Network models of spatial oligopoly with an application to deregulation of electricity generation

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Overview
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2 The price regulation model
3 The Bertrand model
4 The limit pricing model
5 The simulated effects of power market deregulation in upstate New York
6 Conclusions

Purpose of the paper
• Present two linear programming models of noncooperative oligopolistic spatial markets
• To illustrate the model’s usefulness for policy analysis, the models are used to assess the allocative efficiency of a hypothetical deregulated power market relative to the present (situation in 1985) system of price regulation

Oligopolistic models, because...
• Economies of scale in generation
• Firms will compete primarily with neighbours, because of transmission costs
• There are already now a small number of firms in many regions

Network models, because...
• Power plants, transmission lines and customers are distributed irregularly
• Generation and transmission costs, as well as demand functions of customers differ by location
• Transmission constraints may give market power for some firms in some regions

Why two models of oligopoly?
• The Bertrand model represents a relatively intense level of competition
• Provides a lower price estimate in deregulation scenario
• The limit pricing model represents collusive behaviour of the existing firms to maximize profits and prevents entrants
• Provides an upper price estimate in deregulation
Industry structure

- Independent competing producers
- Generation companies are divested from their transmission and distribution properties
- Transmission fees are distance dependent
- Both regulated and deregulated power prices include the average cost of transmission
- Customers are price takers, purchasing their peak and off-peak power from the lowest bidder

Spatial price structure

- The two oligopoly models presented are based on spatial price discrimination, because...
- Discrimination is likely to occur
- Linear programs can be used to calculate discriminatory price equilibria
- Equilibria based on other types of pricing structures may be difficult to calculate

Firm behavior and conjectures

- Customers purchase from the lowest bidder (homogeneous products)
- Price competition: Firm’s decision variable is price
- Equilibrium depend on the beliefs the firms hold concerning the reactions of the rivals
- Deregulation does not affect efficiency of production

The price regulation model

- Provides a baseline for deregulation scenarios
- Prices are fixed \( \Rightarrow \) Firms cooperate to minimize the costs s.t. in each node:
  - A prespecified set of demands is met
  - Total generation \( \leq \) maximum generation
  - Peak generation \( \leq \) expected capacity
  - Maximum power flow \( \leq \) transmission cap.

The Bertrand model: The assumptions

- Gives lower bounds for prices in deregulation
- Firms believe: rivals do not react to price changes, equilibrium price is the second lowest marginal cost
- Total marginal cost increase with distance from the plant, but price decreases
- Price must compensate the foregone revenue + any change in transmission costs

Spatial price discrimination
The variables of the Bertrand model

- \( q_i^T \) = total quantity demanded in node \( i \)
- \( q_{pif} \) = quantity supplied (MW) by firm \( f \) to node \( i \) during period \( p \)
- \( x_{pihf} \) = power generation by plant \( h \) of firm \( f \) at node \( i \) during period \( p \)
- \( y_{pjif} \) = power flow from node \( i \) to node \( j \) during period \( p \)

The Bertrand model

- Objective:
  \[
  \text{Maximize } \sum_i I_i(q_i^T) - (E_i + N_i)q_i^T \]
  \[
  \text{subject to:}
  \sum_h x_{pihf} - \sum_j \left[ (1-L_{pji}) y_{pjif} - y_{pijf} \right] + q_{pif} = 0,
\]

Parameters of the Bertrand model

- \( C_{ihf} \) = variable generation cost for plant \( h \) at node \( i \)
- \( E_i \) and \( N_i \) are exploitation and node fees
- \( T_{ij} \) = wheeling fee ($/MW-year) applied to flows between \( i \) and \( j \)
- \( I_i'(q_i^T) \) = demand curve integral. \( I_i'(q_i^T) \) is concave and \( I_i'(0) \) is finite

Calculation of the Bertrand equilibrium

- An initial set of \( E_i \), the difference between the second lowest and the lowest marginal cost, is assumed
- The Bertrand model is used to calculate new values of \( E_i \) from the dual variables of the power balance constraints (\( \lambda_{qij} \))
- New \( \lambda_{qij} \) values are calculated
- This is repeated until convergence of \( E_i \)

Calculation of a restricted Bertrand equilibrium

- If demand is inelastic, a restricted model is used, which omits the \( q_i^T \) variables and fixes the total demand each period
- After a model run, Bertrand prices are estimated as \( N_i + \) weighted sum across the periods of the second largest \( \lambda_{qij} \) of the firms
- New demands are calculated using demand function and the model is resolved
Properties of Bertrand model equilibrium solution

- It can be shown that the fixed point solution of the Bertrand model represents Bertrand-Nash equilibrium.
- If successive solutions of the restricted model converge to a constant set of prices, the resulting point is a Bertrand equilibrium.
- If demand is elastic, the restricted model should not be used.

The limit pricing model: The assumptions

- Firms collude to maximize total profits such that potential entrants anticipate zero profit.
- New firms can enter only between the existing firms.
- Entrants exhaust their capacity.
- Spatial price discrimination.
- An entrant believes pre- and post-entry prices represent Bertrand equilibrium.

The limit pricing model: The assumptions (2)

- An entrant builds one coal-fired generation unit and combustion turbines for peaking.
- Post-entry prices decrease at a rate equal to transmission costs as one moves away from the entrant’s site.

Limit pricing solutions are obtained in three steps:

1. Determine zero-profit prices for each possible entry node.
2. Limit price: $P_{\text{L}} = \min \{ P_{\text{ip}} + T + \alpha(N_e - N) \}$.
3. Solve the price regulation model using the quantities demanded implied by the limit prices to generation costs, profit, welfare.

Industry structure of power industry in Upstate New York

- New York State is included, but excluding the service territories of Consolidated Edison Company and Long Island Lightning Company.
- 6 major generating companies: 5 private and 1 public company - however, all forms are assumed to behave in the same manner.
- 59 generating plants in 38 counties.
Capacity and production structure

- Total generating capacity 15320 MW:
  - Oil-fired steam plants 4612 MW
  - coal-fired steam plants 3507 MW
  - hydro 3908 MW
  - nuclear 1858 MW
  - the rest (1435 MW): 1000 MW pumped storage + several combustion turbines
- 90 transmission links connect the nodes

Demand curves

- A constant elasticity demand curve is calibrated on 1980 price-quantity point for each node
- price is assumed to equal the average 1980 regulated rate, minus administrative and distribution costs
- short-run power price elasticity is set equal to -0.1

About the entrants...

- Each entrant is assumed to build a 600 MW coal-fired plant, plus sufficient reserve margin capacity (oil-fired combustion turbines)
- Limit prices are 1990 expected fuel prices in 1980 dollars
- The entry is possible only in some nodes between existing companies

Results

<table>
<thead>
<tr>
<th>Solution</th>
<th>Average price</th>
<th>Generation Profit</th>
<th>Social Welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>$/kWh peak MW</td>
<td>$million/yr</td>
<td>$million/yr</td>
<td></td>
</tr>
<tr>
<td>Price regulation</td>
<td>0.0336</td>
<td>11935</td>
<td>0</td>
</tr>
<tr>
<td>Deregulation: Bertrand</td>
<td>0.0476</td>
<td>10594</td>
<td>98</td>
</tr>
<tr>
<td>Deregulation: Limit pricing</td>
<td>0.0507</td>
<td>10301</td>
<td>1650</td>
</tr>
</tbody>
</table>

- Profits and social welfare are presented as differences compared to price regulation

Price changes and welfare effects

- Marginal generation costs of oil-fired steam plants is 5 cents/kWh, but the average cost is only 3 cents/kWh ⇒ prices up by 46–78%
- Social welfare goes up slightly in the short run: Firm’s profits go up, but consumers would be worse off, on the average
- Deregulation leads to more efficient allocation of resources

Price changes and welfare effects (2)

- Firms have some market power: Bertrand prices are 2.2% higher than marginal costs
- One source of market power are high-cost lines
- Considerable welfare gains can be obtained if deregulation motivates firms to increase production efficiency
- 5-10 times bigger welfare gains in long run
Conclusions

• The short-run welfare gains are uncertain because it is difficult to estimate the price elasticity of demand in regulation.
• Long-run welfare gains are difficult to estimate, but they are probably higher than short-run welfare gains because price elasticities of demand and supply are greater in magnitude in the long run ⇒ reallocation gains may be considerable in the long run.

Conclusions (2)

• The power companies may develop their production structure and production efficiency even in regulated markets (long run cost minimization), but consumers would have no incentive to change their consumption patterns.
• ⇒ long-run welfare gains from the deregulation are probably greater than from the regulation.

Conclusions (3)

• Special characteristics of electricity networks, like loop flows and Kirchoff’s laws, which may give additional market power for some firms, are not taken into account.
• Modeling these characteristics explicitly may change the results, especially if the capacity limits of links are binding.

Questions concerning the article

• Entry is taken into account only in the limit pricing model. Is it consistent to exclude entry from the Bertrand model? There may be entrants in oligopoly case, too. If the two models were to be used to evaluate deregulation effects, should they have the same assumptions regarding entry?

Questions concerning the article (2)

• Would it be better to use limit prices as explicit upper bounds for prices in Bertrand model to prevent entry?
• The competition between the oligopolists in the Bertrand model would then drive the prices equal or below the limit prices.

Suggestions for further modeling

• Special characteristics of electricity networks (like Kirchoff’s laws) could be modelled as constraints.
• In markets of different industries with scale economies and transportation costs firms typically compete on some decision variables and collude on other.
• Colluding/competing features could be added to the Bertrand/regulation model.
References and related material


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References and related material (2)