An Analysis of Interfirm Cooperation: Theory and Evidence from Electric Power Pools*

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I. Introduction

A power pool is a group of two or more electric public utilities that coordinate their activities with regards to the generation and transmission of electricity. Coordination can occur along several dimensions including the connection of generation facilities with transmission lines, joint planning for the construction of new facilities and lines, and meeting demands for electricity by dispatching from the least-cost generating source across member utilities at any given time. Utilities participating in pools will enjoy benefits and incur costs that generally depend on the degree of coordination. As argued below, loose coordination will mean low costs but few benefits, while tight coordination means high costs but greater benefits.

Coordination in U.S. power pools runs from moderately tight to very loose [5; 6].¹ Overall, however, there is a tendency towards looseness. In 1964, the Federal Power Commission (FPC) issued the *National Power Survey* which indicated that closer coordination could produce substantial savings in the cost of energy production. A decade later, Breyer and MacAvoy [3] concluded that pooling has not grown substantially since the Commission's report, and "... that there should be considerably more coordination *at this time* than now exists." They based their assertion on calculations of potential cost savings. The magnitude of these savings is impressive, with estimates running as high as several billion dollars annually. More recently, the 1979 *National Energy Act* exempted utilities from state laws that prevent voluntary coordination where such coordination is designed to obtain economic utilization of resources. The Federal Energy Regulatory Commission was also instructed by the *Act* to submit a report to the President and Congress on the opportunities for future pooling.

In view of the apparent potential benefits of power pooling, the lack of progress towards achieving a highly integrated electric power industry requires explanation. Power

* Helpful comments and suggestions were provided by Scott Atkinson, Larry Kirsch, Chuck Mason, Todd Sandler and Fred Sterbenz. Any errors are the sole responsibility of the authors.

1. The concepts of looseness and tightness of nonmarket organizations are examined in detail by Sandler and Cauley [25] and are applied to governments in Sandler, Cauley and Tschirhart [26].

pooling is an exercise in interfirm cooperation. For a pool to be effective, well-defined agreements must be developed among the member utilities. The agreements will allow the benefits to be shared; but they will also create costs for the members. These costs may take a variety of forms including foregone opportunities of interactions with nonpool utilities, and the costs of group decision making inherent in any cooperative venture where individuals do not have identical goals. That there are both benefits and costs to power pooling suggests that from the utilities' perspectives an optimum configuration of pooling exists that accounts for the benefit/cost tradeoff. The aforementioned looseness of existing power pools implies that utilities perceive the marginal costs of further coordination to outweigh the marginal benefits.

The purpose of this paper is to develop and test a model for analyzing the extent to which an individual utility participates in a pool. The paper avoids the normative issue of an optimum configuration of pools from society's perspective; and it is useful in explaining the current status of the industry.² The benefits and costs of pool membership are incorporated in a profit-maximization model of an individual utility. An optimum degree of coordination for the utility is shown to depend on the benefits and costs, and on the degree to which other utilities are committed to the pool. Coordination also depends on the utility's behavior with regards to other utilities: Cournot type behavior leads to loose arrangements while tight arrangements result when utilities are more willing to share information and costs. The pooling environment is also contrasted to the more general case of interfirm cooperation in oligopoly markets, and it is offered as an example of why more collusion does not occur. Because utilities are regulated by state commissions, the effect that these government institutions have on pooling is also analyzed.

The model is tested using data from 83 utilities in 19 U.S. power pools. The results lend strong support to the hypothesis that a utility incorporates the costs of group decision making, the effects of regulatory bodies, and the usual factor costs in its choice to cooperate with other utilities in power pools.

II. Benefits and Costs of Pooling

The benefits enjoyed through power pooling have been well documented [3; 15]. Briefly, they include the following major categories:

- i) Cost savings in generating equipment that stem from staggering the construction of new facilities and constructing optimum size facilities that account for seasonal diversity loads and maintenance schedules of all pool members;
- ii) The cost savings in reserve generating capacity needed to maintain a particular reliability of service; and
- iii) Dispatching economy energy whereby pool-wide demands for power are met using the least-cost generating source available.

2. While theoretical work on public utilities abounds, very little has been done on power pooling. Berkowitz [2] derives welfare-maximizing prices for power exchange in an existing grid; and Tepel [29] examines optimal power exchanges in a profit maximization setting. Neither of these authors was concerned with the fundamental question of whether a firm should join a pool in the first place.

In the following model, the benefits of power pooling will be restricted to the cost savings in reserve generating capacity. This will simplify the exposition while still allowing an examination of the central issues in power pooling. Also, these benefits are the largest of the three categories. Utilities maintain generating capacity in operating reserve status to meet unexpected increases in demand, equipment failures, and maintenance. The level of reserves needed depends primarily on the size of on-line generating units and the loss-of-load probability the utility wants to achieve.³ An isolated utility may determine that a particular level of reserves is needed to meet the risk of excess demand; but this level can be reduced through coordination, since the risks confronted by two or more coordinated utilities are less than the sum of risks confronted by the utilities in isolation.

To model the benefits and costs of reserve pooling, the utility's choice of generation capital stock will be dichotomized into production capital and reserve capital. Production capital is combined with a variable input to satisfy all demand barring any equipment failures or unexpected surges in demand. Let $f(K, L)$ be the utility's production function where K is expenditures on production capital and L is a variable input.⁴ In order to ensure a reliable, steady flow of output, the utility must acquire reserve capital to back up K . The needed reserves can be expressed as a percentage of K , or αK , where the percentage depends on the targeted loss-of-load probability.⁵ Thus, the model is cast in a nonstochastic setting; the utility has addressed the problems of random demand and supply through its selection of α . Avoiding the explicit introduction of random elements lends tractability to the model while still allowing for a clear presentation of how the utility weighs the benefits and costs of power pooling.

To meet this reserve capital requirement, the utility has a choice between acquiring its own reserve generating units or joining a power pool to tap other pool members for reserves. Denote the units of generation reserves acquired by the utility outside any pooling arrangement as K^s , and those units of reserves drawn through a pooling arrangement as K^d . The utility must satisfy

$$K^s + K^d \geq \alpha K. \quad (1)$$

Constraint (1) allows for a mixture of pooling and nonpooling expenditures to satisfy reserve requirements.

The level of reserves that can be drawn from the pool depends on the extent to which other utilities are involved. The greater their involvement, the more the utility can draw. Also, the utility must contribute to the pool in order to draw; and the greater the contribution, the more that can be drawn. Let K^p and K^o be the capital contribution to the pool of the utility and other utilities respectively. Then the most that can be drawn from the pool by the utility is constrained by

$$K^d \leq b(K^p; K^o) \quad (2)$$

3. Loss-of-load probability is the probability of the system load (demand) exceeding the available generating capacity under the assumption that the peak load of each day lasts all day [9].

4. This is a single period model with a single technology. Peak and off-peak periods and a diverse technology could be incorporated; however, the intent here is to concentrate on benefits of pooling and the institutional considerations that create transaction costs. Consequently, to avoid notational and mathematical complexity, a simple production technology is used that is sufficient for the task.

5. Typical values for α range between 15 and 30 percent.

where $\partial b / \partial K^o > 0$ and $\partial b / \partial K^p > 0$. When no other utilities contribute to the pool, $K^o = 0$ and the utility can draw at most $K^d = b(K^p; 0) = K^p$. Also, $b(0; K^p) = 0$ so that the utility must contribute some capital to the pool, otherwise (1) must be satisfied with nonpool reserve generation only, i.e., K^s .

Constraint (1) is essentially a reliability requirement which must be met with either pooling or nonpooling reserves. Therefore, $b(K^p; K^o)$ and K^s are the two ways in which reliability is produced. Moreover, $\partial b / \partial K^p \equiv b_p$ is the marginal reliability from a unit of pooled reserves, while the marginal reliability from a unit of nonpooled reserves is 1. The benefits of pooling are captured by the function $b(K^p; K^o)$. For instance, if more firms join the pool and K^o increases, $b(K^p; K^o)$ increases as well to reflect the gains from greater demand diversification and alternating equipment failures. If there is any advantage to pooling through cost savings in reserve generating capacity, then for some K^p and K^o it must be that

$$b_p > 1. \quad (3)$$

Below it is shown that (3) must hold if the utility is to join a pool. To summarize, (3) implies that a unit of pooled reserves goes further toward satisfying (1) than does a unit of nonpooled reserves. Benefits for the utility are endogenously determined by its choice of K^p and exogenously determined by other utilities' choices of K^o . The values of K^p and K^o are measures of the commitment to pooling made by the utility and other utilities respectively.

Costs of pooling are comprised of both capital outlays and transaction costs. The major capital outlays are for the necessary transmission lines and generating units shared by pool members. The transaction costs are less tangible. First are the losses of flexibility that are inherent in contractual arrangements. Pool members may be restricted in selling power to nonmembers, while they may be forced to sell to members at low, fixed rates. Members also may be required to abide by pool decisions concerning the timing and construction of new plants. And pool members in one state open themselves to being influenced by regulatory commissions if other states in the the pool crosses state borders.

A second type of transaction cost involves the extensive decision making required for the operation of the pool. How should costs of transmission lines and new, jointly-owned facilities be allocated among members? How should savings from economy energy be allocated? Are environmental regulations being violated? And should small utilities without large generating units be allowed to join a pool? Large utilities argue that their small counterparts enjoy the benefits of pooling without covering a fair share of the costs [18]. These decisions and others are typically made by committees comprised of representatives from each member utility. For example, the New York Power Pool provides for an executive committee, an operating committee, a planning committee, an environmental committee and a public relations committee. The responsibilities of each committee and the interaction among the committees are detailed in the pool agreement. This must be done with care to avoid conflicts and overlapping jurisdictions. Nevertheless, committees generally expend considerable time and effort to reach conclusions, and they incur administrative and operating costs which must be allocated among the members.

Finally, there are enforcement costs of ensuring compliance with pooling agreements. Metering equipment must be installed to measure energy flows, and penalty costs are often assessed when members do not supply the pool with agreed upon reserves. Complete and accurate records must be maintained and made available to all members or their repre-

sentatives. Naturally, as more contingencies are covered by the pool agreement (i.e., as tightness increases), then record keeping and its cost increase.

The pooling costs incurred by a utility depend on its capital commitment and the capital commitment of other utilities to the pool denoted by K^p and K^o respectively, the unit cost of capital, r , and the transaction costs denoted by the shift parameter t . The utility pays $rK + rK^s$ for generating equipment and nonpool reserves. Let $\tilde{r}(K^p; K^o, r, t)$ be the total cost of capital contributed to the pool where $\tilde{r}(K^p; K^o, r, t) > rK^p$. Thus the total cost of pooled capital exceeds the capital cost alone, since committing to the pool gives rise to the transaction costs cited above. In addition, $\partial\tilde{r}/\partial K^o \equiv \tilde{r}_o > 0$ and $\partial\tilde{r}/\partial t \equiv \tilde{r}_t > 0$; greater commitments from other utilities and increases in t increase costs because higher levels of coordination are required. The utility is either dealing with additional members, or the existing members, because they have more at stake, are likely to place more restrictions on the utility. Finally,

$$\partial\tilde{r}/\partial K^p \equiv \tilde{r}_p > r \quad (4)$$

so that the marginal cost of pooled capital exceeds the marginal capital cost, again because of the transaction costs.

III. The Choice to Power Pool

Revenue for the utility is given by $R(K, L) = p(f(K, L))f(K, L)$, provided the utility satisfies constraint (1) with regards to reserves. Reserve capital, K^s and K^d , are not in the revenue function, since on the average only K is needed to generate output. When a portion of K fails or demand unexpectedly increases, then reserves must be used to maintain output and revenue. $R(K, L)$ can be thought of as a level that is maintainable because of reserves, and an accurate statement of revenue provided the reserve constraint is met and α is chosen properly.⁶

Because maintaining reserves is costly and excess reserves would not add to revenue, constraint (1) will be satisfied by equality. Substituting (1) into the pooling constraint, (2), the Lagrangian for the utility's problem becomes

$$L = \Pi + \tau(b(K^p; K^o) - \alpha K + K^s) \quad (5)$$

where τ is a multiplier and $\Pi = R(K, L) - rK - rK^s - \tilde{r}(K^p; K^o, r, t) - wL$. The price of the variable input is w . The Kuhn-Tucker conditions are given by (6) through (16) where function arguments are dropped and subscripts indicate partial derivatives.

$$\tau: \quad \tau[b - \alpha K + K^s] = 0 \quad (6)$$

$$b - \alpha K + K^s \geq 0 \quad (7)$$

$$K: \quad K[R_K - r - \tau\alpha] = 0 \quad (8)$$

$$R_K - r - \tau\alpha \leq 0 \quad (9)$$

$$L: \quad L[R_L - w] = 0 \quad (10)$$

6. The choice of α is a difficult task. Both theoretical [31] and empirical [28] studies have suggested that α is set too high in the U.S. This exacerbates the over-reliability problem shown in this paper.

$$R_L - w \leq 0 \quad (11)$$

$$K^s: K^s[-r + \tau] = 0 \quad (12)$$

$$-r + \tau \leq 0 \quad (13)$$

$$K^p: K^p[-\tilde{r}_p + \tau b_p] = 0 \quad (14)$$

$$-\tilde{r}_p + \tau b_p \leq 0 \quad (15)$$

$$\tau, K, L, K^s, K^p \geq 0 \quad (16)$$

Provided $K > 0$, then either $K^s > 0$, $K^p > 0$, or both are positive in order to satisfy the reserve requirement. Conditions (12)–(16) admit three possibilities which can be best illustrated using (17).

$$rb(K^p; K^o) - \tilde{r}(K^p; K^o, r, t) \quad (17)$$

The second term is the total cost of pool expenditures including both capital and transaction costs. The first term is the expenditure that would have to be made on reserve generation, K^s , in order to provide as much reserves as $b(K^p; K^o)$ does via the pool. Therefore, (17) is the benefits minus the costs of pooling, or net benefits expressed as the cost savings pooling affords over acquiring nonpool generation reserves only.

The partial derivative of net benefits with respect to K^p is the marginal benefit of pooling minus the marginal cost given by

$$rb_p - \tilde{r}_p. \quad (18)$$

From (12)–(16), a negative value of (18) at the optimum implies $K^s = \alpha K$ and $K^p = 0$: marginal benefits of pooling are less than marginal costs at the optimum and the utility does not become a member. Transaction costs are viewed by management as outweighing the potential benefits of sharing reserves, and management is unwilling to sacrifice authority to pool committees.⁷ Alternatively, if (18) is positive at the optimum, then $K^s = 0$ and $b(K^p; K^o) = \alpha K$. Here the utility opts to secure all required reserves through a pooling arrangement. Management does not fear a loss of autonomy in cooperating to the fullest extent possible. The third possibility is an interior solution with (18) equal to zero and $K^s > 0$ and $b(K^p; K^o) > 0$. The utility joins the pool, but also acquires generation reserves. The commitment to the pool is at a level where the marginal benefits and marginal costs of further commitment are equal.⁸ For the latter two solutions where there is a pooling commitment, (4) implies that $b_p > 1$; that is, the utility will pool only if the marginal reliability of pooled reserves is greater than that for nonpooled reserves.

IV. Starting a Power Pool and Threshold Effects

Power pooling as a cooperative venture requires potential members to agree on a variety of issues before a pool can form. Utilities may begin slowly by coordinating along a few

7. In 69% of the pooling agreements reported on by Cramer and Tschirhart[6], the voting rule used by the most important or senior committees is unanimity which indicates a reluctance on the part of the utilities to relinquish authority.

8. A special case is where benefits and costs are linear; that is, $b(K^p; K^o) = K^p b(K^o)$ and $\tilde{r}(K^p; K^o, r, t) = K^p \tilde{r}(K^o, r, t)$ where $b(K^o) > 1$ and $\tilde{r}(K^o; K^o, r, t) > r$. Then it can be shown that the utility chooses either all pooling or no pooling; there is no intermediate solution.

dimensions. If this is beneficial, further coordination follows, whereas if this is not beneficial, the pool flounders and may dissolve. Naturally, each utility is occupied with its self-interests, and will attempt to extract large benefits and low costs. Adopting a hard line in negotiations, however, can mean the loss of the pool and its associated benefits. Thus, the signals sent between the utilities at each stage of negotiations must encourage positive responses that will eventually engender a viable pool.

The model can be used to explore the possible outcomes of negotiations by noting the utility's response to alternative values of K^o . Assuming an interior solution, the pertinent comparative static result can be obtained. Details appear in the Theory Appendix. The reaction process is determined by

$$\partial K^p / \partial K^o = [1/|\mathbf{H}|][\tilde{r}b_{po} - r_{po}][R_{KK}R_{LL} - R_{KL}^2] \quad (19)$$

where $\mathbf{H}$ is a bordered Hessian matrix presented in the Appendix and b_{po} and $\tilde{r}_{po}$ are the cross-partial derivatives of b and $\tilde{r}$ with respect to K^p and K^o . In addition, the Appendix provides conditions for which $|\mathbf{H}| > 0$ and $R_{KK}R_{LL} - R_{KL}^2 > 0$.

The sign of (19) depends on the second bracketed term. If an increase in commitment by other utilities yields an increase in the marginal benefits of pooling that exceeds the increase in marginal costs, then the utility responds with a greater commitment. In this case,

$$rb_{po} - \tilde{r}_{po} > 0 \quad \text{and} \quad (\partial K^p / \partial K^o) > 0. \quad (20)$$

However, if the increase in marginal cost exceeds the increase in marginal benefits, then

$$rb_{po} - \tilde{r}_{po} < 0 \quad \text{and} \quad (\partial K^p / \partial K^o) < 0. \quad (21)$$

The utility will decrease its commitment in response to increased commitments by others. A third possibility is to have

$$rb_{po} - \tilde{r}_{po} = 0 \quad \text{and} \quad (\partial K^p / \partial K^o) = 0. \quad (22)$$

These results are shown graphically in Figure 1 for two utilities. The horizontal axis measures the first utility's commitment to the pool, while a second utility's commitment is measured along the vertical axes. Curves OV and OU are reaction curves. The slope of OV is determined by the sign of (19). The curve is drawn so that (20) holds for $K^o < K^{o'}$ and (21) holds for $K^o > K^{o'}$. This would seem to be a reasonable scenario. For pools to exist at all there must be a region where OV is positively sloped. But there will be a limit on how much any utility needs to commit to a pool. In the extreme, if the other utility builds virtually all the reserve generation (K^o large), then the utility in question would need to make a very small commitment. Therefore, OV should eventually be negatively sloped as K^o increases.

Given a particular value of K^o , curve OV shows the first utility's commitment response. For an initial pool size, say $\bar{K}^o$, the first utility weighs the benefits and costs of joining the pool, and profit maximization calls for a commitment of $\bar{K}^p$. This is communicated to the second utility, which then increases its commitment to $\bar{K}^o$. When the first utility observes $\bar{K}^o$, it decides that a greater commitment is justified given that its marginal benefits at $\bar{K}^p$ exceed its marginal costs for $K^o = \bar{K}^o$. The utility's response is a move to $\bar{K}^p$ according to (20). The arrows indicate that path $a b c \dots e$ will be followed, where e is a stable equilibrium.

Figure 1

Equilibrium and stability are dependent on the shape of the reaction curves, or on the benefits and costs of pooling. Suppose for low values of K^o , $rb_p - \tilde{r}_p < 0$ and the costs of joining a pool exceed the benefits. Then, as shown in Section III, the utility will choose not to join the pool. However, for larger K^o , suppose $rb_p - \tilde{r}_p \geq 0$ and pooling is profitable. This situation gives rise to curves OK^oV and OK^pU in Figure 2 where an unstable equilibrium exists at e' . For any initial offer of $K^o < K^o_t$ both utilities will cycle back to the origin and no pool forms. There is a threshold effect attributable to high start-up costs. The costs may be the large outlays for transmission lines necessary for interconnection; or they may represent the perceived costs of decision making and loss of flexibility that, to a great extent, depend on the attitudes of management. A more independent minded management will perceive costs to be higher and, therefore, be less likely to pool.

The interaction between the utilities depicted in Figures 1 and 2 represents Cournot type behavior. Each utility commits to a level of pooling reserves as if the other utility will not respond with a new commitment. And commitments can be made without providing justification or indicating what future responses might be. This suggests that there is little coordination between the utilities. Neither appears willing to enter into more comprehensive negotiations where both would reveal more information about their operations, and partake in give and take sessions where one utility can more directly influence the commitment of the other. Cournot equilibriums like point e are referred to, therefore, as low coordination solutions indicative of loose pools.

Other behavioral possibilities are illustrated in Figure 3. Isoprofit contours for both

Figure 2

utilities are shown where Π^o (Π^p) is the maximum profit for the utility providing K^o (K^p). By construction, the reaction paths must pass through the left-most and right-most (bottom-most and top-most) points on each contour for the utility providing K^o (K^p). Points along segment $\Pi^p \Pi^o$ form the contract curve in that neither utility can increase profit without the other utility losing profit.

Solutions along the contract curve in Figure 3 imply more tightly coordinated pools than does Cournot behavior and point e . Each utility is abandoning the naive assumption that its counterpart will not react to changes in capital commitment. Instead, they are willing to exchange information to arrive at a mutually agreeable solution. For instance, if the first utility offers $K^{o'}$ on the vertical axis, then $K^{p'}$ is the profit-maximizing response by the second utility. But the first utility would like the second to offer $K^{p''}$. A bargaining process ensues to choose a point along segment ab . Point c is the eventual selection along ab , since from any other point along ab , both utilities can improve their profit. (Of course, the first utility may change the initial offer of $K^{o'}$ during bargaining.)

Power pools can be likened to cartels: although pool members do not share a market, they can increase profits through cooperation as in a cartel. Furthermore, there is an incentive for pool members to cheat, or deviate from the negotiated solution which, again, is similar to a cartel. From point c in Figure 3, the utility has an incentive to cut back from $K^{p''}$ to $K^{p'}$. This could be accomplished, say, by not maintaining adequate spinning reserves for the other utility to tap in an emergency and as specified in a pooling agreement. If the other utility detects the discrepancy, negotiations will likely falter and a low co-

Figure 3

ordination solution result. Even worse, there are instances where negotiations fail so completely that fairly tight pools dissolve.⁹

The failure to attain points like *c* is probably common in the industry. Oliver Williamson offers reasons why oligopolists have difficulty colluding [35]. He constructs a situation where oligopolists consider colluding to maximize joint profits, but where there are no legal barriers to collusion. Since there are no legal barriers to power pooling, Williamson's observations are pertinent here. The first problem he cites is specifying a contract which requires "... an inordinate amount of knowledge about the cost and product characteristics of each firm, the interaction effects between the decision variables within each firm, and the interaction effects of decision variables between firms" [35, 240–1]. In addition, a wide range of contingent future events must be anticipated if the contract is to be complete. For electric utilities, this means that members must share information regarding demand forecasts, load characteristics, generating capacity, and purchased power from other sources. Then, if members accept one another's information, they must plan for future loads and how best to meet them, how payments should be made for exchanging power, whether wheeling power is an obligation, and how members are to maintain their own and others' equipment. These lists are far from exhaustive, but they are illustrative of the myriad difficulties in negotiating pool agreements. Williamson concludes that elementary bounded rationality is more effective in preventing collusion than are legal barriers. Certainly the loosely connected power industry, where legal barriers to pools are nonexistent, supports this conclusion.

9. This was the case with CARVA in Virginia and the Carolinas and IL-MO in Illinois and Missouri [32]. One of the reasons given for the dissolution of CARVA was the failure to agree on reserve requirements.

Beyond contract specification, Williamson points to several other key problems for colluding oligopolists including: (1) whether parties can agree to reducing output so that joint-profits can be maximized; (2) firms have an incentive to distort their costs when profits are to be distributed; and (3) penalties must be implemented for would-be violators of the collusive arrangement. For utilities in power pools, analogous problems are: (1) whether members can agree to give preferential treatment to other members even when nonmembers offer better opportunities; (2) distorting costs can be advantageous when supplying other members with power; and (3) pool agreements must provide for monitoring member reserve levels and must specify a penalty cost for deficits.

V. Regulatory Considerations

Public utilities in the U.S. are regulated by state governments. To the extent that regulation is effective, restrictions are placed on the utilities' decision making. A utility that operates entirely within a single state only needs to be responsive to a single state commission. But if the utility joins a pool with members in other states, then it becomes indirectly responsive to the commissions in those states. Commissions directly influence the pooling utilities within their state borders; in turn, utilities will account for this influence in negotiations with out-of-state members.

The basic problem is that a utility is a natural monopoly within a geographic area, and this area defines an economic operating region for the utility. Pooling combines the economic operating regions of member utilities into a larger economic operating region. The geographic area covered by the larger region will be determined by the location of urban centers and the presence of boundaries such as international borders. There is a natural economic operating region for a pool analogous to the natural monopoly concept. But the economic operating region will most likely not coincide with the political regions delineated by state boundaries. Thus, pools operate within one set of regions while state commissions operate in a different, overlapping, set of regions. This creates a coordinative quagmire. Pooling utilities will be treated differently as they answer to their own state's commission, versus outside commissions, while commissions are concerned with the welfare of consumers in their state and not neighboring states served by the same pool. And commissions generally do not coordinate efforts with neighboring state commissions which makes an optimum region-wide power system fortuitous at best.

The issue to be addressed here is whether commission activities are supportive of power pooling efforts. There are a myriad of activities which may have some effect, and two of them are considered below. The empirical model in the next section utilizes an index to capture regulatory activities.

First, Breyer and MacAvory cite an example of a lack of coordination among states. "State commissions, each anxious to protect the interests of the home state, may require a level of reserve capacity within the state that is excessive with regard to the system as a whole" [3, 156]. Referring to the model, this commission behavior essentially places a ceiling on K^p and requires that constraint (1) be satisfied with more K^s than the utility might otherwise choose. These restrictions are a direct impediment to pooling ventures.

A second commission activity is rate-of-return regulation practiced by the state commissions. There are many theoretical and empirical papers examining the effect of a

rate-of-return constraint on firm behavior, and it is instructive to append this constraint to the pooling problem. Letting s be the allowed rate-of-return by the commission, the constraint is

$$R(K, L) - wL \leq s(K + K^s + K^p) \quad (23)$$

where, following the literature, s is assumed to be greater than r but less than the unregulated monopolist's rate-of-return.¹⁰ Using λ as the multiplier on (23), the Kuhn-Tucker conditions with respect to K^s and K^p are

$$K^s: K^s[-r + \lambda s + \tau] = 0 \quad (24)$$

$$-r + \lambda s + \tau \leq 0 \quad (25)$$

$$K^p: K^p[-\tilde{r}_p + \lambda s + \tau b_p] = 0 \quad (26)$$

$$-\tilde{r}_p + \lambda s + \tau b_p \leq 0. \quad (27)$$

Assuming an interior solution $K^s, K^p > 0$, this regulated solution can be compared with the unregulated interior solution. Recall for the unregulated case, an optimum requires

$$rb_p - \tilde{r}_p = 0. \quad (28)$$

For the regulated utility from (24)–(27)

$$rb_p - \tilde{r}_p = \lambda s(b_p - 1) > 0. \quad (29)$$

Assuming the regulatory constraint is binding and $\lambda > 0$, then the inequality in (29) follows from (4), and (25) and (27) satisfied as equalities.¹¹

From the second-order conditions in the Appendix,

$$rb_{pp} - \tilde{r}_{pp} < 0. \quad (30)$$

Results (28)–(30) imply that the unregulated firm chooses a greater K^p than does the regulated firm. Although pooling capital is more efficient in satisfying the reliability constraint, it contributes less to the rate base. Consequently, the utility is biased away from pooling by rate-of-return regulation.

This result holds for all values of K^o : thus, in Figure 3, curve $OU(OV)$ shifts down (left) and the pool under regulation is more loose. If the utilities on the axes are in neighboring states where one is regulated and one is not, both are influenced by the regulating state. The bias against pooling means that each utility is not minimizing the cost of maintaining reserve requirements. This is not to say that each utility is being overly reliable, since it is maintaining an availability of no more than αK which is presumably optimal. However, the pool as a whole comprised of the utilities in a particular region is

10. Note that the net operating revenue on the left-hand side of (23) does not include a term for the cost $\tilde{r}(K^p, K^o, r, t)$. This is because part of the cost, rK^p , is treated in the same way as rK and rK^s which also do not appear; and the other part represents transactions costs as described earlier which will not be recognized as costs by the commission and cannot, therefore, be included.

11. It is easy to show that a necessary condition for the regulated utility to pool ($K^p > 0$) is that $b_p > 1$; that is, the marginal reliability from pooled reserves must exceed that of nonpooled reserves. The implication is that in spite of a return to capital constraint, the utility will not rate-base pad by employing unproductive capital. This is consistent with Zajac's [37] results.

being overly reliable. Costs could be decreased without a loss in reliability by each utility increasing K^p and decreasing K^s . This bias is a more subtle result of rate-of-return regulation than the familiar Averch-Johnson over-capitalization bias, since it is observable only at the regional level and not at the firm level.

VI. Testing the Model

Testing the model is essentially a matter of estimating the firms' input demand for pooled capital. The theory illustrates that this demand is a function of input prices, capital contributed by other pool members, transaction costs, technological benefits of pooling capital, and regulatory activities. Accordingly, input demand is estimated using the usual input prices, but also using pool oriented variables that capture the behavioral aspects of pooling decisions. The dependent variable and the independent variables with the expected signs on their coefficients are as follows:

Dependent Variable

The theory separates pooled capital from nonpooled capital, and it is the demand for the former that is to be estimated. The measure of pooled capital used is the percentage of a firm's total kilowatts of generating capacity that exists in plants which are jointly owned with other pool members. These percentages range from 0 to 72.

Input Prices

Capital, labor, and fuel are the three major inputs for electric utilities, and all three of their prices are used in the estimation. The labor and fuel prices are represented above by w , and from the Theory Appendix the expected sign on their coefficients is zero. Labor and fuel input price changes do not alter the benefits and costs of pooled capital. This is not to say that the firm's choice of capital, K , is independent of these prices; but once capital is chosen, the portion of that capital which will be jointly owned is independent of these prices. However, as also shown in the Theory Appendix, the sign on the price of capital is ambiguous. This follows because an increase in the price of capital, on the one hand, encourages the firm to meet its reserve requirements through greater pool commitments, since, by (3), pooled capital contributes more to satisfying reserve requirements than does nonpooled capital. But, on the other hand, an increase in the price of capital discourages the firm from further pooling if the marginal cost of pooling reserves increases.

Capital Contributed by Pool Members

Denoted by K^o in the theory, this variable is measured for each firm as the total kilowatts in the firm's pool that are jointly owned minus the firm's share of this total. This captures the capital contribution of other firms. As (20)–(22) and Figures 1–3 demonstrate, the expected sign on this variable depends on the marginal benefits and costs of further commitments and the interactions among the firms during negotiations. As argued in Cramer and Tschirhart [5; 6], pools tend towards looseness and low coordination. Accordingly, the expected sign is positive as in (20).

Transaction Costs

As shown in the Theory Appendix, increased transaction costs will discourage pooling. Two measures of transaction costs are used. First is the number of firms in a pool. As the number increases, negotiations become more difficult and pooling is discouraged. This variable will be the same across firms in the same pool. Second, a dummy variable is used to distinguish between firms that market both gas and electricity and firms that market electricity only. The former are expected to have more complex internal hierarchies and greater management diversity which result in increased transaction costs. Thus, gas and electric firms are expected to pool capital to a lesser degree.

Technological Benefits

The function $b(K^P; K^O)$ was used above to capture the technological benefits a firm enjoys in sharing capital with pool members. These benefits depend, in part, on the relative sizes of the member firms. As alluded to earlier, Kahn asserts that large firms are reluctant to pool with small firms. This is tested with a measure of the firm's size in kilowatts divided by the average size of the pool members. A negative sign would support the assertion. Further, to test whether firms are more likely to share capital when the pool members are diverse in size versus similar, the standard deviation of the pool members' sizes divided by the mean size is used. As with the number of firms in a pool, this variable is also the same across firms in a given pool.

Regulatory Activities

There are numerous activities engaged in by state commissions that may influence a firm's decision to share capital. Several of these are discussed in Section V. Rather than single out any one activity, an index of six different activities is used. The index encompasses: (1) allowed rate of return; (2) regulatory lag; (3) whether historical or future test year is used in hearings; (4) whether construction work in progress is allowed in the rate base; (5) whether benefits from investment tax credits and accelerated depreciation are flowed through; and (6) whether an automatic adjustment clause is used. More detail regarding this index is given by Dublin and Navarro [7]. Using the index, states are characterized according to the favorability of the regulatory climate from the firms' perspective. A dummy variable is used to distinguish those firms operating in a "very favorable" climate from all other firms. Nineteen percent of the firms in the sample fall into the former category. Very favorable climates are expected to discourage pooling capital. The principle reason for firms to pool is to enjoy cost savings. Firms operating in very favorable climates have less incentive to save costs *by pooling*, because commissions respond favorably to the firms' requests in other areas. These firms need not seek the more creative cost savings practices available in pools, especially when they engender avoidable transactions cost. Moreover, encouraging pooling is not among the six criteria in the index, and historically, commissions have not been active along these lines. Therefore, the very favorable climate does not imply that power pools are encouraged.

Public versus Private

About ten percent of the firms in the sample are publicly owned, and a dummy variable is used to distinguish them from private firms. Because the theory assumes profit-maximizing

behavior usually associated with private firms only, no definitive expectation follows on the sign of this variable.

VII. Regression Results

In order to test the above contention that a firm's proportion of pooled capital depends on input prices, the amount of capital contributed by other pool members, transaction costs, technological benefits, and regulatory activities, ordinary least squares (OLS) estimates were computed for the following equation:

$$\begin{aligned} PJKW = & \beta_0 + \beta_1 PL + \beta_2 PF + \beta_3 PK + \beta_4 K^o + \beta_5 NOF + \beta_6 GAED \\ & + \beta_7 RSF + \beta_8 SDM + \beta_9 VFD + \beta_{10} PPD \end{aligned} \quad (31)$$

where:

$PJKW$ = the percentage of the firm's capital which is contributed to the pool, i.e., which is jointly owned

PL = the price of labor

PF = the price of fuel

PK = the price of capital

K^o = the total amount of capital contributed to the firm's pool by all other firms in that pool

NOF = the number of firms in the pool in which the firm belongs

$GAED$ = a gas and electric dummy variable where:

$$GAED = \begin{cases} 1 & \text{if the firm is a gas and electric utility} \\ 0 & \text{if the firm is only an electric utility} \end{cases}$$

RSF = the relative size of the firm, i.e., the size of the firm in relation to the mean firm size in the pool

SDM = the standard deviation of the pool members' sizes divided by the mean size

VFD = a very favorable dummy where:

$$VFD = \begin{cases} 1 & \text{if the firm is located in a state with a "very favorable regulatory climate"} \\ 0 & \text{otherwise} \end{cases}$$

PPD = a public or private dummy variable where:

$$PPD = \begin{cases} 1 & \text{if the firm is publicly owned} \\ 0 & \text{if the firm is privately owned} \end{cases}$$

All variables are assumed to influence $PJKW$ in a linear fashion.¹²

12. This assumption was tested using the log of likelihood function statistic. Linear-linear and linear-log functional forms were compared and this statistic was maximized using the linear-linear form. Since $PJKW$ took on the value of zero for some firms a double log form could not be tested. In addition, we suspected some form of heteroscedasticity. However, all attempts to identify the correct form met with little or no success. The various specifications of heteroscedasticity we used yielded little if any improvements when generalized least squares (GLS) estimates were calculated. Even though we still suspect some form of heteroscedasticity it doesn't appear to be a major problem.

Table I

Dependent Variable	<i>PJKW</i>		
Number of observations	83		
Sum of squared residuals	1.00053		
R-squared	.544		
Adjusted R-squared	.480		

	Estimated Coefficient	t- Statistic	Observed Significance Level
Constant	.306E-1	.981	.329
<i>PL</i>	.125E-3	.519	.605
<i>PF</i>	-.393E-5	-.446	.656
<i>PK</i>	.383E-4	1.053	.295
<i>K</i> ^o	.128E-9	1.835	.071
<i>NOF</i>	-.357E-2	-2.035	.045
<i>GAED</i>	-.740E-1	-2.522	.014
<i>RSF</i>	-.401E-1	-2.093	.039
<i>SDM</i>	.105	2.334	.022
<i>VFD</i>	-.103	-2.565	.012
<i>PPD</i>	.290	3.924	.0001

Using all available information for 1980, data was collected for 83 firms in the Western, South Central, North Central, and Northeast regions. Data on jointly-owned capital for firms in the Southeast region was unavailable. Omitting this region should not significantly affect the results of the model, because when (31) was estimated with regional dummy variables included, the coefficients on these variables were highly insignificant. More complete information on how the variables were constructed and on the data sources is given in the Data Appendix.

The results of estimating (31) are summarized in Table I. The statistics suggest that (31) is consistent with the above theoretical model. All non-price (or behavioral) variables are significant at the .95 level of confidence or greater except for *K*^o which is significant at the .93 level of confidence.¹³ Moreover, these variables all have the correct sign as suggested by the theory. The fact that the input price variables are insignificant is also consistent with the theoretical model.

Of particular interest is the variable *K*^o; the amount of capital contributed to the pool by all other firms. Following the theoretical results, the positive and highly significant sign on this variable indicates that existing pools tend towards looseness. The highly significant sign associated with *VFD* suggests that regulatory agencies could be instrumental in reversing this trend toward looseness and in fostering a more optimal pooling situation. As expected the signs of both *NOF* and *GAED* are negative and highly significant affirming the contention that transaction costs discourage pooling.

The assertion made by Kahn that large firms are reluctant to pool with small firms is

13. This is to say that the observed significance level for the nonprice variables is .05 or less except for *K*^o whose observed significance level is .071. For a more detailed explanation of observed significance levels, or prob-values, see Wonnacott and Wonnacott, pg. 90.

borne out in the result that RSF is negative and significant up to the .96 level of confidence. This also suggests that the smaller a firm is relative to the average size firm in a pool, the greater the technological benefits that firm can enjoy by joining a pool. That is, through pooling small firms can benefit from economies to scale which on their own they are not able to realize. Larger firms, on the other hand, can benefit from economies to scale on their own, and they perceive pooling with smaller firms as not yielding benefits.

Finally, the fact that PPD is positive and significant up to the .999 level of confidence suggests that publicly owned firms are more apt to offer a greater degree of commitment towards pooling than privately owned firms.

VIII. Conclusions

Power pools afford an opportunity to study the interactions of monopolists as they contract among themselves to enhance profits. By sharing inputs they can lower the production costs of given output levels. But why, given these recognized, well-documented benefits, has the power industry not become more integrated? The reason is that there are also substantial transaction costs involved in pooling which utilities weight against the benefits. Transaction costs are not generally considered in studies of pooling opportunities; but they are very real costs which the individual utility confronts. The theoretical model in this paper captures these costs, and analytically characterizes the utility's optimum level of pooling commitment. The results are supportive of Williamson's work on the difficulty of contracting between firms. That is, even in the absence of legal barriers to cooperation, and regulatory impediments aside, firms have difficulty establishing pools.

The empirics lend support to both Kahn's assertion that large firms are reluctant to pool with small firms, and to Cramer and Tschirhart's hypothesis that U.S. pools tend to be loosely coordinated. In addition, several policy implications emerge from the analysis with regards to further coordination. First, regulatory commissions can be instrumental in coordination efforts. Their activities to date have not been aimed at encouraging or discouraging coordination; nevertheless, the regulatory environment has had a significant influence on pools. Interstate cooperation among regulatory authorities is needed to encourage pooling and obtain region-wide solutions to region-wide problems.

Second, the transaction costs of pooling, $\tilde{r}(K^P; K^O, r)$, need to be reduced wherever possible. As the number of firms in a pool increases, the time and effort spent in negotiating pool agreements increase. This follows from the empirics and is underscored by interviews with public utility executives where Breyer and MacAvoy find that "... bargaining over how to divide the potential gains from coordination ... has not worked well" [3, 108]. Methods of allocating the gains should be acceptable to all member utilities. This can be likened to a game where players are receiving payoffs, and acceptability requires the payoffs to be in the core of the game. By way of example, suppose the pool members exchange economy energy and must allocate the savings in generation costs among themselves. One approach used is the high-low method whereby utilities selling energy are matched with those buying energy according to the spreads between the seller's cost and the buyer's value. The highest value is matched with the lowest cost, the second highest value with the second highest cost, etc. Without difficulty, one can construct numerical

examples where this approach yields allocations that are not in the core.¹⁴ Consequently, member utilities have incentives to participate in nonpool transactions. These outcomes can be avoided by using appropriate allocation methods and thereby removing an impediment to pooling by lowering transaction costs.¹⁵

Finally, Christensen and Green examined the available cost savings of coordination and found that the "... savings from increased coordination have proved to be illusory" [4, 152]. This suggests that the benefits of coordination may not be as large as others have claimed, thereby explaining loose coordination.¹⁶ This paper offers alternative explanations for loose coordination: transaction costs and unfavorable regulatory environments.

Theory Appendix

Assuming an interior solution to the unregulated firm's maximization problem so that Kuhn-Tucker conditions (7), (9), (11), (13), and (15) are satisfied by equality, comparative static results can be obtained (Takayama [27, 153]). The comparative-static equation in matrix form is

$$\mathbf{H}\mathbf{V} = \mathbf{P} \quad (32)$$

where $\mathbf{H}$ is the bordered Hessian

$$\mathbf{H} = \begin{bmatrix} \gamma & K & L & K^s & K^p \\ 0 & -\alpha & 0 & 1 & b_p \\ -\alpha & R_{KK} & R_{KL} & 0 & 0 \\ 0 & R_{LK} & R_{LL} & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ b_p & 0 & 0 & 0 & \gamma b_{pp} - \tilde{r}_{pp} \end{bmatrix}$$

and $\mathbf{V}^T = [(\partial\gamma/\partial K^o), (\partial K/\partial K^o), (\partial L/\partial K^o), (\partial K^s/\partial K^o), (\partial K^p/\partial K^o)]$ and $\mathbf{P}^T = [-b_o, 0, 0, 0, \tilde{r}_{po} - \gamma b_{po}]$.

Sufficient conditions for a maximum are that $|\mathbf{H}^4| < 0$ and $|\mathbf{H}| > 0$ where $\mathbf{H}^4$ is formed by deleting the last row and column of $\mathbf{H}$. Thus

$$|\mathbf{H}^4| = -(R_{KK}R_{LL} - R_{KL}^2) < 0 \quad (33)$$

$$|\mathbf{H}| = -(\gamma b_{pp} - \tilde{r}_{pp})(R_{KK}R_{LL} - R_{KL}^2) > 0. \quad (34)$$

Diminishing returns to revenue is assumed for both inputs ($R_{KK} < 0$ and $R_{LL} < 0$) and along with (33) this implies a strictly concave revenue function. For (34) to hold it must be that

$$\gamma b_{pp} - \tilde{r}_{pp} < 0 \quad (35)$$

14. See Cramer and Tschirhart [6] for a numerical example and more detail.

15. Some appropriate methods include game-theoretic solutions such as the Shapley value and the nucleolus. See, for example, Hamlen, Hamlen, and Tschirhart [16]. The nucleolus always yields a core solution when the core exists. The structure of economy energy exchanges ensures core existence.

16. However, Christensen and Green did not consider the increased reliability that may have been afforded by pooling which could bias downward their estimates of cost savings. Huettner [17] updates their study and investigates firm scale economies with pooling variables included.

or that the net benefit function given by (17) is strictly concave at the optimum. In the text, (17) is assumed to be a strictly concave function for all K^p .

Applying Cramer's Rule to (32) yields (19). Other comparative static results above include

$$\partial K^p / \partial r = [(b_p - \tilde{r}_{pr}) / |\mathbf{H}|] [R_{KK} R_{LL} - R_{KL}^2] \quad (36)$$

$$\partial K^p / \partial w = 0 \quad (37)$$

$$\partial K^p / \partial t = -(\tilde{r}_{pt} / |\mathbf{H}|) [R_{KK} R_{LL} - R_{KL}^2]. \quad (38)$$

The sign of (36) is ambiguous; the sign of (38), however, is negative by (33), (34), and by assuming that increased transaction cost increases the marginal cost of pooling capital.

For the regulated firm, the bordered Hessian becomes

$$\mathbf{H}_R = \begin{bmatrix} \lambda & \gamma & K & L & K^s & K^p \\ 0 & 0 & s - R_K & w - R_L & s & s \\ 0 & 0 & -\alpha & 0 & 1 & b_p \\ s - R_K & -\alpha & R_{LL}(1 - \lambda) & R_{KL}(1 - \lambda) & 0 & 0 \\ w - R_L & 0 & R_{LK}(1 - \lambda) & R_{LL}(1 - \lambda) & 0 & 0 \\ s & 1 & 0 & 0 & 0 & 0 \\ s & b_p & 0 & 0 & 0 & \gamma b_{pp} - \tilde{r}_{pp} \end{bmatrix}$$

where $(1 - \lambda) > 0$ from $K^s > 0$, (25), and $r < s$. Moreover, assuming a binding regulatory constraint and $\lambda > 0$, then $w - R_L = 0$ from the Kuhn-Tucker condition with respect to L which is

$$(R_L - w)(1 - \lambda) = 0. \quad (39)$$

Second-order sufficient conditions for a maximum require $|\mathbf{H}_R| > 0$ and $|\mathbf{H}_R^5| < 0$ where $\mathbf{H}_R^5$ is $\mathbf{H}_R$ with the last row and column deleted. Thus,

$$|\mathbf{H}_R^5| = R_{LL}(1 - \lambda)(s\alpha + s - R_K)^2 < 0 \quad (40)$$

$$|\mathbf{H}_R| = s^2(b_p - 1)^2(R_{KK}R_{LL} - R_{KL}^2) + R_{LL}(s\alpha + s - R_K)^2(\gamma b_{pp} - \tilde{r}_{pp}) > 0 \quad (41)$$

where the inequalities hold for reasons given above.

Data Appendix

Further definitions and reference numbers of relevant sources.

PJKW: Amount of kilowatts of capacity the firm jointly owns divided by the firm's total kilowatts of capacity. See also section IV; [33; 34].

PPD: [33; 34].

NOF: [10; 11; 12; 13; 14].

SDM: [10; 11; 12; 13; 14].

RSF: The firm's total kilowatts of capacity [33; 34] divided by the mean total kilowatts of capacity in the firm's pool [10; 11; 12; 13; 14].

- VFD*: For a definition of "favorable regulatory climate" refer to section VI above as well as Dublin and Navarro [7].
- PKO*: Total kilowatts in the firm's pool that are jointly owned [10; 11; 12; 13; 14] minus the firm's share of this total [33; 34].
- PL*: Total labor expenditures divided by the sum of (a) the number of full time employees multiplied by 40 and (b) the number of part time employees multiplied by 20 [33; 34].
- PF*: Total fuel expenditures divided by the total BTUs burned [32].
- PK*: The rate at which the firm could borrow funds equal to the most recently issued long term debt with twenty or more years to maturity [20; 21] multiplied by an index of electric utility construction costs for the region in which the firm is located. These indices are as follows for 1982: North Atlantic = 220, South Atlantic = 225, North Central = 226, South Central = 234, Plateau = 235, and Pacific = 243. The index = 100 in 1973 [8].

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