An Oligopolistic Electricity Market Model with Tradable NO_x Permits

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Outline

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II. Model Structure and Computation Approach

III. Application

Interaction of PJM Electricity and USEPA NO_x Budget Program

- ***a. Background***
- ***b. Assumptions***

IV. Results

Comparison of perfect competition with different scenarios

- ***a. Price***
- ***b. Social Welfare***
- ***c. Productive and NO_x Trading Efficiency***
- ***d. Strategy Rationale***

V. Conclusion

THIS SLIDE SHOULD BE OMITTED IN A 10 MINUTE TALK, WILL TAKE TOO LONG (YOU SHOULD PRACTICE YOUR TALK TO SEE WHICH SLIDES CAN BE DONE QUICKLY AND WHICH SEEM LIKE DISTRACTIONS

What might be the effect of policies concerning…

- **Generation structure** (mergers, ownership, distributed resources, entry…)
- **Transmission investment** (new lines …)
- **Market rules**
  - Transmission pricing (taxes, congestion pricing, counterflows, zonal …)
  - Access (retail load, generators, arbitragers …)
  - Environmental markets (green certs., CO2 trading …)

…upon…

- **Economic efficiency** (allocative & productive efficiency)
- **Income distribution** (TSO revenues, profits, consumer surplus)
- **Emissions**

…considering generator strategic behavior?

- **Bidding**
- **Capacity withdrawal**
- **Manipulation of transmission** (deliberate congestion, decongestion)
- **Manipulation of emissions markets** (withholding of allowances)*****

II. Model Structure and Computational Approach: Direct Solution of Equilibrium Conditions

Producer A

Choose gen & sales to maximize profit

s.t. capacity

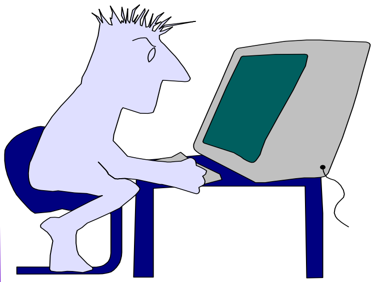
$\Rightarrow$ 1st order conditions

Producer B

Choose gen & sales to maximize profit

s.t. capacity

$\Rightarrow$ 1st order conditions



ISO: Choose Transmission Flows to Max Value of Network

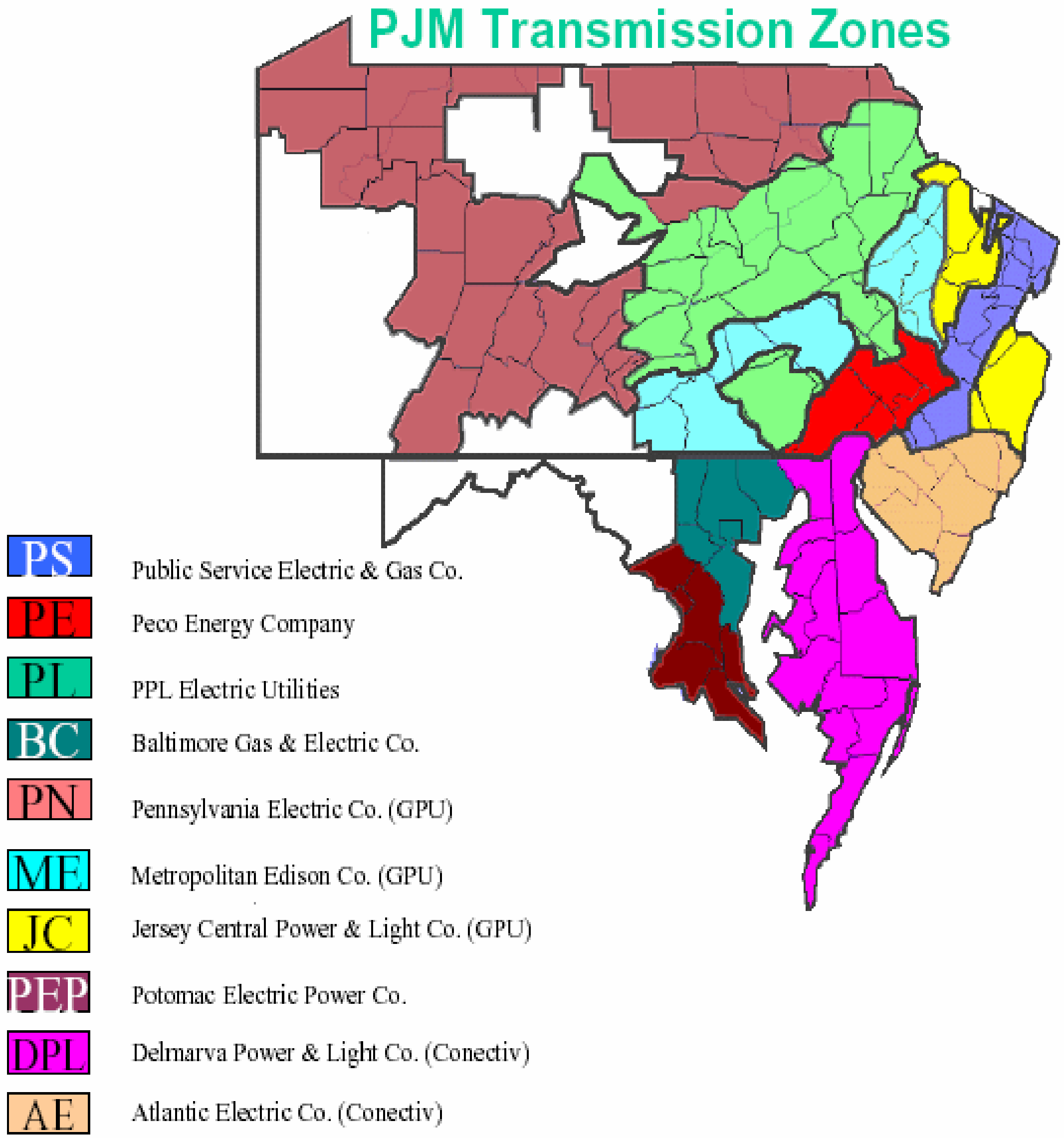
s.t. transmission constraints $\Rightarrow$ 1st order conditions

Consumers: Max Value - Expenditures (Demand Curve)

Market Clearing Conditions

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

III. Application Background
PJM Market and USEPA NO_x Program



PJM Market

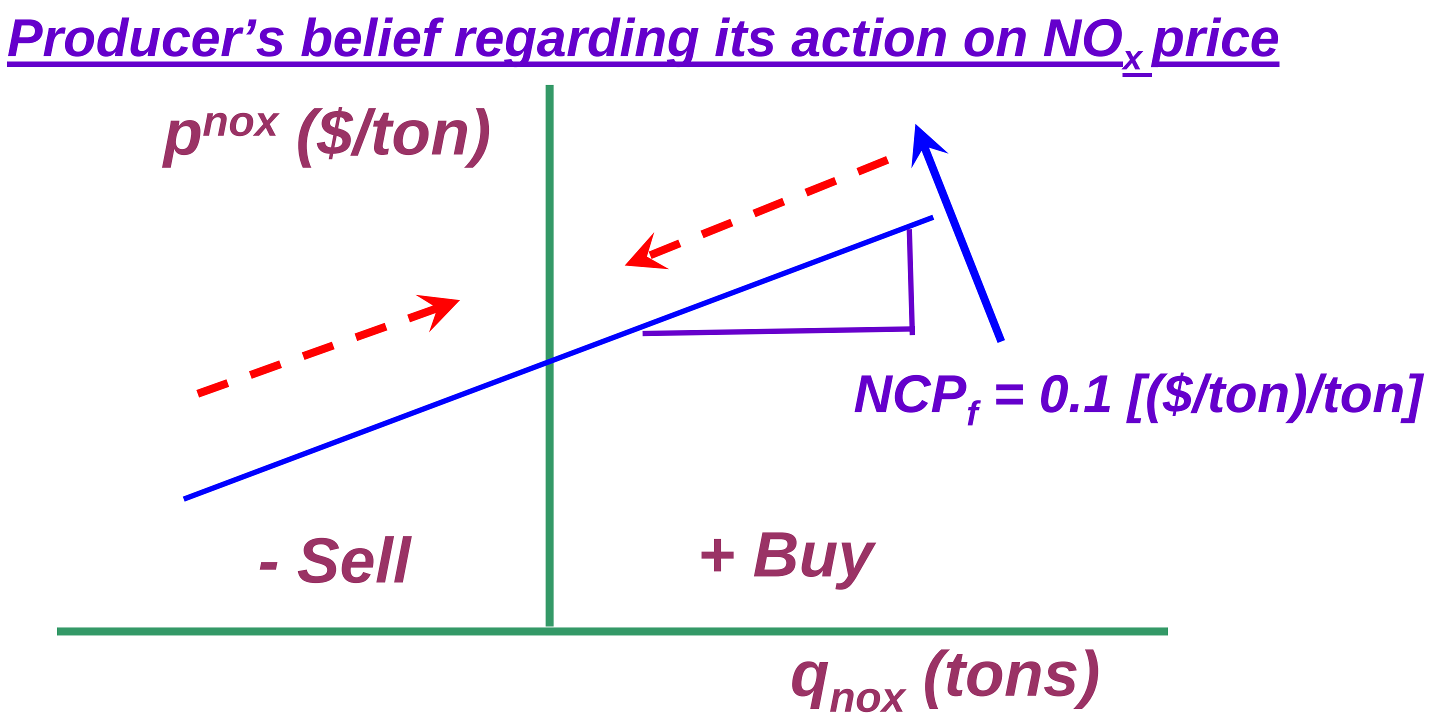
USEPA NO_x Program

Need to give credit for Figure …

Model Assumptions

- **Network and Load**
  - *Load duration curve (LCD) approximated by 5 blocks*
  - *Only 500 kV line → 14 nodes, 18 arcs*
  - *No transmission losses*
  - *Power Transfer and Distribution Factors (PTDFs)*
- **Producers**
  - *791 generators*
  - *6 largest producers (capacity share: 4% to 18%)*
    - *Cournot strategy in electricity market*
    - *Conjectured pricing in NO_x market*
  - *Remaining produces price takers (3 producers)*
- **Consumer**
  - *Linear demand Curve*
- **ISO**
- **Importer**

NO_x Conjectured Pricing



qNO$_x$: Net Position in NO$_x$ permit market → Sell (-) and Buy (+)

Scenarios Investigated

A. Perfect competition (*COMP*)

- *Price-taking behavior in power & allowances markets*

B. Oligopoly in electricity market (*CONOURT*)

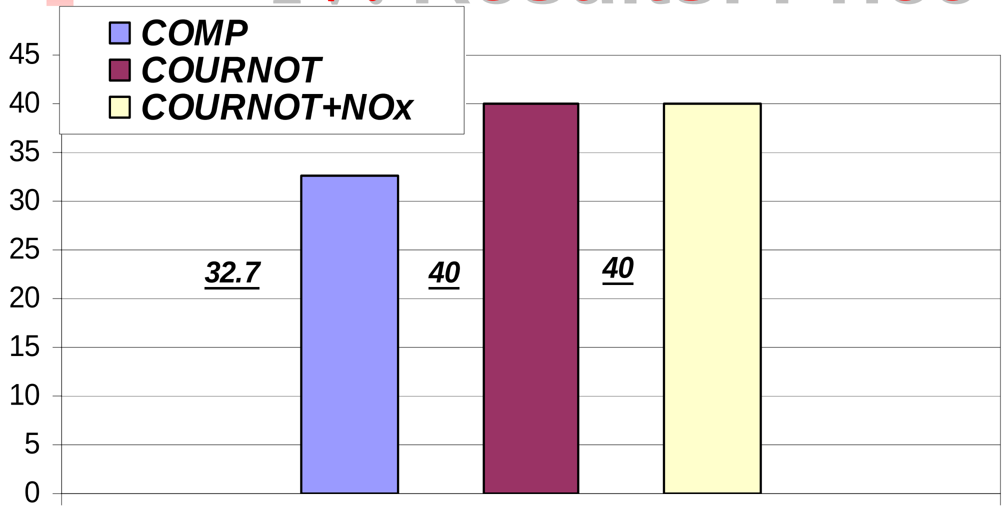
Cournot strategy for 6 largest in electricity market

- *No Conjectured NO_x Pricing*

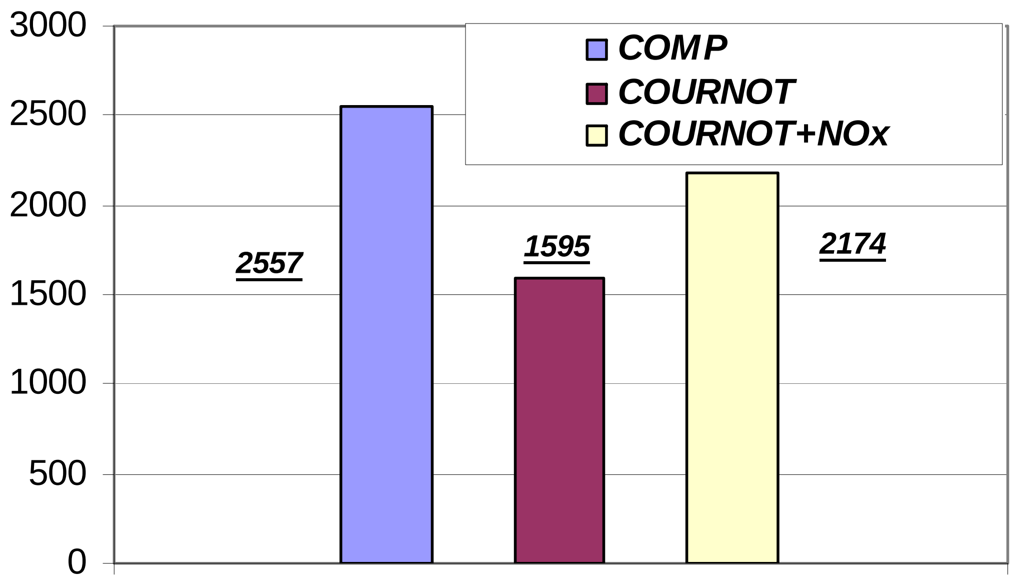
C. Oligopoly in both markets (*CONOURT+NO_x*)

- *For 6 largest producers: Cournot strategy in electricity market plus Conjectured NO_x Pricing in NO_x market*
  - *$NCP_{2,3,5,6,7}$ =0.1 [($/ton)/ton]*
  - *NCP_4 = 1.5 [$/ton)/ton] ← The largest producer with a long position in the NO_x market*

IV. Results: Price Comparison



Sale-Weighted Electricity Price($/MWh)



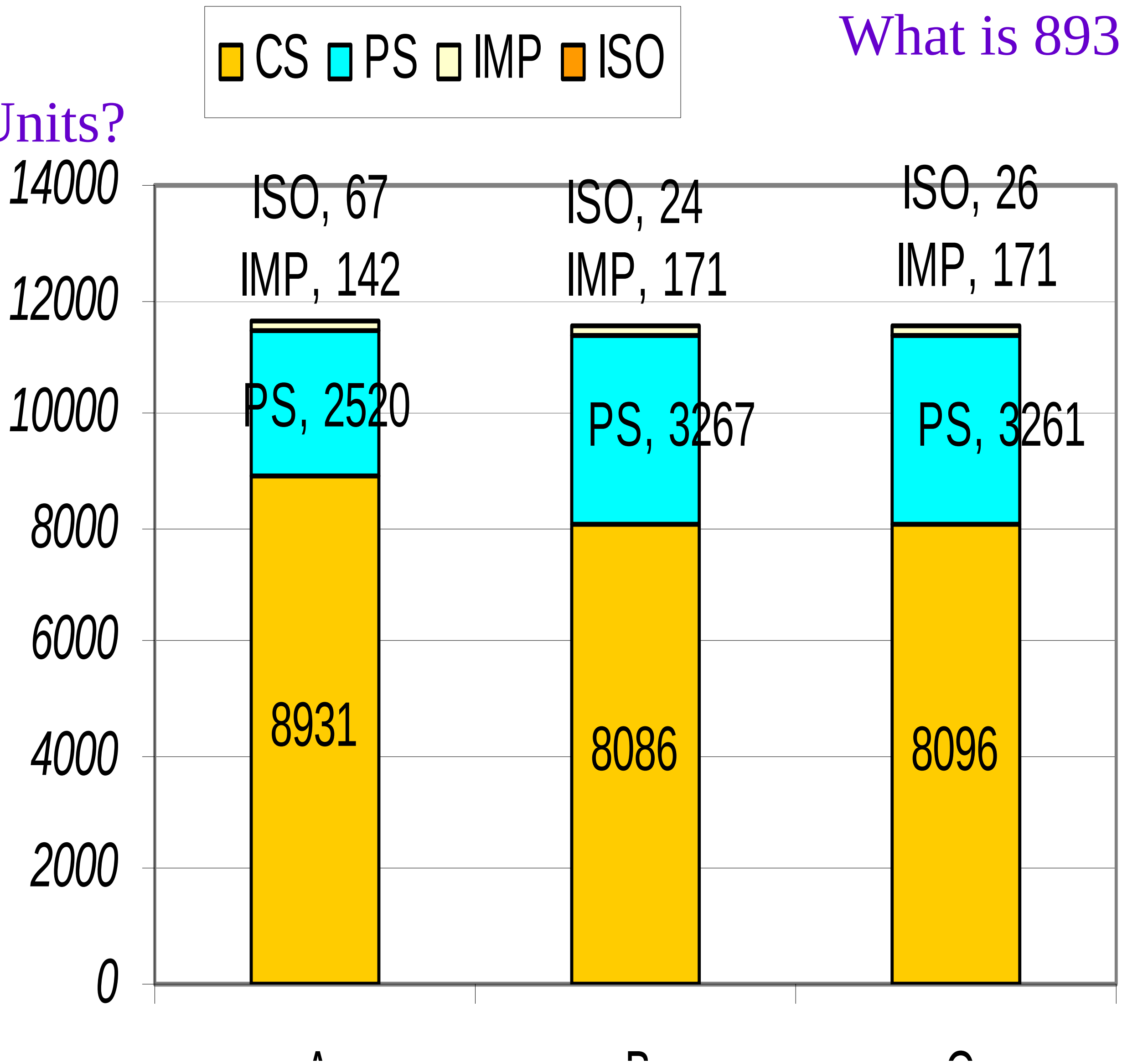
NOx Permit Price ($/ton)

- *Price of electricity goes up as producers restrain output*
- *Peak period electricity price increase by 37% and 34% compared with COMP for COURNOT and COURNOT+NO_x , respectively*
- *Price of NO_x decreases as a result of producers reducing energy output, suppressing NO_x permit demand*
- *Producer 4 drives up NO_x permit price if strategic in emissions market (HOW??)*

Welfare Analysis: *Compared to Competitive Scenario*

Can't see total welfare (should show)
What is 8931? (Label as CS)

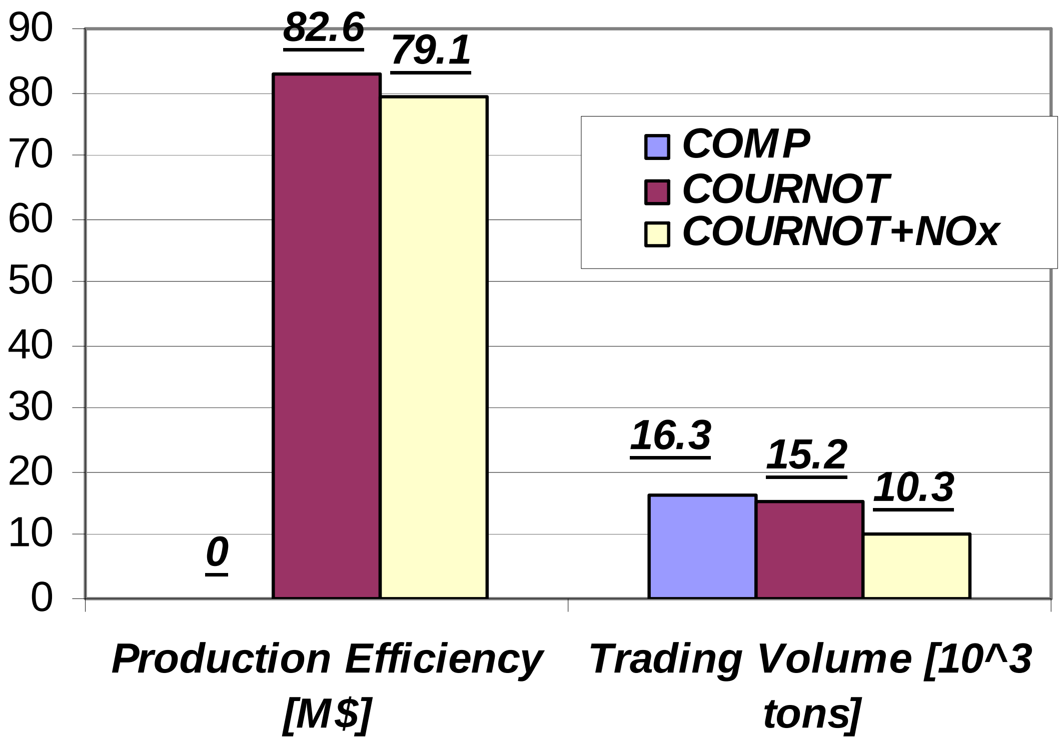
Units?



- ***SW (social welfare) declines by 112 and 106 [M$/yr] for Cournot solutions***
- ***PS (producer surplus) goes up as producers exercise market power***
- ***IMP (Importer) revenue goes up as electricity prices go up***
- ***ISO revenue goes down as less power being transferred***

Efficiency Comparison

Compared to Competitive Scenario



Definition of measurement:

a. Productive Inefficiency
= (GC_i –GC_{COMP}|load)[M$]*

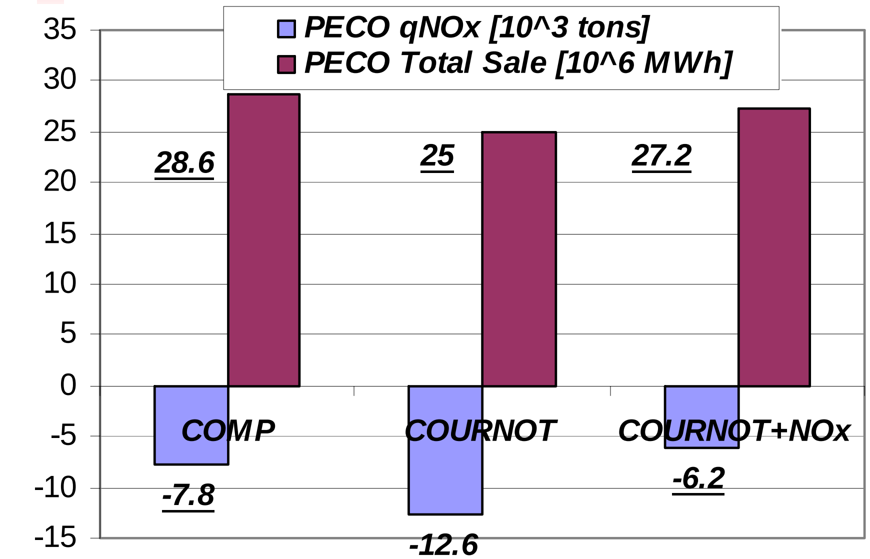
b. NO_x Trading Inefficiency
=($Trade^{NOx}{}_i$ – $Trade^{NOx}{}_{COMP}$) [10^3 tons]

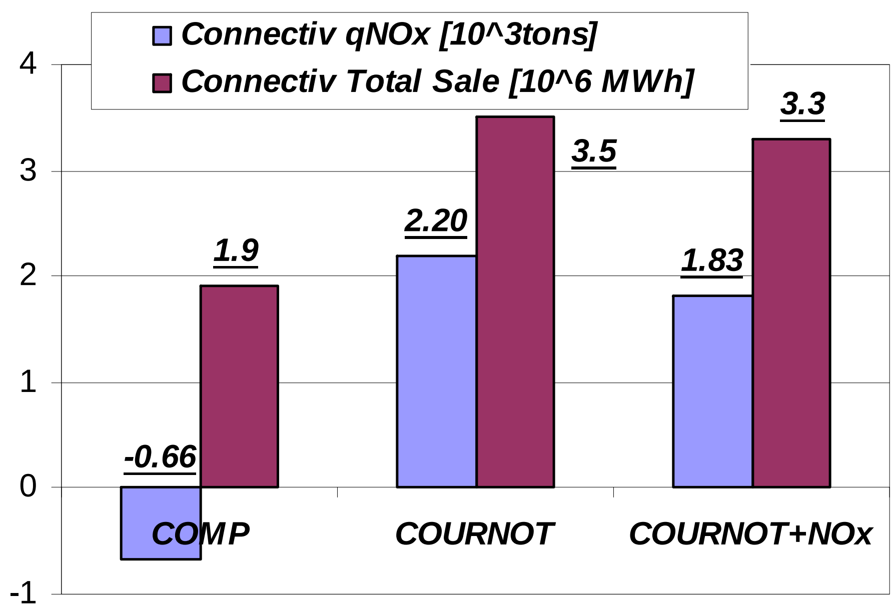
Market power leads to:

a. A 8.0% and 7.7% of productive inefficiency for COUNOT and COURNOT+NO_x

b. A 6.8% and 36.5% decrease in NO_x trading volume

Player Strategies in NOx Market





(Net Sale of Permits - qNOx [tons]: Sell (-)/Buy(+))

- **PECO: Compare with COMP**
  - *Restrain output and sell more NO_x permits in COURNOT → price falls from $2,557 to $1,595*
  - *Expand output and sell fewer NO_x permit in COURNOT+NO_x →Price falls only to $2,174*

- **Connectiv: Compare with COMP**
  - *Increase output by 84% due to higher electricity prices in COURNOT → become net buyer in NO_x market*
  - *Shrink output by 6% in COURNOT+NO_x compared with COURNOT due to higher costs associated with NO_x permits*

V. Conclusion

- ***Interactions between electricity and NO_x market can be investigated by Cournot and conjectured NO_x pricing assumptions in a large-scale model***
- ***Detailed representation of market allows a variety of welfare and efficiency analyses, and to gain insight on players' strategy***
- ***The model is capable of answering various policy questions, such as:***
  - ***"What would the NO_x price be if the CAP is imposed over entire year?" This is not an exciting conclusion to end with. Have more questions pointing to future research (e.g., optimal manipulation of NOx market)***