A Structural Model for Coupled Electricity Markets

Commodity Markets and their Financialization, IPAM

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Outline

Motivation

Basic Market Coupling

A Structural Model for Coupled Markets

Futures in Coupled Markets

Options in Coupled Markets

Application to the French-German Market
Agenda

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Application to the French-German Market
German and French Power Prices from Jan 2010 to Dec 2011
German vs French Power Prices - 2010 and 2011

Electricity Prices in France and Germany in Hour 24 from 2010-01-01 to 2010-11-09

Electricity Prices in France and Germany in Hour 24 from 2011-01-01 to 2011-11-09
Market Coupling

- Neighbouring electricity markets are typically coupled via transmission capacities owned by the TSOs.
- Transmission capacities can be integrated in the price finding algorithm of cooperating exchanges via implicit auctioning.
- With implicit auctions players do not receive allocations of cross-border capacity themselves but bid for energy on their Exchange. The Exchanges then use the available cross-border transmission capacity to minimize the price difference between two or more areas.
- The Central Western Europe (CWE) initiative couples Belgium, France, the Netherlands, Germany and Luxemburg.
CWE Region
Market Coupling II

- The North-Western-European (NWE) Region was implemented in February 2014. It consists of the power exchanges APX, Belpex, EPEX SPOT and Nord Pool Spot and 13 TSOs from the involved countries.

- In May 2014, Spain and Portugal joined; in February 2015, Italy coupled with France, Austria and Slovenia. As a result, the coupled area is called Multi-Regional Coupling and covers now 19 countries, standing for about 85% of European power consumption.

- A similar deployment is also planned for the intraday timeframe.
NWE Coupling
Press release 17. April 2015

The Power Exchanges EPEX SPOT and APX Group, including Belpex, intend to integrate their businesses in order to form a Power Exchange for Central Western Europe (CWE) and the UK.

The integration of EPEX SPOT and APX Group will further reduce barriers in power trading in the CWE and UK region. Overall, the integration will lead to a more effective governance and further facilitate the creation of a single European power market fully in line with the objectives of the European electricity regulatory framework.
Markets covered by APX Group and EPEX SPOT
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Formal Definitions

- A **Market Area** is a set of nodes and edges in an electric network, for which a unique energy price is calculated (’spot’ i.e. day-ahead).

- Two market areas A and B are **interconnected**, if there exists an edge, which connects a node in A with a node in B.

- An edge which connects two market areas is called **interconnector**.

- The sum over the available capacities of all interconnectors between A and B is called **available (cross boarder) transmission capacity (ATC)**.

- ’**Market coupling** uses implicit auctions in which players do not actually receive allocations of cross-border capacity themselves but bid for energy on their exchange. The exchanges then use the available cross-border transmission capacity to minimize the price difference between two or more areas.’ (EPEX SPOT)
Economic Assumptions

Starting point for our model is the following structure of a hybrid model

- price independent demand
- market supply curve has exponential shape
- fuels prices shift market supply curve multiplicatively
- market clearing price is given as intersection of supply and demand
Market Mechanism

Market Mechanics in Hybrid Model
Market Mechanism - two Markets
Market Mechanism - Coupling
Market Mechanism - Coupling
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Model for Demand and Fuel

Let

1. $D_1^1 = f^1(t) + \tilde{D}_t^1$ be demand in country 1,
2. $D_2^2 = f^2(t) + \tilde{D}_t^2$ be demand in country 2 and
3. $S_t$ the average of fuels prices used to produce electricity such that

$$Z_t | \mathcal{F}_s \equiv \begin{pmatrix} \tilde{D}_t^1 \\ \tilde{D}_t^2 \\ \ln(S_t) \end{pmatrix} | \mathcal{F}_s \sim F_{s,t}(x)$$

with $F_{s,t}$ being any elliptical distribution function.

Example: $F_{s,t} = N(\mu(s, t), \Sigma(s, t))$.

Define for any Matrix $B \in \mathbb{R}^{m \times 3}$:

$$BZ_t | \mathcal{F}_s \sim F_{s,t}^B$$
Model for the Market Supply Curve

We assume the Market Supply Curve in Country $i \in \{1, 2\}$, $C^i$, to be given as a function of capacity $\xi$ and fuels price $S$:

$$C^i(\xi, S) = Se^{a_i + b_i \xi} + c.$$  

I.e. we assume

- constant production capacities
- production costs consist of fuels cost and fuel price independent costs (labour costs,...).
- exponential dependence of the market clearing price on demand.
Cross Border physical Flows

We denote the physical flow from country 2 to country 1 by $E_t$. The maximum capacity is restricted and depends on the direction of the flow:

$$E_t \in [E_{\text{min}}, E_{\text{max}}], \ E_{\text{min}} \leq 0, \ E_{\text{max}} \geq 0.$$ 

Note that, if

- $E_{\text{min}} = E_{\text{max}} = 0$, markets are not connected and thus, pricing might be done independently.
- $E_{\text{max}} = - E_{\text{min}} \to \infty$, the interconnector is never congested and thus, one unique market price for both markets exists at all hours.
Cross Border physical Flows in case of coupled markets

In interconnected markets, only the electricity which is not imported has to be produced. Thus, the electricity price is determined as

\[ P_t^1(D_t^1, E_t, S_t) = C^1(D_t^1 - E_t, S_t) = S_t e^{a_1 + b_1(D_t^1 - E_t)} + c. \]

Here, \( E_t \) is the imported amount and \( D_t^1 - E_t \) is the residual demand which has to be satisfied by local production. Define:

\[
\begin{align*}
A_1 &= \{ \omega \in \Omega : P_t^1(D_t^1, E_{\text{max}}, S_t) \geq P_t^2(D_t^2, -E_{\text{max}}, S_t) \} \\
A_2 &= \{ \omega \in \Omega : P_t^1(D_t^1, E_{\text{min}}, S_t) \leq P_t^2(D_t^2, -E_{\text{min}}, S_t) \} \\
A_3 &= \Omega \setminus (A_1 \cup A_2)
\end{align*}
\]

Then, the cross border flow in case of coupled markets is

\[
E_t^*(\omega) = \begin{cases} 
E_{\text{max}}, & \text{if } \omega \in A_1 \\
E_{\text{min}}, & \text{if } \omega \in A_2 \\
\frac{a_1 - a_2}{b_1 + b_2} + \frac{b_1}{b_1 + b_2} D_t^1(\omega) - \frac{b_2}{b_1 + b_2} D_t^2(\omega), & \text{if } \omega \in A_3
\end{cases}
\]
Market Clearing Prices

Given the cross border physical flow which minimizes price differences between countries, the resulting electricity price for country 1 may be stated as:

\[
P^1_t(\omega) = P^1_t(D^1_t, E^*_t, S_t) = \begin{cases} 
C^1(D^1_t(\omega) - E_{\text{max}}, S_t(\omega)) & \text{if } \omega \in A_1 \\
C^1(D^1_t(\omega) - E_{\text{min}}, S_t(\omega)) & \text{if } \omega \in A_2 \\
C^m(D^1_t(\omega) + D^2_t(\omega), S_t(\omega)) & \text{if } \omega \in A_3 
\end{cases}
\]

The function \(C^m\) can be viewed as the aggregated market supply curve for both countries and is given by

\[
C^m(\xi, S) = Se^{a_m + b_m \xi} + c
\]

with \(a_m = \frac{a_1 b_2 + a_2 b_1}{b_1 + b_2}\) and \(b_m = \frac{b_1 b_2}{b_1 + b_2}\). Equivalent results hold for \(P^2_t\) in country 2.
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Distribution of the market clearing prices

Defining $P_t = (P^1_t, P^2_t)^T$ we find the distribution function:

$$F_{P_t|\mathcal{F}_s}(x) = \mathbb{Q}(P_t \leq x|\mathcal{F}_s)$$

$$= \mathbb{Q}(\{P_t \leq x\} \cap A_1|\mathcal{F}_s) + \mathbb{Q}(\{P_t \leq x\} \cap A_2|\mathcal{F}_s) + \mathbb{Q}(\{P_t \leq x\} \cap A_3|\mathcal{F}_s)$$

$$= F_{s,t}^M(d_1(x)) + F_{s,t}^M(d_2(x)) + \left( F_{s,t}^M(d^u_3(x)) - F_{s,t}^M(d^l_3(x)) \right)$$

with

$$d_1(x) = \begin{pmatrix} \ln(x_1 - c) - a_1 + b_1 E_{\text{max}} \\ \ln(x_2 - c) - a_2 - b_2 E_{\text{max}} \\ a_1 - a_2 - (b_1 + b_2) E_{\text{max}} \end{pmatrix}, \quad M_1 = \begin{pmatrix} b_1 & 0 & 1 \\ 0 & b_2 & 1 \\ -b_1 & b_2 & 0 \end{pmatrix}$$

$$d_2(x) = \begin{pmatrix} \ln(x_1 - c) - a_1 + b_1 E_{\text{min}} \\ \ln(x_2 - c) - a_2 - b_2 E_{\text{min}} \\ -a_1 + a_2 + (b_1 + b_2) E_{\text{min}} \end{pmatrix}, \quad M_2 = \begin{pmatrix} b_1 & 0 & 1 \\ 0 & b_2 & 1 \\ b_1 & -b_2 & 0 \end{pmatrix}$$

$$d^u_3(x) = \begin{pmatrix} \ln(\min(x_1, x_2) - c) - a_m \\ -a_1 + a_2 + (b_1 + b_2) E_{\text{max}} \end{pmatrix}, \quad d^l_3(x) = \begin{pmatrix} \ln(\min(x_1, x_2) - c) - a_m \\ -a_1 + a_2 + (b_1 + b_2) E_{\text{min}} \end{pmatrix}, \quad M_3 = \begin{pmatrix} b_m & b_m & 1 \\ b_1 & -b_2 & 0 \end{pmatrix}$$
Futures prices in the structural model

We consider futures with hourly delivery. Denote by $F^i(s, t)$ the futures price of electricity in country $i$ at time $s$ for delivery in $t$. Under a risk-neutral measure we have

\[
F^1(s, t) = \mathbb{E}_s^Q[P^1_t] = \int_{\Omega} P^1_t(\omega) \mathbb{Q}(d\omega)
\]

\[
= \int_{A_1} C^1 \left( D^1_t(\omega) - E_{\max}, S_t(\omega) \right) \mathbb{Q}(d\omega)
+ \int_{A_2} C^1 \left( D^1_t(\omega) - E_{\min}, S_t(\omega) \right) \mathbb{Q}(d\omega)
+ \int_{A_3} C^m \left( D^1_t(\omega) + D^2_t(\omega), S_t(\omega) \right) \mathbb{Q}(d\omega)
\]

and equivalent for country 2.
Futures prices in the structural model II

Assume

\[ Z_t \mid \mathcal{F}_s \equiv \left( \begin{array}{c} \tilde{D}_1^t \\ \tilde{D}_2^t \\ \ln(S_t) \end{array} \right) \mid \mathcal{F}_s \sim \mathcal{N}(\mu(s, t), \Sigma(s, t)), \]

then

\[
\int_{A_1} C^1 \left( D_1^t(\omega) - E_{\text{max}}, S_t(\omega) \right) \mathbb{Q}(d\omega)
\]

\[= c \cdot \Phi \left( \frac{a_1 - a_2 - (b_1 + b_2)E_{\text{max}} - \bar{b}_3^T \mu}{\sqrt{\bar{b}_3^T \Sigma \bar{b}_3}} \right) \]

\[+ e^{a_1 - b_1 E_{\text{max}} + \bar{b}_1^T \mu + \frac{1}{2} \bar{b}_1^T \Sigma \bar{b}_1} \Phi \left( \frac{a_1 - a_2 - (b_1 + b_2)E_{\text{max}} - \bar{b}_3^T \mu - \bar{b}_3^T \Sigma \bar{b}_3}{\sqrt{\bar{b}_3^T \Sigma \bar{b}_3}} \right) \]

where \( \bar{b}_3 = (-b_1, b_2, 0)^T \).
Futures prices with delivery period

Prices for futures with delivery in a set $\mathbb{T}$ of hours are given as

$$F^i(s, \mathbb{T}) = \frac{1}{|\mathbb{T}|} \sum_{t \in \mathbb{T}} F^i(s, t).$$
Example of futures prices

![Graph showing futures prices depending on interconnector capacity]
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Plain Vanilla Calls

Consider a plain vanilla call which is written on the electricity spot price in country 1 with delivery at a future time $t$. Its payoff is

$$(P_t^1 - K)^+$$

and its value at time $s$ is

$$V_s = \mathbb{E}_s^Q \left[ (P_t^1 - K)^+ \right].$$

Again, we use the decomposition

$$\left\{ \omega \in \Omega : P_t^1 \geq K \right\} = (A_1 \cap B_1) \cup (A_2 \cap B_2) \cup (A_3 \cap B_3)$$

with

$$B_1 = \left\{ \omega \in \Omega : C^1(D_t^1 - E_{\text{max}}, S_t) \geq K \right\}$$

$$B_2 = \left\{ \omega \in \Omega : C^1(D_t^1 - E_{\text{min}}, S_t) \geq K \right\}$$

$$B_3 = \left\{ \omega \in \Omega : C^m(D_t^1 + D_t^2, S_t) \geq K \right\}.$$
Plain Vanilla Calls II

According to the partition of the region of exercise, the value of the call might be written as

\[
V_s = \mathbb{E}_s^Q \left[ (P_t^1 - K)^+ \right]
\]

\[
= \int_{A_1 \cap B_1} C_1(D_t^1 - E_{\text{max}}, S_t) dQ + \int_{A_2 \cap B_2} C_1(D_t^1 - E_{\text{min}}, S_t) dQ
\]

\[
+ \int_{A_3 \cap B_3} C_m(D_t^1 + D_t^2, S_t) dQ - K \left( \mathbb{Q}(A_1 \cap B_1) + \mathbb{Q}(A_2 \cap B_2) + \mathbb{Q}(A_3 \cap B_3) \right).
\]
Plain Vanilla Calls III

In the case of \( F_{s,t} = N(\mu(s, t), \Sigma(s, t)) \) we get

\[
V_s = e^{a_1-b_1 E_{\text{max}}+\mu(s,t)^T \bar{b}_1 + \frac{1}{2} \bar{b}_1^T \Sigma(s,t) \bar{b}_1} \Phi_2 \left( d_4, M_4 \left( \mu(s, t) + \Sigma(s, t) \bar{b}_1 \right), M_4 \Sigma(s, t) M_4^T \right) \\
+ e^{a_1-b_1 E_{\text{min}}+\mu(s,t)^T \bar{b}_1 + \frac{1}{2} \bar{b}_1^T \Sigma(s,t) \bar{b}_1} \Phi_2 \left( d_5, M_5 \left( \mu(s, t) + \Sigma(s, t) \bar{b}_1 \right), M_5 \Sigma(s, t) M_5^T \right) \\
+ e^{a_m+\mu(s,t)^T \bar{b}_m + \frac{1}{2} \bar{b}_m^T \Sigma(s,t) \bar{b}_m} \left( \Phi_2 \left( d_6^u, M_6 \left( \mu(s, t) + \Sigma(s, t) \bar{b}_m \right), M_6 \Sigma(s, t) M_6^T \right) \\
- \Phi_2 \left( d_6^l, M_6 \left( \mu(s, t) + \Sigma(s, t) \bar{b}_m \right), M_6 \Sigma(s, t) M_6^T \right) \right) \\
- \tilde{K} \left( \Phi_2 \left( d_4, M_4 \mu(s, t), M_4 \Sigma(s, t) M_4^T \right) + \Phi_2 \left( d_5, M_5 \mu(s, t), M_5 \Sigma(s, t) M_5^T \right) \right) \\
+ \Phi_2 \left( d_6^u, M_6 \mu(s, t), M_6 \Sigma(s, t) M_6^T \right) - \Phi_2 \left( d_6^l, M_6 \mu(s, t), M_6 \Sigma(s, t) M_6^T \right) \right)
\]
Call option price depending on Strike

- Call value in country 1 depending on Strike
- Call value in country 2 depending on Strike
- Implied Volatility (country 1) depending on Strike
- Implied Volatility (country 2) depending on Strike
Implied at-the-money volatility depending on Interconnector capacity
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Application to the French-German Market
Construction of a Fuel Basket

Prices of year-ahead Futures on Fuels

- API #2
- NCG
- Brent

Electricity year-ahead Futures Prices and Fuels Basket

- Phelix 1st Generic
- French 1st Generic
- Weighted Fuels Basket
Modeling the Fuels Basket

We assume that the fuels basket price $S_t$ follows the following simple SDE:

$$d \ln(S_t) = k^S(\theta^S - \ln(S_t))dt + \sigma_S dW_t^S.$$

We use daily data from 2012 to calibrate the model which yields the following parameters:

\[
\begin{array}{ccc}
\kappa^S & \theta^S & \sigma_S \\
5.99 & 3.69 & 0.2028 \\
\end{array}
\]

Table: Annualized parameters for fuels basket
Market Supply Curves

Denote by $\tilde{D}_t^i$ the realized expected day-ahead demand in country $i$ at time $t$ and $\tilde{P}_t^i$ the realized day-ahead price. Then,

$$\tilde{E}_t = E_t(\tilde{D}_t^1, \tilde{D}_t^2, a_1, a_2, b_1, b_2, c, E_{\min}, E_{\max})$$

denotes the realized expected day-ahead exchange and

$$P_t^i(\tilde{D}_t^i, \tilde{E}_t, a_i, b_i, c, E_{\min}, E_{\max})$$

the model implied electricity price.

We determine the parameters of the market supply curve by minimizing

$$\sum_{i=1}^{2} \sum_{t \in T} \|\tilde{P}_t^i - P_t^i(\tilde{D}_t^i, \tilde{E}_t, a_i, b_i, c, E_{\min}, E_{\max})\|^2 \rightarrow \min.$$
Market Supply Curves - Parameters

We find the following parameters:

<table>
<thead>
<tr>
<th>Germany</th>
<th>France</th>
<th>Interconnector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Value</td>
<td>Parameter</td>
</tr>
<tr>
<td>$a_1$</td>
<td>-2.35</td>
<td>$a_2$</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.035</td>
<td>$b_2$</td>
</tr>
<tr>
<td>$c$</td>
<td>3.08</td>
<td>$c$</td>
</tr>
</tbody>
</table>

Table: Estimates of model parameters for the German and French market

- Market supply curve in France in more convex as in Germany.
- Sharp increases in electricity prices occur at higher demand levels in France.
Market Supply Curves - Model Fit

German historical electricity prices and model prices at historical demand levels

French historical electricity prices and model prices at historical demand levels
Market Supply Curves - Weekly Fit

German historical electricity prices and model prices at historical demand levels

French historical electricity prices and model prices at historical demand levels
Expected Day-Ahead Demand in 2012 - France and Germany

Expected Day-Ahead Demand in Germany

Expected Day-Ahead Demand in France
Expected Day-Ahead Demand - Model

We assume that demand $D_t$ can be modeled as the sum of a deterministic function $f(t)$ and a stochastic part $X_t$:

$$D_t^i = f^i(t) + X_t^i$$
$$dX_t^i = -\kappa^i X_t^i dt + \sigma_i dW_t^i.$$  

The deterministic function consists of a time varying weekly shape and a level adjustment:

$$hour(t) = \text{hour of the week of } t$$
$$week(t) = \text{week of } t$$

$$\lambda(t) = \frac{1 - \cos(\frac{2\pi \text{week}(t)}{52.3})}{2}$$

$$l(t) = x_1 \sin(\frac{2\pi \text{week}(t) - x_2}{52.3}) + x_3$$

$$f(t) = \lambda(t)f^{\text{summer}}(\text{hour}(t)) + (1 - \lambda(t))f^{\text{winter}}(\text{hour}(t)) + l(t)$$
Expected Day-Ahead Demand - Seasonality
German Demand - Weekly patterns and deterministic Part

Weekly Profile of Demand

Deterministic Demand Function

- Rüdiger Kiesel
- IPAM
French Demand - Weekly patterns and deterministic Part

Weekly Profile of Demand

Deterministic Demand Function

Demand in GW

Hour of the Week

Hour of the Year
Demand - Stochastic Part

For the stochastic parts of the two demand processes we find the following annualized parameters:

<table>
<thead>
<tr>
<th>Germany</th>
<th>Parameter</th>
<th>Value</th>
<th>France</th>
<th>Parameter</th>
<th>Value</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\kappa_1$</td>
<td>219.48</td>
<td></td>
<td>$\kappa_2$</td>
<td>139.39</td>
<td>$dW_t^1 dW_t^2$</td>
</tr>
<tr>
<td></td>
<td>$\sigma_1$</td>
<td>156.90</td>
<td></td>
<td>$\sigma_2$</td>
<td>97.22</td>
<td></td>
</tr>
</tbody>
</table>

Table: Estimates of model parameters for the German and French market

This translates into $X_t | \mathcal{F}_s \sim N(X_0 e^{-\kappa_i(t-s)}, \frac{\sigma_i^2}{2\kappa_i} (1 - e^{-2\kappa_i(t-s)})$. 
Demand - Stochastic Part

Stochastic Processes $\chi^2$ and $\chi^3$

Residuals Germany

Residuals France

Dependence of Residuals

Histogram Germany

Histogram France
Joint Distribution of Risk Factors

We assume that demand in France and Germany and the fuel basket form a multivariate normal distribution:

\[
\begin{pmatrix}
    D_1^t \\
    D_2^t \\
    \ln(S_t)
\end{pmatrix} \mid \mathcal{F}_s \sim N(\mu(s, t), \Sigma(s, t))
\]

with parameters

\[
\mu(s, t) = \begin{pmatrix}
    f_1(t) + X_se^{-\kappa_1(t-s)} \\
    f_2(t) + X_se^{-\kappa_2(t-s)} \\
    S_se^{-\kappa S(t-s)} + \theta S \left(1 - e^{-\kappa S(t-s)}\right)
\end{pmatrix}
\]

\[
\Sigma(s, t) = \begin{pmatrix}
    \frac{\sigma_1^2}{2\kappa_1} \left(1 - e^{-2\kappa_1(t-s)}\right) & \frac{\sigma_1\sigma_2\rho}{\kappa_1+\kappa_2} \left(1 - e^{-(\kappa_1+\kappa_2)(t-s)}\right) & 0 \\
    \frac{\sigma_1\sigma_2\rho}{\kappa_1+\kappa_2} \left(1 - e^{-(\kappa_1+\kappa_2)(t-s)}\right) & \frac{\sigma_2^2}{2\kappa_2} \left(1 - e^{-2\kappa_2(t-s)}\right) & 0 \\
    0 & 0 & \frac{\sigma_S^2}{2\kappa_S} \left(1 - e^{-2\kappa_S(t-s)}\right)
\end{pmatrix}
\]
HPFC at 2014-05-21
Effects of Interconnector Capacity on HPFC
Effects of Interconnector Capacity on Traded Products

Futures Prices as Function of Interconnector Capacity

Peak-Base-Spread as Function of Interconnector Capacity
As an example, we study the effect of interconnector capacity changes on the value of a virtual power plant contract. Let the contract be specified as follows:

- Duration of the contract: 2015-01-01 to 2015-12-31
- Plant location: Germany
- Plant Capacity 1 MW
- Marginal Costs 50Euro/MWh
- No ramping time
- No start-up or shut-down costs.

I.e. the plant is basically a strip of calls on the hourly electricity price in Germany during the year 2015 with Strike 50.
**Example - VPP Profitability**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>-3.5/2.8</td>
<td>34.42</td>
<td>43.70</td>
<td>864</td>
<td>5,601</td>
<td>9,426</td>
<td>3,825</td>
</tr>
<tr>
<td>0</td>
<td>33.11</td>
<td>41.09</td>
<td>573</td>
<td>3,887</td>
<td>7,534</td>
<td>3,647</td>
</tr>
<tr>
<td>2</td>
<td>33.85</td>
<td>42.29</td>
<td>738</td>
<td>4,723</td>
<td>8,435</td>
<td>3,712</td>
</tr>
<tr>
<td>5</td>
<td>34.95</td>
<td>43.97</td>
<td>985</td>
<td>6,430</td>
<td>10,246</td>
<td>3,816</td>
</tr>
<tr>
<td>10</td>
<td>36.34</td>
<td>45.76</td>
<td>1,312</td>
<td>8,905</td>
<td>12,640</td>
<td>3,734</td>
</tr>
</tbody>
</table>

*Table: Power plant profitability depending on interconnector capacity*
Conclusions + Literature

- We presented a two-market-one-fuel structural model and analysed spot, futures and option prices using semi-analytical expressions.
- The model allows to study the effect of interconnector capacity on spot, futures and option prices.
- Clémence Alasseur and Olivier Féron (EDF) extended the model to the two-market-multi-fuel case.
- Füss, Mahringer and Prokopczuk (St. Gallen) study the empirical effect of market coupling in the CWE area and present a theoretical discussion of implicit and explicit coupling schemes.
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References

- EPEX SPOT SE *Data Download Center*, www.epexspot.com


- Rene Carmona, Michael Coulon, Daniel Schwarz *Electricity Price Modeling and Asset Valuation: A Multi-Fuel Structural Approach*

- Rene Carmona, Michael Coulon *A Survey of Commodity Markets and Structural Models for Electricity Prices*