

Spot Market, Forward Contracts and Capacity Investment in Electricity

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Outline

- Introduction
- A simple electricity pricing and investment model
 - Supply function equilibrium in spot market
 - Arbitrage between spot and forward markets
 - Cournot competition in long-term investments
- Resource adequacy, options, and reserves
- Conclusion

Introduction

- Mixed experience in spot and forward markets
- Basic roles of spot trading, forward contracting, and long term investment
- Investments have been deterred by regulatory uncertainty
- Resource adequacy requires regulation attention
- Reserves and options share some desirable features
- Progress in supply function equilibrium offers a new analytical approach

Characteristics of Electricity Markets

- Electricity is not storable \Rightarrow coordinated markets
 - Demand and supply must be balanced in real-time
 - System reliability is a public good
- **Externality** is prevalent throughout the system \Rightarrow contrived markets
 - Excessive peak demand reduces system reliability
 - Transmission congestion/losses due to loop flows
 - Environmental impacts
- The network is governed by **Nonlinearity** \Rightarrow imperfect markets
 - Economies of scale/scope
 - Shift factors vary with power flow patterns
 - Fixed unit commitment costs, minimum run
- Commercial exchange is handicapped by the limited availability of real-time transaction information ⇒ incomplete markets

Spot Market



Firm's Decision Problem

$$\begin{aligned} & \underset{s_{i},S_{i},x_{i},X_{i},Y_{i},K_{i}}{Max} \int_{0}^{\hat{p}} \pi(p)x_{i}(p)dp + \pi(0)X_{i}(0) - k_{i}K_{i} + \\ & \delta \int \int_{0}^{\hat{p}} \left\{ (p - c_{i}) \left[S_{i}(p) + X_{i}(p) \right] - Y_{i}(p) \right\} h(p | \phi) f_{\phi}(\phi) dp d\phi \end{aligned}$$

$$H(p) = \Pr\{P(\sigma) < p\} = \Pr\{D(p) + \sigma < S(p) + X(p)\} = F(S(p) + X(p) - D(p))$$

$$h(p|\phi) = H'(p|\phi) = [s(p) + x(p) - D'(p)]f_{\sigma}(S(p) + X(p) - D(p) - \phi|\phi).$$

$$S'_{i}(p) = s_{i}(p)$$
$$X'_{i}(p) = x_{i}(p)$$
$$Y'_{i}(p) = X_{i}(p)$$
$$S_{i}(p) + X_{i}(p) \le K_{i}$$

Oligopolistic Competition in Spot and Forward Markets

Supply function equilibrium in spot markets

 $S_{i}(p) = (p - c_{i}) [S'_{-i}(p) + X'_{-i}(p) - D'(p)]$

• Arbitrage between spot and forward markets

$$\pi(p) = \delta E\left\{ \left(P(\sigma) - p \right)^{+} \right\} + \pi(\hat{p})$$

• Optimal investment as a Cournot game

$$\delta E\left\{\left(P(\sigma)-c_i\right)^+\right\}-k_i\geq 0$$

Supply Function Equilibrium in Spot Market

- The presence of capacity constraints produces unique supply function equilibrium (e.g. Holmberg)
- Each firm acts as a monopolist with respect to its residual demand
- The presence of contracts has two effects
 - increases the elasticity of each firm's residual demand
 - reduces each firm's portfolio share of spot trading

$$\frac{p-c_i}{p} = \frac{S_i(p) + X_i(p)}{p\left[S'_{-i}(p) + X'_{-i}(p) - D'(p)\right]} \frac{S_i(p)}{S_i(p) + X_i(p)}$$

Lerner Index = (1/Elasticity) x Share

Example 1

Suppose that each of n identical firms has zero marginal cost, there are no contracts, and demand is inelastic.



Supply Function Equilibrium With Optimal Capacity Investment (Random Rationing)



Supply Function Equilibrium With Optimal Capacity Investment (Random Outage)



Cournot competition in long-term investment mitigates market power

- Investment financing facilitated by forward contracts
- As a result, firms enter forward market entailing greater competition
- Forward market facilitated by Cournot competition
 - Incentive is stronger for forward contracts than options
- Incentives for adequate investment remains an open issue
 - System reliability remains a public good that requires regulatory attention
 - Suboptimal investment persists in the presence of incomplete markets
 - Uncertainty in the value of load losses and the capacity cost underlie the regulatory uncertainty

Advantages of Using Options to Ensure Resource Adequacy

- The presence of options increases the elasticity of each firm's residual demand
- The demand side obtains benefits from increased reliance on options
- The consumers incur no costs provided that the noarbitrage condition is preserved
- It facilitates entry and an increase in the number of firms further reduces spot prices
- The optimal strategy for the demand side is full reliance on options and forward contracts
- Envision bargaining between suppliers and demand, with some rents to suppliers

Value of options in reserves markets

- Reserves and energy are complements from a demand perspective
- But they are substitutes from a supply perspective
- Reserves are option contracts from a risk
 perspective
- Demand-side reserves, e.g. interruptible service, should be allowed to participate in the reserve market

Structure of electricity supply



References

Resource Adequacy and Market Power Mitigation, Hung-po Chao and Robert Wilson, Electric Power Research Institute, July 2004. Electric Power Research Institute

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Resource Adequacy via Option Contracts, H. Chao, S. Oren and R. Wilson, Working Paper, Electric Power Research Institute, May 2005