} = \sqrt{\phi_{it} g_{it}} u_{it}$$

where

$$g_{it} = (1 - \alpha_{ii} - \beta_i - \frac{\gamma_{ii}}{2}) + \alpha_{ii} \left(\frac{\varepsilon_{it-1}^2}{\phi_{it-1}} \right) + \beta_i g_{it-1} + \gamma_{ii} \left(\frac{\varepsilon_{it-1}^2}{\phi_{it-1}} \right) I_{\{\varepsilon_{it-1} < 0\}},$$

$$\phi_{it} = f\left(u_{1t-1}, \ldots, u_{i-1,t-1}, u_{i+1,t-1}, \ldots, u_{nt-1}\right) l_i(t),$$

$I_{\{\varepsilon_{it-1}<0\}}$ is a dummy variable equal to one when the past shock of asset i is negative, and $l_i(t)$ is a deterministic function of time.

In this application:

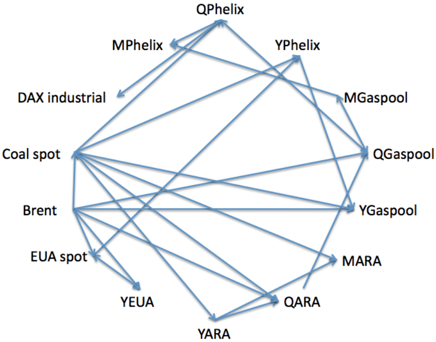
$$\phi_{it} = c_i \exp\left(\sum_{j=1, j\neq i}^{n} (\vartheta_{ij} u_{jt-1} + \alpha_{ij} |u_{jt-1}|) + \kappa_i' \mathrm{d}_t \right)$$

where d_t are deterministic terms including seasonal dummies.

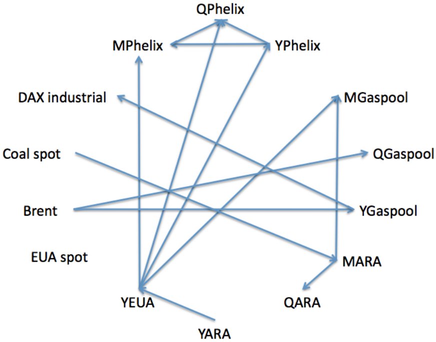
Networks of Causal Relationships

Causal relationships reflect physical relationships in the energy market (subsitution, merit-order) and spillover effects

Mean Network



Variance Network



Outline

Factor model: Dynamic PCA

Dynamic PCA based on the daily correlation matrices estimated with the Dynamic Conditional Correlation (DCC) model

$$H_t = D_t R_t D_t = D_t \left(A_t \Lambda_t A_t' + R_{\zeta_t} \right) D_t$$

where $D_t = \text{diag}(\sigma_{1t}, ..., \sigma_{nt})$, A_t is a matrix of s eigenvectors associated with the s largest eigenvalues that are contained in the diagonal matrix $\Lambda_t = \text{diag}(\lambda_{1t}, \lambda_{2t}, ..., \lambda_{st})$ with $\lambda_{1t} \geq \lambda_{2t} \geq ... \geq \lambda_{st}$, $s \leq n$ and R_{ζ_t} is the correlation matrix of idiosyncratic terms ζ_t.

Standardized residuals $u_{it} = (r_{it} - \mu_{it})/\sigma_{it}$ becomes a function of the first s dynamic principal components and idiosyncratic terms

$$u_{it} = \sum_{j=1}^{s} a_{ijt} y_{jt} + \zeta_{it}$$

where a_{ijt} is the element of the eigenvector associated with asset i and principal component y_{jt} extracted from R_t, and $\zeta_{it} = u_{it} - \sum_{j=1}^{s} a_{ijt} y_{jt}$.

Restrictions on the dynamic PCA

The energy crisis condition is defined by 2 factors:

$$\mathrm{E}_{t-1}\left(u_{it}|energy\,crisis\right) := \mathrm{E}_{t-1}\left(u_{it}|r_{EnMt} > C,\, r_{Mt} < 0\right)$$

- the return on the non-energy sector: $r_{Mt} \simeq y_{Mt} = y_{1t} = a'_{1t}u_t$
- the energy market return: $r_{EnMt} \simeq y_{EnMt} = y_{2t} = a'_{2t}u_t$

Restricted PCA (Ng et al. (1992)): the 1st component is restricted to be the non-energy return (DAX industrial index)

$$\max_{a_{1t}} a'_{1t} R_t a_{1t}$$
$$\text{s.t. } a'_{1t}a_{1t} = 1,\, a_{i1t} = 0 \quad \forall t, \forall i \neq DAX\ industrial$$

The other dynamic components are mutually orthogonal and orthogonal to the industrial component

$$\max_{a_{jt}} a'_{jt} R_t a_{jt}$$
$$\text{s.t. } a'_{jt}a_{jt} = 1,\, a'_{jt}a_{lt} = 0 \quad \forall t, \forall l \neq j$$

Tail expectations

The non-energy market return: $r_{Mt} \simeq y_{Mt} = y_{1t} = a'_{1t} u_t$
The energy market return: $r_{EnMt} \simeq y_{EnMt} = y_{2t} = a'_{2t} u_t$

The tail expectation $\mathrm{E}_{t-1}(u_{it}|\textit{energy crisis})$ is approximated by

$$\sum_{j=1}^{s} [a_{ijt}\mathrm{E}_{t-1}(y_{jt}|y_{EnMt} > C, y_{Mt} < 0)] + \mathrm{E}_{t-1}(\zeta_{it}|y_{EnMt} > C, y_{Mt} < 0)$$

A nonparametric estimator of tail expectations is

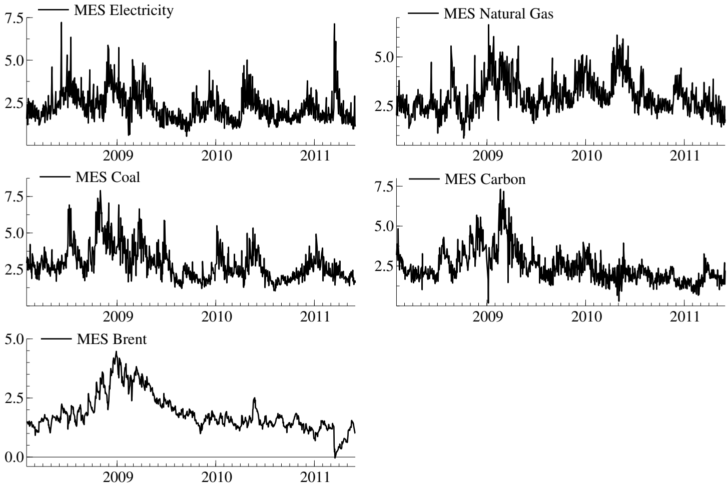
$$\hat{\mathrm{E}}(y_{jt}|y_{EnMt} > C, y_{Mt} < 0) = \frac{\sum_{\tau=1}^{T} y_{j\tau}\Phi\left[\left(\frac{y_{EnM\tau}}{\sqrt{\lambda_{EnM\tau}}} - \frac{C}{\sqrt{\lambda_{EnMt}}}\right)h^{-1}\right] I(y_{M\tau} < 0)}{\sum_{\tau=1}^{T} \Phi\left[\left(\frac{y_{EnM\tau}}{\sqrt{\lambda_{EnM\tau}}} - \frac{C}{\sqrt{\lambda_{EnMt}}}\right)h^{-1}\right] I(y_{M\tau} < 0)}$$

where $\Phi(\cdot)$ is the Gaussian cummulative distribution function. The same estimation procedure applies to $\mathrm{E}(\zeta_{it}|y_{EnMt} > C, y_{Mt} < 0)$.

Outline

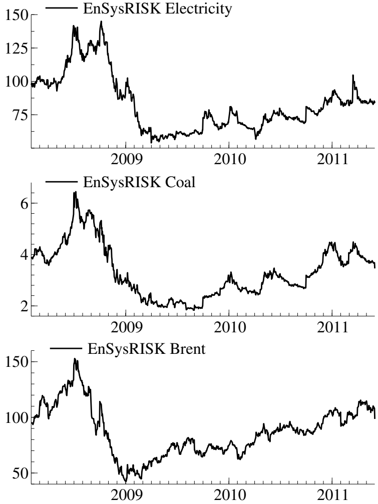
The conditional MES of energy assets

$$MES_{it}(C) = \mu_{it} + \sigma_{it}\mathrm{E}_{t-1}\left(\sum_{j=1}^{s} a_{ijt} y_{jt} + \zeta_{it} \,|\, y_{EnMt} > C,\, y_{Mt} < 0\right)$$



EnSysRISK

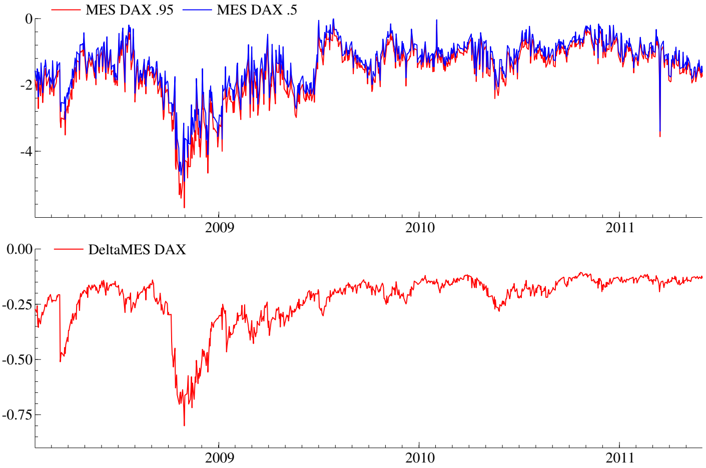
EnSysRISK = the total cost in million euros of each energy commodity class to the German non-energy sector during a potential energy crisis



$$MES_{Mt}(C) = \mu_{Mt} + \sigma_{Mt} \mathrm{E}_{t-1} \left(\sum_{j=1}^{s} a_{Mjt} y_{jt} + \zeta_{Mt} | y_{EnMt} > C, y_{Mt} < 0 \right)$$

'Net' impact of the energy crisis:

$$\Delta MES_{Mt}(C) = MES_{Mt}(C) - MES_{Mt}(VaR(r_{EnMt})_{0.5})$$



Summary

Energy Systemic Risk: the risk of an energy crisis raising the prices of all energy commodities with negative consequences for the real economy

EnSysRISK: the total cost of an energy commodity to the rest of the economy during an energy crisis

EnSysRISK increases with

- high MES
- high prices
- high dependence of the economy on the energy source

The MES captures co-movements in energy assets

- Causal relationships in means and variances reflect possible spillover effects from one product to another
- Tail exposure to common factors: the MES is conditional on extreme energy market shocks from the supply side (restricted dynamic PCA)

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