Locational-based Coupling of Electricity Markets: Benefits from Coordinating Unit Commitment & Balancing Markets

(EPRG Working Paper 1022 / Cambridge Working Paper in Economics 1044)

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Overview

1. **What** are we estimating?
2. **How**?
   a) Modelling framework
   b) Numerical application
3. What are the **results** in a "base case"?
4. How do these results depend on various parameters **(sensitivity)** ?
5. What can we **conclude**?

1. What are we estimating?

Potential Benefits of LMP:

- Short-run improvements
  - within-country dispatch
  - **international dispatch/trade**
  - **unit commitment**
  - demand response
  - avoiding inc-dec-games
- Long-run improvements
  - siting of investment
  - mix of investment
  - less transmission investment needed

This study (in a simple network + sensitivities)

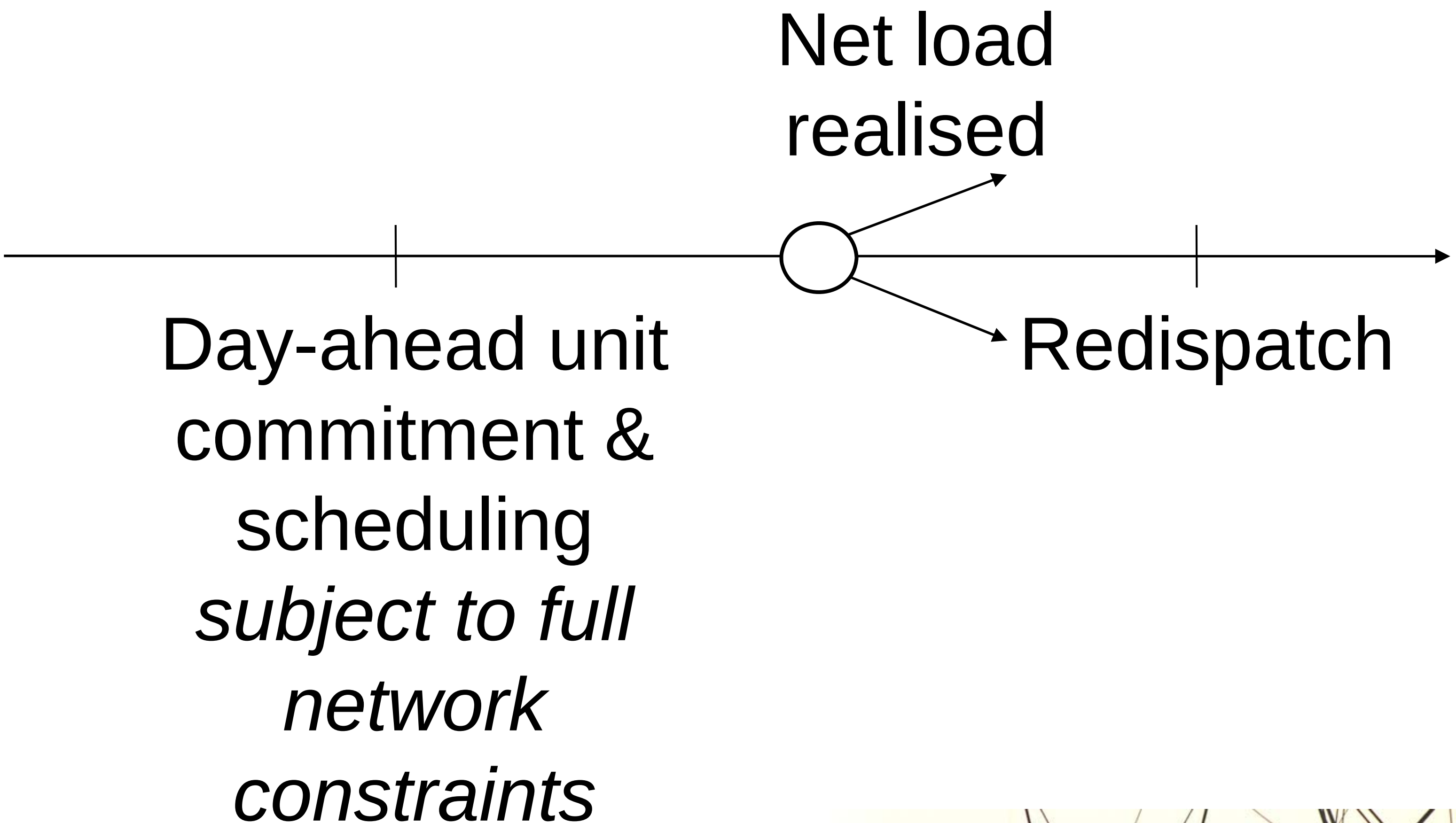
2a. How? Model framework

- **Three models** calculating expected cost (EC) of commitment & dispatch
  1) LMP: commit s.t. full network (*lowest cost!*)
  2) NTC-ID: commit s.t. NTC , followed by international redispatch
     - "Net Transfer Capability"= Total MW limit between countries
     - This is an approximation to true network constraints → cost increase
  3) NTC-NID: commit s.t. NTC, only domestic redispatch
- Calculate **unit commitment benefits:** *EC[NTC-ID] − EC[LMP]*

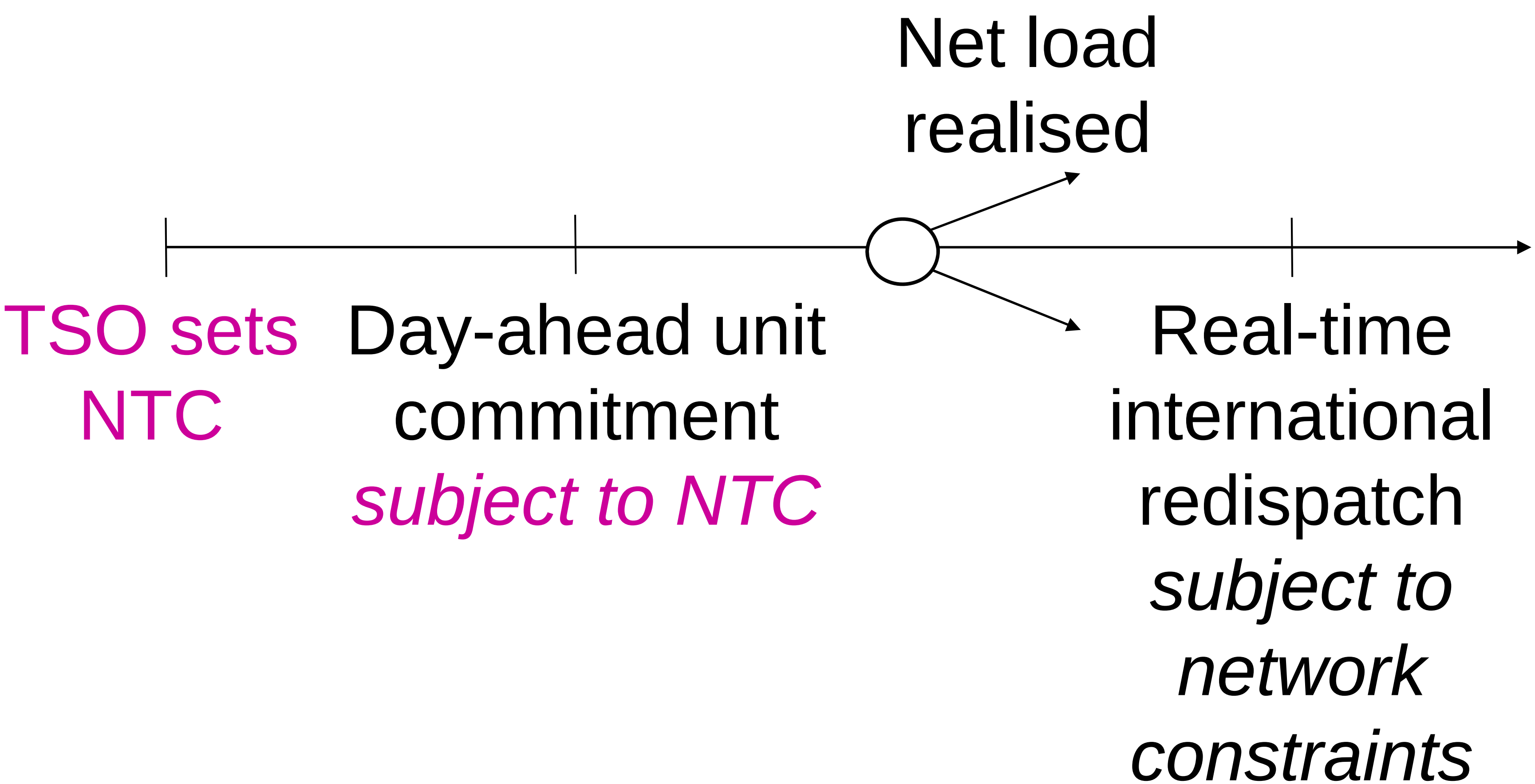
  Quantified for two NTC cases:
  1) Optimal NTC (minimize expected costs) → through search over NTCs
  2) Arbitrary (fixed) NTC
- Calculate **benefits of international redispatch:**

  EC[NTC-NID] − EC[NTC-ID]
- **Sensitivity** analysis to network parameters

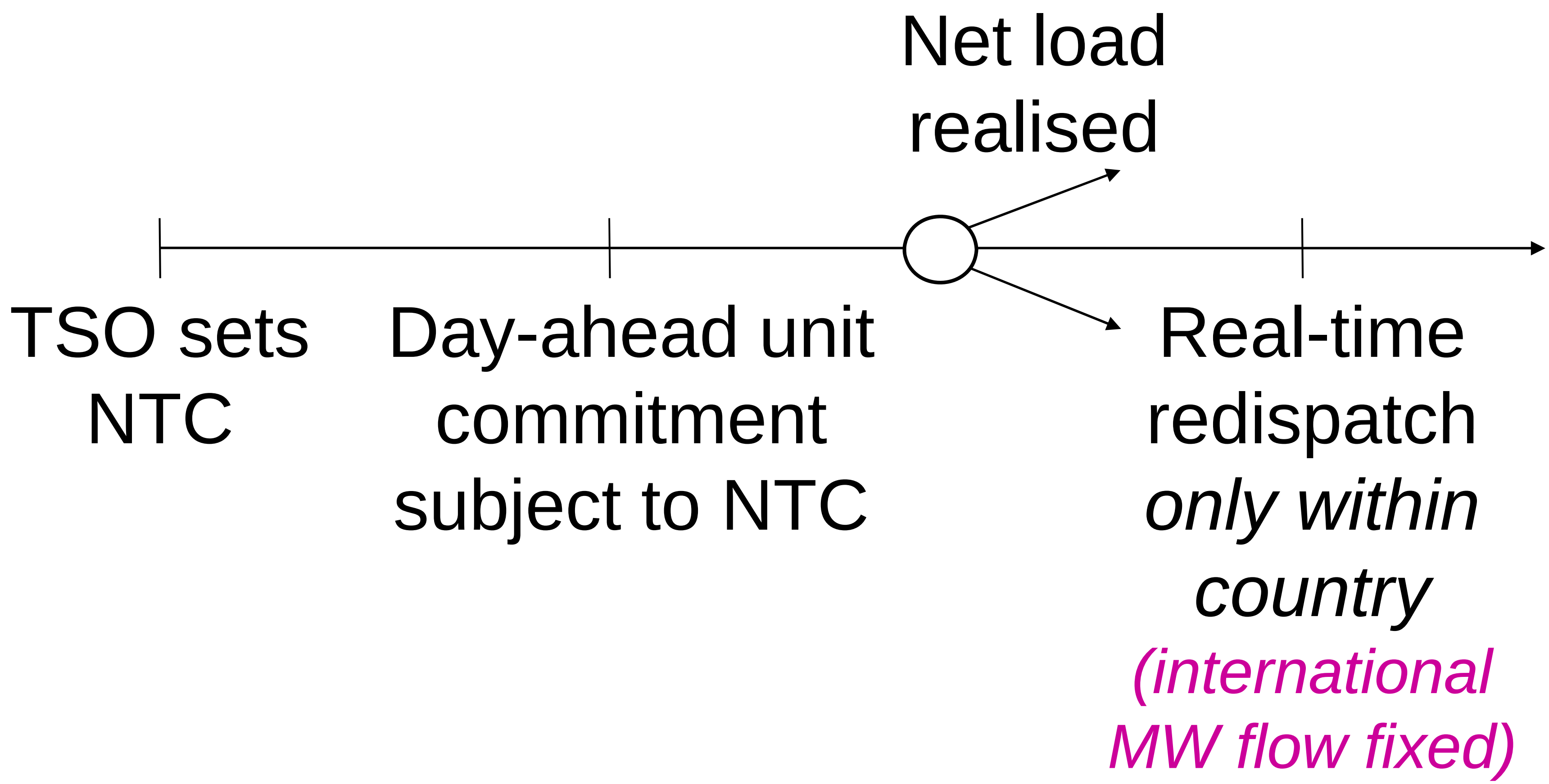
Model LMP


Net load realised
Day-ahead unit commitment & scheduling *subject to full network constraints*
Redispatch

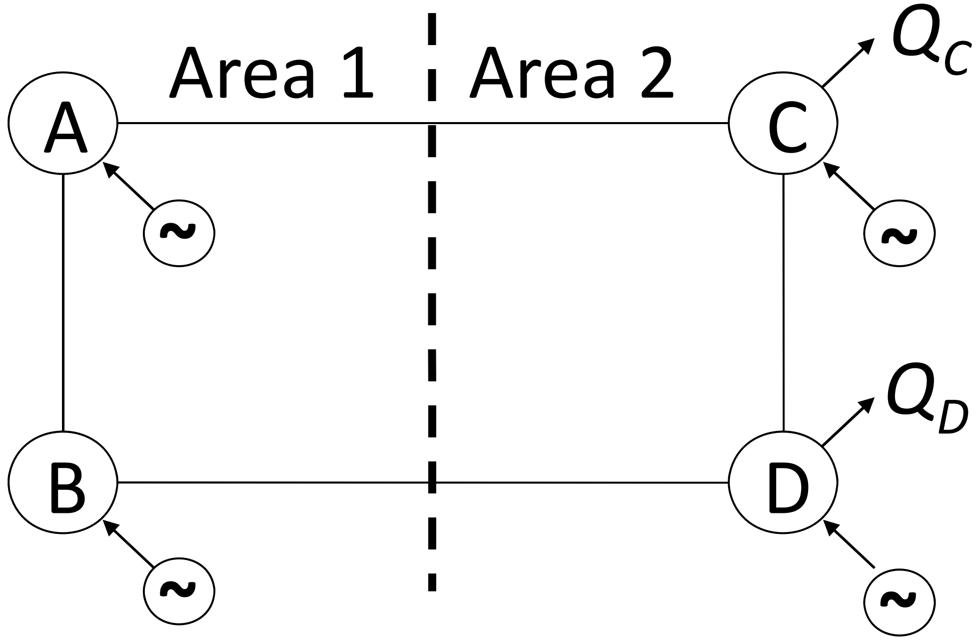
Model NTC-ID


Net load realised
TSO sets NTC
Day-ahead unit commitment *subject to NTC*
Real-time international redispatch *subject to network constraints*

Model NTC-NID



2b. How? Numerical application



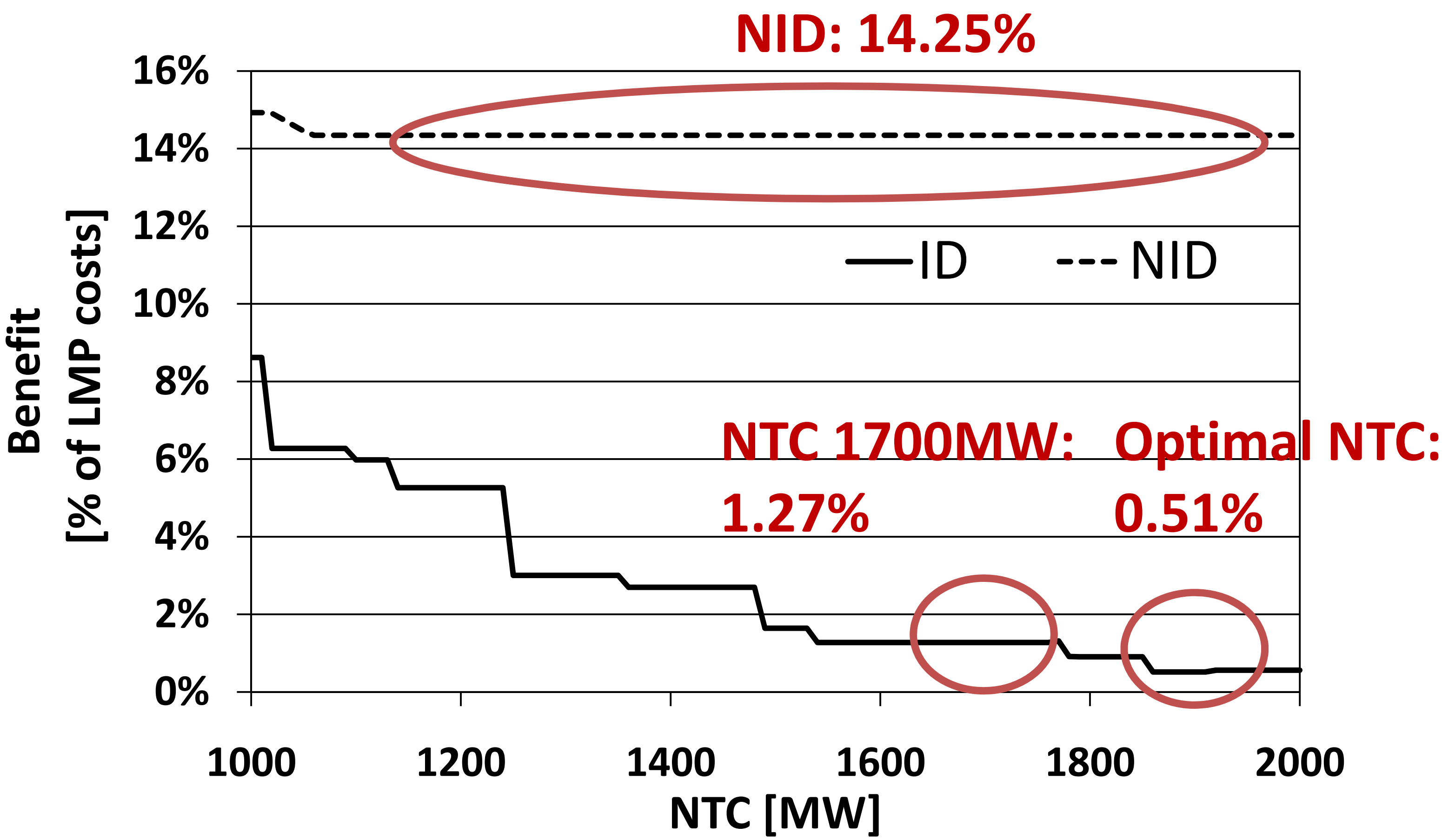
Transmission: Equal reactance, line limits = 1000 MW

- **Hence: 1000 MW ≤ NTC ≤ 2000 MW: search over this interval**

Generation: 12 generators (based on Bard, 1988)

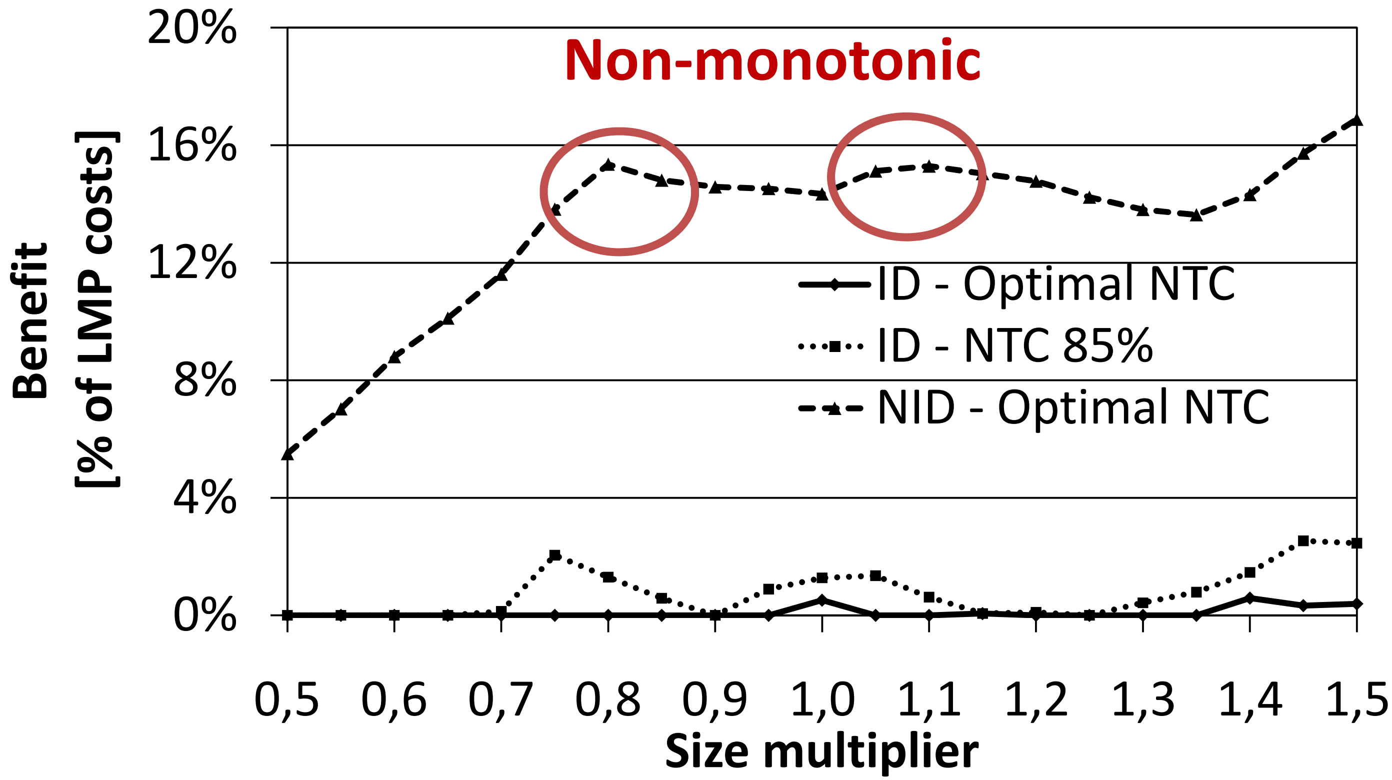
- **Baseloaded plants ignored**
- Day-ahead unit commitment for 24 hours (grouped into 3 time periods)

3. What are the results in a 'base case'?



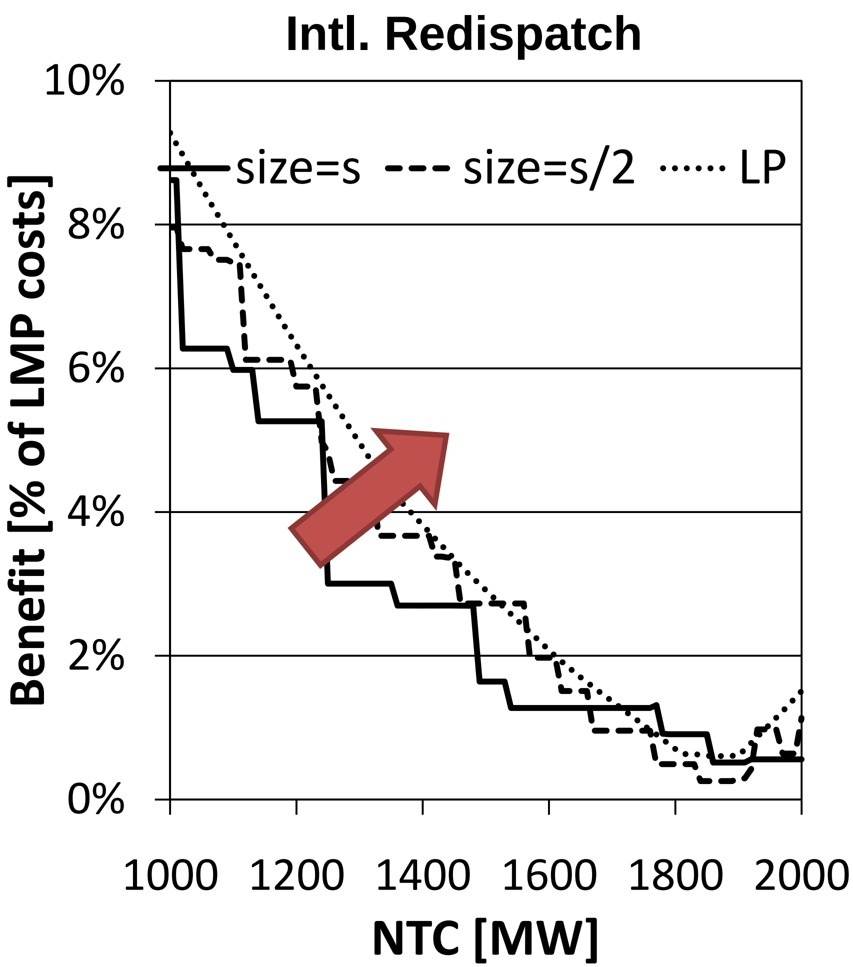
4. Sensitivity: generator size

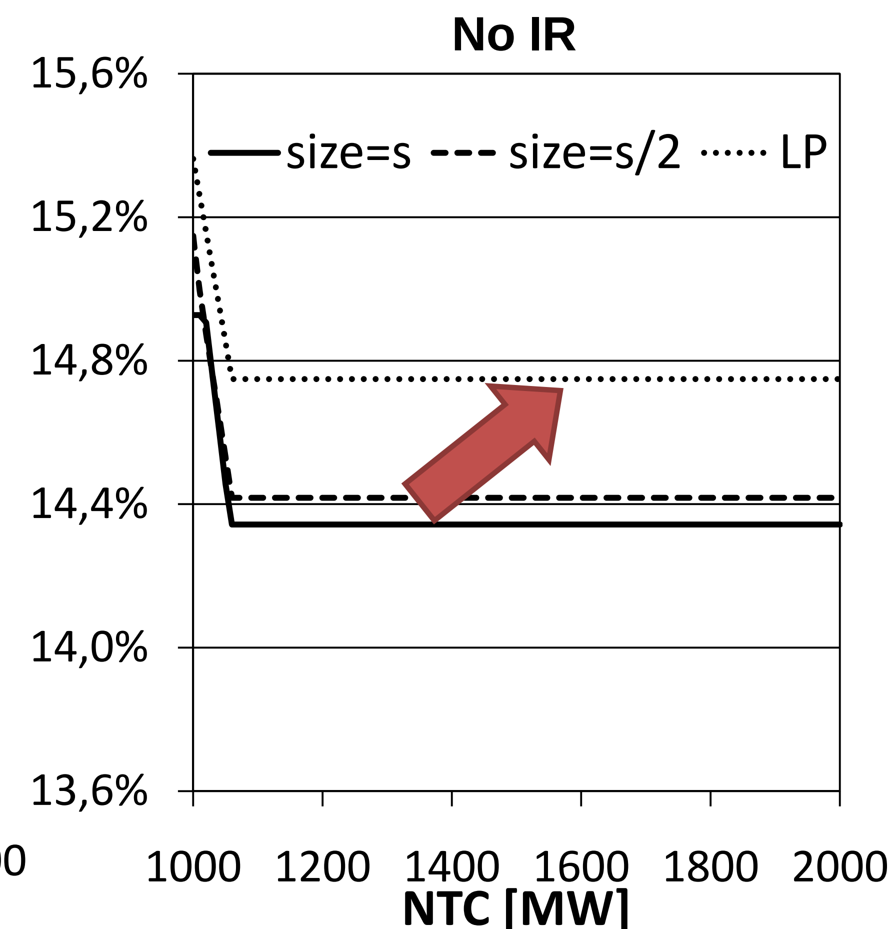
(min run, max run, start-up costs, fixed costs multiplied)



4. Sensitivity: generator lumpiness

Keeping aggregate system capacity constant





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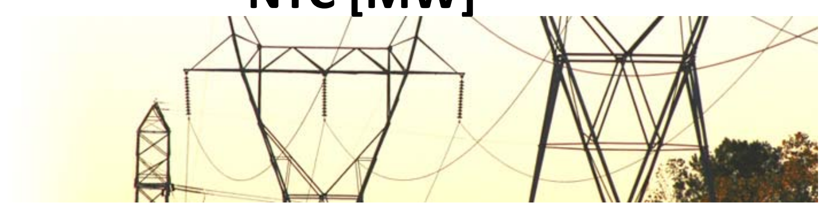
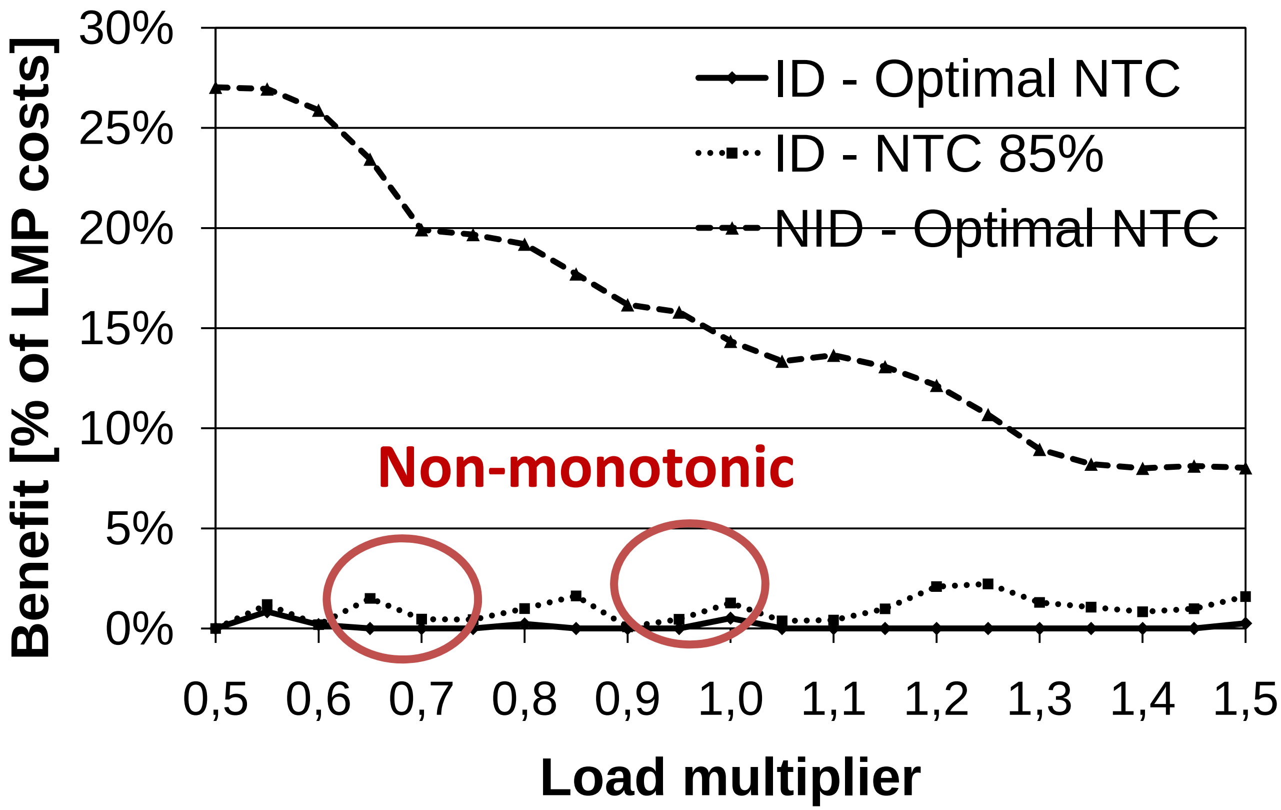


4. Sensitivity: Load levels

Load at all nodes scaled up & down



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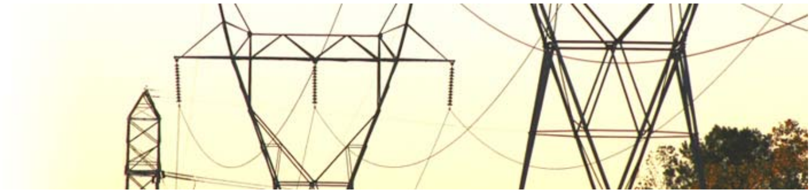

5. What can we conclude?

- LMP can significantly improve unit commitment decisions (saving 0-1% of fuel costs of non-baseload plants)
- Intl balancing can provide significant benefits even if unit commitment decisions consider only NTC constraints
- Magnitudes greatly depend on exact characteristics of the electricity market
- Cf. other studies
  - *0.1% Unit commitment benefits in EU* (R. Barth et al.,Load-Flow Based Market Coupling with Large Scale Wind Power in Europe. 8th Workshop on Large-Scale Integration of Wind Power in Power Systems, 2009)
  - *0.38 €/MWh Intl. redispatch benefits in F-Be-NL-G example* (Oggioni & Smeers, Degrees of Coordination in Market Coupling and Counter-Trading, UCL, 2009)

5. What can we conclude?

- Intl Redispatch:

  ↓generator size, ↑ min run levels

  ↑ load symmetry, ↑ load correlation

- NIR: ↓ generator size, ↑ min run levels

  ↑ transmission capacity, ↓ load level

  ↑ load symmetry ↑ load correlation

  } ↑ benefits

- continuous approximations of binary commitment variables can significantly overstate UC benefits for small systems.

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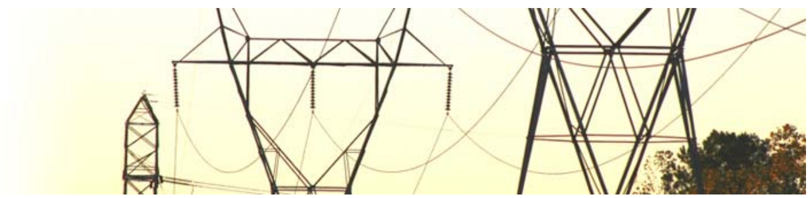

SUPERGEN
FLEXNet

Appendices

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UC model

$$\min_{\{s_{it}, z_{it}, p_{ijt}\}} \sum_{t \in T} \left[\sum_{i \in I} (SU_i s_{it} + H_t FC_i z_{it}) + \sum_{j \in J} PR_j H_t \sum_{i \in I} MC_i p_{ijt} \right]$$

s.t.

$$P_i^{\min} z_{it} \le p_{ijt} \le P_i^{\max} z_{it}$$

$$z_{it} - z_{i,t-1} \le s_{it}$$

$$s_{it} \ge 0$$

$$\sum_{i \in I} p_{ijt} = \sum_{h \in H} Q_{hjt}$$

and for NTC:

$$\sum_{i \in I^A} p_{ijt} + \sum_{i \in I^B} p_{ijt} \le NTC$$

and for LMP:

$$\sum_{h \in H} PTDF_{hk} \left(\sum_{i \in I^h} p_{ijt} - Q_{hjt} \right) \le T_k$$

Dispatch model

$$\min_{\{\overline{p}_{ijt}, l_{jt}\}} \sum_t H_t \left(\sum_{i \in I} MC_i \overline{p}_{ijt} + l_{jt} CL \right)$$

s.t.:

$$P_i^{\min} z_{it}^* \leq \overline{p}_{ijt} \leq P_i^{\max} z_{it}^* \qquad \sum_{i \in I} \overline{p}_{ijt} = \sum_{h \in H} Q_{hjt}$$

$$\sum_{h \in H} PTDF_{hk} \left(\sum_{i \in I^h} \overline{p}_{ijt} - Q_{hjt} \right) \leq T_k$$

and for NID:

$$\sum_{i \in I^A} \overline{p}_{ijt} + \sum_{i \in I^B} \overline{p}_{ijt} + l_{jt} = \sum_{i \in I^A} p_{ijt}^* + \sum_{i \in I^B} p_{ijt}^* \qquad l_{jt} \geq 0$$

Benefit calculation

- Costs for each model:

$$E[TC] = \sum_{t \in T} \left[\sum_{i \in I} SU_i s_{it}^* + H_t FC_i z_{it}^* + \sum_{j \in J} PR_j H_t \sum_{i \in I} (MC_i \overline{p}_{ijt}^* + l_{jt} CL) \right]$$

- Benefit = $E[TC_{NTC}] - E[TC_{LMP}]$