Network Expansion and Welfare Effects in two-stage Cournot Model

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11 April 2014

Structure

Research objective:
Investigate whether the potential to exert market power can be counteracted by increased interconnector capacities

This paper is work in progress and a part of joint project with DIW Berlin, another approach is in the presentation of Alexander Zerrahn and Daniel Huppmann at 11.50 in room A03

Structure of the presentation:

- Mathematical aspects power markets' modeling
- Application to the Western European market data

Equilibrium Problem under Equilibrium Constraints

Three-stage game

1. Planner decides on network expansion
2. Strategic firms decide on generation levels
3. ISO dispatches the market such that flows are feasible

In stage 2, strategic firms know that their generation decision will influece the decision of ISO in stage 3. Hence, in stage 2 to find market equilibrium one has to solve strategic firms' problems subject to an equilibrium dispatch.

i.e. we have Equilibrium Problem under Equilibrium Constraints (EPEC)

MPEC

Mathematical formulation

On upper level strategic firm maximizes its profit in Cournot competition (Equilibrium Problem):

$$\forall i, \max_{g_i} \Pi\left(g_i, g_{-i}\right) \qquad \text{s.t. } 0 \leq g_i \leq g_i^{max}$$

and subject to lower level market clearing by the ISO (Equilibrium Constraints):

$$\begin{aligned} & \max \ \mathit{Welfare}\left(g, d, \delta\right) \\ \text{s.t.} \quad & \mathit{Nodal\ Balance}\left(g, d, \delta\right) = 0 \quad \forall n \\ & \mathit{Feasible\ Flows}\left(\delta\right) \leq 0 \quad \forall l \end{aligned}$$

That is, the upper level equilibrium problem is subject to equilibrium constraints that are nonconvex.

- There are viable methods for solving MPECs
- For EPECs there are no convenient procedures

To deal with non-convexity

Each MPEC is reformulated as mixed-integer linear program by using disjunctive constraints and linearization, an approach presented in (Gabriel, Leuthold, 2010)

Diagonalization algorithm to solve EPEC

Solve EPEC by finding some (if any) point of convergence of an EPEC with given data.

$\rightarrow$ Instead of solving EPEC, solve a sequence of MPECs until the decision variables of all leaders reach a fixed point

- take a starting point
- solve MPEC for each strategic firm while holding the strategies of others fixed (i.e., find best response)
- take best responses from the previous step as a new starting point
- repeat until values converge (if they do)

Gauss-Seidel algorithm
Use the most recent information in calculations: MPECs are ordered from 1 to K, update of the optimal strategy of k-th strategic player at iteration i is based on the strategies found at iteration $i-1$ for Stackelberg leaders from $k+1$ to K and values found at iteration i for Stackelberg leaders from 1 to $k-1$

- solve k-th MPEC holding the strategies of other fixed: $x^i_{-k} = (x^i_1, \dots x^i_{k-1}, x^{i-1}_{k+1} \dots, x^{i-1}_K)$

Data: Western European market

Stylized grid and data taken from (Gabriel, Leuthold, 2010) and (Neuhoff et al. 2005)

- 15 nodes, 28 lines
  - Germany (n1), France (n2), Belgium (n3 and n6) and the Netherlands (n4, n5 and n7)
  - other nodes have no supply and demand and are used to adequately model cross-border flows
- eight types of installed generation capacity: nuclear, lignite, coal, CCGT, gas, oil, hydro and pump
- five generation companies are considered: EON, RWE, Electricite de France, Electrabel and an aggregated player consisting out of smaller firms

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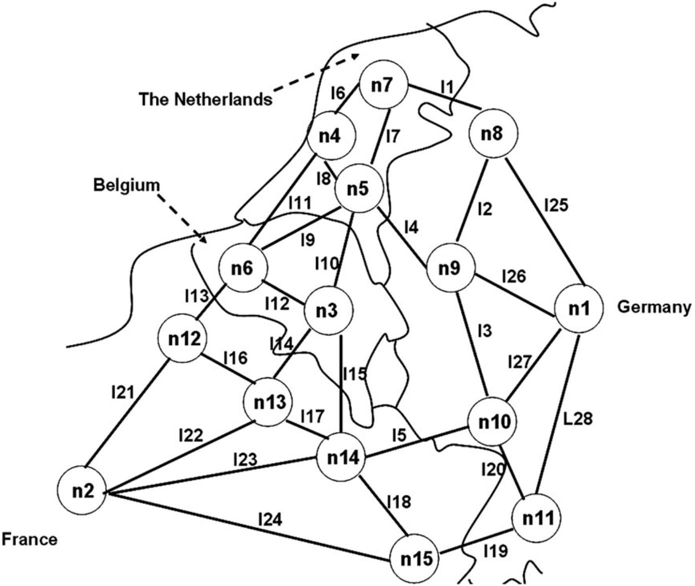

Fig. 2. Stylized network of the Western European grid. Source: Based on Neuhoff et al. (2005).

Perfect competition vs. Strategic generation

	perfect competition	strategic interaction
$price_{n1}$, Germany	22.0	30.0
$price_{n2}$, France	10.0	76.0
$price_{n3}$, Belgium	10.0	52.0
$price_{n4}$, the Netherlands	45.0	45.0
$price_{n5}$, the Netherlands	59.3	45.6
$price_{n6}$, Belgium	22.0	48.0
$price_{n7}$, the Netherlands	41.3	41.4

Perfect competition benchmark results can be found in (Gabriel, Leuthold, 2010)

- Although with strategic generators prices increase in nodes n1, n2, n3 and n6, the Netherlands benefit from the absence of competition: price in node n5 decreases compared to the perfect competition case
- 3 lines are found to be always congested: l10, l13 and l19
- What if they are decongested?

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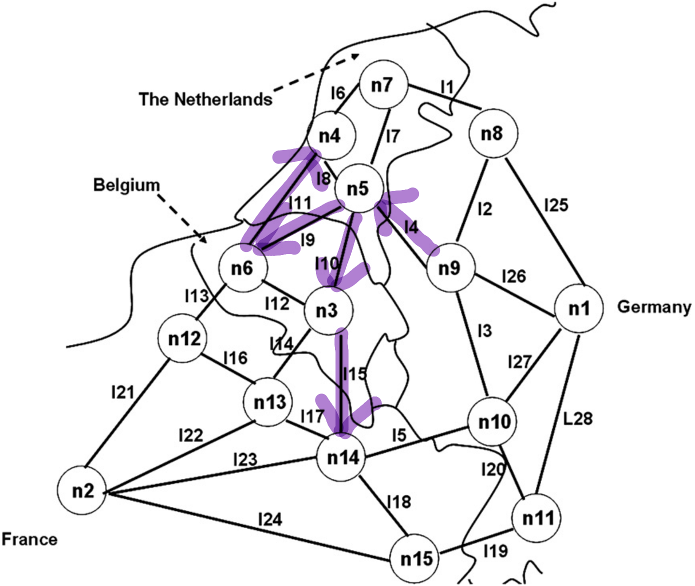

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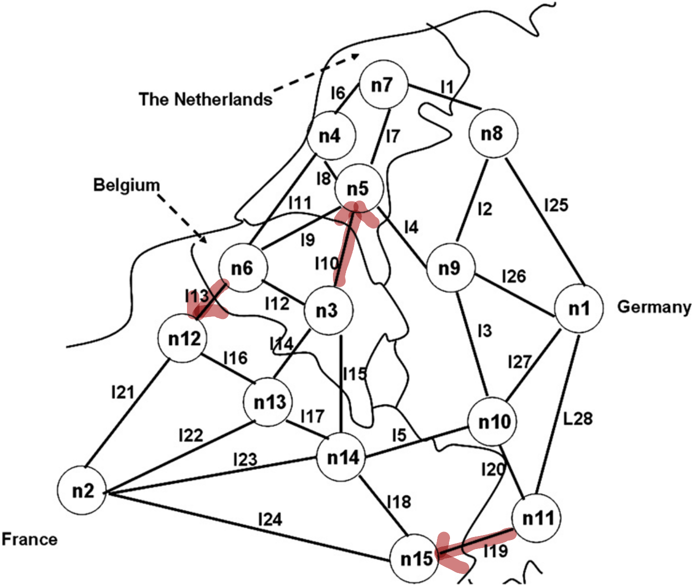

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Perfect competition vs. Strategic generation

	perfect competition	strategic interaction	strategic interaction with expanded lines
$price_{n1}$, Germany	22.0	30.0	30.0
$price_{n2}$, France	10.0	76.0	71.0
$price_{n3}$, Belgium	10.0	52.0	58.8
$price_{n4}$, the Netherlands	45.0	45.0	46.5
$price_{n5}$, the Netherlands	59.3	45.6	45.0
$price_{n6}$, Belgium	22.0	48.0	54.0
$price_{n7}$, the Netherlands	41.3	41.4	40.8

- Decongested lines l10, l13 and l19 lead to the drop of prices in France, prices in Germany remain the same
- Total welfare increases; welfare in France goes up, while welfare in parts of the Netherlands and Belgium goes down

Profits

	perfect competition	strategic interaction	strategic interaction with expanded lines
Electrabel	81.7	332.0	354.1
EON	121.0	238.5	240.2
RWE	94.0	170.0	180.0
Electricite de France	140.0	2054.1	1970.0

Consumer surplus

	perfect competition	strategic interaction	strategic interaction with expanded lines
$n1$, Germany	5320.5	5220.0	5220.0
$n2$, France	5040.0	3762.8	3928.3
$n3$, Belgium	280.0	247.5	237.9
$n4$, the Netherlands	511.9	511.8	508.5
$n5$, the Netherlands	474.4	510.5	511.9
$n6$, Belgium	183.5	168.3	163.1
$n7$, the Netherlands	259.9	259.8	260.5

Welfare

	perfect competition	strategic interaction	strategic interaction with expanded lines
$n1$, Germany	4255.0	4162.6	4141.1
$n2$, France	4519.3	3612.8	3768.3
$n3$, Belgium	254.5	195.5	208.0
$n4$, the Netherlands	396.5	404.3	231.2
$n5$, the Netherlands	384.4	420.5	458.2
$n6$, Belgium	142.1	116.3	111.1
$n7$, the Netherlands	199.9	109.8	200.5
Total	10151.6	9019.9	9118.3

Thank you for your attention!