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: 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)
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
   - Causality in means and variances
   - Factor model and tail expectations

3 EnSysRISK and the impact on the economy
Outline

1. The Energy Systemic Risk Measure: EnSysRISK

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3. EnSysRISK and the impact on the economy
The conditional MES of an energy asset (Acharya et al. (2010), Brownlees and Engle (2011)) is given by

$$MES_{it} = E_{t-1}(r_{it} | \text{energy crisis})$$

Corresponding systemic prices are derived from past price levels

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

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

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

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 $$\nu$$, the exposure at time $$t$$ is

$$w_{it}(\nu) = \zeta_i E_{t-1}(fincons_\tau - inv_\tau) \text{ for } \tau \in [t + \nu; t + 2\nu - 1]$$
The MES of energy markets (1/2)

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

$$\text{MES}_{it}(C) = \mathbb{E}_{t-1}(r_{it} | r_{EnM,t} > C, r_{M,t} < 0),$$

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
Phelix Baseload index = average of 24 day-ahead spot prices

Futures are “insurance contracts” providing protection against the price uncertainty in the spot market

Source: University St Gallen
The MES of energy markets (2/2)

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

\[ MES_{it}(C) = E_{t-1}(\mu_{it} + \sigma_{it} u_{it} | r_{EnMt} > C, r_{Mt} < 0) \]
\[ = \mu_{it} + \sigma_{it} E_{t-1}(u_{it} | r_{EnMt} > C, r_{Mt} < 0) \]

where \( \mu_{it} \) and \( \sigma_{it}^2 \) 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 \( \mu_{it} \) and \( \sigma_{it} \)
  
  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: \( u_{it} = f(y_{it}, \zeta_{it}) \)
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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**

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### Market areas

**NetConnect Germany (NCG):**
- Open Grid Europe GmbH
- Bayernets GmbH
- Eni Gas Transport Deutschland
- GRTgaz Deutschland GmbH
- GVS Netz GmbH
- Thyssengas GmbH (planned in 2nd quarter 2011)

**GASPOOL:**
- Gasunie Deutschland
- Ontras – VNG Gastransport GmbH
- Wingas Transport GmbH & Co. KG

**Title Transfer Facility (TTF):** (planned in 1st quarter 2011)
- Gas Transport Services B.V.

**Source:** EEX
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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

\[
 r_{it} = \pi_i \eta' \ln(p_{t-1}) + \sum_{k=1}^{K} \delta'_{ik} r_{t-k} + \sum_{m=1}^{M} \theta'_{im} x_{t-m} + \phi'_{i} q_t + \epsilon_{it}
\]

where \(\eta\) are the cointegrating vectors,
\(\pi_i\) are error-correction parameters,
\(\delta_{ik}\) 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

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

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

\( I_{\{\varepsilon_{it-1} < 0\}} \) 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:

\[ \phi_{it} = c_i \exp \left( \sum_{j=1, j \neq i}^{n} (\vartheta_{ij} u_{jt-1} + \alpha_{ij} |u_{jt-1}|) + \kappa'_j d_t \right) \]

where \( d_t \) are deterministic terms including seasonal dummies.
Causal relationships reflect physical relationships in the energy market (substitution, merit-order) and spillover effects.

**Mean Network**

**Variance Network**
Multiplicative Causality GARCH Variances

Log-likelihood GARCH = -27335
Log-likelihood MC-GARCH = -27059

- MC-GARCH Electricity vs. GARCH Electricity
- MC-GARCH Natural Gas vs. GARCH Natural Gas
- MC-GARCH Coal vs. GARCH Coal
- MC-GARCH Carbon vs. GARCH Carbon
- MC-GARCH Brent vs. GARCH Brent
- MC-GARCH DAX vs. GARCH DAX
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Factor model: Dynamic PCA

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

\[ H_t = D_t R_t D_t = D_t (A_t \Lambda_t A_t' + R_{\zeta_t}) D_t \]

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 \( R_{\zeta_t} \) is the correlation matrix of idiosyncratic terms \( \zeta_t \).

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:

\[ E_{t-1}(u_{it}\mid \text{energy crisis}) := E_{t-1}(u_{it} \mid r_{EnMt} > C, r_{Mt} < 0) \]

- 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)

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

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

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

The contribution of the energy trend component \( \frac{\lambda_{EnM,t}}{\sum_{j=1}^{n} \lambda_{j,t}} \) as a dynamic measure of energy market integration (Billio et al. (2010), Kritzman et al. (2011))

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Energy trend component contribution (%)
Energy Systematic Risk

The correlation with the energy trend component \( \lambda_{EnMt} a_i^2, EnMt \) as a measure of energy systematic risk
Tail expectations

The non-energy market return: $r_{Mt} \sim y_{Mt} = y_{1t} = a_{1t}' u_t$

The energy market return: $r_{EnMt} \sim y_{EnMt} = y_{2t} = a_{2t}' u_t$

The tail expectation $E_{t-1}(u_{it}|\text{energy crisis})$ is approximated by

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

A nonparametric estimator of tail expectations is

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

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

\[
MES_{it}(C) = \mu_{it} + \sigma_{it}E_{t-1} \left( \sum_{j=1}^{s} a_{ij}y_{jt} + \zeta_{it} | y_{EnMt} > C, y_{Mt} < 0 \right)
\]
The Energy Systemic Risk Measure: EnSysRISK

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EnSysRISK and the impact on the economy
EnSysRISK = the total cost in million euros of each energy commodity class to the German non-energy sector during a potential energy crisis
'Net' impact on the economy

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

'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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