Oligopolistic Power Markets with Transmission, Forward Contracts, Reserve Markets and NO_x Permits

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Outline

Overview of Questions

Model Structure and Computational Approach

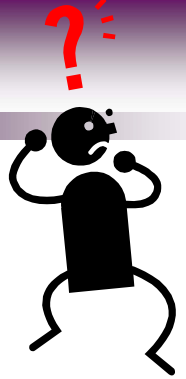
Application:

Interaction of PJM Electricity and USEPA NO_x Budget Program

1. *Background*
2. *Assumptions*

Results

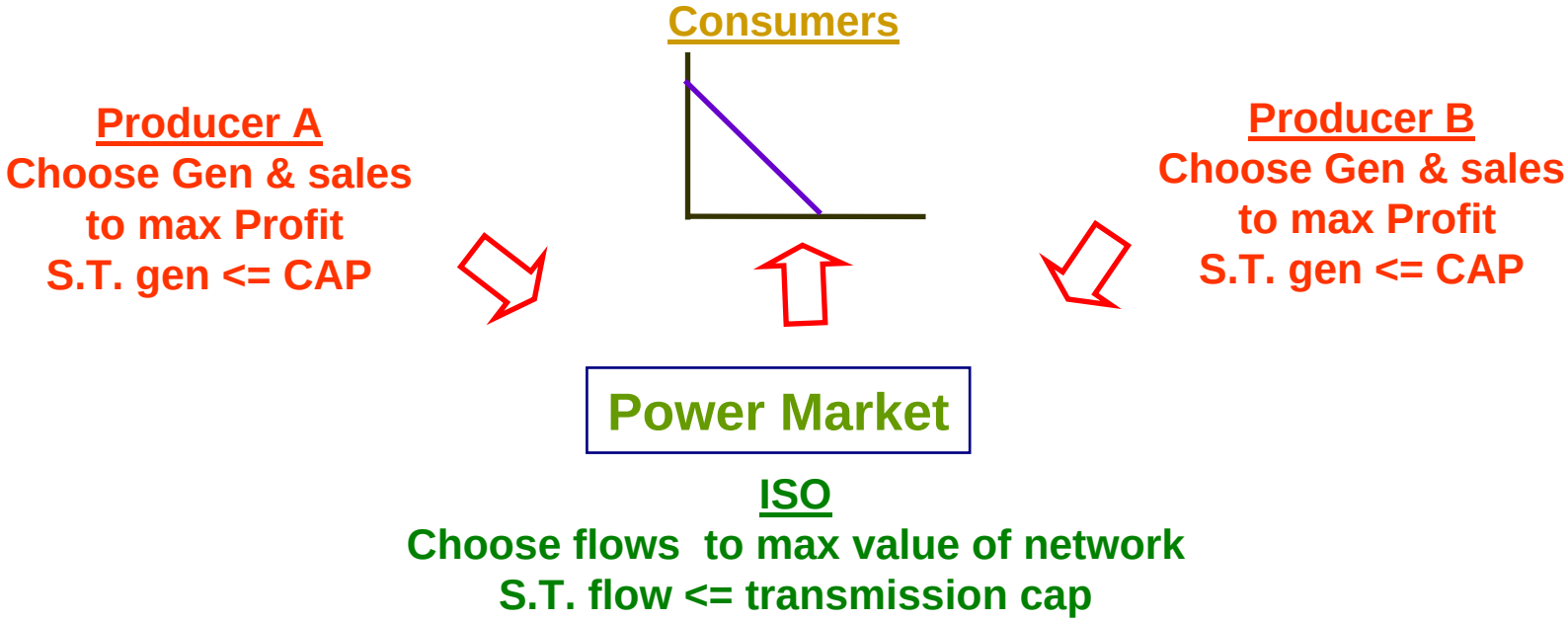
1. *Comparison of perfect competition and Cournot*
   a. *Price*
   b. *Social welfare*
   c. *Productive inefficiency*
   d. *Strategy rationale*
2. *Comparison of Cournot with & without forward contracts*
3. *Sensitivity Analysis*



Questions of Interest

- *Given the interactions of power (spinning reserves and forward contracts) and NO_x markets, compared with competitive case:*
  - *What is the impact on power and NO_x prices?*
  - *What is the overall social welfare impact?*
  - *What is the magnitude of productive inefficiency?*
  - *What is the rationale for players' behavior in power and NO_x market?*

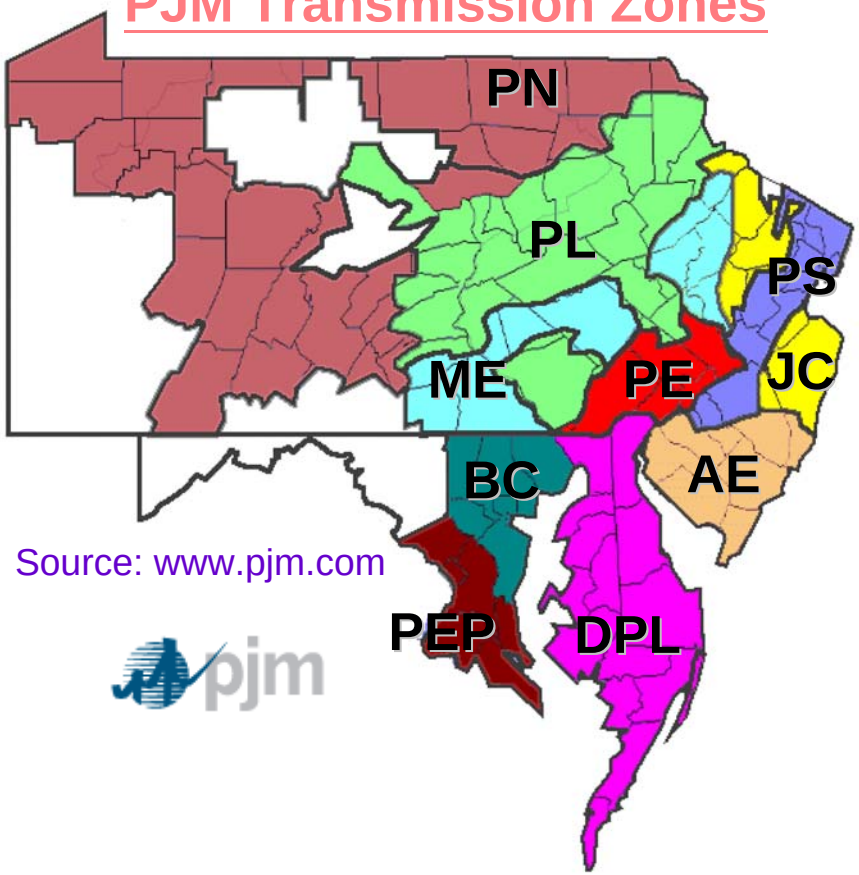
Model Structure and Computational Approach: Direct Solution of Equilibrium Conditions



1. *Identify players in the markets and write down their optimization problems;*
2. *Derive first order conditions;*
3. *Impose market clearing conditions;*
4. *Solve model by Complementarity solver – PATH*

Application Background
PJM Market and USEPA NO_x Program

PJM Transmission Zones



Source: www.pjm.com

PJM Market (2000)

- *Peak Load 53,000 MW*
- *Average Load-weighted Price 30.7 [$/MWh]*
- *Moderate Concentrated-HHI (hourly) (avg. roughly 1,500)*
- *14 node, 18 arc system*
- *9 producers*

USEPA NO_x Program

- *Cap-and-Trade*
- *May 1st – Sep. 30th (3,672 hrs)*
  - *Approximated by a 5-block*
- *Nine States participated in 2000*

Scenarios Investigated

Perfect competition (COMP)

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

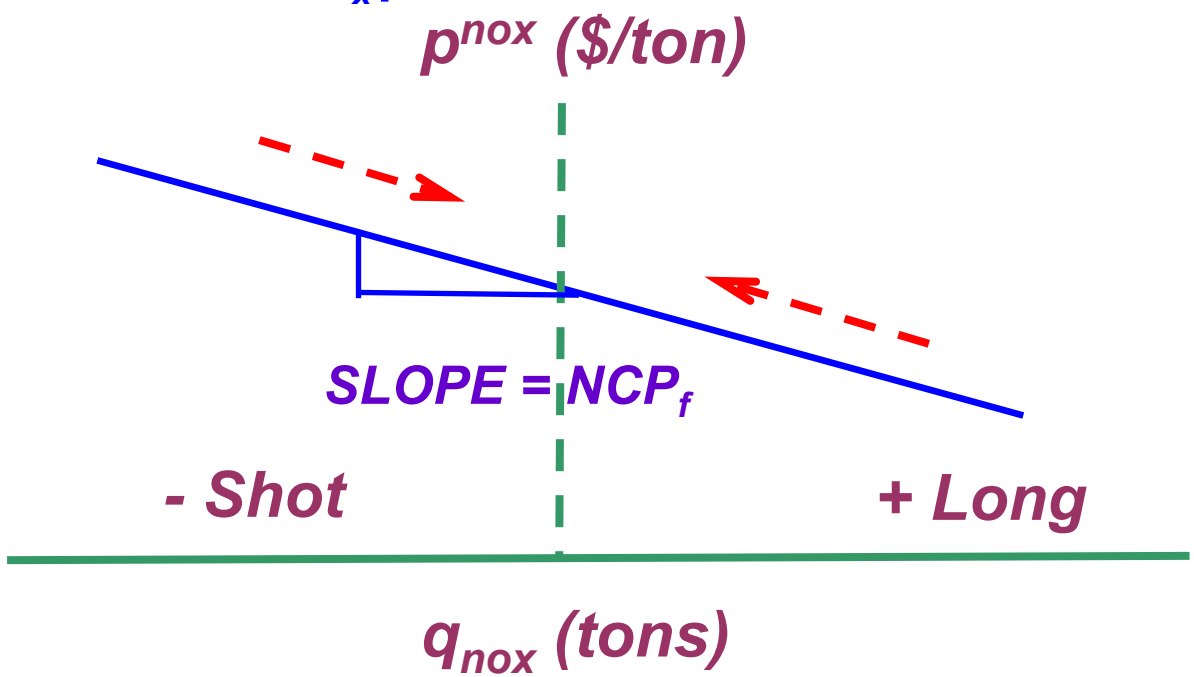
Oligopoly with forward contracts in both markets (COURNOT)

For 6 largest producers:

- ***Cournot strategy in electricity market***
- ***Pricing taker in reserve market***
- ***NO_x conjectured pricing in NO_x market***
  - ***$NCP_{2\text{-}7}$ =0.1 [($/ton)/ton]***

NO_x Conjectured Pricing

Approximate producer's belief regarding its action on NO_x price



q_{nox} : Net position in NO_x permit market
Sell/Long (+) and Buy/Short (-)

Mathematical Formulation Suppliers

+ Power $MAX_{s_{if},g_{if},r_{if}} \sum_i [P_i (s_{if} + \sum_{g \neq f} s_{ig}) - W_i](s_{if} - S_{if}^F)$

- Cost $- [C_{if}(g_{if}) - W_i g_{if}]$

+ Res $+ \sum_i p_t^R r_{if}$

- Permit $- p^{NO_x}(e_f^{NO_x} - \overline{Q}_f^{NO_x})$

S.T.:

Gen $g_{if} + r_{if} \leq \overline{G}_{if}, \forall i$

Res $r_{if} \leq \overline{R}_{if}, \forall i$

Balance $\sum_i s_{if} = \sum_i g_{if}$

Conjecture $p_f^N = p^{N^*} + NPC_f(e_f^{NO_x} - e_f^{NOx^*})$

Non negative $s_{if}, g_{if}, r_{if} \geq 0, \forall i$

Arbitrageur

$$MAX_{a_i} \sum_i (p_i^E - W_i) a_i$$

$$S.T.: \sum_i a_i = 0$$

Consumers

$$p_i^E = P_i^0 - \frac{P_i^0}{Q_i^0}(ts_i + a_i), \forall i$$

ISO

$$MAX_{y_i} \sum_i W_i y_i$$

$$S.T.: \sum_i PTDF_{ki} y_i \le T_k, \forall k$$

Market Clearing Conditions

Energy $\sum_f s_{if} + a_i - \sum_f x_{if} = y_i, \forall i$

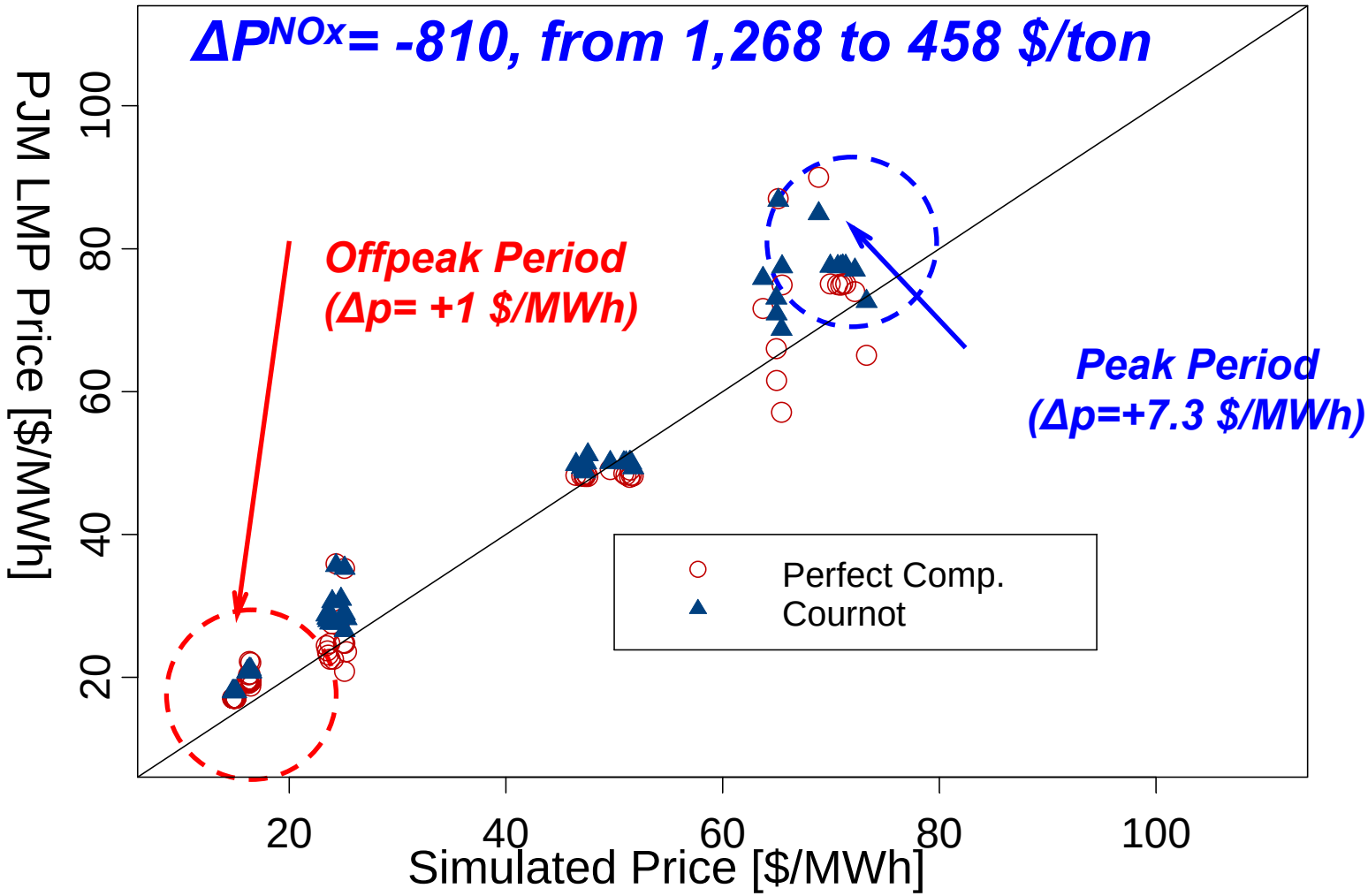
NOx $0 \le p^{N*} \perp \sum_{f,i}(e_{if}) - \overline{E}_f \ge 0$

Reserve $0 \le p^R \perp \sum_{i,f} r_{if} - \sum_{i,f} s_{if} RM \ge 0$

Consistency $e_f^{NOx*} = e_f^{NO_x}, \forall f$

Price Comparisons I

between Competitive and Cournot w/ forward contracts



Welfare Analysis I:
Compared to competitive scenario

- *SW (social welfare) declines by 0.5%*
- *CS (consumer surplus) goes down by 0.56%*
- *PS (producer surplus) goes up by 22 M$ as producers exercise market power*
- *ISO revenue goes down by 40% as less power being transferred*

Efficiency Comparison I :

Compared to competitive scenario

Productive Inefficiency is defined as the increase in cost relative to least-cost means of serving MW load

Market power leads to:

20 M$ (or 1.68%) production inefficiency over five-month period (cheap generation is withheld by Cournot firms)

Player's Strategies

PECO: largest in power and longest in permit

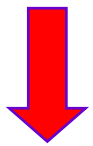
- *Cournot in power*
- *conjectured price response in permit market*

Conectiv: small fringe

- *competitive*

PECO restrains output, sells more NO_X permits

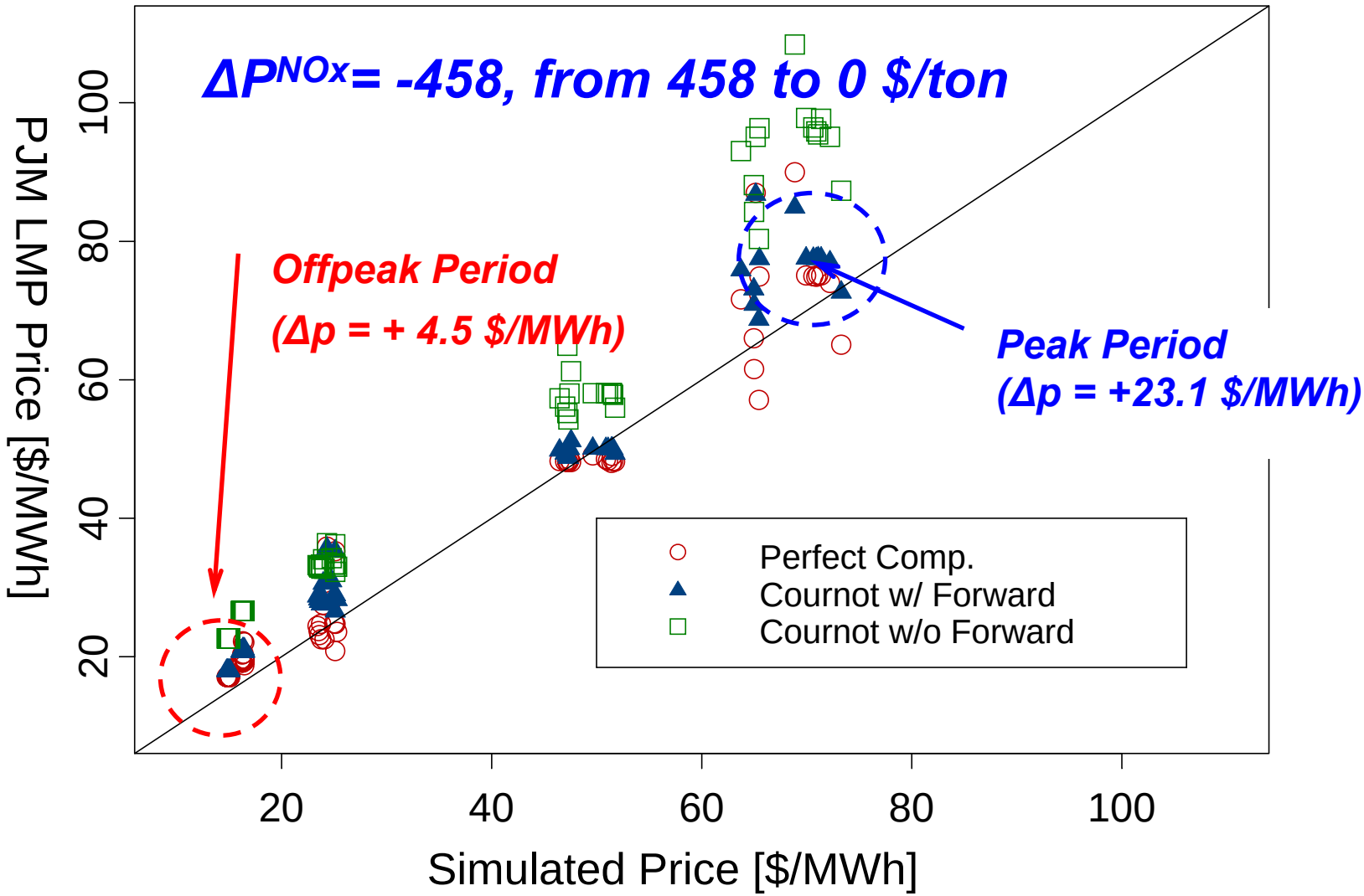
$p^E \uparrow, p^{NO_x} \downarrow$



Conectiv: output +15%
Permits sales - 56%
revenue - 5M$

Price Comparisons II

between Cournot w/ and w/o forward contracts



Welfare and Inefficiency Analysis II: *Compare Cournot w/ contracts*

- *CS (consumer surplus) in w/o forward contracts case goes down by 29.6%*
- *ISO revenue in w/o forward contracts case goes up by 28%*
- *Productive inefficiency in w/o forward contracts case increases by 64 M$ (or from 1.6% to 7.3%)*

Sensitivity Analysis

- *Explore the potential of market power in an environment in which supply of permits is limited*

- *Assumptions*

  Similar to Cournot scenario with forward contracts but

  – NCP_{PECO}*=1.5 [($/ton)/ton]*
  – *An equal reduction of 20% of permits by each firm in the market*

Player's Strategies II

PECO: largest in power and longest in permit

- *Cournot in power*
- *conjectured price response in permit market*

Conectiv: small fringe

- *competitive*

Compared with NCP_{PECO}=0.1 [($/ton)/ton]

PECO expands output by 7.3%, restricts sale of NO_X permits by 45%

$p^E \uparrow, p^{NO_x} \uparrow$

PECO's profits goes up by 2.7 M$

Player's Strategies II

PECO: largest in power and longest in permit

- *Cournot in power*
- *conjectured price response in permit market*

Conectiv: small fringe

- *competitive*

Compared with $NCP_{PECO}=0.1$ [($/ton)/ton]

PECO expands output by 7.3%, restricts sale of NO_X permits by 45%

↓

$p^E \uparrow, p^{NO_x} \uparrow$

↓

PECO's profits goes up by 2.7 M$

$p^{NO_x} \uparrow$

↓

Conectiv shrinks output by 5.5%, increases sale of NO_X permits by 35%

↓

Conectiv's profits goes down by 0.8 M$

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***

- ***Explore market power in a two-stage game structure where in the fist stage, firms purchase allowances through a central auction; and compete in the power markets in the second stage;***

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QUESTIONS AND COMMENTS?