Market Power in Transmission-Constrained Electricity Markets: Analyzing Effects of Market Structure and Design

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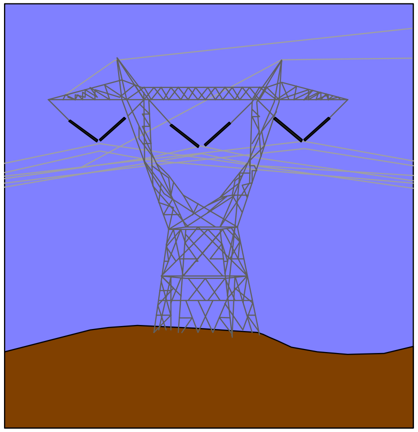
Outline



I. Simple models (for insights):

How can I manipulate prices? Let me count the ways ….

II. Regional models (for numbers):

Analyzing market power in complex markets

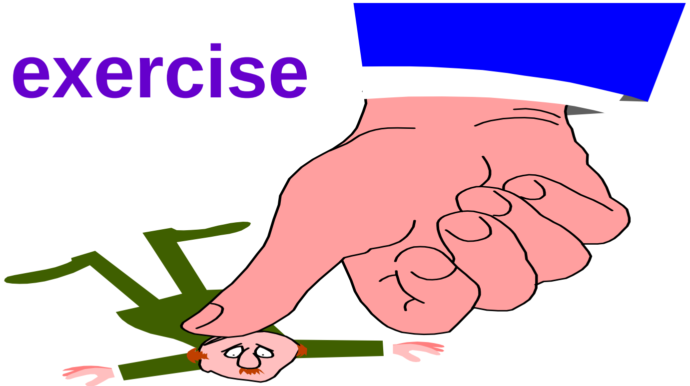
a. Eastern Interconnection:

Who is most vulnerable?

b. Northwest Europe:

How does market power affect the value of new transmission?

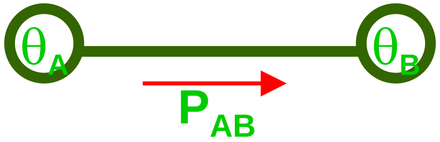
I. Market Power = The ability to manipulate prices persistently to one's advantage



- Generators may be able to exercise market power because of:
  - *economies of scale*
  - *large existing firms*
  - *transmission costs, constraints*
  - *siting constraints, long lead time for generation construction*

Fundamentals:
Review of Linearized DC Model

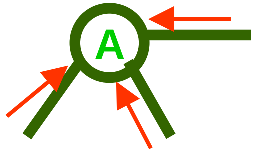
- **Analogue to Ohm's Law:**



$(\theta_A - \theta_B) \propto P_{AB}*R_{AB}$

(ΔVoltage angle ∝ power*reactance)

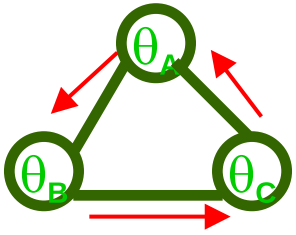
- **Analogue to Kirchhoff's Current Law:**



$\Sigma_j \; P_{Aj} = 0$

(No net power inflow to a bus)

- **Analogue to Kirchhoff's Voltage Law:**



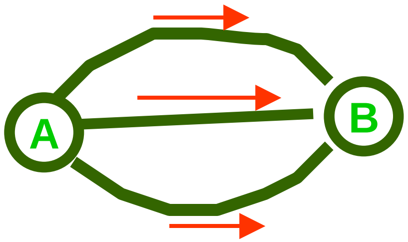
$(\theta_A - \theta_B) + (\theta_B - \theta_C) + (\theta_C - \theta_A) = 0$

(Sum of voltage differences around any loop = 0)

$\Rightarrow P_{AB}*R_{AB} + P_{BC}*R_{BC} + P_{CA}*R_{CA} = 0$

Odd Implications of Laws

- **Can't "route" flow**
  - **parallel flows**
  - **"paths" are a fiction**



- **Adding a line can *worsen* transmission capability**

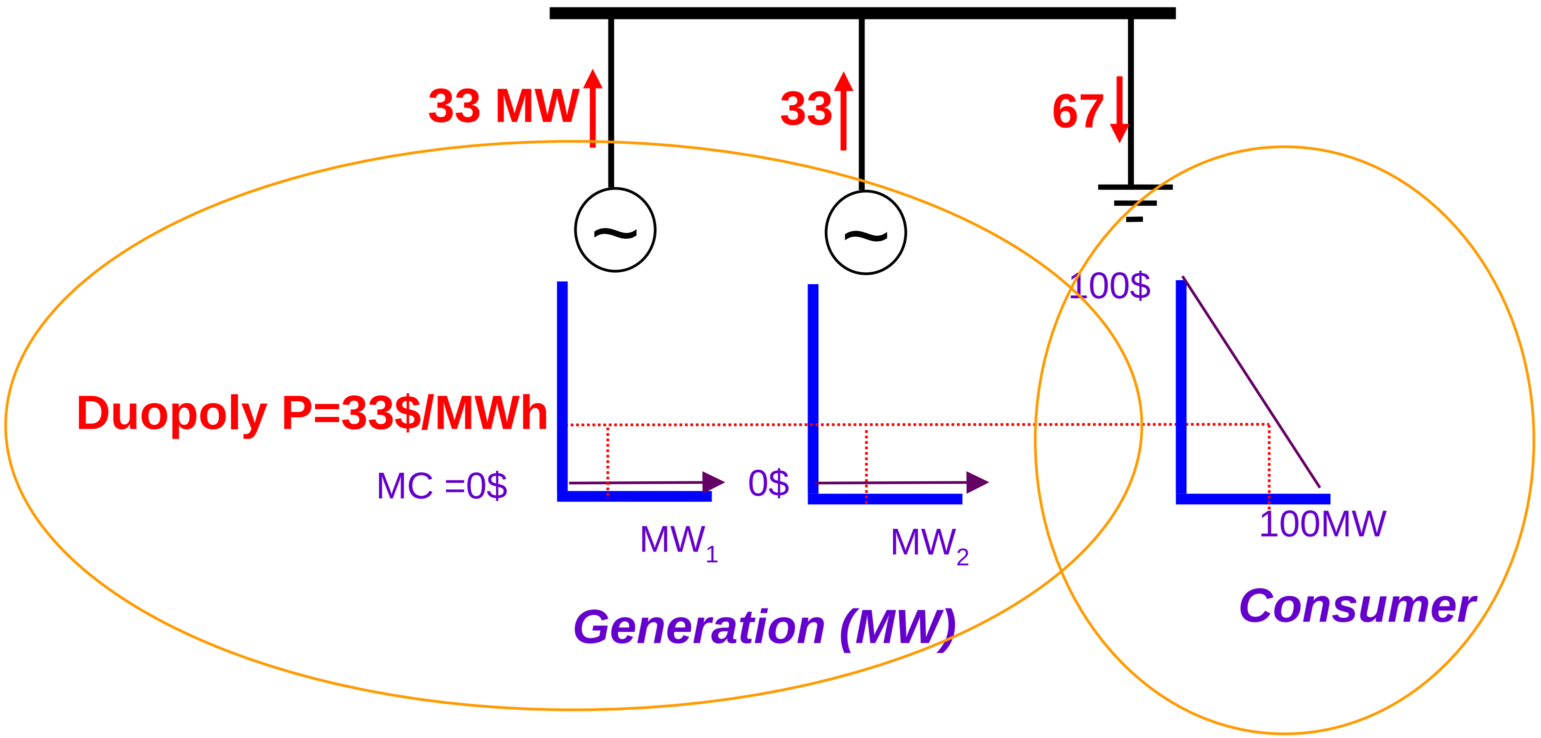
- **Even if no generation constraints are binding, marginal cost at a bus can be:**
  - **< 0, or**
  - **>> the highest marginal cost of any generator**

Three Modes of Exercising Market Power in Transmission-Constrained Power Markets

1. Modes *not* depending on transmission constraints
   - Withdraw capacity in regional market
   - Increase input costs of rivals (NOx allowances in California; Wolak & Kolstad)
2. Modes depending on Current Law only (can happen in radial market)
3. Models depending on Current & Voltage Law (network effects)

Note: "Dec game" (and many other California games) *not* market power--rather, arbitrage arising from poor market design

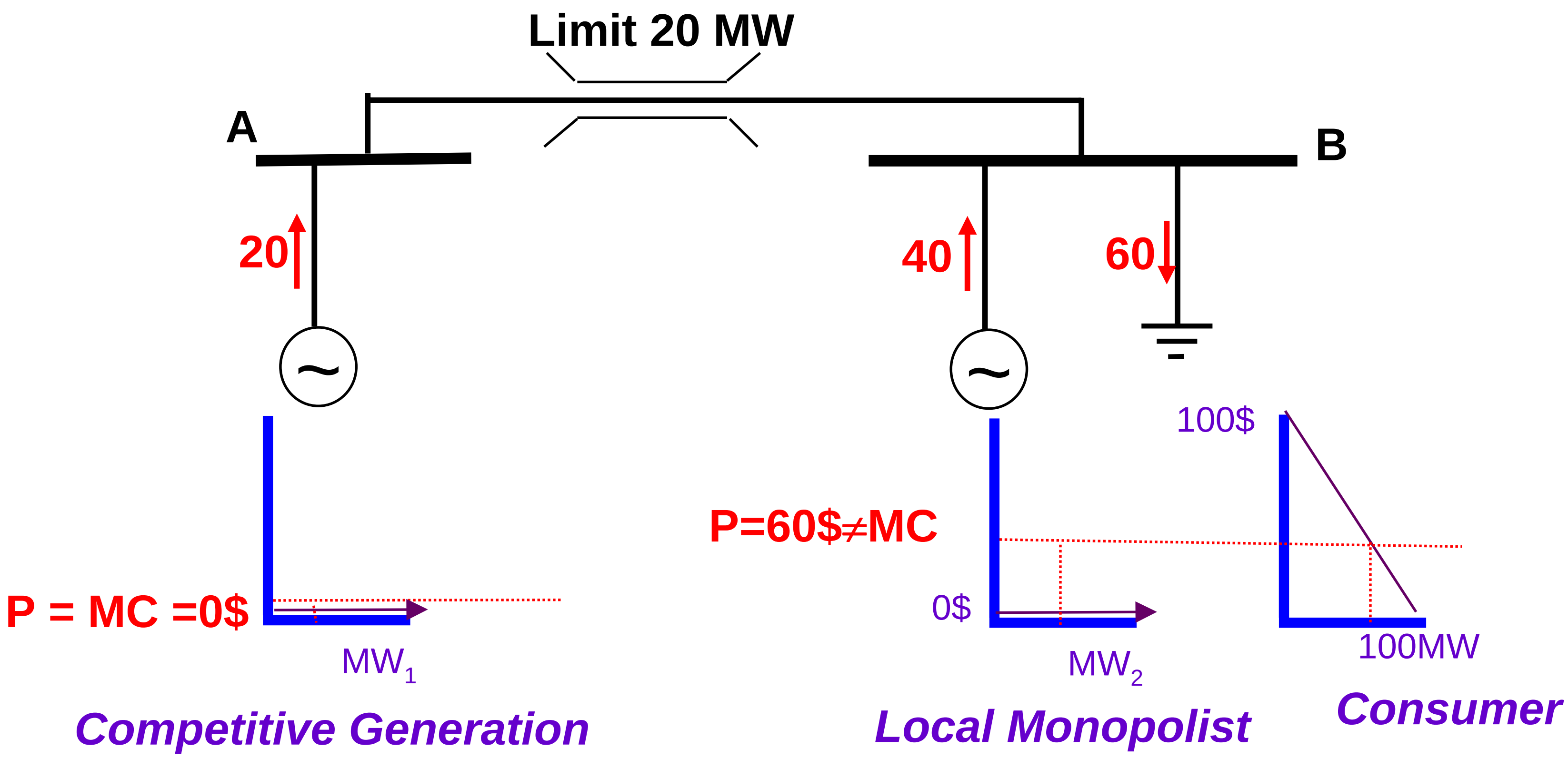
1. Classic Market Power Exercise: Duopoly at Single Bus



- ***Competition:*** **P = \$0, Q= 100 MW**
- ***Duopoly:*** **P = \$33, Q = 67 MW**

Consumers lose!

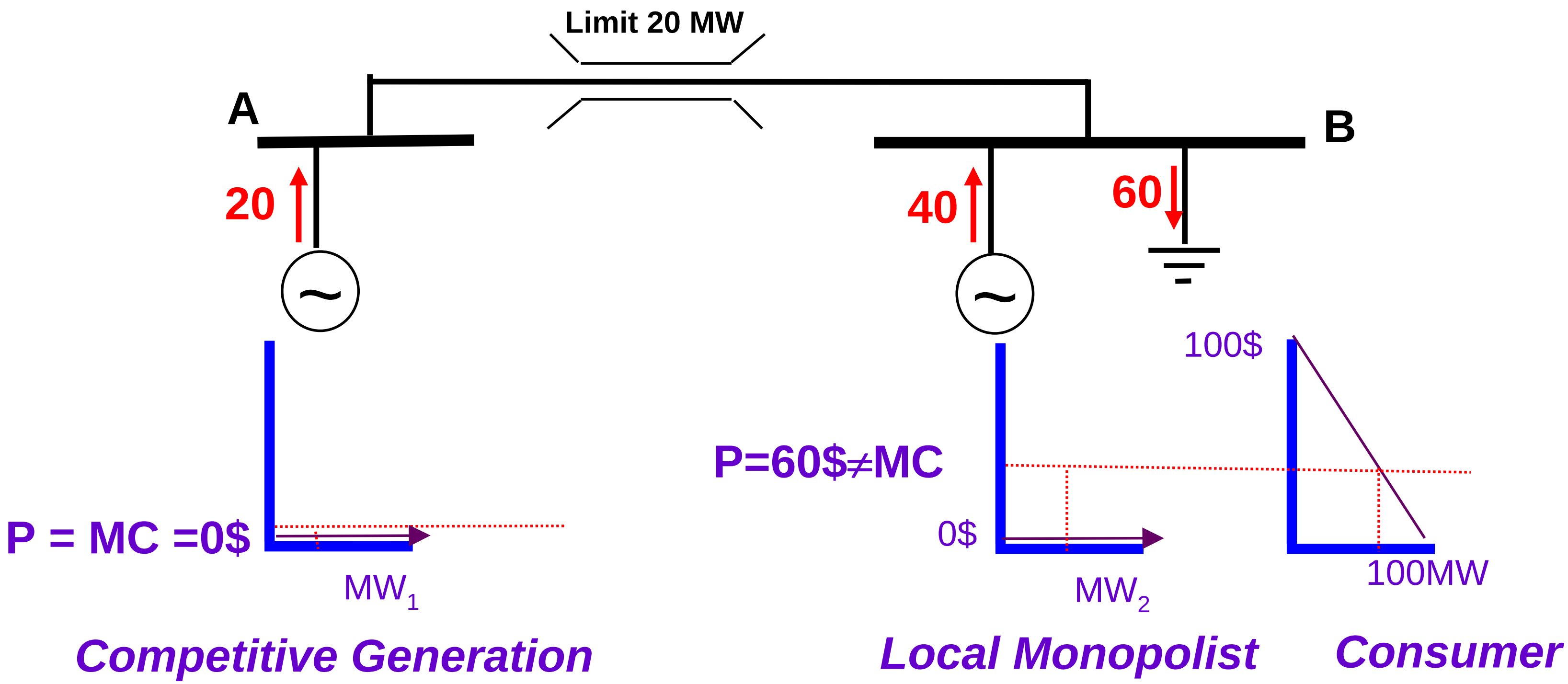
2. Market Power in a Radial System: Monopolist in Load Pocket on Two Bus System



- ***Competition:*** P_A = \$0, P_B = \$0, Q= 100 MW
- ***Local monopoly:*** P_A = \$0, P_B = \$60, Q = 40 MW

  Consumer loses!

2. Financial Transmission Rights Can Exacerbate Market Power: Generator in Load Pocket Owns FTRs *into* Pocket (Joskow & Tirole, 2001)



- ***Without*** **FTRs, local monopolist maximizes:**

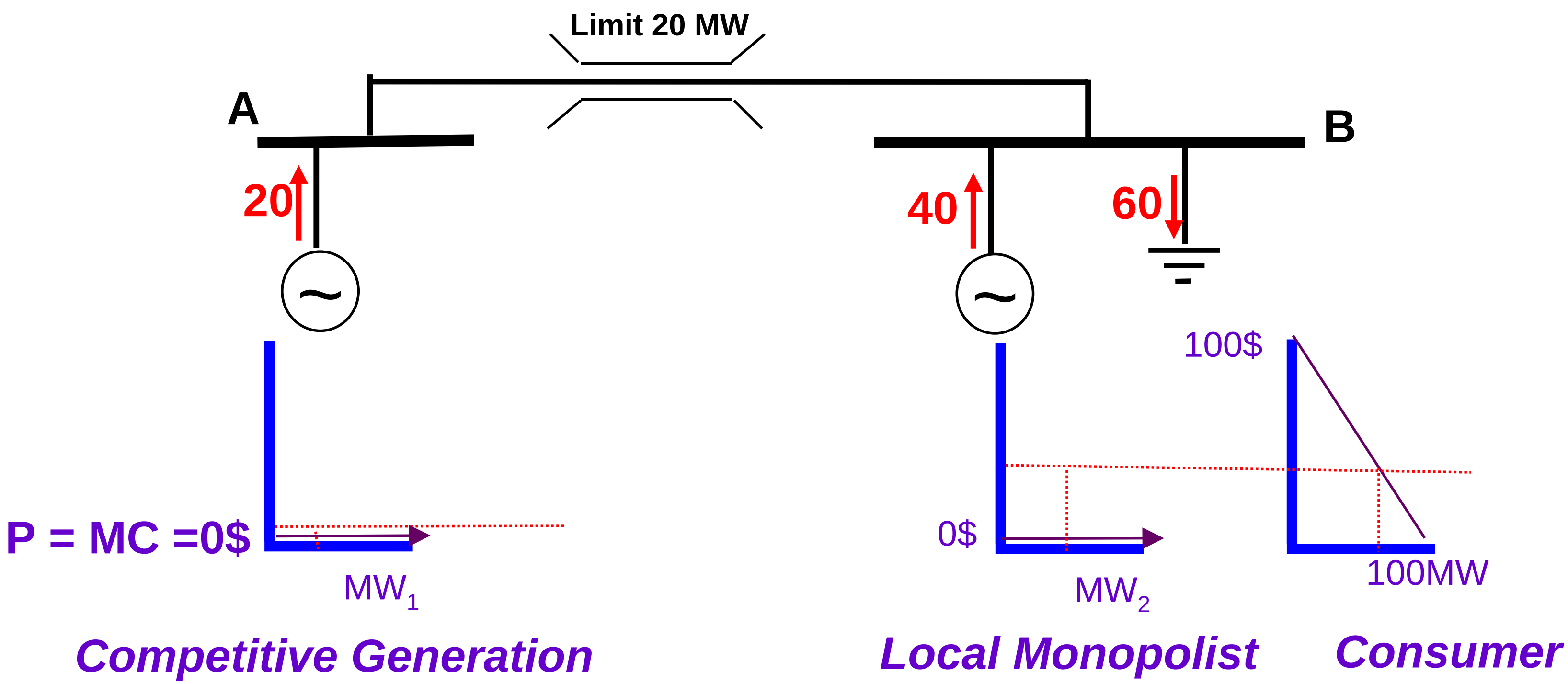
  $P_B(20+g_B)*g_B \quad \Rightarrow$ **Strong incentive to withhold capacity**

- ***With*** **FTRs from A into B, local monopolist maximizes:**

  $P_B(20+g_B)*g_B + (P_B(20+g_B) - P_A)*FTR$

  $\Rightarrow$ **Stronger incentive to withhold capacity**

Financial Transmission Rights Can Weaken Market Power: Generator in Load Pocket Owns FTRs *out of* Pocket
(Joskow & Tirole, 2001)



- ***Without*** **FTRs, local monopolist maximizes:**

  $P_B(20+g_B)*g_B \Rightarrow$ **Strong incentive to withhold capacity**

- ***With*** **FTRs from B out to A, local monopolist maximizes:**

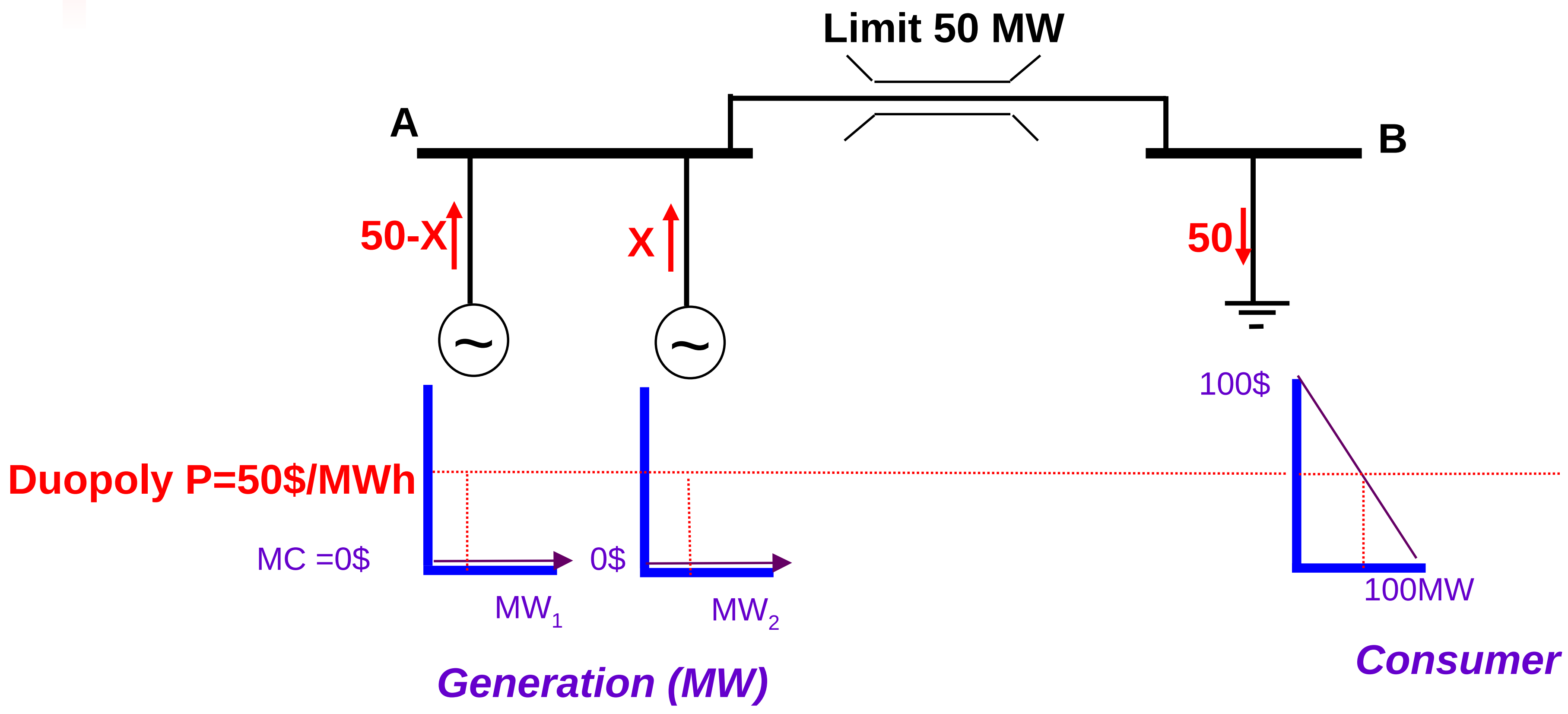
  $P_B(20+g_B)*g_B - (P_B(20+g_B) - P_A)*FTR$

  $\Rightarrow$ **Weaker incentive to withhold capacity**

  (e.g., Cramton PJM proposal to mitigate local market power)

2. Duopoly on Two Bus System:

Cournot Model (Oren 1997) in which duopolists "see" constraint



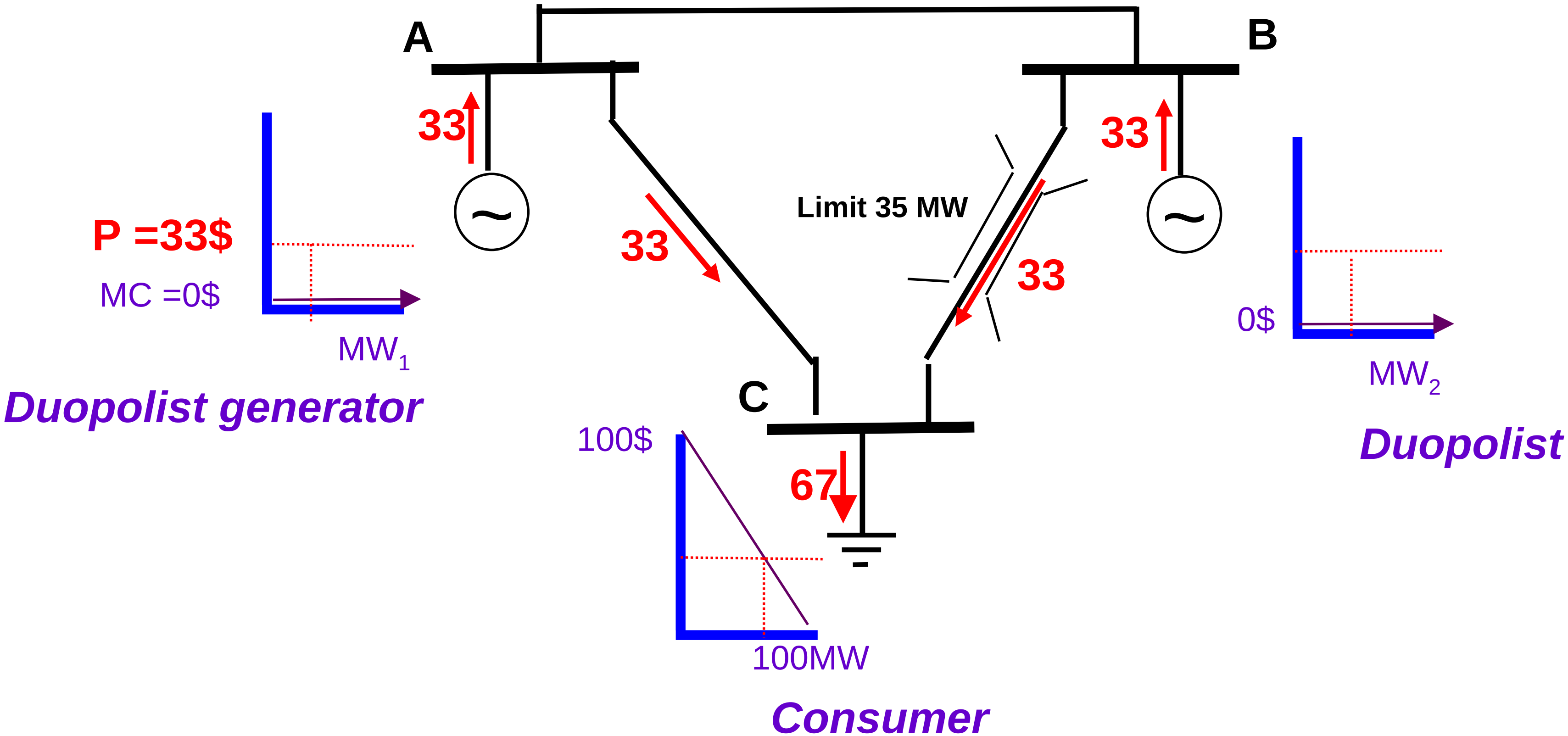
- ***Competition:*** **P_A = \$0, P_B = \$50, Q= 50 MW**
- ***Duopoly:*** **P_A = \$50, P_B = \$50, Q = 50 MW**

  ISO loses!

3. Voltage Laws

- **Increased competition can *increase* prices**
- **Optimal strategy for large company may be to *expand* production at some plants to congest grid**

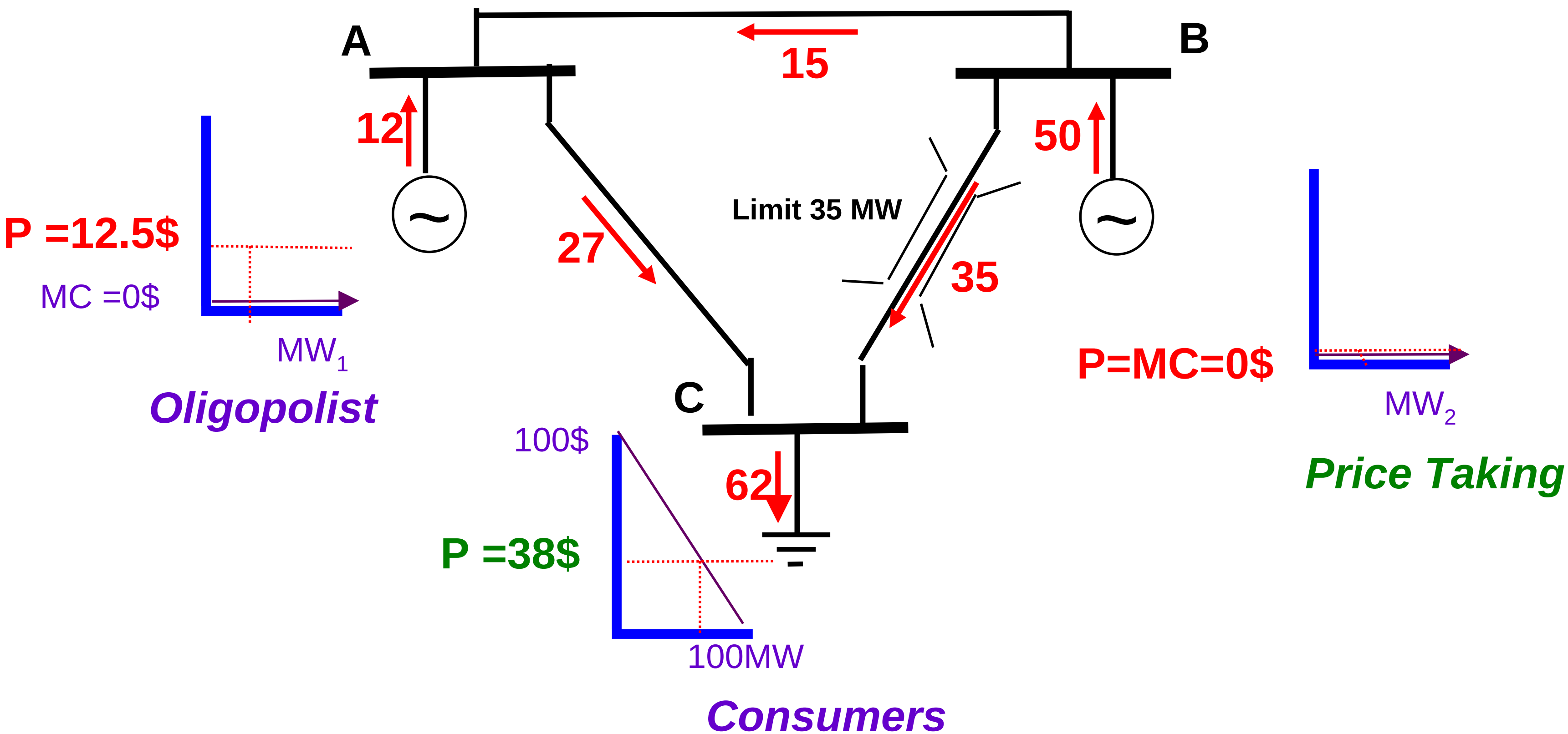
Duopoly With Identical Costs at Two Different Buses: Transmission Not Binding, Prices Identical Everywhere



- **All lines have same reactance**
- **No congestion: $P_A = P_B = P_C = \$33$**

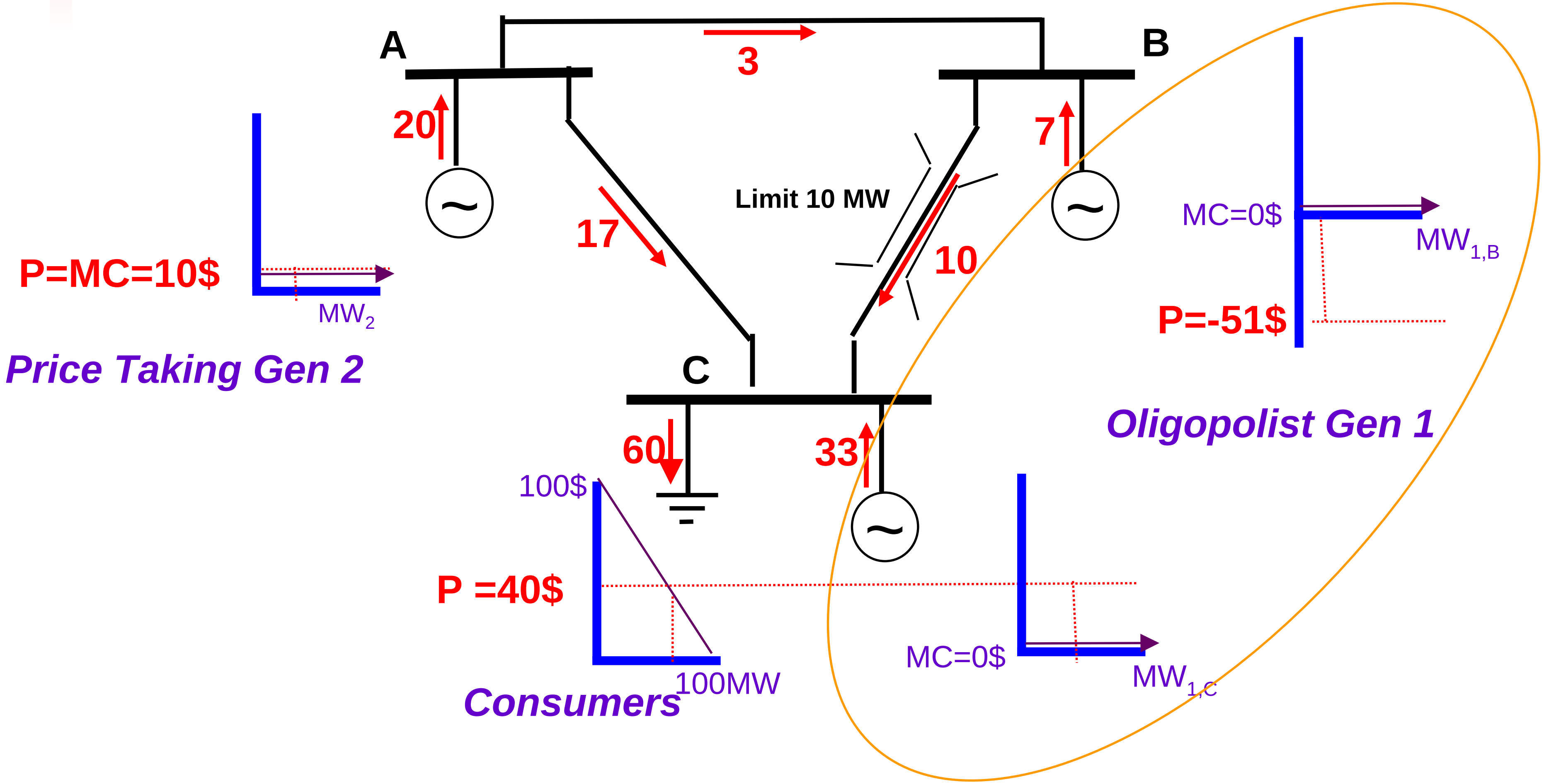
More Competition Can *Worsen* Consumer Welfare: Generator at B Mitigated (Competitive, bids zero), Generator at A still has Market Power: Cournot Energy Market, Bertrand (Price Taking) for Transmission Service

(Smeers & Wei, 2000; Hobbs, 2001)



- Competitive generation expands output from 33 MW to 50 MW
- Prices now higher for consumers: P_C rises from \$33 to \$38

Optimal Market Power Strategy: *Expand Output* and Lower Local Price
Generator 1 (at B and C) is Oligopolist, Generator 2 (at A) is Price Taking



- **Oligopolist optimally sells 7 MW at B below cost**
  - **⇒rival must cut production from 40 MW to 20 MW at A**
  - **⇒oligopolist can sell *more* at C (33 MW instead of 30 MW)--at *higher* price ($40 rather than $30)**

II. Evaluating Designs & Anticipating Problems with Complex Models: Questions

What might be the effect of policies concerning…

- Generation structure
- Transmission investment
- Market rules

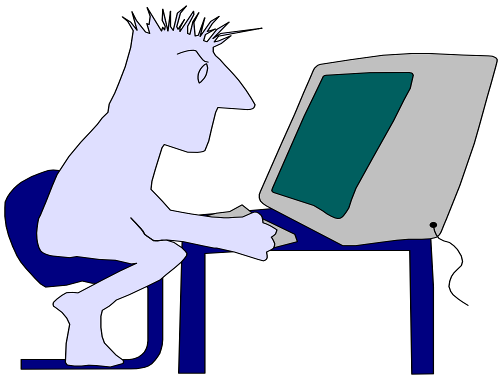
…upon…

- Economic efficiency
- Income distribution
- Emissions

…considering generator strategic behavior?

- Bidding
- Capacity withdrawal
- Manipulation of transmission
- Manipulation of emissions allowances markets

Projecting Prices & Assessing Market Power: Our Approach



- **Equilibrium models**
- **Variations:**
  - ***Market mechanisms***
  - ***Electrical network***
  - ***Interactions among players***
- ***But:***

"The principal result of theory is to show that nearly anything can happen" (Fisher, 1991, oft quoted by R. O'Neill)

Computational Approach: Direct Solution of Equilibrium Conditions

Producer A

Choose gen & sales to maximize profit

s.t. capacity

$\Rightarrow$ 1st order conditions

● ● ● ● ●

Producer B

Choose gen & sales to maximize profit

s.t. capacity

$\Rightarrow$ 1st order conditions

ISO: Choose Transmission Flows to Max Value of Network s.t. transmission constraints $\Rightarrow$ 1st order conditions

Consumers: Max Value - Expenditures (Demand Curve)

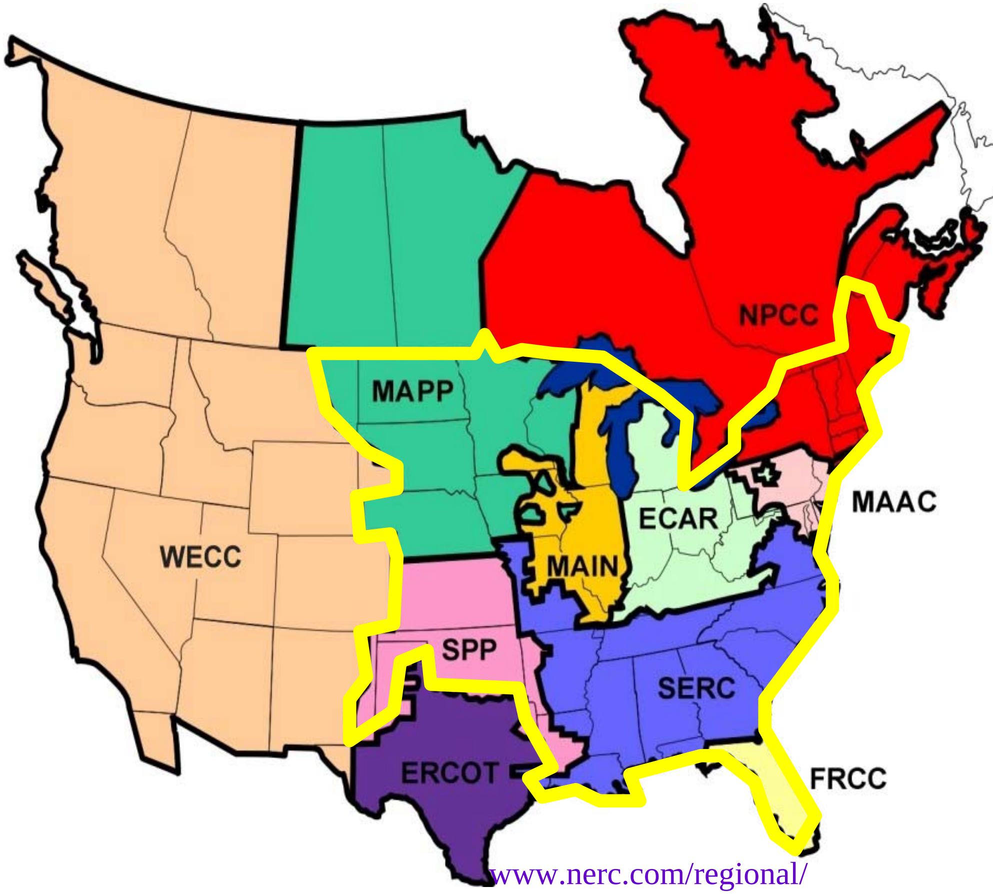
Market Clearing Conditions

1. Derive first-order (KKT) conditions for each player
2. Impose market clearing conditions
3. Solve resulting system of conditions (*complementarity problem*) using PATH

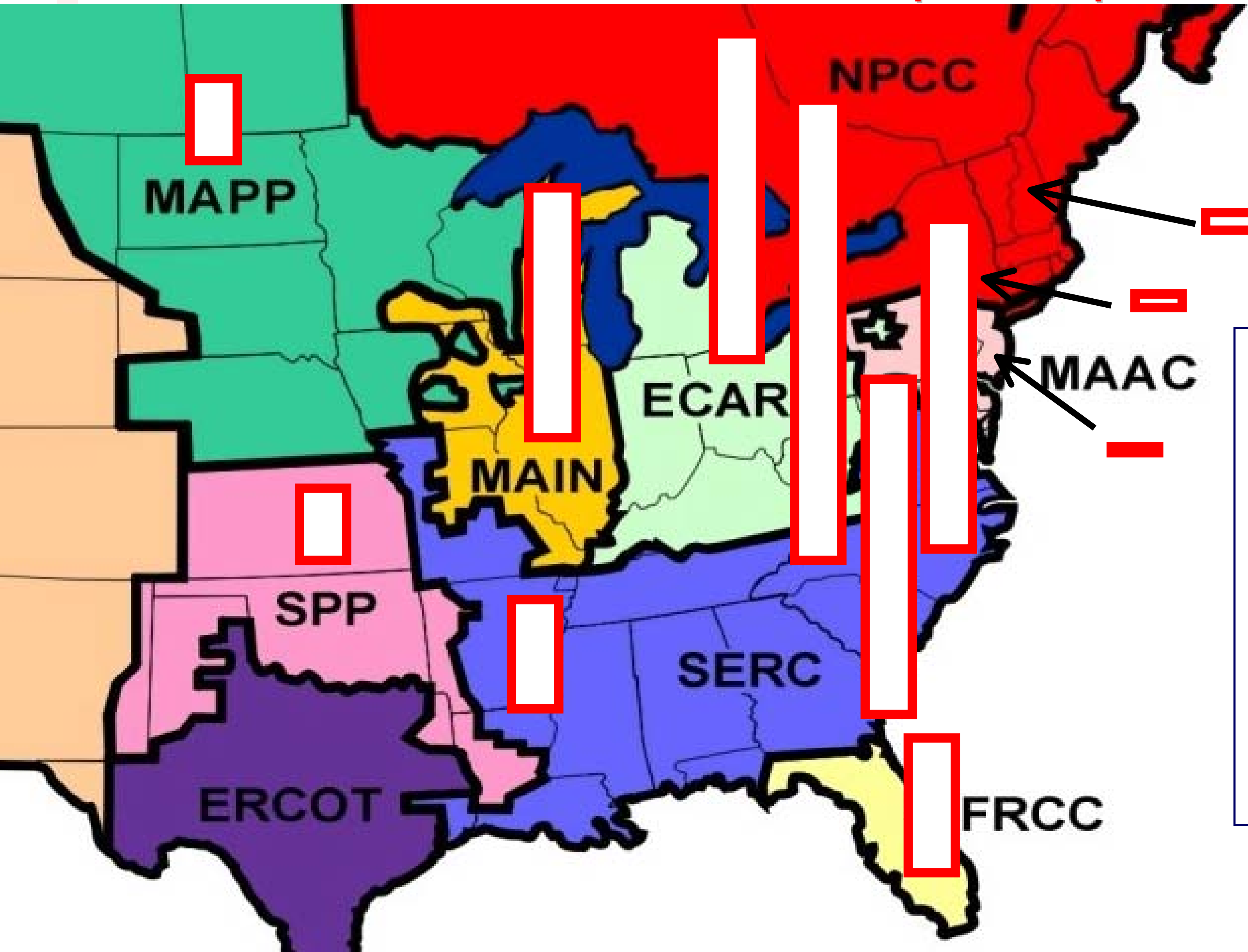
US Eastern Interconnection Cournot Model

(Udi Helman (FERC) Ph.D. thesis, JHU)

- **100 nodes representing:**
  - US Control Areas
  - Interconnections with ERCOT, WECC, & Canada
- **2725 generating plants; ~600,000 MW capacity**
- **829 firms (including 528 NUGs)**
  - ~100 largest (> 1000 MW) are Cournot (regardless of current ownership)
  - rest competitive “fringe”
- **Linearized DC load flow**
  - 814 interfaces



Variations in Market Power over Space: $(P_{cournot} - P_{Comp})/P_{comp}$

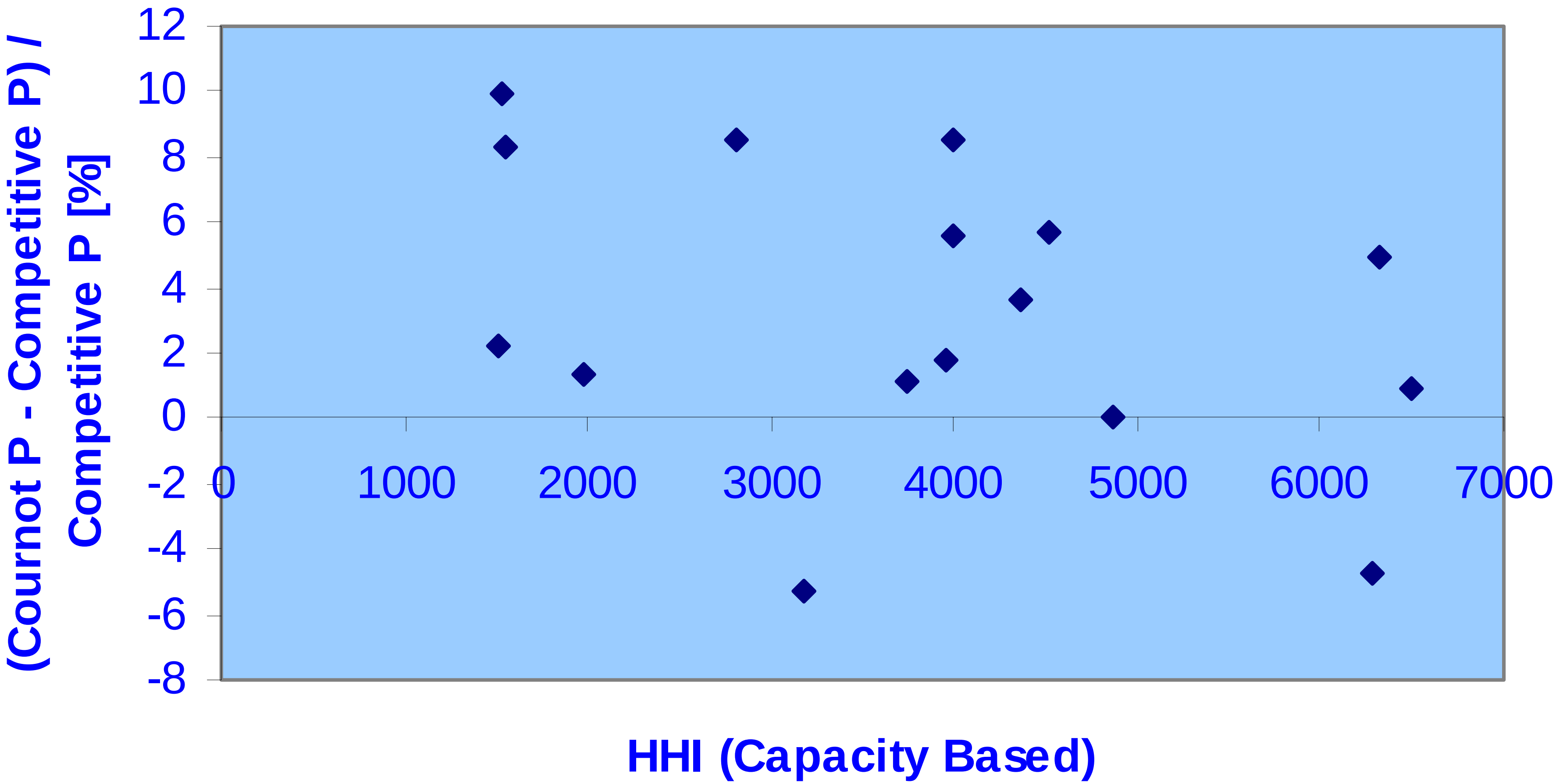


$\varepsilon = -.1$

Hour 12, June 2000

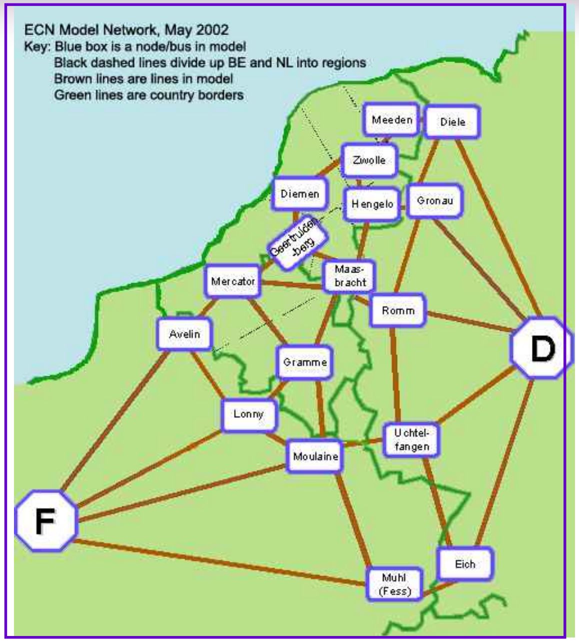
Highest Bar = 34% **

HHIs Poorly Predict Simulated Price Markups
(Control Areas, SPP NERC Region)

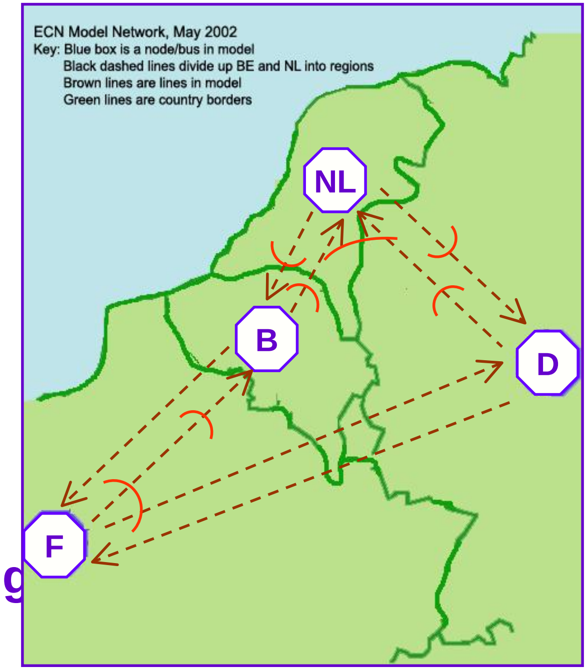


Market Integration: Belgium-Netherlands

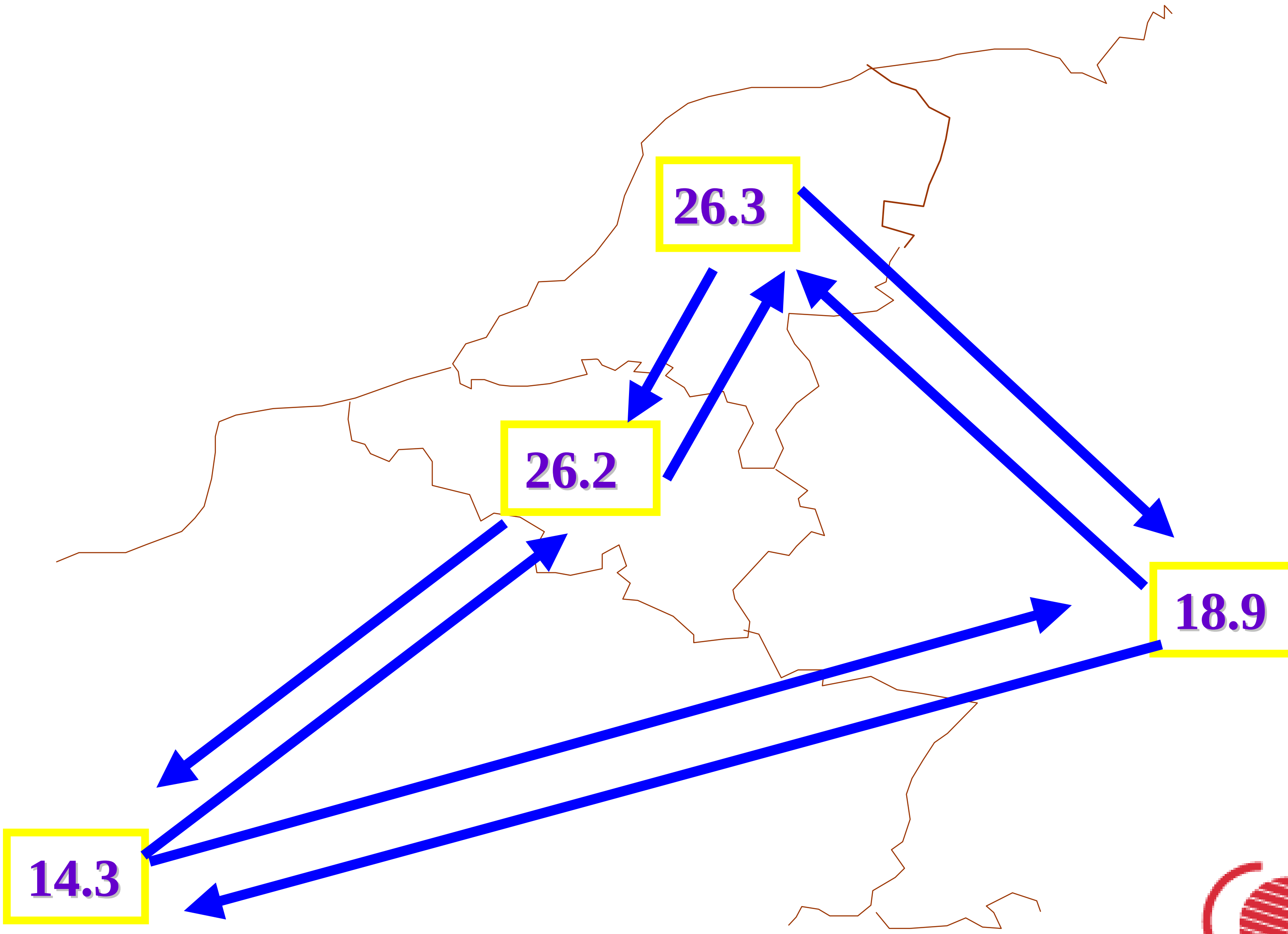
(with Fieke Rijkers & Adrian Wals, ECN)



- **COMPETES**
  - *Competition and **M**arket **P**ower in **E**lectric **T**ransmission and **E**nergy **S**imulator*
- **Cournot generators compete bilaterally**
- **Competitive arbitragers in some markets**
- **Two transmission pricing systems:**
  - **Physical network**
    - **Linearized DC load flow**
    - **Several nodes per country**
    - **Multiple networks ("n-1" contingencies)**
  - **Path-based representation**
    - **One node per country → one market price per country**
    - **Interfaces defined between countries**
    - **Crediting for counterflows (netting vs. no-netting**

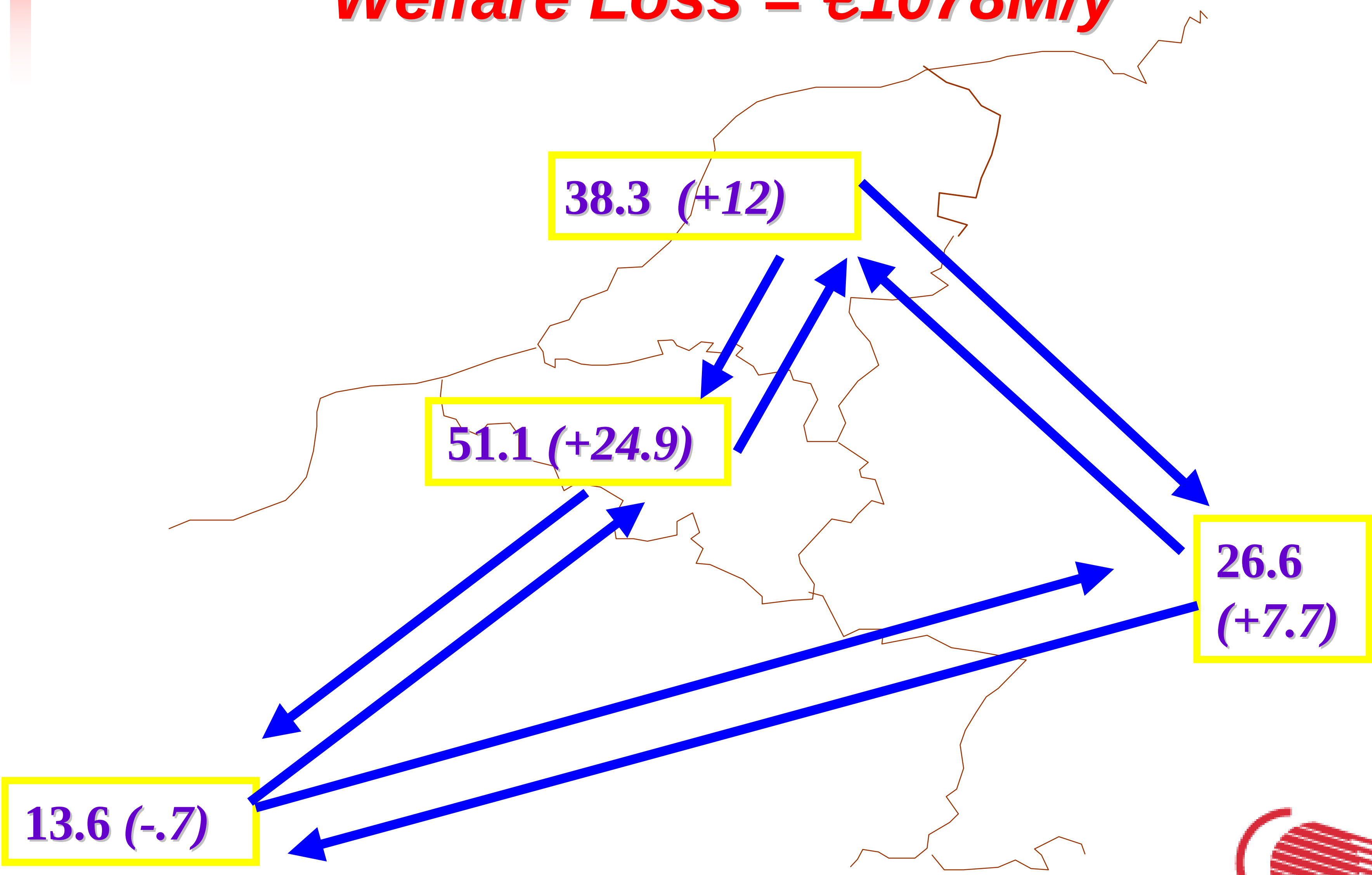


Competitive Prices (€/MWh)



Cournot Prices (Assuming No Netting of Flows)

Welfare Loss = €1078M/y



Value of New Transmission

- Literature: value can be higher under oligopoly
  - because transmission intensifies competition
- Transmission policy matters! Value (10^6 €/y) of +50% Interface Capacity:

Scenario	Cost Savings	Consumer Value Increase	Net Welfare Improvement
Competitive	172	28	200
Cournot	170	10	180
Cournot, No Netting	117	294	411

ECN

Market Power Research: Some Suggestions

- Dynamic models of implicit collusion
  - *Static models don't capture "repeated game" nature of power markets*
- "Gotcha!": How can we reasonably infer that market power has been exercised?
  - *Usual approach: estimate marginal cost curve, compare to bids & market outcomes (Bushnell, Joskow/Kahn …)*
  - *Nonconvexities can lead to mistaken diagnoses of "capacity withholding" (Harvey/Hogan, Rajaraman/Alvarado)*
  - *Let's simulate! For realistic systems, how large might these price distortions be?*
  - *Bayesian combination of models, expert judgment, empirical data?*
- Empirically compare models
  - "Run-up": higher P-MC margins when capacity is short