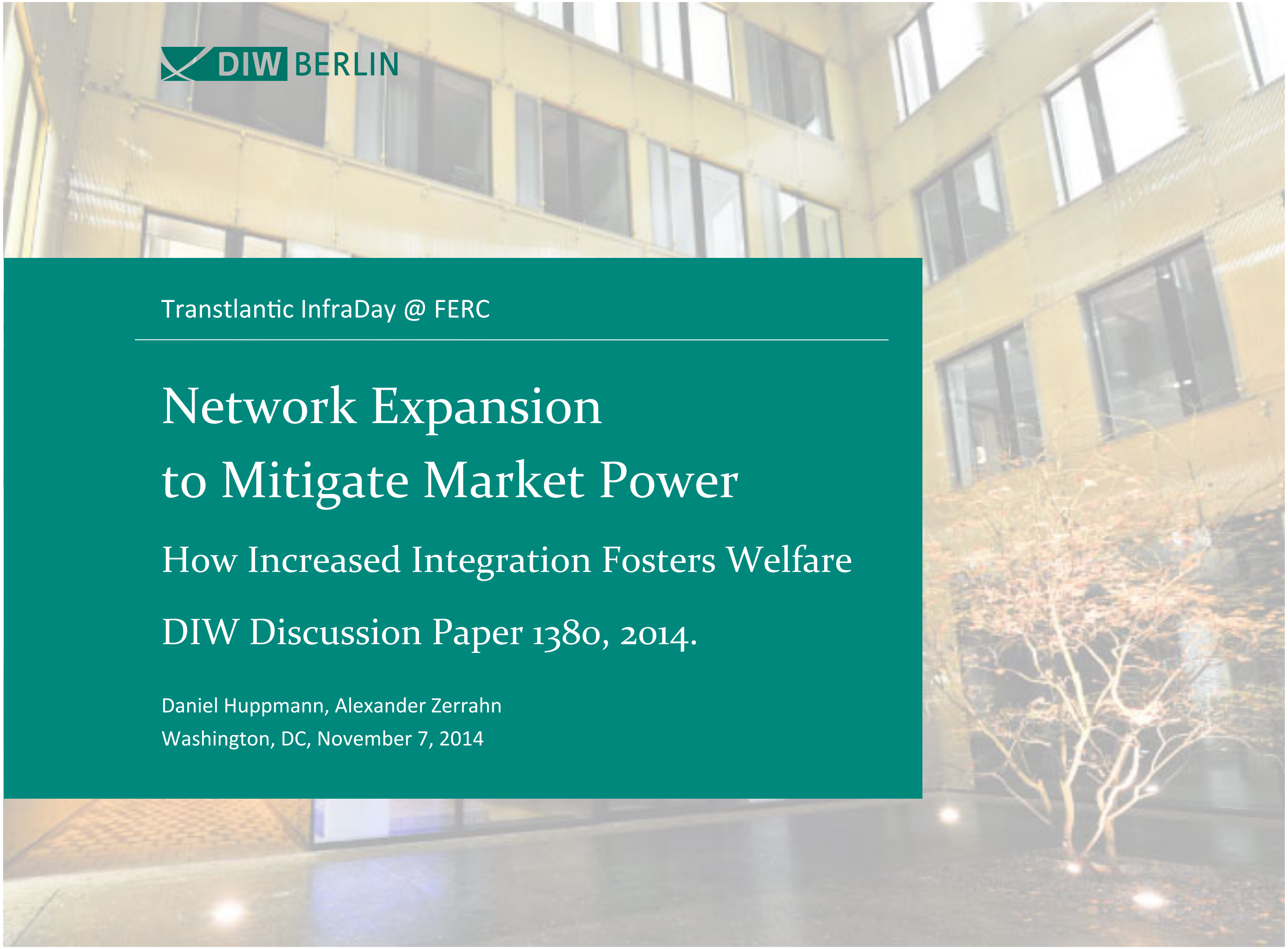

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Transtlantic InfraDay @ FERC

Network Expansion to Mitigate Market Power

How Increased Integration Fosters Welfare

DIW Discussion Paper 1380, 2014.

Daniel Huppmann, Alexander Zerrahn

Washington, DC, November 7, 2014

Agenda

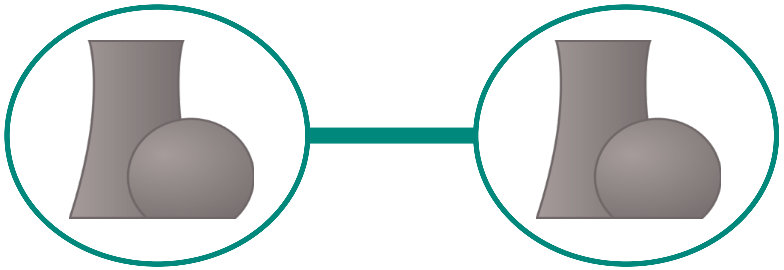
1. Theory: *Market power in constrained networks*
2. Policy: *The economics of network investment*
3. Math: *A three-stage model for network investment and strategic generators*
4. Example: *A toy model for illustration purposes*
5. Conclusion and outlook

1

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

1

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

2

Policy:

The economics of network investment

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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

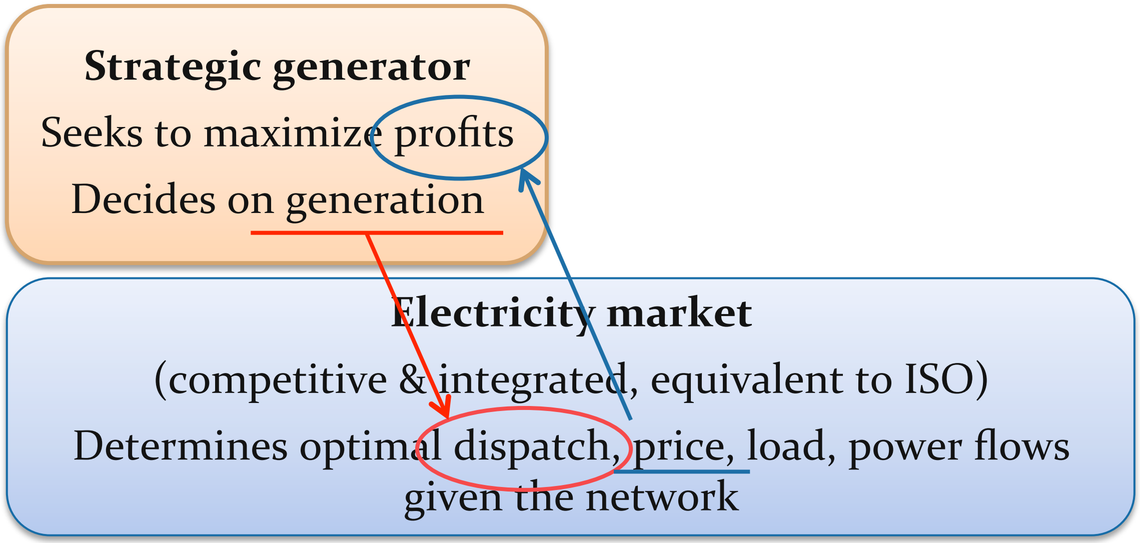
3

The ugly math:

A three-stage model for network investment and strategic generators

3 Strategic generation in the power grid (I)

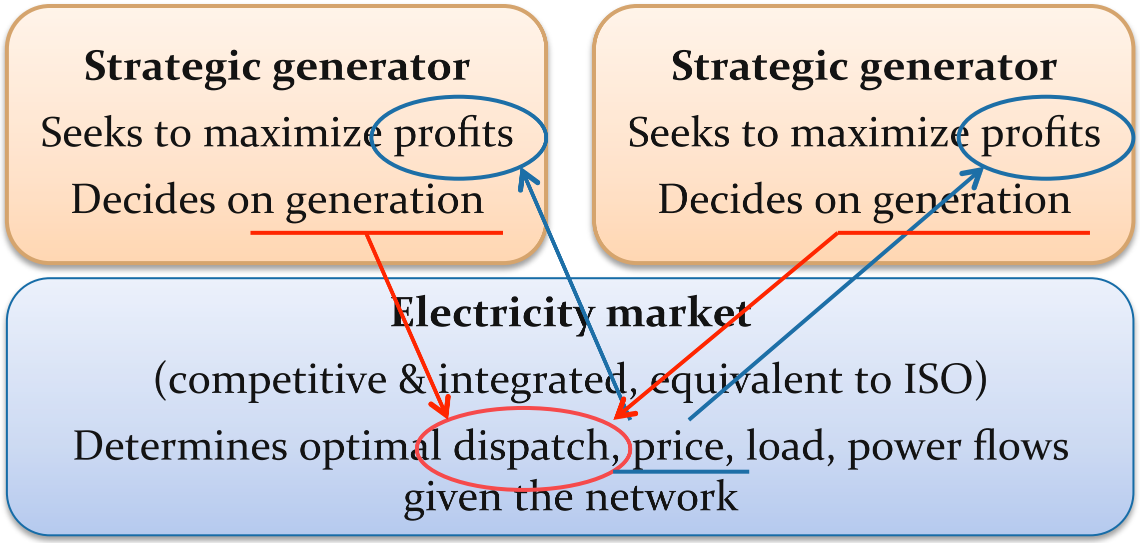
Modelling a strategic generator taking into account its impact on nodal prices is mathematically challenging



⇒ 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

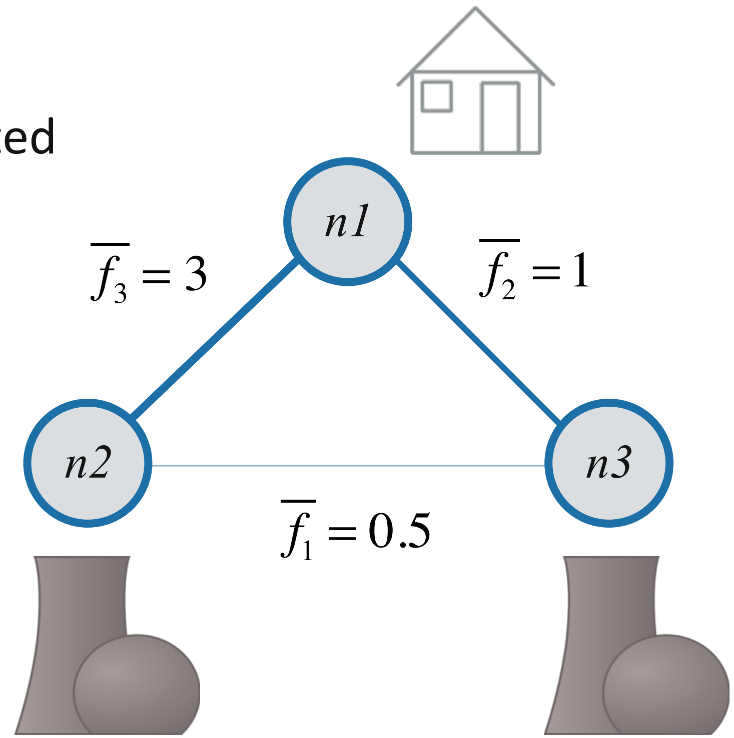
⇒ The resulting problem is a non-convex (bilinear)
Mixed-Integer Quadratically Constrained Quadratic Program

4

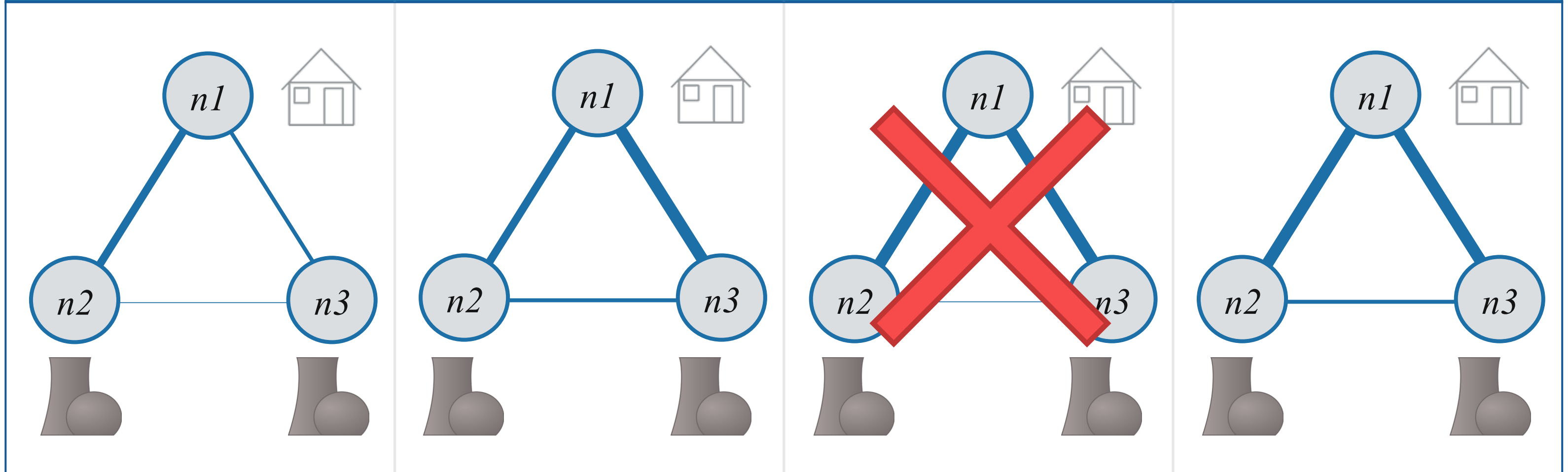
A numerical example:
A toy model for illustration purposes

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

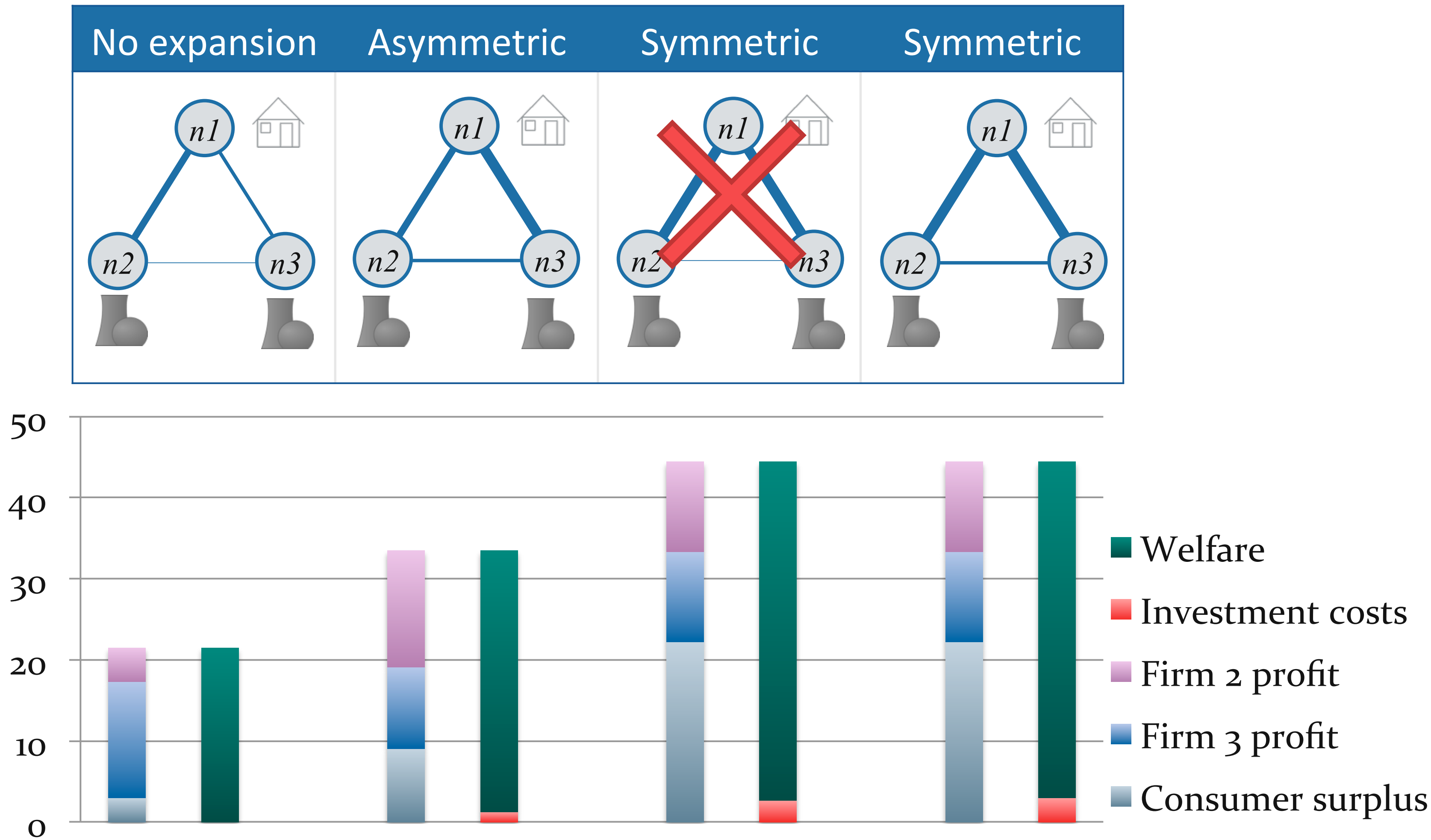


	No expansion		Asymmetric		Symmetric		Symmetric	
Generation	1.90	0.55	1.75	2.50	3.33	3.33	3.33	3.33
Price at $n1$	7.55		5.75		3.33		3.33	

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“...?

5

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!

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