A MARKET POWER MODEL WITH STRATEGIC INTERACTION IN ELECTRICITY NETWORKS

William W. Hogan
Center for Business and Government
John F. Kennedy School of Government
Harvard University
Cambridge, Massachusetts 02138

International Program on Privatization and Regulatory Reform
Harvard Institute for International Development

July 15, 1997

Electricity restructuring requires open access to the transmission essential facility. Open access reduces or removes vertical market power. But open access does not eliminate horizontal market power. Concentration of ownership of generation coupled with market pricing could lead to higher prices and reduced welfare.

- **Horizontal Market Power is a Concern.** Regulators consistently express reservations about competition and market pricing for generation due to the problems of concentration of ownership.

  "Market power on the part of sellers is the ability profitably to maintain prices above competitive levels by restricting output below competitive levels."[1]

- **Market Definition Depends on the Open Access Rules.** Market power analysis depends on a better understanding of the open access rules. Until the rules are set, it may not be possible to identify the extent of market power.

- **Transmission Constraints Complicate the Analysis of Market Power.** There is general recognition that transmission constraints can segment markets and have a significant impact on the ability to exercise market power.

[1] Gregory J. Werden, "Identifying Market Power in Electric Generation," Public Utilities Fortnightly, February 15, 1996, p. 16.

Electric power generation is still not a fully competitive market. Some power plants are located in strategic locations or needed to provide critical services such as reactive power support. Other facilities may be owned by a single firm with market power. The challenge is to develop policies to deal with these conditions while moving to a broader system of market-based pricing.

- **Regulation.** Power plants located in strategic positions may be subject to continued regulation and cost-based pricing, even in a more competitive, "deregulated" market.

- **Contracts.** A contract to provide the services of a generating unit at a specified price transfers the beneficial economic interest in the plant from the owner to the contract holder. The operator then has incentives to pursue efficient operation.

- **Divestment.** Concentrated ownership gives horizontal market power that may be beyond easy regulation or contracting. Here the call has been for separation of ownership of generation and transmission, and divestment of generation to reduce or the incentive for strategic operation of one plant for the benefit of others.

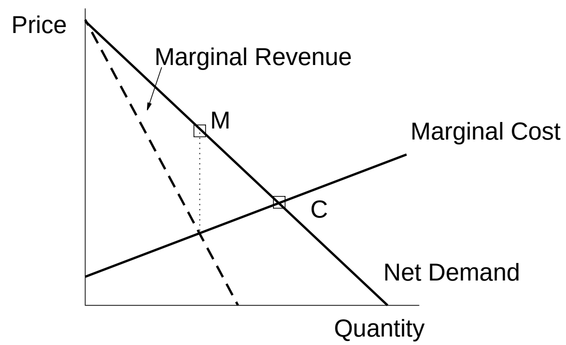
  - UK regulator called for National Power and Powergen to divest of 6000 MWs.

  - California regulators directed Pacific Gas & Electric and Southern California Edison to divest of fifty percent of their fossil generation.

The number of generating plants to divest is a policy matter complicated by the choice of the most efficient plants to divest. Divesting higher cost plants rather than low cost plants produces lower prices (Borenstein and Bushnell).

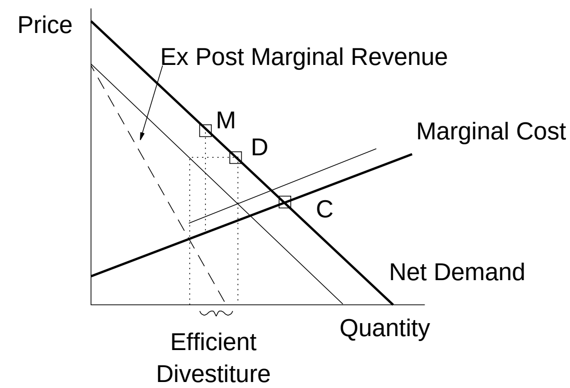
Monopolist Facing a Net Demand from a Competitive Fringe
Reduces Production and Raises Price

(C: Competitive Equilibrium; M: Monopoly Result)



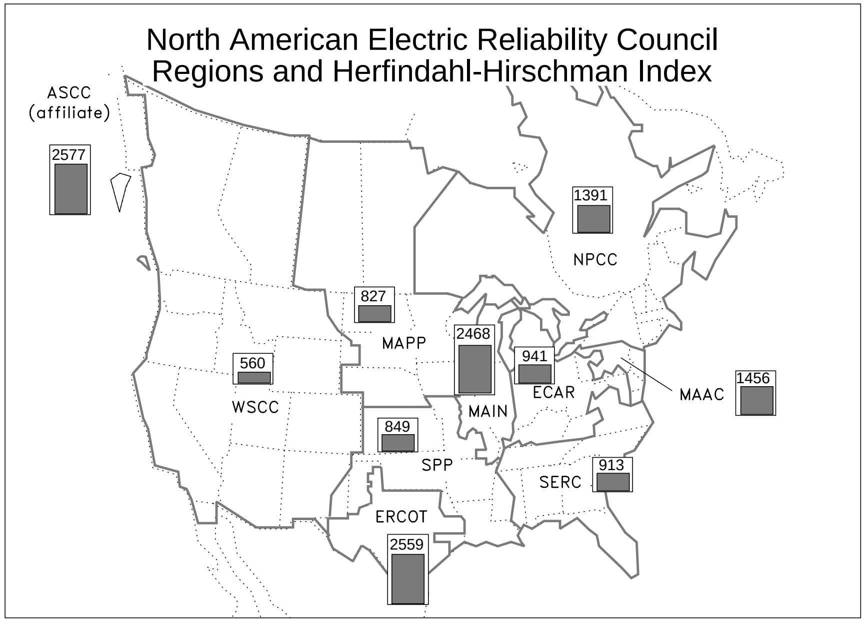
Efficient Divestiture to the Competitve Fringe
Selects the Ex Post Marginal Output

(C: Competitive Equilibrium; M: Monopoly Result; D: Divestment Result)



For a single period, and a given level of divestment, the total welfare efficient choice would be to divest the plants that would be marginal *after* divestment. Selecting more expensive plants would not affect prices but would raise total generation costs. Selecting lower cost plants would shift the marginal cost curve enough to raise prices and lower production. Even for a single period, therefore, selection of the efficient divestment choice would depend on a forecast. With the real problem involving a single divestment applied to multiple periods, market simulations may be needed for workable solutions.

The regions in the United States enjoy a wide variety of ownership patterns and potential for market power. The degree to which these large regions will define the "geographic" market for market power analysis will depend on the scope and nature of transmission constraints.[2]



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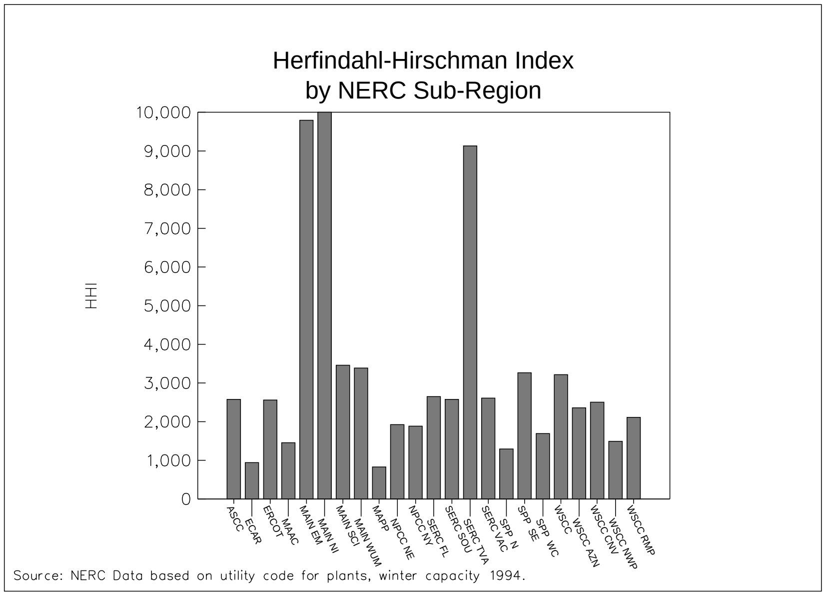
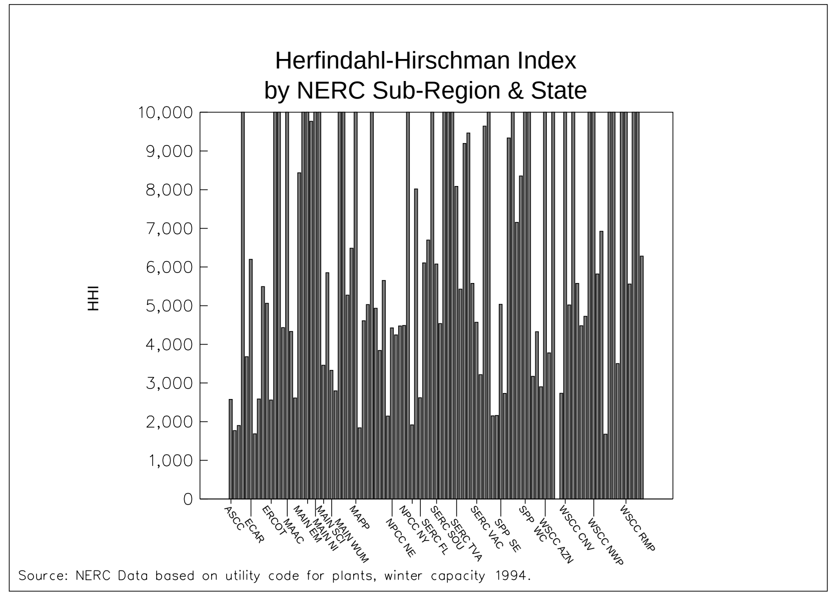
[2] The Herfindahl-Hirschman Index is the sum of the squares of the market shares. If measured in percentages, the index for a monopoly would be $100^2 = 10,000$. With an infinite number of firms of equal size, the limiting value is zero. In the case of the oil pipeline market, "The Department [of Justice] and the Commission staff have previously advocated an HHI threshold of 2,500 and it would be reasonable for the Commission to consider concentration in the relevant market below this level as sufficient to create a rebuttable presumption that a pipeline does not possess significant market power."

The scope of transmission constraints could substantially determine the degree of market power and the necessity for further mitigation or regulation.



Source: NERC Data based on utility code for plants, winter capacity 1994.

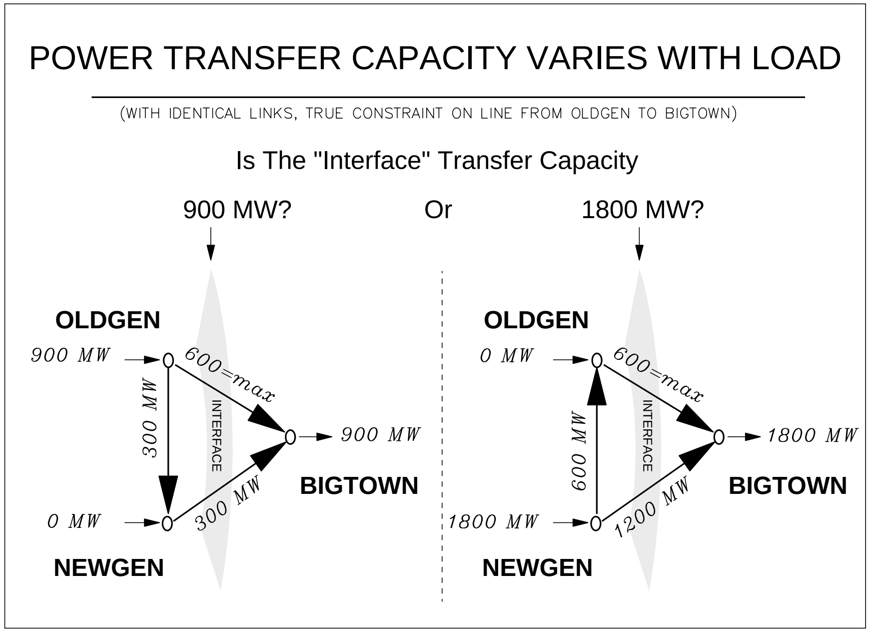


Source: NERC Data based on utility code for plants, winter capacity 1994.

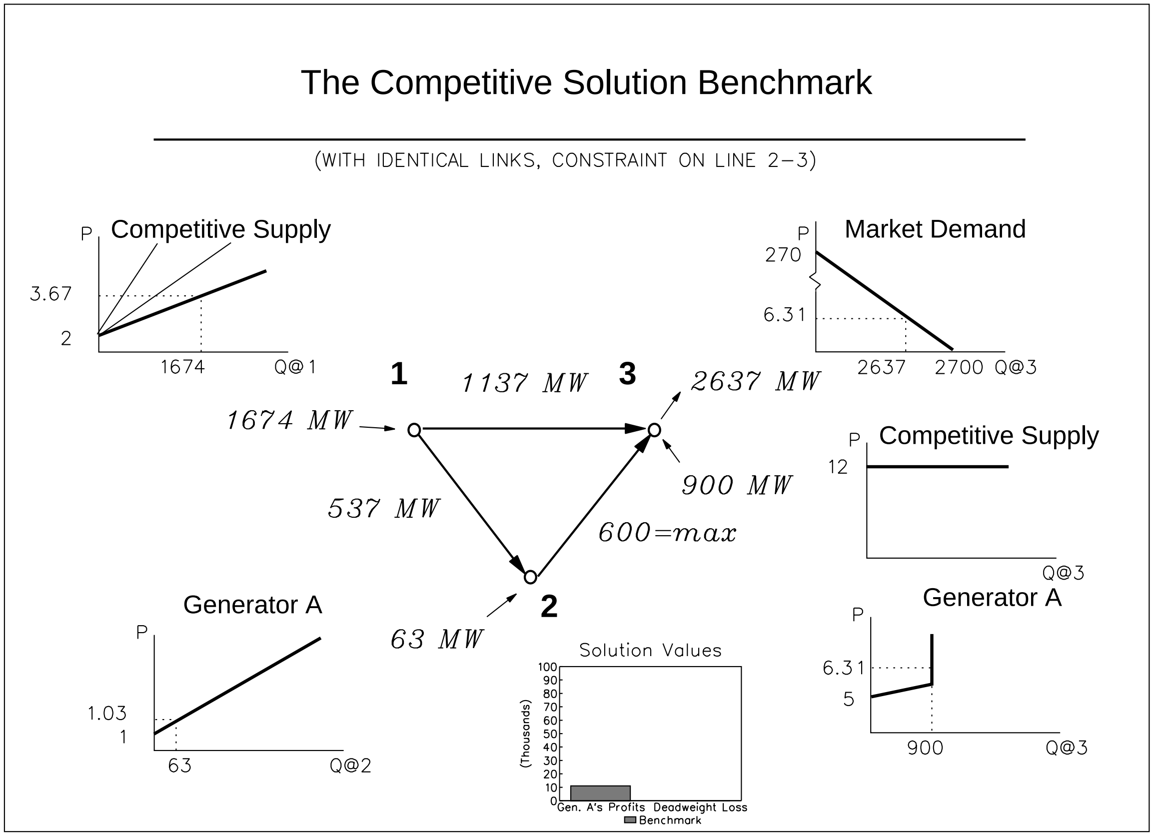
Detailed analyses of transmission capacity may be necessary, and in many cases the results could be surprising. For example, constraints on the transmission system may be greater during off-peak periods when not all plants are running and there is an economic incentive to use transmission to reach distant, cheaper plants. Furthermore, when the complex transmission interactions are considered, the topology of the market will be driven by electrical distance not geographic distance. With the sometimes poor correlation between electrical topology and geographic topology, we should be prepared for surprises in the definition of the electrical market.

Electric transmission network interactions can be large and important.

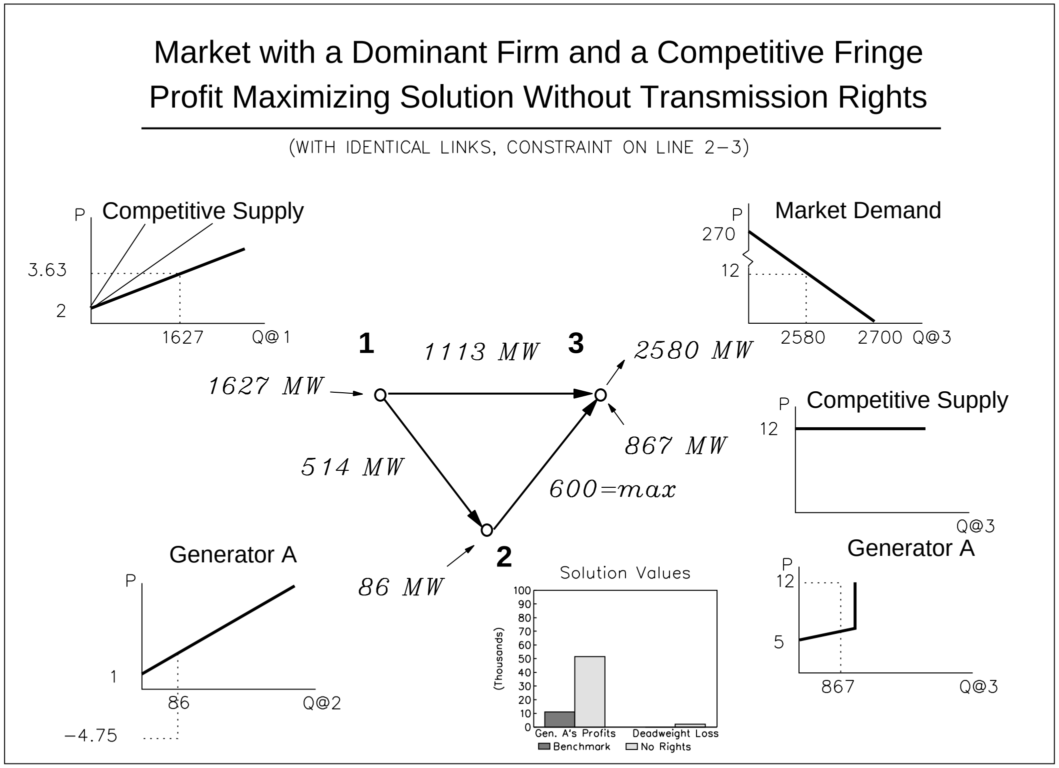
- Conventional definitions of network "Interface" transfer capacity depend on the assumed load conditions.
- Transfer capacity cannot be defined or guaranteed over any reasonable horizon.



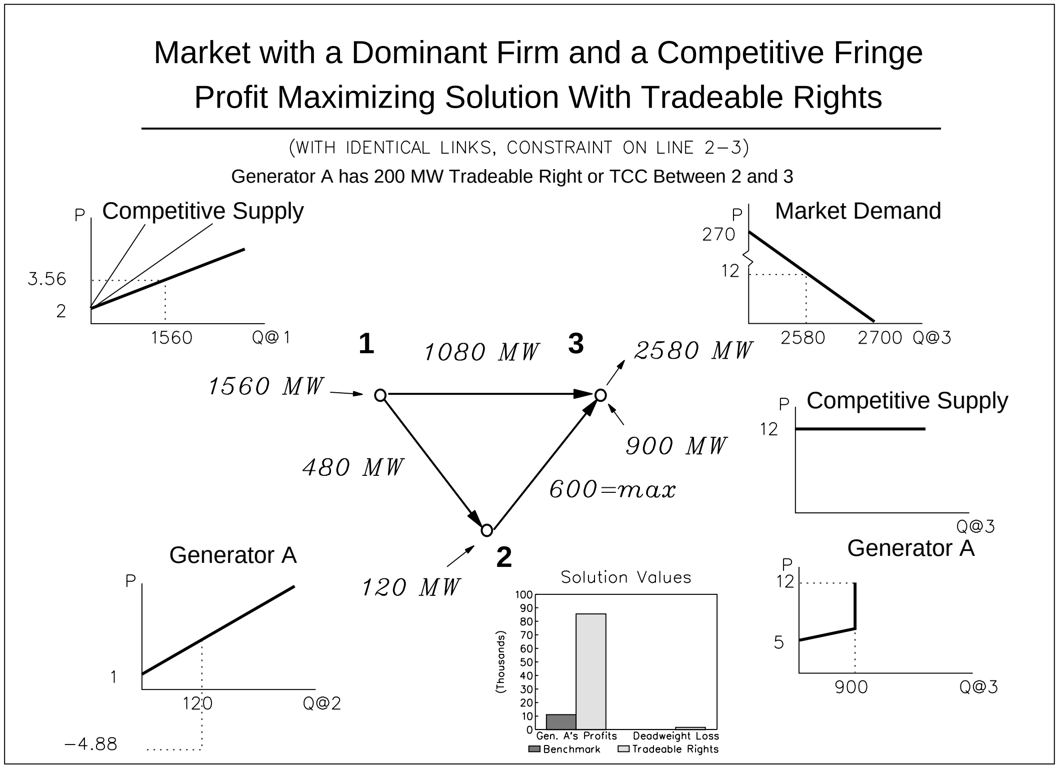
Application of a market model in a transmission grid illustrates some of the special conditions that may arise due to network interactions. Supply and demand equilibrium, with all participants acting as price taking participants, provides a competitive benchmark.



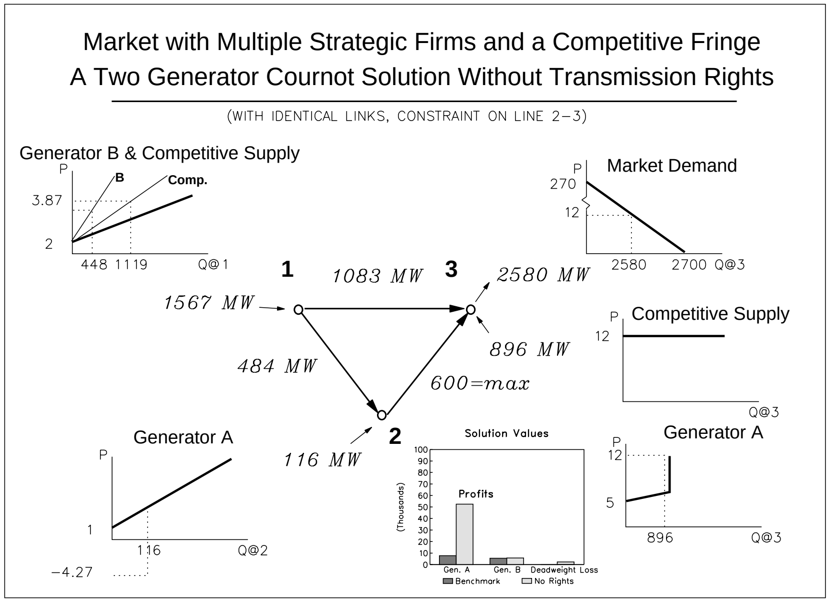
Under the Cournot model, the dominant firm (A) chooses output levels and the competitive fringe sets the market price. Knowing this, the dominant firm sets output to maximize profits. The interaction through the network makes it profitable to operate some generation at a loss, increasing production above the competitive benchmark, and benefitting from the effect of partially blocking a transmission constraint.

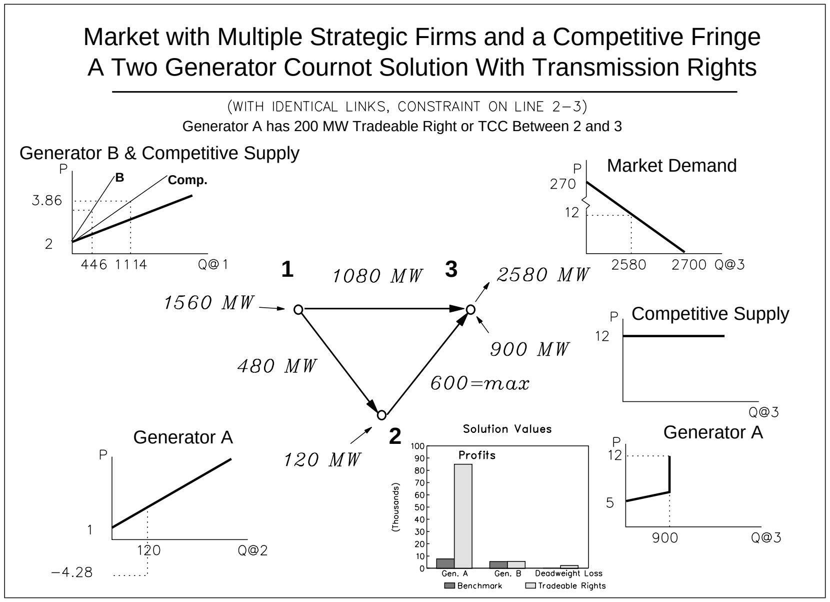


There may be a system of tradeable transmission rights or transmission congestion contracts. Ownership of these rights would provide an additional source of profit from the exercise of market power. In this case, the dominant firm further increases production above the competitive case, but still profits more from the disproportionate impact on the transmission constraint.

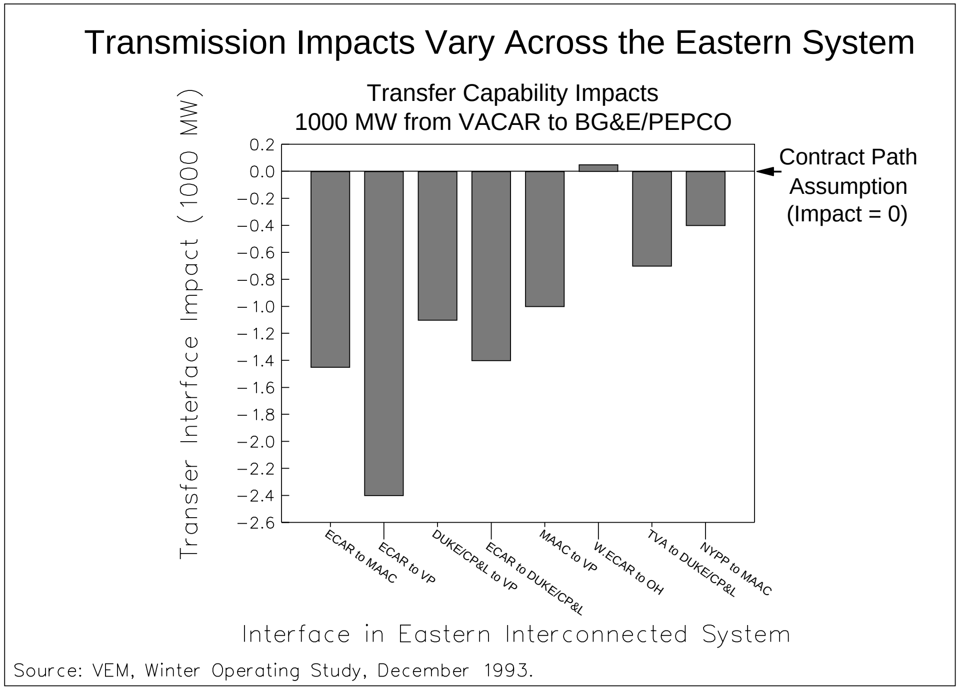


The extension to multiple firms does not change the conclusion. Here generators A and B act as Cournot dominant firms. In both cases, with and without transmission rights, generator A enjoys strategic locational advantages relative to the constraint and finds it profitable to increase production relative to the competitive benchmark case.

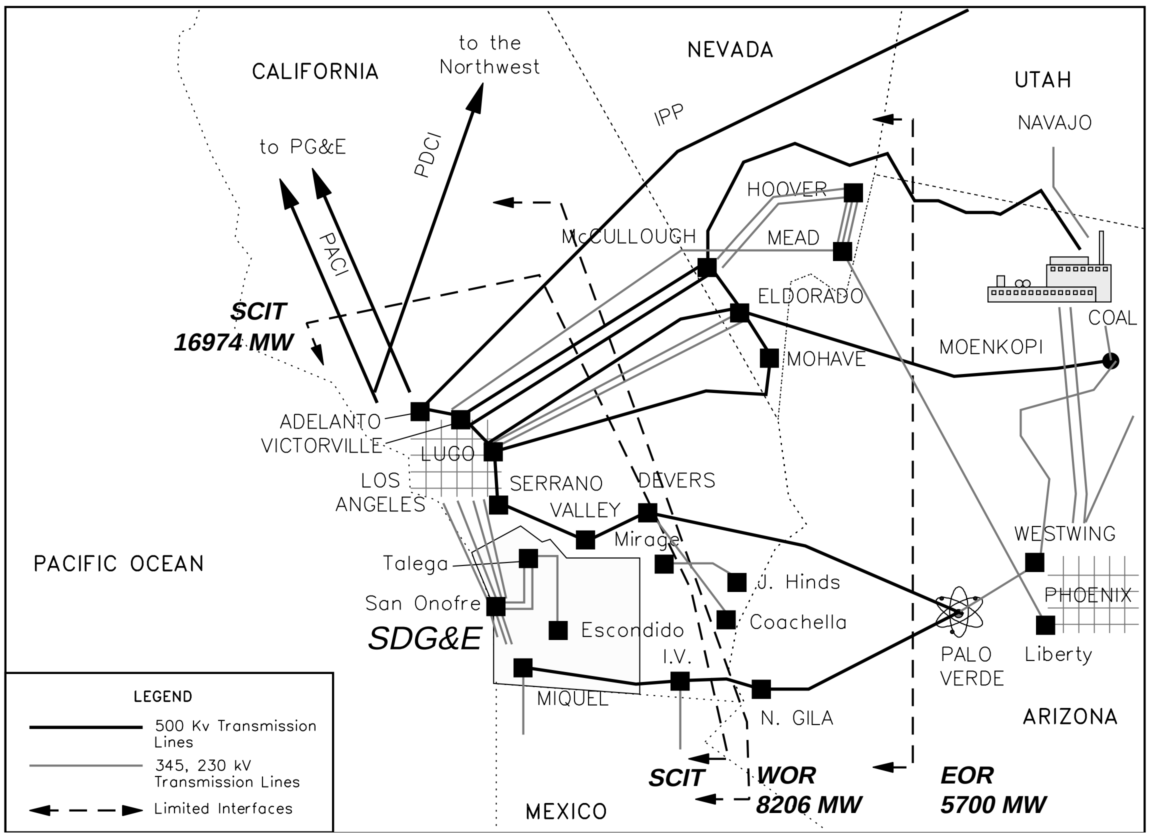




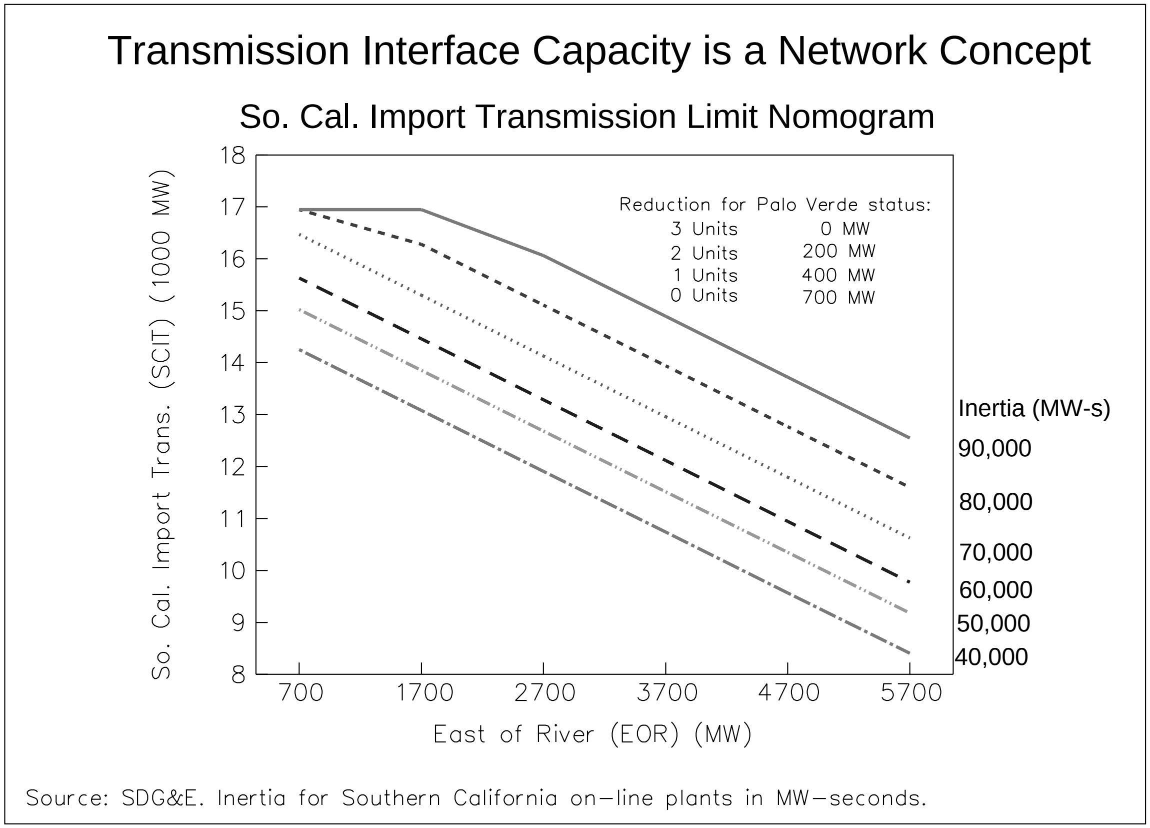
The essential, unusual element of the electricity case is in the complicated joint constraints in the network that create strong interactions between the participants who may have market power. Use of 1 MW of incremental generation at one location can block production of more than 1 MW elsewhere. Hence, an increase in the *use* of the network in one place can reduce the *capacity* in another. Are there places in the real electric network where this form of leverage could exist?.



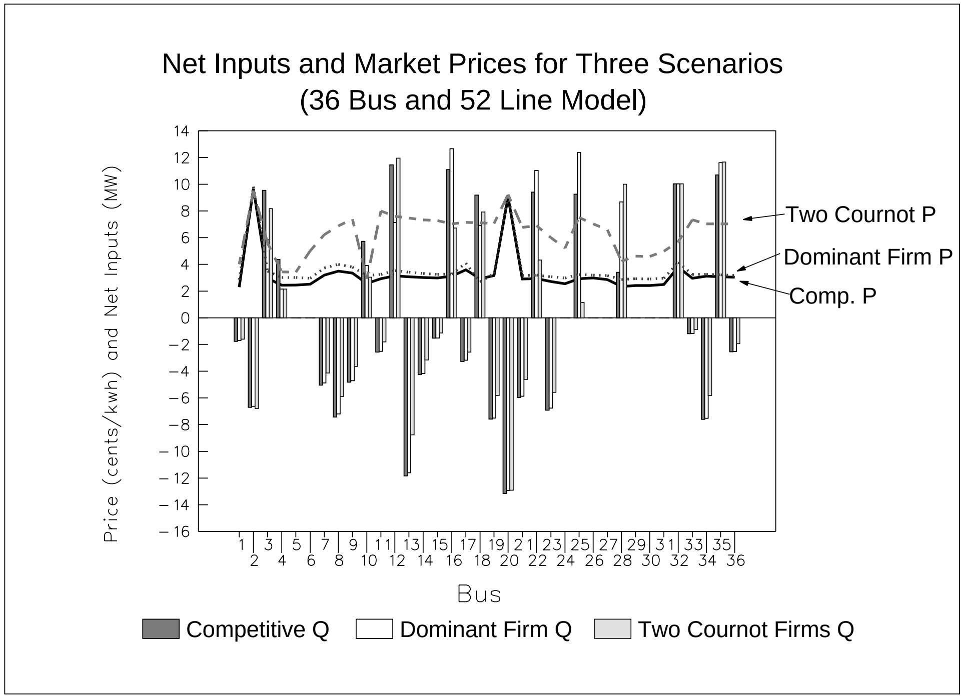
The strong network effects apply in most, or all interconnected grids. In southern California, for example, there are important interfaces with maximum limits that cannot be achieved simultaneously. Complex "nomograms" summarize the simultaneous constraints. (see next page)



The SCIT "nomogram" for southern California illustrates the strong interdependencies of network flows. The interaction dictates that each additional 1 MW on the "EOR" interface would require a reduction of more than 2 MW on the remaining flows affecting the "SCIT" interface.



The model of imperfect competition could be extended to a more realistic network. A test with a model including 36 buses and 52 lines, with generating units at thirteen locations owned by two large firms and a competitive fringe, and some arbitrary constraints on various transmission lines yields prices and production profiles differing sharply from the competitive benchmark and varying depending on the degree of imperfect competition and the interaction with the constraints.



The illustrative calculations for the simple three bus model suggest a number of challenges for market power analysis in the presence of transmission constraints. Issues to address include:

- Ownership of geographically dispersed generation can create market power through interactions in the network. Electric topology is not the same as geographic topology.

- The examples illustrate conditions where the benefits of blocking bottlenecks outweigh losses in local production. It may be profitable for the leader to produce below marginal cost and block a more than proportional amount of competitive supply.

- In the examples, tradeable rights or equivalent transmission congestion contracts appear better for the monopolist and better for society, compared to no rights or the "use it or lose it" transmission right. Is this true in general?

- Will detailed analysis of complicated divestment choices in real networks be necessary?

  "A far more refined analysis would combine existing transmission models with information on loads, generating capabilities, and unit marginal cost schedules, at all relevant points within the transmission network. All this information should be readily available, and could be used within a computer program that minimizes the cost of satisfying the specified loads, given generation capacity and costs, as well as transmission costs and constraints."[3]

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[3] Gregory J. Werden, "Identifying Market Power in Electric Generation," Public Utilities Fortnightly, February 15, 1996, p. 19.

Appendix

A Model of Market Power and Strategic Interaction in Electric Networks

This market power analysis in the presence of transmission constraints includes "Cournot" dominant firms and a competitive fringe of price taking consumers and producers. The competitive (partial) equilibrium can characterized as the solution to a social welfare maximization problem known as the "economic dispatch."

Let:

- d_S, d_F : the vectors of loads at each the n buses across all the elements of each set. Hence, for $i \in S$, d_i is an n-vector of the loads at each bus for this large strategic firm in the set S. Similarly for d_j with $j \in F$.
- g_S, g_F : the vectors of generation at each bus, with the same index definitions of the n-vectors as for the loads.
- y : the n-vector of net inputs, i.e. generation minus load, (g-d).
- B(), C() : the differentiable benefit and cost functions for load and generation,
- K() : the differentiable functions defining Kirchoff's Laws on electricity and all the network constraints on net inputs.

For the competitive fringe, the assumption is that the strategies of the Cournot participants (d_D, g_D) are taken as given, and the fringe participants achieve a competitive partial equilibrium. Under reasonable regularity conditions, this competitive equilibrium for the fringe participants can be characterized as the solution of an optimization problem:

(1.1) $$\max_{d_F,\, g_F,\, y} \quad B_F(d_F) - C_F(g_F)$$

(1.2) $$\sum(d_S - g_S) + \sum(d_F - g_F) + y = 0 \;,$$

(1.3) $$K(y) \le 0.$$

Given the optimization formulation of the competitive fringe model, we can apply the usual theory to derive the K-K-T equilibrium constraints.

(1.1) $\max_{d_F, g_F, y} \quad B_F(d_F) - C_F(g_F)$

(1.2) $\sum(d_S - g_S) + \sum(d_F - g_F) + y = 0$,

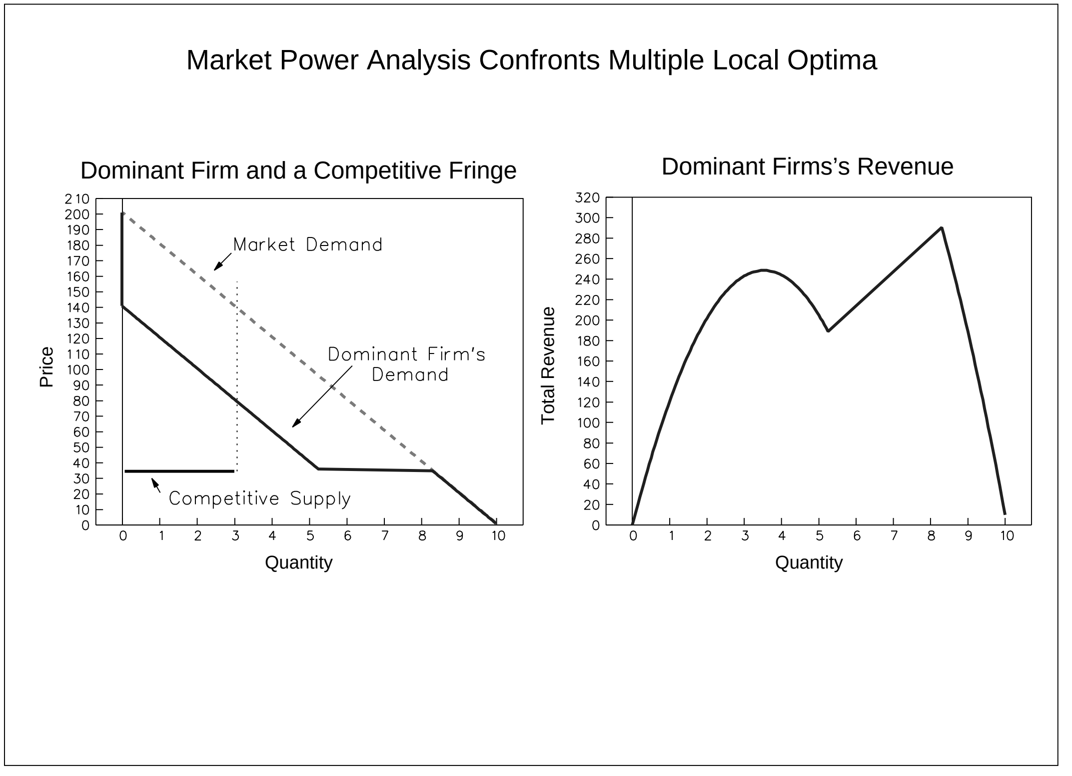
(1.3) $K(y) \leq 0.$

Let the Lagrangian be:

$$\mathcal{L}(d_S, g_S, d_F, g_F, y, \mu, p) = B_F(d_F) - C_F(g_F) - p^t(\sum(d_S - g_S) + \sum(d_F - g_F) + y) - \mu^t K(y).$$

Here the market prices arise as the dual variables for the locational balance equations (1.2). Viewed as a function of the dominant firm strategies, the price functions derived from the competitive fringe model are typically not everywhere differentiable.

A model of imperfect competition provides one framework for market power analysis. A dominant firm confronts the market demand not met by the competitive fringe. Calculation of the profit-maximizing solution for the dominant firm presents computational challenges even without considering the special conditions of electric transmission grids.



For each Cournot firm, the strategies of the other firms and the equilibrium constraints for the competitive fringe define a mathematical program with equilibrium constraints (MPEC). The objective is to maximize the benefits of purchases and sales plus returns on transmission congestion contracts.

(2.1) $$\max_{d_i,\, g_i,\, d_F,\, g_F,\, y,\, \mu,\, p} \quad B_i(d_i) - p^t d_i + p^t g_i - C_i(g_i) + p^t TCC_i$$

s.t.

(2.2) $$\nabla_{d_F} \mathcal{L}(d_i, g_i, d_{S\backslash i}, g_{S\backslash i}, d_F, g_F, y, \mu, p) = 0 \,,$$

(2.3) $$\nabla_{g_F} \mathcal{L}(d_i, g_i, d_{S\backslash i}, g_{S\backslash i}, d_F, g_F, y, \mu, p) = 0 \,,$$

(2.4) $$\nabla_{y} \mathcal{L}(d_i, g_i, d_{S\backslash i}, g_{S\backslash i}, d_F, g_F, y, \mu, p) = 0 \,,$$

(2.5) $$d_i - g_i + \sum(d_{S\backslash i} - g_{S\backslash i}) + \sum(d_F - g_F) + y = 0 \,,$$

(2.6) $$K(y) \leq 0 \,,$$

(2.7) $$\mu^t K(y) = 0 \,,$$

(2.8) $$\mu \geq 0 \,.$$

A mutually consistent solution for each Cournot firm defines the Nash-Cournot equilibrium.

The complementarity condition is the source of substantial computational difficulty in solving MPEC problems. One approach is to relax the complementarity conditions and apply a penalty function, successively increasing the penalty, to converge to a solution to the first order conditions.

(3.1) $$\max_{d_i,\, g_i,\, d_F,\, g_F,\, y,\, \mu,\, p,\, \varepsilon} B_i(d_i) - p^t d_i + p^t g_i - C_i(g_i) + p^t TCC_i - t\,\varepsilon^2$$

s.t.

(3.2) $$\nabla_{dF}\mathcal{L}(d_i, g_i, d_{S\backslash i}, g_{S\backslash i}, d_F, g_F, y, \mu, p) = 0 ,$$

(3.3) $$\nabla_{gF}\mathcal{L}(d_i, g_i, d_{S\backslash i}, g_{S\backslash i}, d_F, g_F, y, \mu, p) = 0 ,$$

(3.4) $$\nabla_{y}\mathcal{L}(d_i, g_i, d_{S\backslash i}, g_{S\backslash i}, d_F, g_F, y, \mu, p) = 0 ,$$

(3.5) $$d_i - g_i + \sum(d_{S\backslash i} - g_{S\backslash i}) + \sum(d_F - g_F) + y = 0 ,$$

(3.6) $$K(y) \leq 0 ,$$

(3.7) $$\mu^t K(y) - \varepsilon = 0 ,$$

(3.8) $$\mu \geq 0 .$$

Supporting papers and additional detail can be obtained from the author. William W. Hogan is the Thornton Bradshaw Professor of Public Policy and Management, John F. Kennedy School of Government, Harvard University, and Senior Advisor, Putnam, Hayes & Bartlett, Inc., Cambridge MA. This presentation draws on work for the Harvard Electricity Policy Group and the Harvard-Japan Project on Energy and the Environment. Judith Cardell and Carrie Cullen Hitt collaborated in the underlying analysis of electricity market power issues. The author is or has been a consultant on electric market reform and transmission issues for British National Grid Company, General Public Utilities Corporation (working with the Supporting PJM Companies), PJM Office of Interconnection, Duquesne Light Company, Electricity Corporation of New Zealand, National Independent Energy Producers, New York Power Pool, New York Utilities Collaborative, San Diego Gas & Electric Corp., Trans Power of New Zealand, and Wisconsin Electric Power Company. The views presented here are not necessarily attributable to any of those mentioned, and the remaining errors are solely the responsibility of the author.