DIW BERLIN

Transtlantic InfraDay @ FERC

Network Expansion to Mitigate Market Power

How Increased Integration Fosters Welfare

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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

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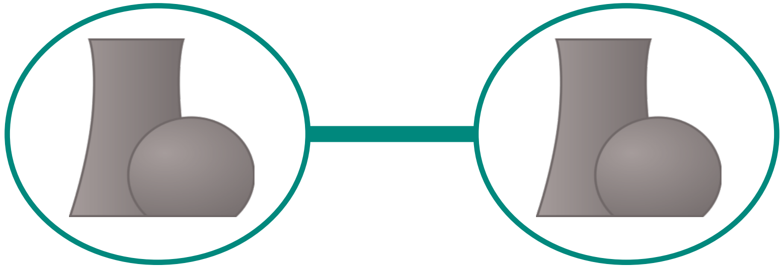
Theory:
Market power in constrained networks

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

Numerical modelling: Capturing strategic behaviour is complicated

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

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Policy:

The economics of network investment

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 *marginal cost of investment = 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

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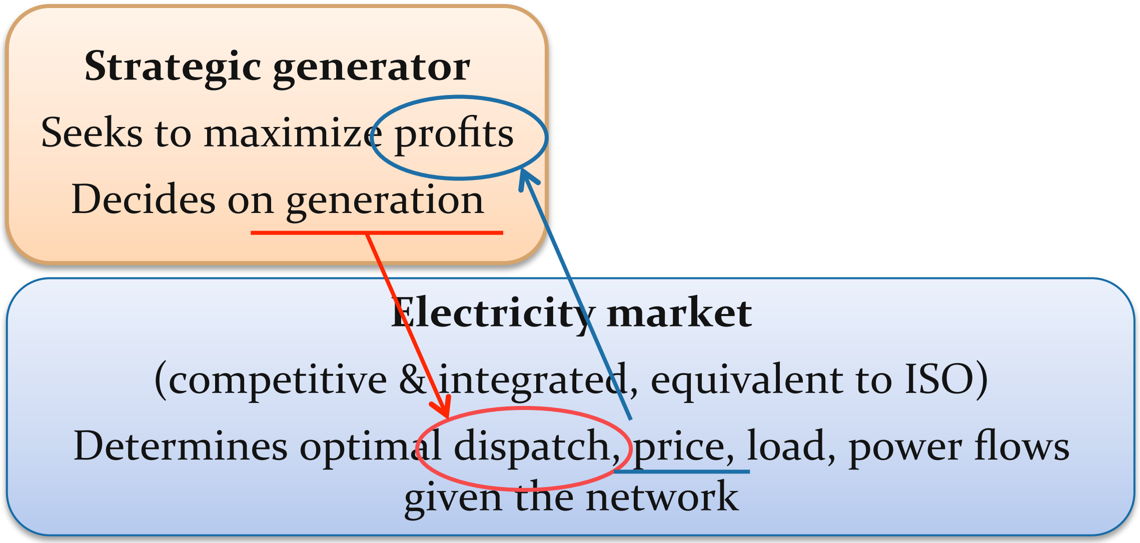
The ugly math:

A three-stage model for network investment and strategic generators

3

Strategic generation in the power grid (I)

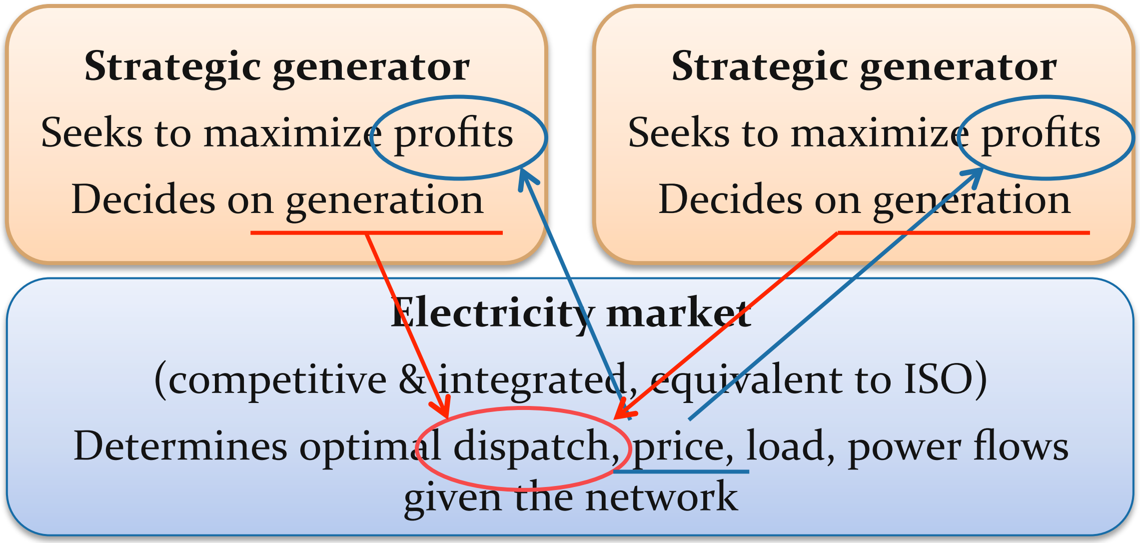
Modelling a strategic generator taking into account its impact on nodal prices is mathematically challenging



⇒ This yields a *Mathematical Program under Equilibrium Constraints* (MPEC, e.g., Gabriel and Leuthold, 2010; Ruiz and Conejo, 2009)

Strategic generation in the power grid (II)

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

I

Network planner

Seeks to maximize aggregate welfare

Decides on grid upgrades

Solve welfare maximization constrained by reformulated lower-level equilibrium conditions

II

Strategic generator | **Strategic generator**

Each strategic generator faces a bilinear optimization problem under equilibrium constraints

Take KKT conditions and reformulate using disjunctive constraints

III

Electricity market (ISO)

Welfare maximization of spot market reformulated using strong duality

⇒ The resulting problem is a non-convex (bilinear) *Mixed-Integer Quadratically Constrained Quadratic Program*

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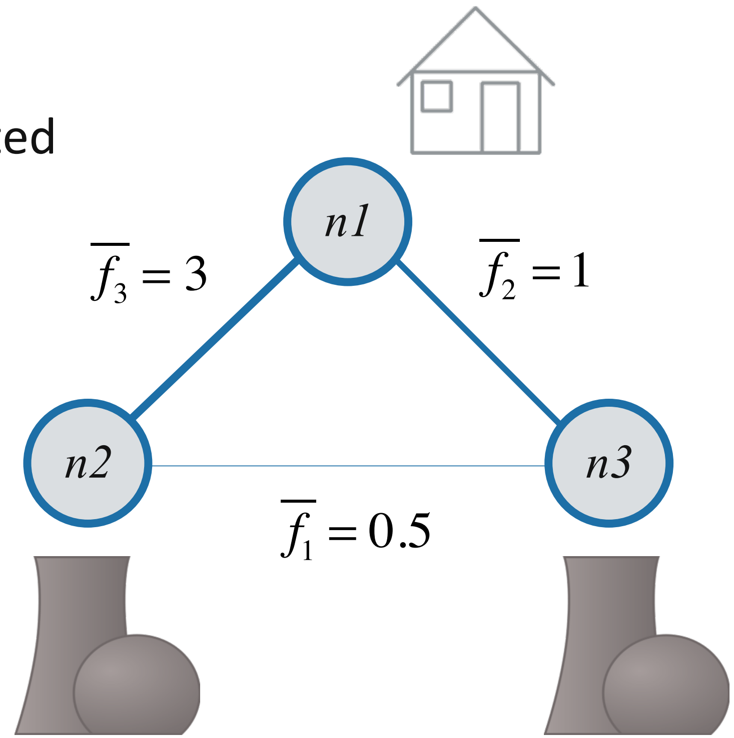
A numerical example:

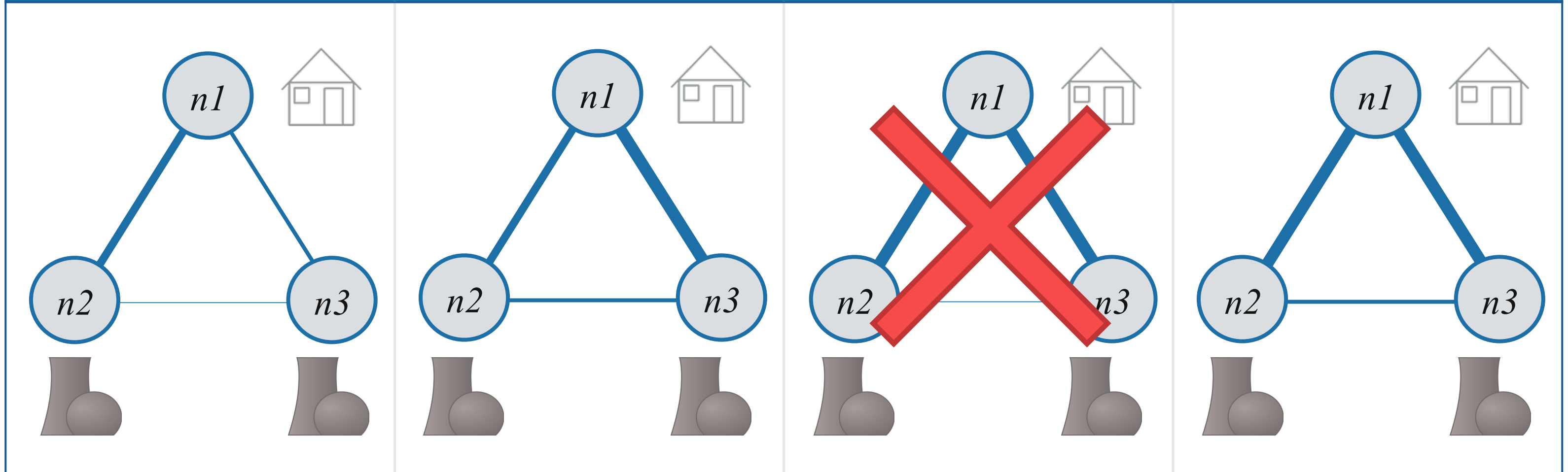
A toy model for illustration purposes

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



Potential Nash equilibria: benchmark & after expansion

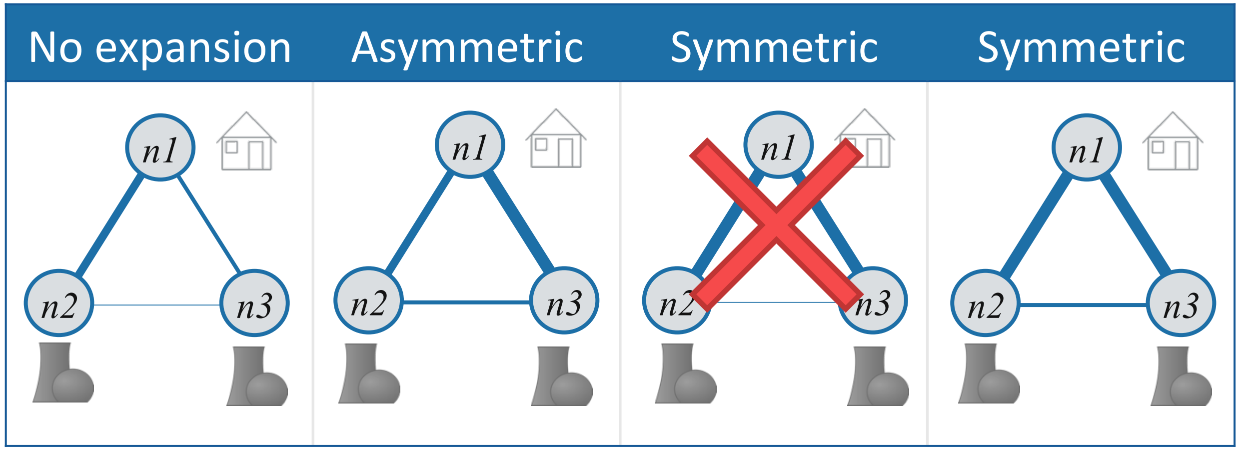


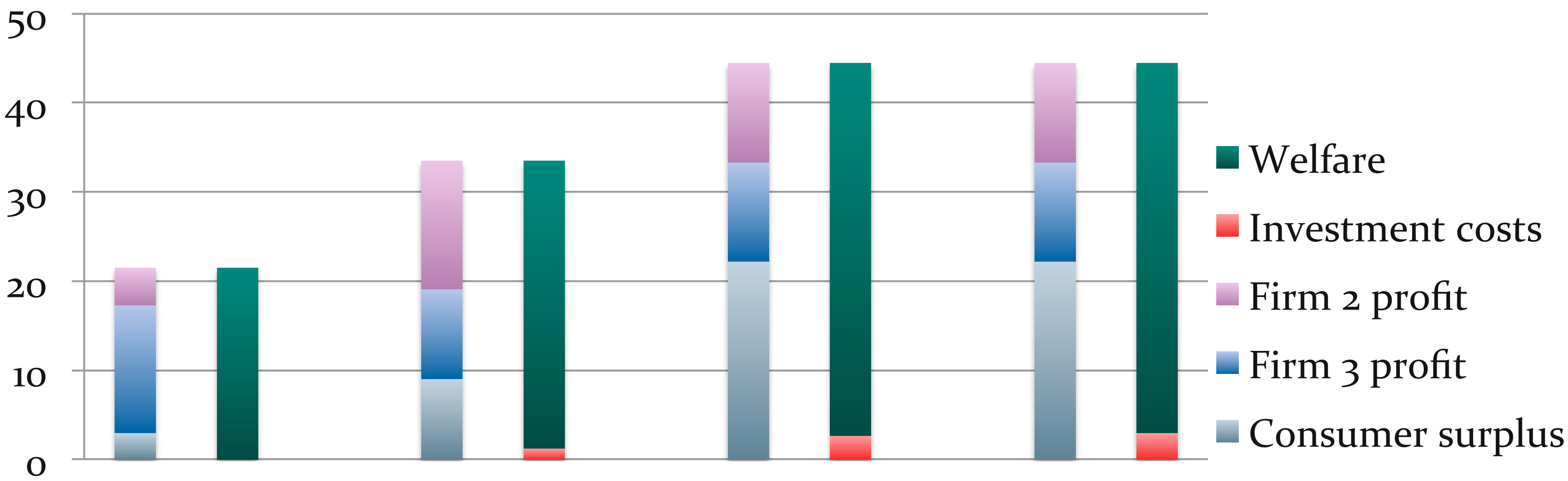
	No expansion		Asymmetric		Symmetric		Symmetric	
Generation	1.90	0.55	1.75	2.50	3.33	3.33	3.33	3.33
Price at $n1$	7.55		5.75		3.33		3.33	

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

Potential Nash equilibria: welfare effects





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"...?

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Conclusion and outlook

5 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!

German Institute for Economic Research (DIW Berlin)
Deutsches Institut für Wirtschaftsforschung e.V.
Mohrenstraße 58, 10117 Berlin
www.diw.de/english

Daniel Huppmann, dhuppmann@diw.de
Alexander Zerrahn, azerrahn@diw.de