Integration of European Electricity Markets: Evidence from Spot Prices

Klaus Gugler, Adhurim Haxhimusa, Mario Liebensteiner*
*Contact: mario.liebensteiner@wu.ac.at

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Research Question

- ***How well integrated are European electricity markets?***
  - Assessment of current state of well-functioning of market interaction
  - Propagation of **EU internal energy market**
  - **Why market integration?**
    - Supply security – enhanced balancing of supply
    - Reduces need for reserve capacity
    - Better integration of intermittent renewables
    - Increases welfare (and consumer surplus) through allocative efficiency
    - Induces competition
    - Limits market power (strategic withholding of capacity)
    - Mitigation of uncertainty (better investment signals?)
    - Reduction of spot prices (on average, but winners & losers)

How to Integrate Markets?

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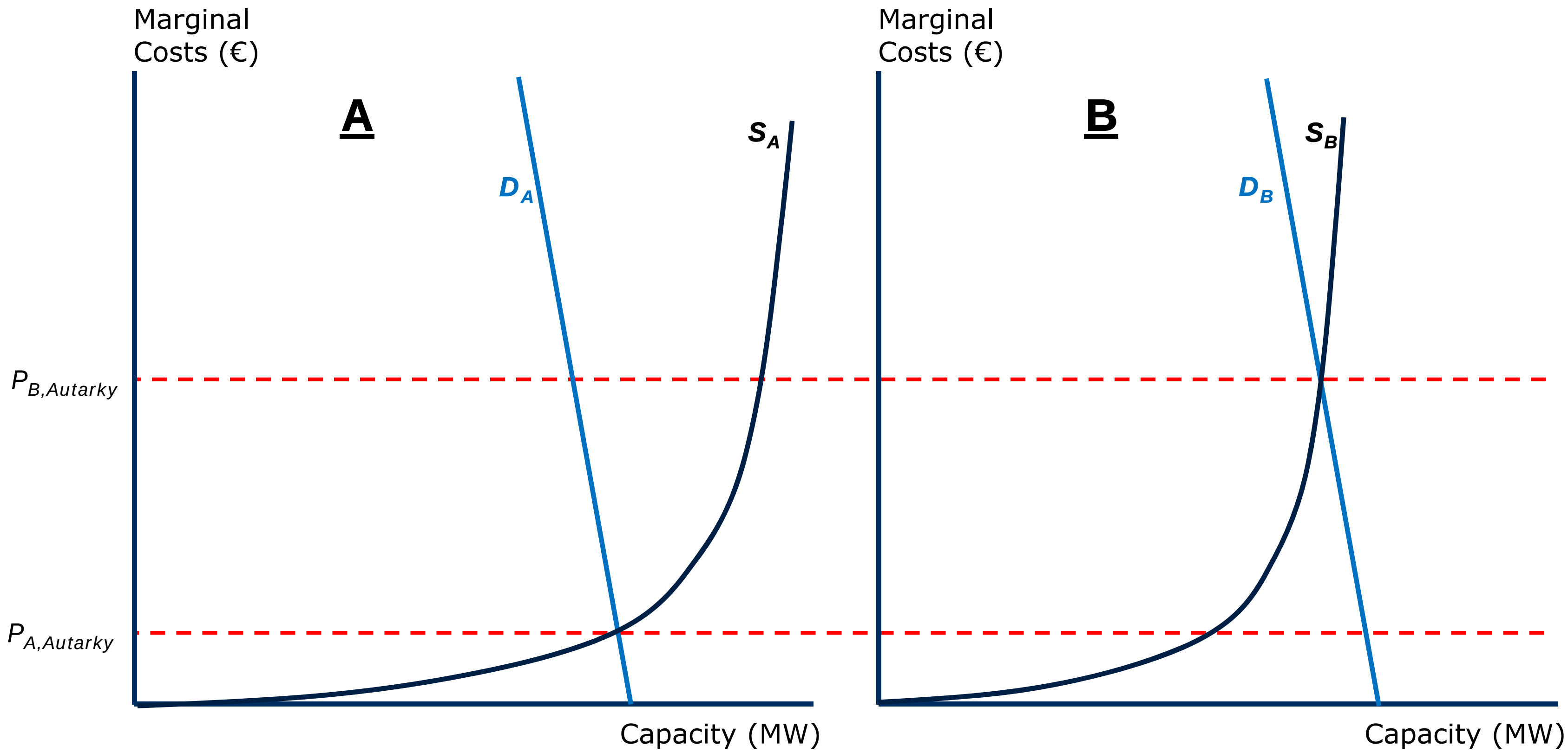
- Investment in interconnector capacity
- Reduction of (intra-market) transmission bottlenecks
- Market coupling: efficient auctioning of capacity
  - Explicit auctions:
    - Power and interconnector capacity are auctioned *separately*
    - Consequences: coordination failures and strategic withholding of interconnection capacity
  - Implicit auctions:
    - Power and interconnector capacity are auctioned *simultaneously* (and synchronization of market rules, e.g. closing hours)

Price Convergence

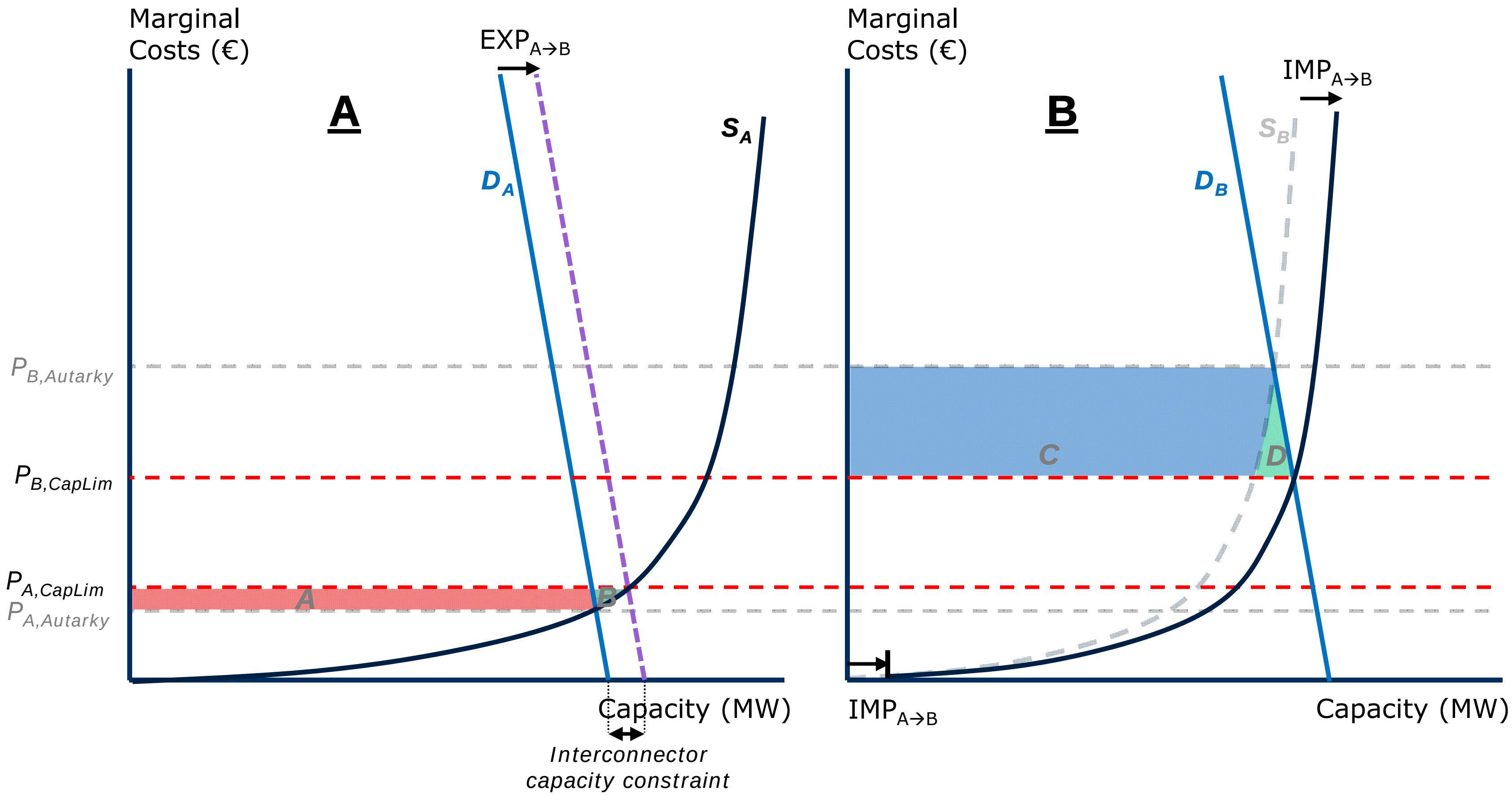
- Market integration is a prerequisite for price convergence
  - ☑ Market coupling
  - ☑ Uncongested interconnection capacity
  - → Unconstrained electricity trade: Law of One Price holds (!)
  - Caution: “spurious” convergence (!):
    - Markets’ merit orders determine magnitude of price differences
    - If supply & demand similar, prices converge (but not because of trade)
- Price convergence from market integration
  - On average lower prices, but…
  - … Prices in high-price market decrease
  - … Prices in low-price market increase
  - **Creates winners and losers!**
  - Thus, practical implementation of market integration cumbersome
    - E.g. discussion on market splitting between DE and AT

Scenario 1: Autarky



1) Autarky: $\boldsymbol{P_A} < \boldsymbol{P_B}$

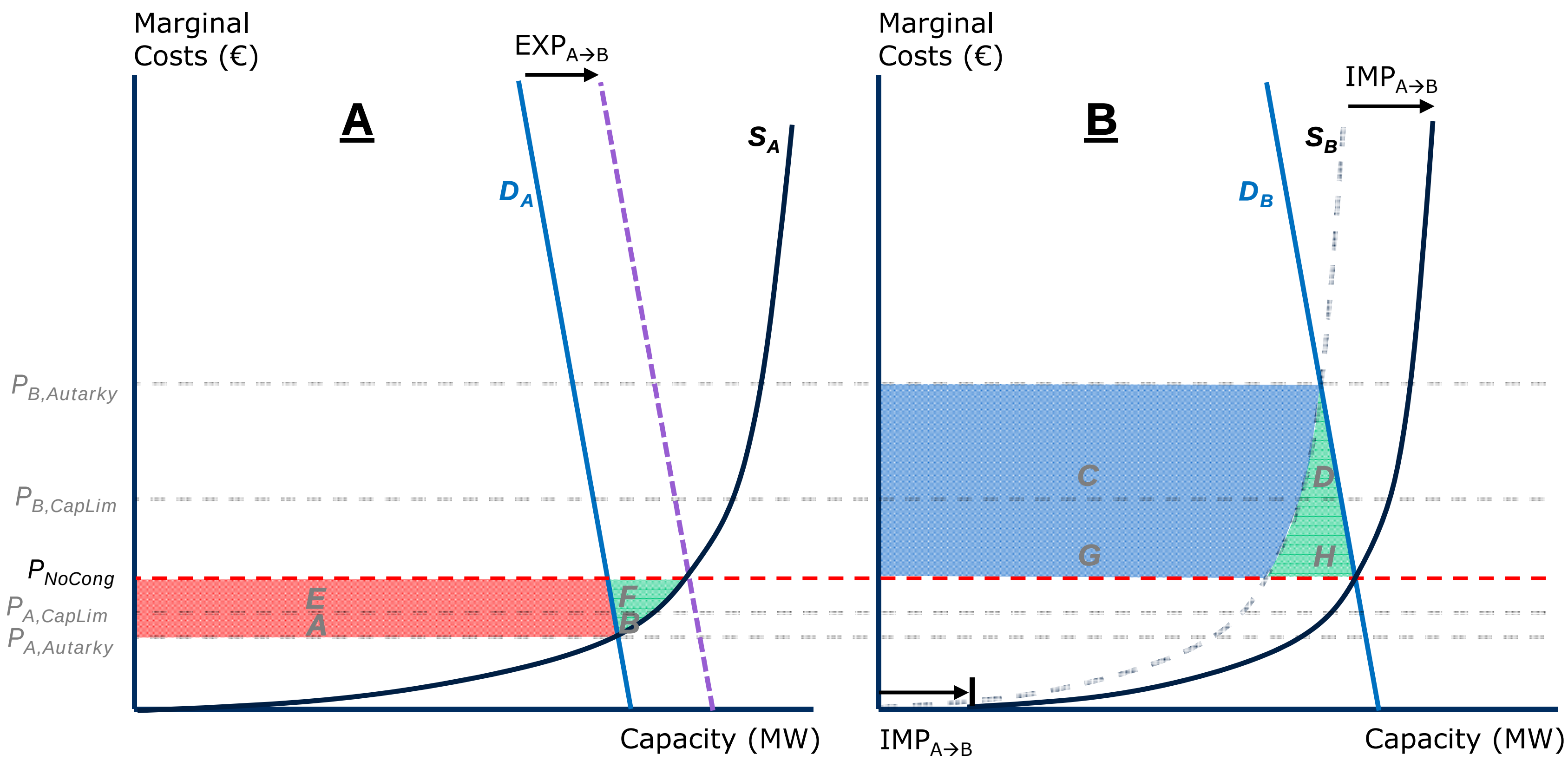
Scenario 2: Limited Interconnection Capacity



1) Autarky: $\boldsymbol{P_A} < \boldsymbol{P_B}$

2) Constrained trade: $P_A < \boldsymbol{P_{A,CapLim}} < \boldsymbol{P_{B,CapLim}} < P_B$
   Consumers: −A+C+D, Producers: +A+B−C, Welfare: +B+D

Scenario 3: Full Market Integration

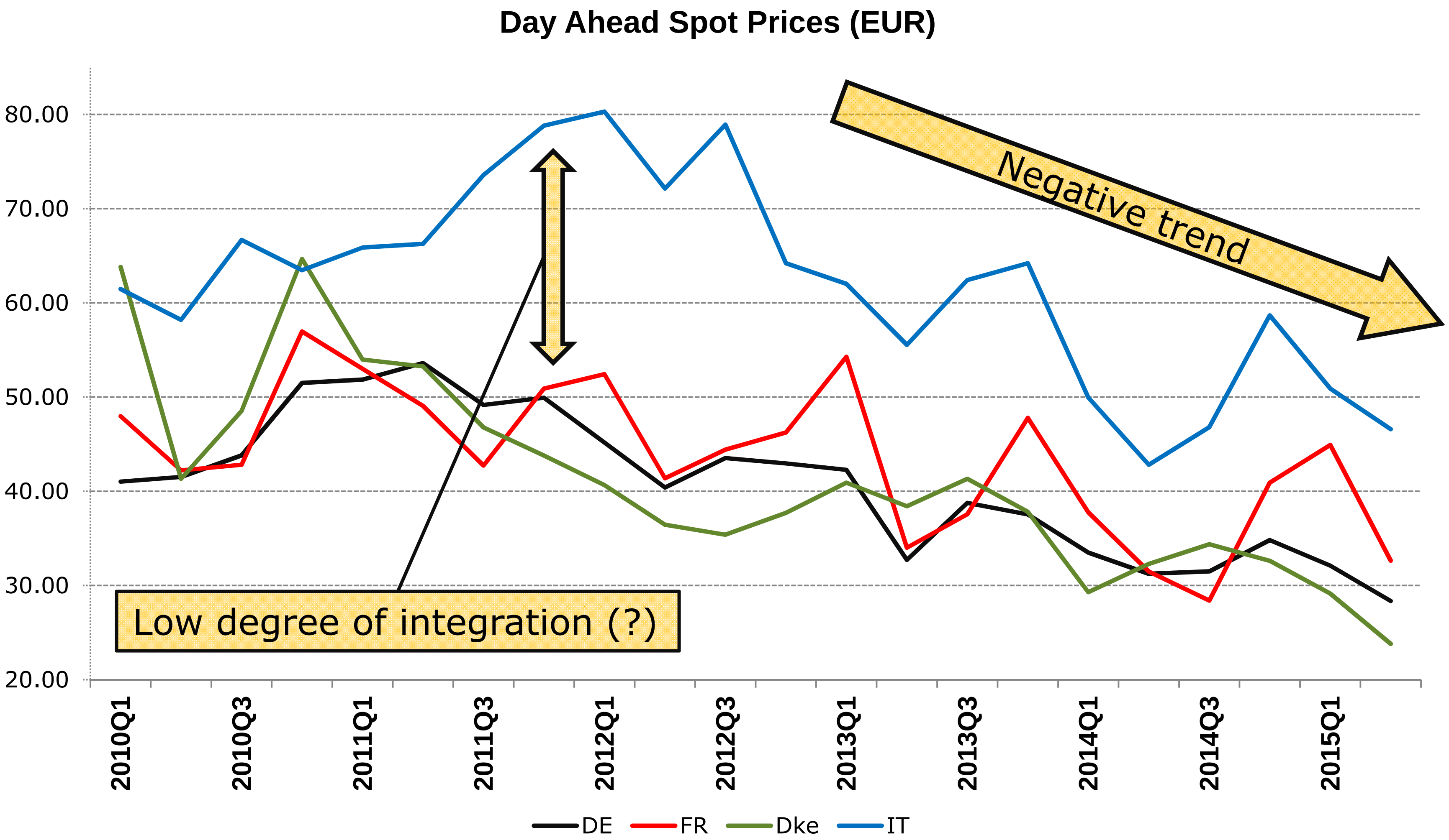


1) Autarky: $\boldsymbol{P_A} < \boldsymbol{P_B}$
2) Constrained trade: $P_A < \boldsymbol{P_{A,CapLim}} < \boldsymbol{P_{B,CapLim}} < P_B$
   Consumers: −A+C+D, Producers: +A+B−C, Welfare: +B+D
3) Unconstrained trade: $P_A < P_{A,CapLim} < \boldsymbol{P_{NoCong}} < P_{B,CapLim} < P_B$
   Consumers: −A+C+D−E+G+H, Producers: +A+B−C+E+F−G, Welfare: +B+D+F+H

Share of Electricity Traded at Power Exchanges

		Volumes Traded (GWh)		National load (GWh)		Share (%)	
Country	Exchange	2010	2014	2010	2014	2010	2014
DE/AT	EPEX	205,000	285,000	547,000	625,000	37%	46%
FR	EPEX	52,600	73,100	512,000	514,000	10%	14%
CH	EPEX	9,325	22,000	58,500	51,400	16%	43%
SL	SP	179	6,806	7,086	14,100	3%	48%
ESP	OMIP	196,000	187,000	260,000	265,000	75%	71%

- Share of electricity traded via power exchanges increases
- Rising significance of power exchanges over time



- Changing supply structures (more RES) lead to drop in spot prices
- Some markets seem better integrated (DE, FR, DKe) than others (IT)

Direction of Congestion

Direction of congested hours: DE and selected neighbors

Direction	Market Coupling	2010	2011	2012	2013	2014	2015Q1,2
DE-->FR		90.4%	10.8%	30.4%	41.9%	31.7%	66.7%
FR-->DE		84.6%	27.0%	6.9%	11.5%	17.3%	6.5%
Total	09.11.2010	91.5%	37.8%	37.3%	53.4%	49.1%	73.3%
DE-->HU			94.3%	99.8%	99.4%	100.0%	100.0%
HU-->DE			96.8%	98.9%	99.1%	98.8%	99.4%
Total	no MC		99.5%	100.0%	100.0%	100.0%	100.0%

DE-FR:
- Market coupling has led to reduction in congested hours
- Over time, congestion increased (due to RES production in DE)

DE-HU:
- Without market coupling, congestion throughout
- In absence of market coupling: capacity misallocation → interconnectors congested in both directions

Methodology (1)

- **1st stage: Cointegration analysis:**

$P_{A,t} = \alpha + \beta P_{B,t} + Z_t$:

α…systematic difference (transport costs, institutional differences)
β…long-run equilibrium relation between P_A and P_B

1. **Full convergence** (full market integration):
   - $\alpha_1 = 0,\ \beta_1 = 1$, if export < capacity and market coupling = 1
2. **Partial convergence:**
   - $\alpha_2 > 0,\ 0 < \beta_2 < 1$, if export = capacity and/or market coupling = 0
     → deviation in relative efficiency
3. **Autarky:**
   - $\alpha_3 > 0,\ \beta_3 < \beta_2$, if export = 0 (implies market coupling = 0)
     → deviation in relative efficiency becomes larger

Methodology (2)

- **2^{nd} stage: Error Correction Model**

1. $P_{A,t} = \alpha + \beta P_{B,t} + \boldsymbol{Z_t}$
   - $\boldsymbol{\widehat{Z}}$ … Error correction term: deviations from long-run relation (i.e. prediction errors)
2. $\Delta P_{A,t} = \gamma + \delta \Delta P_{A,t-24} + \boldsymbol{\eta \widehat{Z}_{t-24}} + \theta' X + \varepsilon_t$

Model valid for **daily prices** or **hourly prices during interconnection congestion**

Δ represents difference (e.g. $\Delta P_{A,t} = P_{A,t} - P_{A,t-24}$),

X = structural variables:

- Number of congested hours
- Market coupling dummy
- Solar & wind forecasts
- Fuel prices (coal, gas, oil)
- Seasonality (day of week, months, years, holidays)

Data & Add-Ons to Existing Literature

- Hourly data, 2010/Q1–2015/Q2
- 25 electricity markets: SK, CZ, EST, LT, LV, FIN, NO1, NO2, NO3, NO4, NO5, ES, PT, SE1, SE2, SE3, SE4, DKW, DKE, IT, HU, SL, CH, FR, DE
- We discuss lag structure (1h, 24h – demand and supply stickiness)
- Relevant market: hour of the day (not whole day)
- Inclusion of congestion & market coupling
  - Direction of congestion (without MC, interconnectors may be congested in both directions)
  - No congestion & market coupling: prices converge instantaneously
  - → Error correction model misleading
  - → Focus on congestion spells (i.e. consecutive congested hours)
    - How efficiently do markets work during congested hours?

First Stage Results: β -coefficients above given thresholds

Adjunct market pairs											
Year	Pairs	β> 0.95		β> 0.90		β> 0.80		β> 0.70		β> 0.60	
2010	50	14	28%	19	38%	23	46%	28	56%	36	72%
2011	72	31	43%	35	49%	44	61%	52	72%	56	78%
2012	72	28	39%	33	46%	44	61%	53	74%	62	86%
2013	76	27	36%	38	50%	49	64%	50	66%	58	76%
2014	76	30	39%	33	43%	46	61%	52	68%	56	74%
2015Q1	76	32	42%	39	51%	46	61%	52	68%	61	80%

Indirect market pairs											
Year	Pairs	β> 0.95		β> 0.90		β> 0.80		β> 0.70		β> 0.60	
2010	292	24	8%	31	11%	43	15%	61	21%	81	28%
2011	434	37	9%	43	10%	71	16%	96	22%	124	29%
2012	434	33	8%	43	10%	83	19%	141	32%	194	45%
2013	524	94	18%	118	23%	153	29%	177	34%	202	39%
2014	524	98	19%	113	22%	139	27%	165	31%	198	38%
2015Q1	524	133	25%	154	29%	185	35%	221	42%	260	50%

- Over time, price correlations between markets increase
- Adjacent market pairs exhibit already high correlations
- Indirect market pairs' correlations catch up (= better international integration?)

Results 2nd Stage: Daily Peak vs. Off-Peak: DE/AT and selected neighbors

Peak period

		FR		IT	
	$\Delta P_{DE,t-1}$	0.0004		-0.0182	
1.	ECT_{t-1}	-0.4513	***	-0.2778	***
2.	$\#cong\_hours$	-0.2091	***	-0.0056	
3.	$dummy\_MC$	1.4540	*	0.7810	
	$\Delta solarforecast$	0.0022		0.0023	
	$\Delta windforecast$	-0.0000		-0.0000	
	Δp_gas	0.8129	***	0.7292	***
	Δp_oil	-0.0535		-0.0279	
	Obs.	1,944		1,944	
	R2	0.411		0.383	

Off-Peak period

	FR		IT	
$\Delta P_{DE,t-1}$	-0.1745	***	-0.1928	***
ECT_{t-1}	-0.4925	***	-0.2204	***
$\#cong\_hours$	-0.6260	***	-0.0261	
$dummy\_MC$	-3.4946	***	0.8305	
$\Delta solarforecast$	-0.0006	***	-0.0008	***
$\Delta windforecast$	-0.0000		-0.0000	
Δp_gas	1.8034	***	1.8127	***
Δp_oil	-0.1349		-0.0330	
Obs.	1,944		1,944	
R2	0.707		0.659	

Notes: Dependent variable: $\Delta P_{DE,t}$. Regressions include seasonal fixed effects (dow, months, years, holidays), constant.

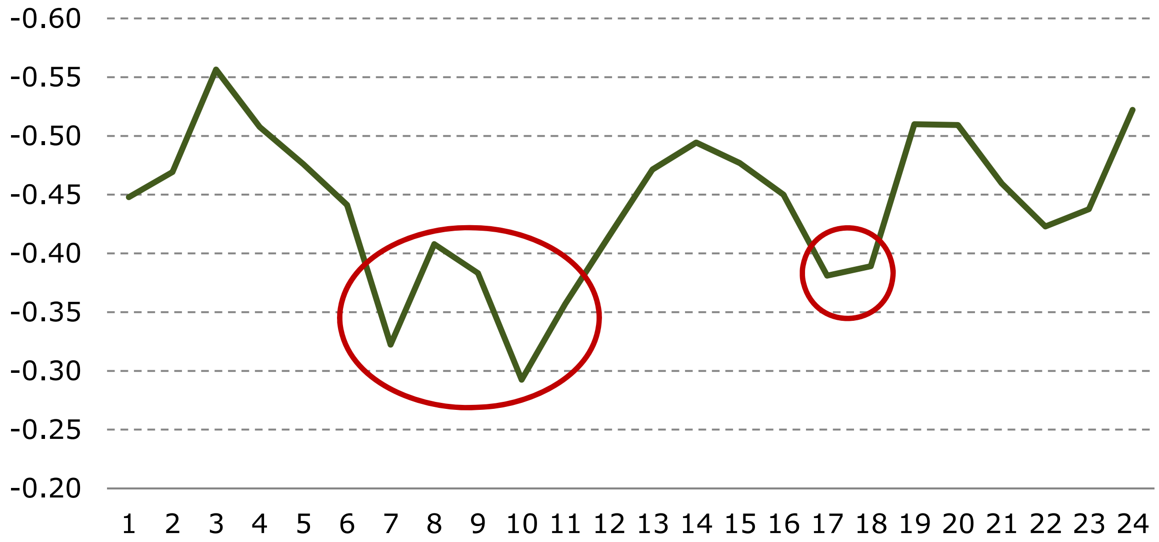
1. DE-FR exhibit higher efficiency (are better integrated) than DE-IT
2. DE price lower during times of congestion
3. Market coupling in DE leads to higher prices during peaks & lower prices during off-peaks

2nd stage results conditional on congestion spells: Error correction term between DE and FR at given hours

2nd Stage: DE-FR

	ECT		Obs.
Hour 01	-0.45	***	1035
Hour 02	-0.47	***	989
Hour 03	-0.56	***	972
Hour 04	-0.51	***	987
Hour 05	-0.48	***	1030
Hour 06	-0.44	***	1008
Hour 07	-0.32	***	975
Hour 08	-0.41	***	955
Hour 09	-0.38	***	896
Hour 10	-0.29	***	891
Hour 11	-0.36	***	914
Hour 12	-0.41	***	930
Hour 13	-0.47	***	1007
Hour 14	-0.49	***	995
Hour 15	-0.48	***	937
Hour 16	-0.45	***	801
Hour 17	-0.38	***	738
Hour 18	-0.39	***	708
Hour 19	-0.51	***	800
Hour 20	-0.51	***	921
Hour 21	-0.46	***	1022
Hour 22	-0.42	***	988
Hour 23	-0.44	***	1007
Hour 24	-0.52	***	1200

DE-FR: ECT during congestion spells, by hour



Market works less efficient betw. 06:00-11:00 & 17:00-18:00

Discussion & Conclusions (1)

- Market integration necessitates
  - Reduction of transmission bottlenecks, interconnection capacity, market coupling
- Fully integrated electricity markets:
  - One single spot price
  - Represents normative benchmark for policy analysis
  - Optimization of social welfare, but also welfare redistribution (!)
  - Practical implementation tough
  - Market integration reduces need for reserve capacity…
  - … as long as supply technologies are not too similar across markets

Discussion & Conclusions (2)

- Electricity markets become better integrated over time
  - But seem far from being perfectly integrated
  - Some markets tend to be more efficient (DE & FR, DE & CH) than others
  - Market coupling and interconnection congestion may bring about price increases and declines during peak or off-peak periods
- On the notion of market integration:
  - One price desirable given differences in transmission costs? → price discrimination
  - Nodal pricing better?
  - Off-set between costly capacity investment and positive welfare effects

Thank you!

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VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS

Institut für Quantitative Volkswirtschaftslehre
Institute for Quantitative Economics
Welthandelsplatz 1, 1020 Vienna, Austria

DR. MARIO LIEBENSTEINER

T +43-1-313 36-5461
Mario.liebensteiner@wu.ac.at
www.wu.ac.at/iqv

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