Integrated Electricity and Natural Gas Market Modeling

- The Effects of Market Liberalization in Europe -
Agenda

1. Introduction

2. Methodology (Model)

3. Selected Results

4. Conclusion
Research Question

• “Old World“ of the Continental European Gas Market
  – Natural gas sold to power stations by importers / producers in LT contracts at substitute-indexed prices, no resale obligations
  – Hence, price independent of natural gas market fundamentals (supply, demand, infrastructure availability), instead net-back prices for all power generators (limited locational differentiation)

• Natural Gas Market Liberalization (“New World“)
  – Resale obligations challenged / prohibited legally
  – Emergence of liquid natural gas trading points -> reference prices for natural gas usage in power generation

➢ What is the impact of natural gas market liberalization on dispatch and investment decisions in the power sector?
Literature

- no studies with large-scale energy market models
- empirical papers with focus on price relationship:
  - Woo et al. (2003): bi-directional Granger causality, CA 1999-2004
  - Asche et al. (2006): price integration only during times of autarky, UK 1995-1998
- theoretical interactions / analytical papers:
  - demand pull vs. supply push
  - Routledge et al. (2001): price linkage persists even when natural gas is not marginal generation technology
  - Joskow & Kahn (2002)
- simulations with fictional energy systems (usually OR-focus)
  - Geidl and Andersson (2006): favourable characteristics (gas storage vs. transmission of electricity) best exploited in integrated market
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**Integrated Model**

**Model inputs**
- Supply (long term contracts and flexible supply)
- Infrastructure (Pipelines, Storages, LNG Import terminals + additions / expansions)
- Non-power sector gas demand
- Installed Generation Capacities
- Fuel Prices (not natural gas)
- Investment costs for capacity
- Electricity demand
- Renewable energy generation (exogenous)
- CO₂ restrictions

**Regional coverage:**
EU-27 plus Turkey, Norway, Switzerland

**Model outputs**
- Infrastructure Utilization
- Physical gas flows
- Short-run marginal gas supply costs
- Gas supply costs & volumes
- Base & Peak Load Prices
- Power Station Dispatch
- Investment decisions (capacity additions & decommissions)
- CO₂ Emissions & Prices
- ...
Scenario Definitions

“Old World“ Scenario:
• substitute-indexed annually fixed gas price
• identical for all gas-fired generation plants in all countries

Integrated Simulation:
• gas supply endogenized
• natural gas prices may differ across countries and within the year (months, type-days)
• annually fixed border prices per supply country (net-back from Old World Scenario; assumed to be substitute indexed)
• i.e. gas supplied at EU borders at „producer prices“, competitive price formation within the EU
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Electricity Generation by Fuel

Gas-fired generation in 2020:
- generation increases by more than 150%
- 28% of total generation (from 12% in 2008)

Other fuels:
- decline for hard coal, lignite, nuclear power
- RES share in electricity generation up to 33 percent

➢ e.g. in line with scenarios Capros et al. (2000), EWI/EEFA (2008)
### Generation, Capacity, Full load hours by fuel

**Table R2: Simulation results EU-27 power market projection**

<table>
<thead>
<tr>
<th></th>
<th>Generation [TWh, %]</th>
<th>Installed Capacity [GW]</th>
<th>Full load hours per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal</td>
<td>515 (15%)</td>
<td>200 (5%)</td>
<td>107.8</td>
</tr>
<tr>
<td>Lignite</td>
<td>309 (9%)</td>
<td>148 (4%)</td>
<td>50.1</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>414 (12%)</td>
<td>1,142 (28%)</td>
<td>107.1</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>32 (1%)</td>
<td>0 (0%)</td>
<td>38.5</td>
</tr>
<tr>
<td>Nuclear</td>
<td>952 (28%)</td>
<td>804 (20%)</td>
<td>132.5</td>
</tr>
<tr>
<td>Large Hydro</td>
<td>262 (8%)</td>
<td>256 (6%)</td>
<td>127.0</td>
</tr>
<tr>
<td>Wind(^a)</td>
<td>104 (3%)</td>
<td>467 (12%)</td>
<td></td>
</tr>
<tr>
<td>Other RES(^a)</td>
<td>371 (11%)</td>
<td>596 (15%)</td>
<td></td>
</tr>
<tr>
<td>Other(^a,b)</td>
<td>434 (13%)</td>
<td>438 (11%)</td>
<td></td>
</tr>
<tr>
<td><strong>Total(^*)</strong></td>
<td>3,394</td>
<td>4,051</td>
<td></td>
</tr>
<tr>
<td>Non-RES</td>
<td>2,657 (78%)</td>
<td>2,732 (67%)</td>
<td>563.1</td>
</tr>
<tr>
<td>RES</td>
<td>738 (22%)</td>
<td>1,319 (33%)</td>
<td></td>
</tr>
</tbody>
</table>

* Difference compared to consumption (Table 1) due to power consumption by energy storages, losses during transmission and imports / exports with non-model regions (Balkans, non-EU-Eastern Europe)

\(^a\) Exogenous in model simulations based on Bartels (2009) and Nicolosi and Wissen (2009)

\(^b\) Mainly electricity generation by Main Activity Heat (CHP) plants
Electricity and CO₂ Prices

**Electricity Prices:**
- decline 2008 to 2010 due to fuel price developments
- 2008 value in line with average base prices
- (fuel prices constant as of 2010)
- further increases due to capped emissions

**Emission Permits:**
- emission permit prices increase from 22 to 53 EUR / tonne of CO₂
Short-term Dispatch Effect on gas-fired generation (I)

Key:
- Weekday
- Saturday
- Sunday

Fixed Gas price (dotted line)

Integrated Simulation (Continuous Line)
Findings:
Small net-effect, but:

<table>
<thead>
<tr>
<th>Natural Gas Price</th>
<th>Electricity Demand</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>Generation Increases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIGH</td>
<td>Generation Constant (small increase)</td>
<td>Generation Constant</td>
<td>Generation Constant (small decrease)</td>
<td>Generation Constant</td>
</tr>
</tbody>
</table>
Long-run: Implications on investment in technologies

On an aggregate EU-29 level (2020):

- minor effects on gas-fired generation; significant substitution of lignite by hard coal generation

- Consequence of observed short-run effects as CO₂ prices make supply curve flatter in general

- Double fuel switch:
  - natural gas-off peak seasons -> natural gas relatively more competitive than lignite in base load generation
  - natural gas peak seasons -> natural gas loses competitiveness compared to hard coal
Relative Change of natural gas-fired generation per country vs. installed capacity in that country

- e.g. same installed capacity but more generation -> relative move towards off-peak electricity generation from natural gas
- or same installed capacity but fewer generation from gas-fueled power plants -> relative more peak-load generation
Gas-fired generation and capacity 2020 (I)

Effects:

- Eastern European countries in relatively greater geographic proximity to natural gas sources see largest increases in gas-fired generation
- also higher full load hours
- relative declines in countries with limited import capacities for natural gas -> competition for gas with other consumers
Gas-fired generation and capacity 2020 (II)

**Effects**

- significant generation declines in Spain, France -> relatively high dependence on more costly LNG
  - France, Belgium, Germany -> capacity remains unchanged
  - Spain, UK -> decline in line with generation
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Summary

Short-run:
- More gas-fired generation in gas demand off-peak times (base load generation)
- Less gas-fired generation in selected electricity peak demand times (spring and fall seasons)

Long-run:
- Effects on hard coal (positive) and lignite competitiveness (negative) in peak and off-peak hours
- Gas-fired generation moves towards EU borders (i.e. closer geographic proximity to pipeline gas sources in the east)
DIME Electricity Market Model

Dispatch and Investment Model for Electricity Markets in Europe

**Input**
- Total demand
- Residual demand
- Exogenous generation
- Political restrictions
- Existing capacities
- Technical properties of technologies
- Economical properties of technologies
- Fuel prices / volumes
- Existing transmission capacities
- Transmission loss

**Output**
- Commissioning and retirement of capacities by technology
- Installed capacities
- Annual generation structure
- Plant dispatch by load level
- Physical exchange
- Marginal generation costs
- Fixed and variable generation costs
- Fuel consumption
- Carbon emissions
- Carbon prices

Source: EWI
TIGER Natural Gas Market Model

Supply at borders
- volumes & border prices

Gas demand
- by sector, regionalized

Infrastructure
- Capacities (exist. + exp.)

**Linear Optimization**

**Objective:**
Cost-minimal demand satisfaction, restricted by available capacities

*temporal granularity:*
day-types and months

**Infrastructure assets** *(Pipelines, Gas Storages, LNG Terminals)*
- Volumes, utilization, flows etc.

Locational Marginal Cost Price Estimator