Network Expansion to Mitigate Market Power

How Increased Integration Fosters Welfare


Daniel Huppmann, Alexander Zerrahn
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Agenda

1. Theory: *Market power in constrained networks*
2. Policy: *The economics of network investment*
3. Math: *A three-stage model for network investment and strategic generators*
4. Example: *A toy model for illustration purposes*
5. Conclusion and outlook
Theory:

*Market power in constrained networks*
The theoretical background: Strategic behaviour in networks

In constrained networks, strategic generators may choose to congest lines to divide the market and earn monopoly profits

- Bushnell et al. (2000) illustrate this in a simple two-node example

- Cournot generators are able to earn extra rents by congesting the line and barring the other player from exporting to their market
- This is referred to as *passive-aggressive equilibrium*
- But even in this simple example, existence & uniqueness of an equilibrium depend on the line capacity
Applied/numerical modelling has largely abstracted from these effects due to the mathematical complexity

• Generators are frequently modelled as Cournot players (or using conjectural variations or supply function equilibria)
• But in most applied work, strategic players don’t consider their impact on network congestion and resulting price differentials
• The problem becomes even more difficult when including power flow characteristics in networks
cf. Neuhoff et al. (2005)

⇒ Hence, most numerical applied work underestimates the potential for gaming in (electricity) networks
Policy:

The economics of network investment
The benefits of network expansion

Network expansion can yield substantial benefits by improving efficiency and mitigating market power potential

- In a perfectly competitive market, you would invest up to the point where \textit{marginal cost of investment} = \textit{marginal benefits} (efficiency)
- But when generators are aware of their impact on grid congestion, this is quite difficult to compute
- It can be optimal to invest in a line which is not used in equilibrium
- This happens because the passive-aggressive equilibrium is no longer stable and generators revert to the Cournot equilibrium

⇒ With strategic generators present, network investment can yield benefits beyond efficiency gains by mitigating market power
The ugly math:

*A three-stage model for network investment and strategic generators*
Modelling a strategic generator taking into account its impact on nodal prices is mathematically challenging.

- **Strategic generator**
  - Seeks to maximize profits
  - Decides on generation

- **Electricity market**
  - (competitive & integrated, equivalent to ISO)
  - Determines optimal dispatch, price, load, power flows given the network

⇒ This yields a *Mathematical Program under Equilibrium Constraints* (MPEC, e.g., Gabriel and Leuthold, 2010; Ruiz and Conejo, 2009)
Finding an equilibrium between strategic generators is even more challenging

⇒ This yields an Equilibrium Problem under Equilibrium Constraints (EPEC, e.g., Ruiz, Conejo and Smeers, 2012; Pozo et al., 2013)
A network planner decides on investment, balancing costs against efficiency gains and market power mitigation.

The resulting problem is a non-convex (bilinear) Mixed-Integer Quadratically Constrained Quadratic Program.
A numerical example:

A *toy model for illustration purposes*
A simple case study:

- A three node network
- Demand at $n1$, inverse demand function: $p(q) = 10 - q$
- Generation at $n2$ and $n3$
- Marginal generation cost 0
- Initial line capacity as indicated

\[
\begin{align*}
\bar{f}_1 &= 0.5 \\
\bar{f}_2 &= 1 \\
\bar{f}_3 &= 3
\end{align*}
\]
A numerical application – Market power cases

Potential Nash equilibria: benchmark & after expansion

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<thead>
<tr>
<th>No expansion</th>
<th>Asymmetric</th>
<th>Symmetric</th>
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<tr>
<td>Generation</td>
<td>1.90</td>
<td>0.55</td>
<td>1.75</td>
</tr>
<tr>
<td>Price at n1</td>
<td>7.55</td>
<td>5.75</td>
<td>3.33</td>
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The *thin-line* effect (cf. Borenstein et al., 2000):
Line upgrades may be necessary to make Nash equilibria stable against deviations, even if these lines are not utilized in equilibrium.
### A numerical application – Market power cases

#### Potential Nash equilibria: welfare effects

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<td><strong>Graphs</strong></td>
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- **n1**: Firm 1
- **n2**: Firm 2
- **n3**: Firm 3

#### Bar chart

- **X-axis**: Investment costs (0-50)
- **Y-axis**: Welfare
- **Legend**:
  - Welfare
  - Investment costs
  - Firm 2 profit
  - Firm 3 profit
  - Consumer surplus

**Network Expansion to Mitigate Market Power**

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Proactive vs. reactive network investment

• Assume that a benevolent network planner invests as if all generators would act competitively, when in fact they behave strategically (*reactive* investment) (cf. Sauma and Oren, 2006)

• Solve for Nash equilibrium with “competitive” grid investment: In our test case: there exists no Nash equilibrium!

A philosophical question:

What is the interpretation of “no Nash equilibrium“...?
Conclusion and outlook
Conclusions and outlook

Theory and methodology:

- We develop a methodology to identify equilibria between strategic generators accounting for their effect on the network.
- A network planner balances expansion costs against efficiency gains and market power effects.
- There is a lot of ugly math & iterative algorithms to make this work.

Policy:

- Network expansion can greatly mitigate market power potential.
- Only focusing on congested lines can lead to sub-optimal decisions.
- Failing to anticipate strategic behaviour can lead to funny effects.
Thank you very much for your attention!

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