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ANTI-COMPETITIVE PATTERNS OF JOINT BIDDING FOR OFFSHORE PETROLEUM LEASES

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October 28, 1977

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OF
JOINT BIDDING FOR OFFSHORE PETROLEUM LEASES

by

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Sponsored by the
U.S. Geological Survey
Grant No. 14-08-0001-G-419

ABSTRACT

This paper develops a model of joint venture formation and performance in the offshore petroleum leasing market. The model is designed to explain the behavior of firms acting on the incentive to circumvent competition via cooperative action. The analysis focuses on strategic differences between admitting small versus large firms to a joint venture group, the (in)feasibility of alternative distributions of profits among the venture partners, and the competitive impact of the joint venture on the outcome of the lease sale.

ACKNOWLEDGMENT

The U.S. Geological Survey served as a helpful and cooperative sponsor for this research. I owe special thanks to Holly Tomlinson, whose persistence and dedication proved to be an invaluable research aid.

However, the views and conclusions contained in this paper are those of the author, and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

ANTI-COMPETITIVE PATTERNS OF JOINT BIDDING FOR OFFSHORE PETROLEUM LEASES

The Secretary of the Department of the Interior is empowered to confer on private individuals and firms the right to explore for, develop, and produce petroleum on the Outer Continental Shelf (OCS) of the United States. Lease auctions are held periodically to allocate these rights in regions of the OCS which hold particular geological promise. In almost every case the method of auction used is sealed bonus bidding, wherein the party submitting the highest bid is declared the winner and is committed to pay the government the full amount of the stated bid.

A typical lease sale includes numerous individual tracts. In the 36 lease sales held through the end of 1975, a total of 2,636 separate offshore tracts have been leased by the Secretary, in exchange for total bonus payments exceeding $15.8 billion. (See Table 1). The total areal extent of leased properties is approximately 19,400 square miles, the average size of an individual tract being 7.4 square miles. The total number of bids received in the 36 sales exceeds 9,000. Each bidder may bid on as many tracts as it desires. Although fewer than four parties typically enter the competition for an individual tract, many bidders actually participate in each sale, scattering their bids widely among the offered tracts.

Joint bidding occurs whenever two or more independent parties form a cooperative venture to acquire and develop offshore acreage. In recent years more than half the total number of bids received by the Secretary have been tendered jointly. The competitive impact of joint bidding is a major concern of OCS leasing policy. The positive effects of joint

TABLE 1

SUMMARY OF FEDERAL OCS LEASE SALES; 1954-1975[a]

Number of sales	36
Average number of tracts leased per sale	73
Average area of lease rights	7.36 sq. miles
Total bonus paid	$15.88 billion
Average bonus paid per lease	$ 6.02 million
Total number of bids	9,289
Average number of bidders per lease	3.5

[a]Source: U.S. Geological Survey.

bidding, which are fairly well understood, provide the rationale for its continued practice. Joint bidding is believed to help smaller firms overcome substantial barriers to entry in the OCS market. Susan Wilcox finds that joint bidding has been the predominant mode of entry since the inception of offshore leasing in 1954. Walter Mead points out that prohibitive risk-bearing requirements, along with the influences of capital and technological barriers, have contributed to the formation of joint ventures. Joint bidding clearly facilitates a more diversified resource portfolio than could otherwise be attained by an individual firm. However, Darius Gaskins and Barry Vann argue that many firms who join in are sufficiently large and diversified to minimize this benefit. James Ramsey, on the other hand, argues that the marginal portfolio position taken even by large firms requires diversification. In addition to the direct portfolio composition effect, formation of a joint venture enables the participants

to diversify sources of information regarding the geologic and economic potential of specific tracts. Douglass Klein demonstrates how the resulting reduction in uncertainty regarding the tract's value may have a positive influence on the price paid to the seller.

The major concern regarding joint bidding is that it may restrict competition among potential competitors, diminishing the total number of bids received. As summarized by Jesse Markham:

> ... where joint bids are simply substituted for independent solo bids, they reduce the total number of bids. That is, if all the participating firms bid individually on a given tract in any event, joint bids would simply be substituted for a larger number of independent solo bids. If the resulting reduction in total bids is substantial, competition may be adversely affected.

This argument is correct as stated. However, its simplicity invites further analysis of the competitive forces involved. First, we must examine the proposition that joint bids simply displace a greater number of potential bids. Second, we need to qualify the suggestion that the basic impropriety of joint bidding derives from its facility to reduce the total number of bids received. In fact, bid attrition is a sufficient, but not necessary condition for the anti-competitive impact of joint bidding. This point is clarified by a simple example.

Consider two firms which may bid on two tracts. We assume that individually each firm would bid on one of the two tracts--the choice of a specific tract being left to the firm's discretion. Regardless of the tract chosen, each firm bidding separately would suffer a 50% probability of meeting the other in competition. Alternatively, the firms might pool

their capital and bid jointly on both tracts, thereby circumventing the threat of competition. In either event, the total number of bids tendered is two. Apparently, it is the configuration or clustering of bids, rather than their number, that is significantly influenced by the formation of the joint venture. This distinction remains largely unnoticed in the debate over joint bidding.

Markham was the first to test empirically the hypothesis that joint bids displace a larger number of solo bids. Examining data from a 1968 lease sale, he finds no statistical support for this proposition. Elmer Dougherty and John Lohrenz confirm this result in the light of data covering the entire history of offshore bidding: 1954-1976. Wilcox concurs with this finding on the basis of 1954-1973 data, except as it relates to the bidding activity of the eight largest oil companies.[1] Overall, economists have been able to muster only very weak support in favor of the anti-competitive effect.

The purpose of the present paper is to reexamine the theoretical basis for the alleged anti-competitive influence, and to identify likely patterns of joint bidding among firms that are motivated by the incentive to circumvent inter-firm competition. To this end we develop a normative model of joint venture formation and performance in an industry composed of heterogeneous firms.

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[1] Wilcox rejects the null hypothesis that joint bids involving two or more of the "major" companies do not reduce competition. However, the statistical test employed is seriously biased in favor of rejection, as demonstrated by Dougherty and Lohrenz.

To isolate the anti-competitive influence of joint bidding, the model is constructed on the assumption that firms are risk-neutral and of sufficient size (relative to tract value) to overcome the indivisibility barrier to entry. Diversification and entry motives for joint bidding are thereby ruled out. The only incentive for joint bidding is the potential for reducing the number of anticipated competitors by combining with the opposition. The reduction in number of anticipated competitors to be faced by the venture group depends upon its size and membership composition. In general, as the group encompasses additional firms, its deleterious effect on potential competition is strengthened. However, the cost of arranging the venture and implementing the joint bid is also a function of group membership. Organizational costs are a burden on participating firms and must be subtracted from the gains due to cooperative action. The objective of each firm is to identify the "optimal" group--that which offers it the highest net gain--and to see that the venture is arranged.

Of course, the net gain to each firm depends on the distribution of joint venture profit among its members. A natural rule would be for members to share profits in proportion to their participatory working interests. Even under this convention, however, what appears as an optimal group to one firm may not appear so to other prospective members who find themselves facing different opportunities and/or circumstances. A venture is feasible only if all prospective members agree that it is in their interest to join. It must often happen that individual firms are left to pursue second- and third-best alternatives because the ventures they see as optimal are not feasible. To further complicate the

picture, we note that ventures which appear infeasible on a working interest basis (proportional distribution of profits), might be rendered acceptable to all by the judicious use of side payments. In general, the types of behavioral hypotheses we are able to shape regarding venture formation will depend on the types of profit distribution schemes that find use in the industry.

In the next two sections we investigate specific aspects of venture formation and performance. In the first section our view is restricted to ventures that are feasible under a "working interest" distribution formula. Later the significance of over-riding side payments is discussed.

I. Venture Formation Without Side Payments

A. The Basic Model

Consider the sale of T petroleum tracts offered to an industry which consists of J firms. Let J_1 of these be large firms of size S_1, and J_2 (= J - J_1) be small firms of size S_2. At this point the unit of size is immaterial, S_1 and S_2 may be taken as any uniform measure of the scale of operations of the two types of firms.

For convenience we assume the tracts are indistinguishable; each tract holds the same promise of future development and production.[2] The tracts are to be auctioned separately on the basis of sealed tenders. Each firm may bid individually or by joint venture on whatever subset of tracts it desires. We denote by L_j the total number of bids tendered

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[2] The case of heterogeneous tracts is treated by James Smith, chapter 6.

by the j^{th} firm. The firm's working interest share in its i^{th} bid is represented by s_{ji} $(0 \leq s_{ji} \leq 1)$, for $i = 1, \ldots, L_j$.

A key assumption that will be maintained throughout is that the j^{th} firm's bids collectively impute to it equity bidding interest in exactly t_j petroleum tracts, where t_j is proportional to firm size:

$$(1) \qquad \sum_{i=1}^{L_j} s_{ji} \equiv p \cdot S_j \equiv t_j \ , \qquad \text{all } j;$$

... where p is the factor of proportionality.

This is indeed a strong assumption; however, it agrees in sprit with the observed tendency of large firms to participate more actively in OCS lease sales than do small firms. This tendency may be attributed, in part, to imperfections in the market for OCS venture capital which limit each firm's bidding activity to the extent of funds available internally--which we may roughly approximate as proportional to firm size.[3] At a more abstract level, we may think of condition (1) as describing the steady-state behavior of an industry in which all firms are growing at the same proportionate rate. As Kenneth Dam points out, the Interior Department study which precipitated the partial ban on joint bidding among major oil companies is predicated essentially on the steady-state hypothesis. The present analysis is consistent in this respect with Interior's framework for policy evaluation. Moreover, for most of our analysis, condition (1) is

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[3] The simple correlation between the scope of a firm's bidding activity and the firm's size ranges from 0.55 to 0.84 in the five OCS sales treated by Smith, chapter 4. The average correlation is 0.72.

stronger than needed. What is required is that each firm's equity bidding interest in petroleum resources be fixed independently of the pattern of joint venture formation. There is no need for the equity interest to be proportional to firm size.

The operational significance of condition (1) is that it fixes the total number of bids placed by the industry, K_I. To see this we write:

$$K_I = \sum_{j=1}^{J} \sum_{i=1}^{L_J} s_{ji} \; ; \tag{2}$$

which, after substitution from Equation (1) becomes:

$$K_I = \sum_{j=1}^{J} t_j = J_1 \cdot t_i + J_2 \cdot t_2 \, . \tag{3}$$

Thus, the total number of bids tendered by the J firms is independent of the pattern of joint bidding that arises among them. As a result, the anti-competitive influence of joint bidding to be observed in this model is restricted to the "placement" or clustering effect, and does not involve the stronger hypothesis that each joint bid displaces multiple solo bids.[4]

---

[4] To the extent that the total number of bids is diminished by joint bidding, our analysis will understate the anti-competitive impact. However, if contrary to our assumption the practice of joint bidding does influence the extent of individual firms' bidding activity, the effect would appear more likely to be positive. At least two aspects of joint bidding would encourage firms to extend their bidding interests: (1) economies of pre-sale tract evaluation and information exchange among member firms, and (2) diversification economies of joint bidding which render all properties included in the sale more attractive than they otherwise would be. Both factors would be expected to stimulate rather than inhibit individual firms' participation in the lease sale. In this respect, the bias in our analysis, if one exists, is on the side of overstating the anti-competitive impact of joint bidding.

Because tracts are indistinguishable, the bids of each bidding unit (be it an individual firm or a joint venture) are expected, a priori, to be distributed randomly among the T tracts. An observer of the industry would expect to see, on average, n_c bids per tract, where:

$$(4) \qquad n_c = \frac{J_1 \cdot t_1 + J_2 \cdot t_2}{T} \quad .$$

Similarly, a bidding party composed of m_1 large, and m_2 small firms would expect to face $n(m_1,m_2)$ competitors on each tract it pursues, where:

$$(5) \qquad n(m_1,m_2) = \frac{(J_1-m_1)\cdot t_1 + (J_2-m_2)\cdot t_2}{T} \quad .$$

Or, using Equation (4):

$$(6) \qquad n(m_1,m_2) = n_c - \frac{m_1 \cdot t_1 + m_2 \cdot t_2}{T} \quad .$$

The presence of each large firm within the group diminishes competition by t_1/T firms; the presence of each small firm by t_2/T.

The financial performance of the joint venture is related directly to the adverse competitive impact reflected in Equation (6). The expected profitability of bidding against n competitors increases as n is diminished through cooperative action. We can express the expected rent captured by the venture group (m_1,m_2) with a bid in the amount B as:[5]

$$(7) \qquad \text{expected rent } (B|m_1,m_2) = ER[B,n(m_1,m_2)] \ .$$

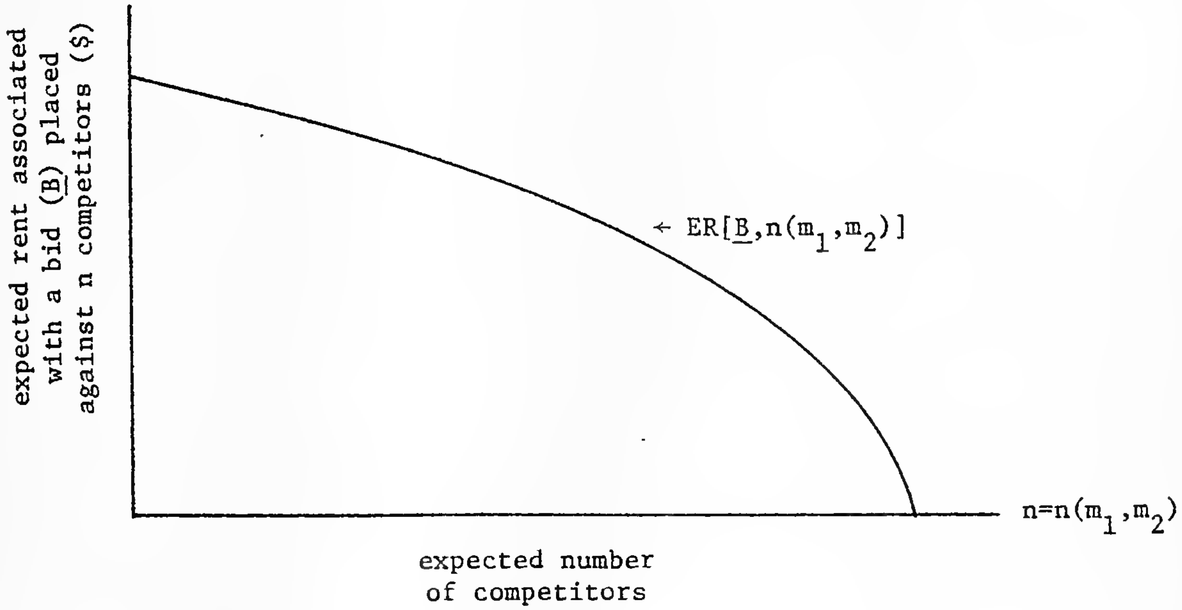
---

[5] By "expected rent" we mean the amount of economic rent captured by the bidding party conditional on the bid being successful, multiplied by the probability the bid will be successful.

The meaning of Equation (7) should be clear. The economic consequences of a bid depend only on the amount of the bid and the number of competitors against which it is matched. The composition of the bidding group is important only as it influences the amount of the bid and the number of competitors to be faced.

Throughout this paper we assume diminishing marginal benefits from eliminating competition. On this assumption, Equation (7) takes the form shown in Figure 1, below.[6]

Figure 1: Expected Rent as a Function of Competition



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[6] We show the form of the relationship between $ER[B,n]$ and n, for arbitrary $B = \underline{B}$. We use the notation: $ER[B,n|B=\underline{B}] = ER[\underline{B},n]$. On intuitive grounds we might expect to observe increasing marginal benefits from eliminating competition, in which case the figure would appear concave with respect to the origin. As it happens, many, but certainly not all of the results reported here are independent of the convexity assumption. The alternative case is explored further by Smith, chapter 6.

Using Equations (6) and (7), we may write:

$$(8) \qquad \frac{\partial}{\partial m_1} ER[B|m_1,m_2] = -\frac{t_1}{T} \cdot \frac{\partial ER}{\partial n} > 0 .$$

Similarly:

$$\frac{\partial}{\partial m_2} ER[B|m_1,m_2] = -\frac{t_2}{T} \cdot \frac{\partial ER}{\partial n} > 0 .$$

Thus, the advantage to bidding in larger groups depends both on the force of competition ($\partial ER/\partial n$), and the relative scope of the bidding interests of prospective group members (t_1/T and t_2/T).

To arrive finally at the net value of forming the group designated (m_1,m_2), we deduct organizational and administrative costs of forming the venture from the value determined in Equation (7). Such costs probably increase at least in proportion to the number of participants, and may depend on the breakdown of group membership between large and small firms. We denote the general form of the organizational cost function as:

$$(9) \qquad \text{organizational cost} = C(m_1,m_2) .$$

Combining Equations (7) and (9), we have the expected net profitability of a bid in the amount B, placed by a group with membership (m_1,m_2):

$$(10) \qquad \pi(B|m_1,m_2) = ER[B,n(m_1,m_2)] - C(m_1,m_2) .$$

B. The Firm's Optimization Problem

Thus far we have done little more than develop some notation to describe the economics of a joint venture bid. We use this in the following paragraphs to specify and solve the firm's optimization problem.

The firm's objective is to select a set of bids which maximize its expected net profit, subject to the constraint that it maintains equity bidding interest in exactly t tracts. For an arbitrary firm this requires the determination of the optimal number of bids, L; their amounts, $(B_1, \ldots, B_L)$; and the percentage working interest in each, $(s_1, \ldots, s_L)$. Using Equation (10), the firm's objective function can be written:

$$\text{(11)} \qquad \max: \sum_{i=1}^{L} s_i \cdot \pi\,(B_i | m_{1_i}, m_{2_i}) \;;$$

$$\text{with respect to: } L, \{s_i\}, \{B_i\}, \{m_{1_i}\}, \{m_{2_i}\} \;;$$

$$\text{subject to: } \sum_{i=1}^{L} s_i = t \;.$$

The solution to this problem is found by first identifying the venture group, (m_1^*, m_2^*), and bid amount, B^*, that maximize the net value of a single bid; and then arranging L^* such bids, where L^* and s_i^* are determined simultaneously to satisfy:[7]

$$\sum_{i=1}^{L^*} s_i^* = t \;.$$

---

[7] The determination of working interest shares, s_i, is a matter of indifference in the present model. Regardless of the firm's negotiated share in the venture, we assume it is able to satisfy its demand for equity oil by entering into the appropriate number of ventures. This result only holds if organizational costs are allocated on the basis of working interest shares. If some fixed level of organizational costs is incurred by group members irrespective of their working interest shares, then the number of joint ventures entered into will not be a matter of indifference. Each firm will be induced to expand working interest shares to reduce the total number of ventures entered. This incentive moves the partners toward a negotiated, perhaps egalitarian solution, and reduces the randomness that might otherwise characterize venture shares.

In other words, the firm's course of action is to determine the parameters of the "optimal" joint venture--$(B^*|m_1^*, m_2^*)$--and to continue forming such ventures until its interest in bidding has been exhausted.

As a special case, assume that organizational costs are the same for large and small firms, and that these costs are proportional to the total number of firms in the group. The cost function becomes:

$$(12) \qquad c(m_1,m_2) = a \cdot (m_1 + m_2) \quad ,$$

. . .where "a" represents unit organizational cost.

In this event no "mixed" ventures will form. Large firms will object to the inclusion of any small firms in their group because the unit cost of eliminating competition from small firms is relatively high. It is always cheaper to eliminate an equivalent degree of large firm competition. We might say the "collusive efficiency" of small firms is relatively low. Consequently, large firms will band together only with other large firms. This compels small firms to associate only with their own kind. We call groups composed exclusively of large firms "primary" groups, and groups composed exclusively of small firms "secondary" groups.

Segregation of firms in primary and secondary groups does not depend on the uniformity of organizational costs. It obtains for any cost differential between large and small firms, so long as the group cost function is additive:

$$(13) \qquad C(m_1,m_2) = a_1 \cdot m_1 + a_2 \cdot m_2 \quad .$$

It is easy to show that large firms exclude small firms whenever their organizational costs are smaller in proportion to firm size than that of

small firms. That is, small firms are excluded if:

(14) $$a_1/S_1 < a_2/S_2 \quad .$$

If the inequality in (14) is reversed, small firms will exclude large firms, and segregation is upheld. The direction of the inequality appears reasonable as shown, so we continue on the assumption that small firms are excluded.[8]

What cost must a primary group pay in order to reduce the level of competition from n_c, the competitive level, to $n°$? To achieve the reduction, m_1° large firms must join the group, where m_1° is determined implicitly [using Equation (5)] by:

$$n^\circ = n(m_1^\circ, 0) = n_c - m_1^\circ \cdot t_1/T \quad .$$

Solving for m_1° explicitly:

$$m_1^\circ = \frac{T}{t_1} \cdot (n_c - n^\circ) \quad .$$

If organizational cost per large firm is a_1 [from Equation (13)], total primary group cost is then:

(15) $$\text{cost}(n^\circ|\text{primary}) = a_1 \cdot m_1^\circ = a_1 \cdot \frac{T}{t_1} \cdot (n_c - n^\circ) \quad .$$

To achieve the same level of competition, a secondary group must incur costs:

(16) $$\text{cost}(n^\circ|\text{secondary}) = a_2 \cdot m_2^\circ = a_2 \cdot \frac{T}{t_2} \cdot (n_c - n^\circ) \quad .$$

---

[8] When side payments are introduced (see the next section) small firms will be permitted to compensate large firms for their (the small firms') collusive inefficiency, and thereby "buy" their way into mixed ventures.

Although it is not obvious from the figure, it is possible to show that the number of firms in the optimal primary group exceeds the number in the secondary group, $m_1^* > m_2^*$. The details of this are left aside.

The case where organizational costs increase more than proportionately due to network diseconomies can be treated analogously. Segregation of firms is maintained because it is still possible to replace smaller firms with their more efficient counterparts without increasing the organizational complexity. The organizational cost functions [e.g., cost $(n|\text{primary})$] become concave in n, but the primary group's curve remains the flatter of the two. The primary group would again face less competition and earn a larger return.[9]

C. Legal Impediments to Venture Formation

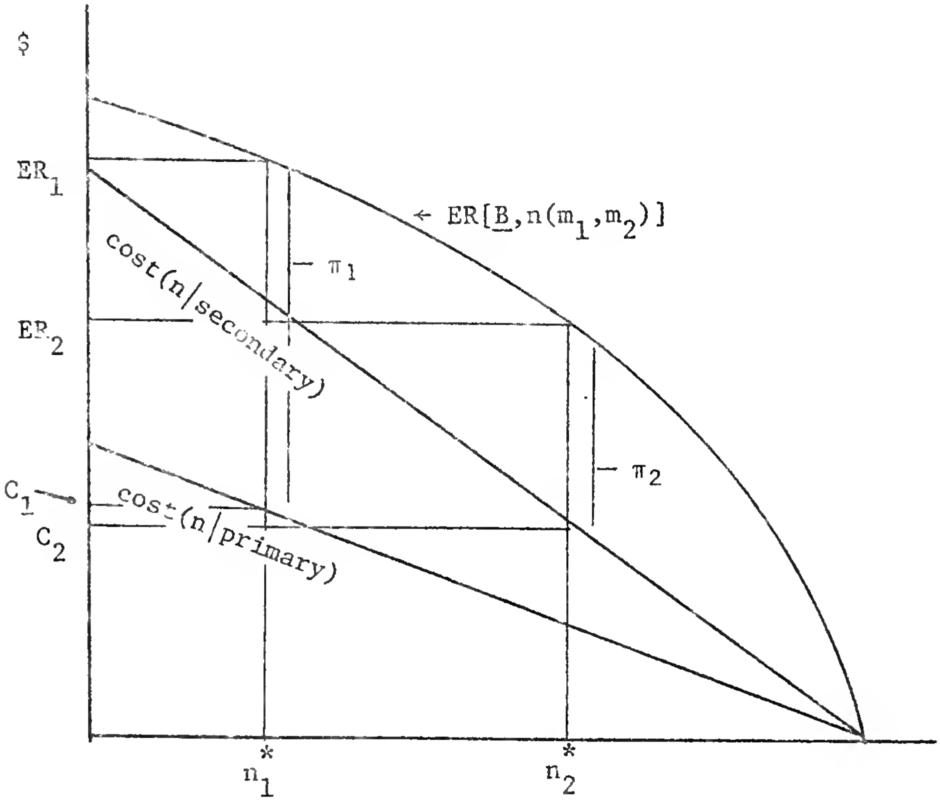
The threat of anti-trust litigation acts as an impediment to the formation of joint ventures that we have not yet discussed. This influence can be introduced in several ways. The most convenient approach is to add implicit "anti-trust costs" to the organizational costs of forming joint ventures. Such costs might reflect the risk of fines, litigation expenses, or simply the loss of goodwill that is suffered by the group membership. We proceed on the assumption that firms perceive these hazards, and confine their activity to those ventures which promise the highest net returns, inclusive of anti-trust penalties.

---

[9] See Smith, chapter 5.

Thus, to achieve any given level of competition, the costs of the primary group are a constant fraction of secondary group costs. Organizational costs for both groups decrease linearly in n°. This situation is charted in Figure 2, below. By inspection, the optimal primary group consists of m_1^* large firms and faces n_1^* anticipated competitors. The optimal secondary group faces more competition, indicated by n_2^*. Because large firms are more efficient at eliminating competition, their profits are larger: $\pi_1 = (ER_1 - C_1)$, compared to $\pi_2 = (ER_2 - C_2)$.

Figure 2: Economics of Primary and Secondary Ventures



expected number of competitors

One possibility is that members of each venture perceive the anti-trust penalty as a fixed charge per unit of competition eliminated by the venture. A secondary group of m firms (which eliminates $m \cdot t_2/T - 1$ competitors) incurs a lower penalty than a primary group of m firms (which eliminates $m \cdot t_1/T - 1$ competitors). A firm tendering a solo bid incurs no anti-trust penalty. Using Equations (4), (9), (15), and (16), we can write the revised organizational cost function as:

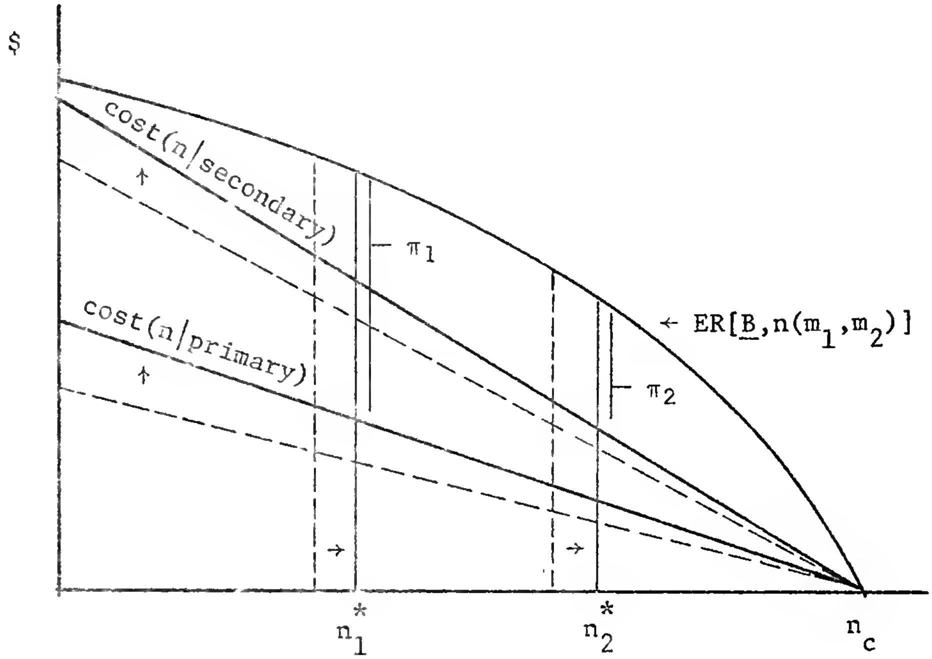
$$\text{(17)} \qquad \begin{aligned} \text{cost}(n|\text{primary}) &= C((n_c - n) \cdot T/t_1, 0) + z \cdot (n_c - n - 1) \\ \text{cost}(n|\text{secondary}) &= C((n_c - n) \cdot T/t_2, 0) + z \cdot (n_c - n - 1) \end{aligned}$$

... where z = the unit anti-trust penalty.

We see that at each point, n, the two cost curves are displaced upward by the same amount. The slope of each curve is incremented uniformly by the factor (-z). The new situation is illustrated in Figure 3, below.

The dotted lines represent the firms' position if they disregard anti-trust and public goodwill factors. The solid lines reflect the internalization of these costs, according to Equation (17). Evidently the threat of a penalty mitigates the anti-competitive influence of joint bidding. Both primary and secondary groups reduce their membership in order to foster additional competition. The degree of adjustment depends upon the size of the penalty. As the diagram is drawn, it would take a sizeable penalty to discourage joint ventures entirely. It is interesting to note that despite the anti-trust penalty, the primary group retains collusive efficiency over the secondary group, and faces fewer anticipated competitors. In order to put small and large firms on an even competitive basis

Figure 3: Impact of Anti-Trust Penalties on Venture Formation



expected number of competitors

it would be necessary to penalize them at differential rates. In terms of effective public policy, this means that anti-trust litigation should be dictated not solely by the degree of anti-competitive impact, but also by the identities of offending parties.

D. Market Outcomes and Bid Clustering

In this section we explore the impact of venture formation on the outcome of the lease sale. Specifically, market bidding patterns are related to the extent of joint bidding among individual firms.

We retain he notation that m_1 large firms make up each primary group participating in the lease sale, and m_2 small firms make up each secondary group. It is immaterial whether these group sizes are determined

by the profit maximizing criterion described earlier (yielding m_1^* and m_2^*), or by some other criterion. Since the industry is comprised of J_1 large and J_2 small firms, we have the following:

$$
(18)\qquad \begin{aligned} \text{number of distinct primary groups} &= J_1/m_1 \quad ; \\ \text{number of distinct secondary groups} &= J_2/m_2 \quad . \end{aligned}
$$

Therefore, the total number of distinct bidding parties which participate in the lease sale equals $J_1/m_1 + J_2/m_2$.[10]

In order to satisfy member firms' objectives regarding resource acquisition [condition (1)], each primary group must tender bids on exactly $m_1 \cdot t_1$ of the T tracts included in the sale. Similarly, each secondary group must bid on exactly $m_2 \cdot t_2$ tracts. Consequently, we have:

$$
(19)\qquad \begin{aligned} p_1 &= \text{prob}\left\{\begin{matrix}\text{specific primary group}\\ \text{bids on generic tract}\end{matrix}\right\} = m_1 \cdot t_1/T \quad ; \\ p_2 &= \text{prob}\left\{\begin{matrix}\text{specific secondary group}\\ \text{bids on generic tract}\end{matrix}\right\} = m_2 \cdot t_2/T \quad . \end{aligned}
$$

The number of "primary" bids received on the generic tract, denoted x_1, is then a binomial variate with probability distribution:

---

[10] Throughout this section we assume that the firms align themselves in stable and distinct groups of the indicated sizes. This assumption could be relaxed to permit alternative forms of inter-venture mingling, with results that are essentially unchanged.

$$\text{prob}(x_1 \text{ primary bids}) = \binom{J_1/m_1}{x_1} \cdot \left(\frac{m_1 \cdot t_1}{T}\right)^{x_1} \cdot \left(1 - \frac{m_1 \cdot t_1}{T}\right)^{T-x_1} ;$$

and expectation:

$$E[x_1] = J_1 \cdot t_1/T .$$

Similarly, the number of "secondary" bids received on the generic tract, denoted x_2, is a binomial variate with probability distribution:

$$\text{prob}(x_2 \text{ secondary bids}) = \binom{J_2/m_2}{x_2} \cdot \left(\frac{m_2 \cdot t_2}{T}\right)^{x_2} \cdot \left(1 - \frac{m_2 \cdot t_2}{T}\right)^{T-x_2} ;$$

and expectation:

$$E[x_2] = J_2 \cdot t_2/T .$$

The expected number of bids received in total ($x = x_1 + x_2$) on a generic tract is:

$$(20) \qquad E[x] = \frac{J_1 \cdot t_1 + J_2 \cdot t_2}{T} = n_c .$$

The average number of bids per tract, E[x] is often taken as a measure of the degree of competition in the lease sale. We can see immediately from Equation (20), however, that the measure is entirely independent of the pattern of joint bidding that arises within the industry. Its value would be the same whether firms joined in a single bidding monopoly or bid completely independently of one another. Consequently, the usefulness of n_c as a measure of competition is limited, as was made clear in the two-firm illustration given earlier.

The variance in the number of bidders per tract is not independent of the pattern of venture formation. It is easy to show that the coefficient of variation equals:

$$\text{(21)} \qquad \frac{\text{std dev }(x)}{E[x]} = (1-r_2)\cdot\left(1-\frac{m_1\cdot t_1}{T}\right) + r_2\cdot\left(1-\frac{m_2\cdot t_2}{T}\right) ;$$

$$\ldots \text{ where } r_2 = \frac{J_2\cdot t_2}{J_1\cdot t_1 + J_2\cdot t_2} = \text{ the share of total bids in the sale that are tendered by secondary groups.}$$

The variance in number of bidders per tract decreases as the degree of joint bidding (measured by m_1 and m_2) increases. Moreover, we can expect the coefficient of variation to decrease as the relative number of large firms participating in the sale (J_1/J_2) increases. This follows directly from Equation (21) and the earlier result that $m_2^* < m_1^*$ (see page 16).

A more informative measure of competition is given by the average number of bids per "active" tract, i.e., tracts receiving one or more bids. It is this set of tracts that actually gets leased, and presumably the transaction price is related to the number of bidders which are involved. In the appendix, we show that the expected number of bids (x) on a generic tract, given that it is active, is given by:

$$\text{(22)} \qquad E[x|\text{active}] = \frac{n_c}{1 - \left[1-\frac{m_1\cdot t_1}{T}\right]^{J_1/m_1} \cdot \left[1-\frac{m_2\cdot t_2}{T}\right]^{J_2/m_2}} .$$

The average number of bids on active tracts is necessarily greater than n_c, due to the likelihood that some of the T tracts included in the

sale will be neglected. We see from Equation (22) that the degree of competition on active tracts is determined by the extent of joint bidding (m_1 and m_2). The function E[x|active] decreases monotonically in both m_1 and m_2.

The expected fraction of tracts which are neglected can also be determined as a function of the degree of joint bidding (see Appendix):

$$(23) \qquad E[\text{fraction neglected}] = \left[1 - \frac{m_1 \cdot t_1}{T}\right]^{J_1/m_1} \cdot \left[1 - \frac{m_2 \cdot t_2}{T}\right]^{J_2/m_2} .$$

Hence, the expected fraction of neglected tracts diminishes as the degree of joint bidding (m_1 and m_2) increases.

The influence of joint bidding on the outcome of the lease sale is demonstrated by some illustrative calculations reported below. Figure 4 reflects an "industry" made up of 25 small, and 10 large firms. Three different scenarios are presented, corresponding to low, medium, and high industry interest in the sale. Under the "Low Interest" scenario, each small firm is assumed to seek equity bidding interest in exactly 1% of the acreage included in the sale; while each large firm seeks exactly 3%. Under the "Medium Interest" scenario, these levels are doubled: small firms seek 2%, and large firms 6% of the sale acreage. Under the "High Interest" scenario, small firms seek 3%, and large firms 9% of the acreage. For each scenario we have calculated and plotted the expected number of bidders per active tract, the coefficient of variation in the number of bidders, and the expected fraction of neglected tracts; based on the formulas in Equations (21), (22), and (23). Figure 5 is entirely analogous,

but the size of the industry is doubled, to include 50 small, and 20 large firms. The extent of joint bidding is measured on the horizontal axes. The sizes of primary and secondary bidding groups--which are assumed equal in the illustration--are varied from 1 firm each (joint bidding prohibited) to 10 firms.

The most noteworthy aspect of the figures is that the degree of competition for active tracts is affected minimally by the extent of joint bidding. The impact of venture formation is easily dominated by the overall level of interest in the sale (represented by the alternative scenarios). A more significant effect of joint bidding is to reduce random deviations from the average level of competition. As we saw earlier, venture formation induces a more uniform distribution of bids among tracts, with less clustering.

These results suggest a non-traditional interpretation of venture formation; joint bidding may permit firms to reduce their uncertainty regarding the degree of competition to be expected in the sale, without necessarily reducing its level.

II. Venture Formation With Side Payments

A. The Basic Model

To this point we have assumed that joint venture profits are distributed on the basis of working interest shares of member firms. On this basis large and small firms are segregated in two non-interacting classes. No small (large) firm is acceptable in a primary (secondary) group due to the disproportionate organizational cost, measured relative to the resulting diminution in competition.

Figure 4: Impact of Joint Bidding--Small Industry

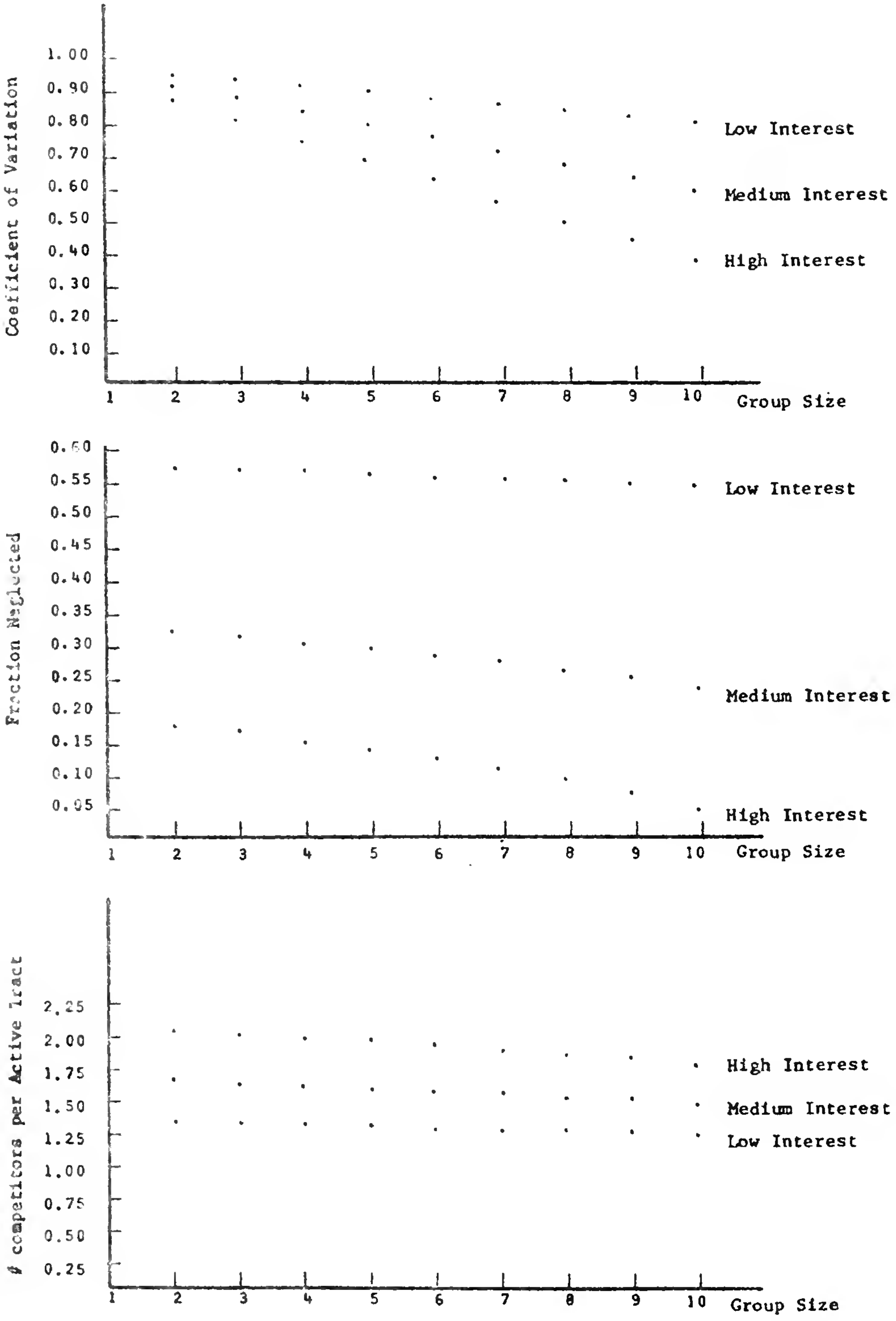
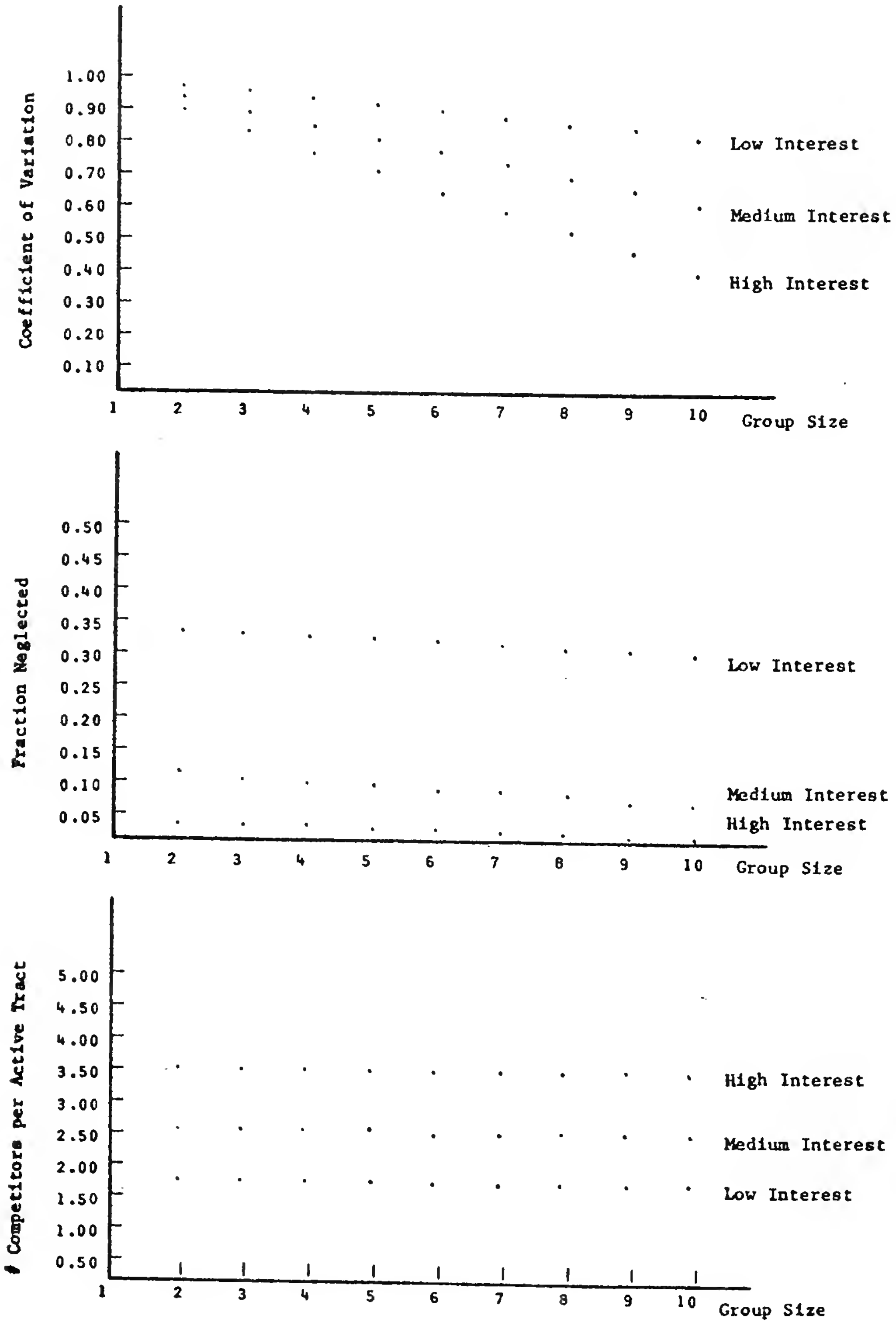


Figure 5: Impact of Joint Bidding--Large Industry



If we abandon the working interest distribution formula, size segregation may not be the optimal course for industry to follow. For example, consider a secondary group that invites the membership of a large firm. By joining, the large firm would not help its cause directly; it could do better (on a working interest basis) to combine with an equivalent number of large firms. However, the position of the small firms would be advanced beyond the level attainable under segregation. Consequently, the small firms would be able to "compensate" the large firm for its cooperation. The question is whether the small firms' position is sufficiently improved to enable them to fully compensate the large firm for its loss of opportunity. If so, the small firms may be able to "buy" the cooperation of the large firm, and a mixed venture will be formed.[11]

If a side payment is successful in attracting one large firm to a secondary group, perhaps more extensive interaction might also be in order. We are able to show that this is so, and to identify some rather interesting characteristics of the resulting mixed ventures. First we need to extend our notation to encompass the mixed venture concept.

We define a group of class k as any joint venture in which large firms constitute exactly k% of the membership, by number. For a group represented by membership (m_1,m_2), we must have $k = m_1/(m_1+m_2)$. Thus, all primary groups are of class $k = 1$. All secondary groups are of class

---

[11] The remaining members of the diminished primary group may attempt and succeed in outbidding the small firms for the cooperation of the renegade. However, not all large firms can be offered more than their working interest in primary group profits, so some large firms will be available for renegade duty.

$k = 0$. In the interval $0 < k < 1$, group membership obeys the relationship:

(24) $$m_1 = \frac{k}{1-k} \cdot m_2 .$$

Next we compute the organizational cost of attaining a level of $n°$ competitors in a group of class k ($0 < k < 1$). Using Equations (5) and (24), we have:

(25) $$n° = n(\frac{k}{1-k} \cdot m_2^\circ, m_2^\circ)$$
$$= \frac{(J_1 - \frac{k}{1-k} \cdot m_2^\circ) \cdot t_1 + (J_2 - m_2^\circ) \cdot t_2}{T} .$$

Thus:

(26) $$n° \cdot T = (J_1 - \frac{k}{1-k} \cdot m_2^\circ) \cdot t_1 + (J_2 - m_2^\circ) \cdot t_2 .$$

Solving for m_2°, the number of small firms included in the group:

(27) $$m_2^\circ = \frac{J_1 \cdot t_1 + J_2 \cdot t_2 - n° \cdot T}{\frac{k}{1-k} \cdot t_1 + t_2} = \frac{T}{\frac{k}{1-k} \cdot t_1 + t_2} \cdot (n_c - n°) .$$

Total group membership is then:

(28) $$m_1^\circ + m_2^\circ = m_1^\circ + \frac{k}{1-k} \cdot m_2^\circ = (\frac{1}{1-k}) \cdot m_2^\circ$$
$$= \frac{T \cdot (n_c - n°)}{k \cdot t_1 + (1-k) \cdot t_2}$$

$$= \frac{T}{t_k} \cdot (n_c - n°) \quad ; \tag{29}$$

... where t_k is an index of the average size of firms in the group of class k.

For given n°, the expression in Equation (29) takes its minimum value for k = 1. That is, membership is minimal in groups of class k = 1 (primary groups). Maximum membership occurs in groups of class k = 0 (secondary groups). On the assumption that organizational cost is an increasing function of group membership, we conclude that the cost for a mixed group of arbitrary class, k, to attain a level of n° competitors is bracketed by the costs experienced by primary and secondary groups. With organizational costs proportional to group membership, we have [using Equations (15), (16), and (29)]:

$$\begin{cases} \text{cost}(n°|\text{primary}) = a \cdot \frac{T}{t_1} \cdot (n_c - n°), \\ \text{cost}(n°|\text{class } k) = a \cdot \frac{T}{t_k} \cdot (n_c - n°), \\ \text{cost } (n°|\text{secondary}) = a \cdot \frac{T}{t_2} \cdot (n_c - n°); \end{cases} \tag{30}$$

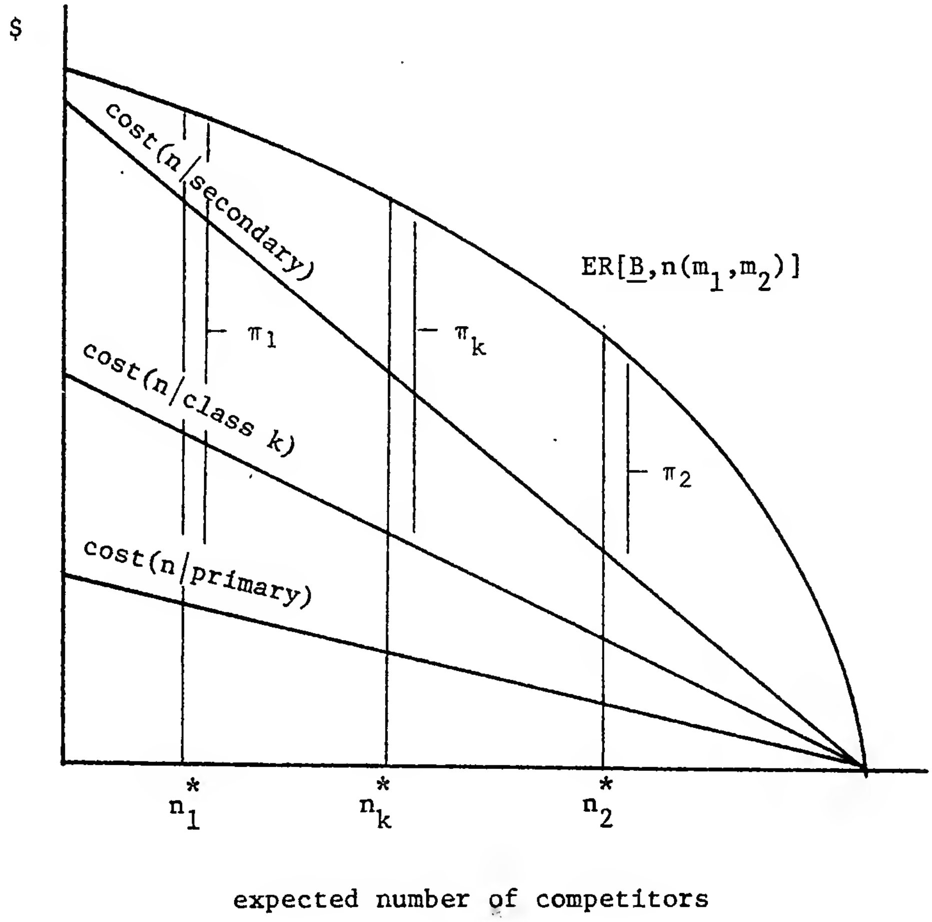
... where unit organizational costs are represented by "a".

The economic opportunities facing groups of class k are represented in Figure 6, below. The organizational cost function is shown relative to its two extremes, as in Equation (30). A group of class k may position itself anywhere along its cost function (the middle ray) by expanding or contracting its membership in the proportion:

$$\Delta m_1 = \frac{k}{1-k} \cdot \Delta m_2 \quad .$$

The optimal size for the group of class k is found, as shown, where the net value of the group, π_k, is maximum. The convexity of the function $ER[B,n(m_1,m_2)]$ assures that the optimal group of class k will face an intermediate level of competition, $n_1 < n_k < n_2$; and experience intermediate net earnings, $\pi_2 < \pi_k < \pi_1$. Relaxing the linearity of the organizational cost function would not alter these results.

Figure 6: Economics of a Class k Venture



The net value of greater and lesser integration can be determined by rotating the cost function between its outer limits and plotting the position of optimal groups of all classes, $0 < k < 1$. It is clear that net earnings of the group decrease monotonically with the degree of small-firm concentration. Whether a particular degree of integration is feasible depends upon whether the small firms benefit sufficiently from integration to fully compensate participating large firms. The conditions under which this occurs are discussed next.

To simplify matters, we assume that the working interest shares of similar firms in the mixed group of class k are identical.[12] Thus, each large firm holds a share $s_1(k)$, and each small firms holds a share $s_2(k)$. Of course, these shares may vary for groups of different classes. Membership of the mixed group is denoted $[m_1(k), m_2(k)]$. We must impose the "adding up" constraint:

$$(31) \qquad s_1(k) \cdot m_1(k) + s_2(k) \cdot m_2(k) = 1 \; ;$$

that is, the joint venture is wholly owned by the members of the group.

The opportunity cost of large firms' participation in the mixed group is set by the profitability of the optimal primary group. In such a group, each large firm would earn an amount $= s_1(k) \cdot \pi_1$, on a working interest basis. The opportunity cost of small firms' participation in the mixed group is set by the profitability of the secondary group, where each small firm earns an amount $= s_2(k) \cdot \pi_2$, on a working interest basis.

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[12] Recall that up to now the working interest of each firm has been a free variable.

In order to form the mixed group, its profitability must be sufficient to permit voluntary transfers from small firms in an amount that equals or exceeds the opportunity cost of the large firms' participation. This condition is satisfied if and only if:

$$(32) \qquad \pi_k \geq s_1(k)\cdot m_1(k)\cdot \pi_1 + s_2(k)\cdot m_2(k)\cdot \pi_2 \quad .$$

If condition (32) can be satisfied for some value of k (the index of integration), subject to the constraint in Equation (31), only then may we expect to observe the formation of mixed ventures.

The first important point is that condition (32) may be satisifed for arbitrary k by taking $s_1(k)$ sufficiently small. In the limit, we could set $s_1(k) = 0$, in which case condition (32) is reduced to: $\pi_k > \pi_2$, which was shown to be true for all k > 0 (see page 30). However, this arrangement represents a rather special form of joint venture. Essentially, the large firms are paid both to not bid against and not bid with the small firms. The idea of such a transaction is not new. It suggests a type of collusion in which joint venture members have "silent partners" whose duty is to avoid bidding on designated tracts. Naturally, each silent partner would receive some consideration (side payment) for its cooperation. Condition (32) demonstrates that this form of behavior is viable, subject to the industry's code of ethics, with the large firms playing the role of silent partner. The condition also shows that the large firm might avoid this role by purchasing a very small share in the secondary group. Although the appearance of collusion might be lessened by this action, the intent and outcome differ in degree rather than kind.

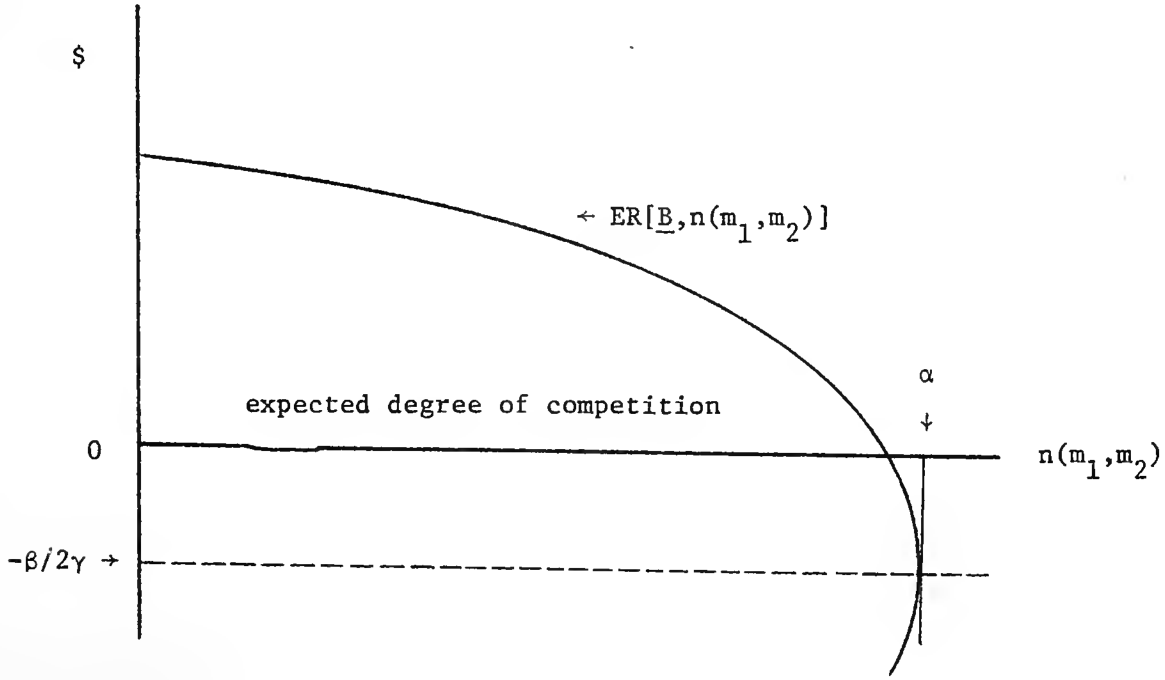
A further conclusion from condition (32) is that as the working interest share of participating large firms is increased, it becomes increasingly difficult to form a viable mixed venture. If large firms insist on playing an active role in the life of the venture ($s_1 \neq 0$), the degree of viable integration becomes limited. To illustrate this effect, we examine a special case in which the maximum viable working interest of large firms is given by the equal-share solution: $s_1(k) = s_2(k)$, for all values of k.

The special assumption needed to reach this conclusion is that the value of bidding against n competitors--our function $ER[B,n(m_1,m_2)]$--varies as the square root of n:

$$(33) \qquad ER[B,n(m_1,m_2)|B] = \frac{-\beta + [\beta^2 - 4\gamma(n-\alpha)]^{.5}}{2\gamma}; \text{ for } n \in [0,n_c] \quad .$$

The exogenous parameters α, β, and γ define the curvature and location of the expected rent function, which would appear as the solid segment in Figure 7.

Figure 7: Quadratic Expected Rent Function



We again assume that organizational costs are proportional to total group membership. These assumptions imply the following net profit function for the optimal mixed venture of class k (see Appendix):

$$\pi_k = \frac{1}{4\gamma} \cdot \frac{t_k}{aT} \quad . \tag{34}$$

To determine the maximal large firm working interest in a viable group of class k, we substitute for π_k in condition (32) using Equation (34), and solve for the value of s_1 which assures strict equality. For all larger values of s_1, the condition would be violated, reflecting the small firms' inability to satisfactorily compensate the large firms. As shown in the Appendix, the maximal value of s_1 is given by:

$$s_1 = \frac{1}{m_1 + m_2} \quad , \tag{35}$$

... which obtains when all firms assume equal shares.

To summarize, the maximal share of each large firm is the reciprocal of the total number of participants. No allocation with greater large firm shares can be supported by side payments. In particular, ventures in which working interests are proportional to firm size are excluded. Although this specific result relies on the special assumptions of our example, the nature of the result is not atypical. In general, large firms must adopt a relatively low profile in mixed ventures if the small firms are to be able to compensate them for participation. A direct relationship between firm size and working interest is ruled out.

The empirical evidence in support of this proposition is especially strong. In recent OCS sales, large firms almost universally assume a

relatively low profile in the mixed ventures that have occurred. We can measure this phenomenon in the following way.

For a given joint bid, we consider all possible pairings of member firms. An individual pairing supports our hypothesis if the working interest of the larger firm measured relative to its size is less than the working interest of the smaller firm measured relative to its size. When this result obtains we say the pairing conforms to a regressive pattern of venture participation, with the larger firm taking a relatively small interest. Conversely, if the relative working interest of the larger firm exceeds that of the smaller firm, we say that the pairing conforms to a progressive pattern of venture participation. The remaining possibility is that the relative working interests of the two firms are equal, in which case the pairing conforms to a proportionate pattern of venture participation.

For nine recent OCS sales, all possible pairings of venture partners which involve the firms included in our data base[13] have beeen examined and classified according to the above scheme. The results appear in Table 2. Over 90% of all pairings conform to the regressive pattern of venture participation, as our theory of mixed ventures would suggest.

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[13] The data base consists of 101 firms which have participated in recent OCS sales. This sample is not exhaustive, but includes all major oil companies and a large number of smaller firms. A complete listing of the firms is presented in Smith, Appendix C.

TABLE 2

PATTERNS OF JOINT VENTURE PARTICIPATION

	Number of Member Pairings which Conform to Indicated Patterns of Venture Participation:		
Sale Date	Progressive	Regressive	Proportionate
12/75	7	183	0
2/75	12	253	0
10/74	57	601	18
5/74	75	456	7
3/74	43	513	2
12/73	65	535	12
12/72	52	1183	0
12/70	31	672	0
2/68	21	204	0
Total--All Sales	363	4600	39
% of Total	7.3	92.0	0.8

B. Joint Venture Compromise

The question of inter-group negotiation and side payments has an additional dimension not yet discussed. Recall that an optimal group is characterized by its membership composition and by the amount of the bid it will tender--(B,m_1,m_2). A firm would be quite dissatisfied to form an optimal venture and have it bid other than the amount thought

to maximize expected profits.[14] Yet, the participants may disagree on the amount of the optimal bid due to differences in their appraisal of the tract and the competitive situation. An important question for research is how such differences are resolved.

An obvious solution would be for dissenting members to leave the group and tender individual bids consistent with their evaluations. However, it may be more rewarding for the dissenter to compromise its beliefs in order to remain with the group and retain the competitive advantage of cooperative action.

If we view the joint venture bid as a negotiated quantity we must ask which firms bear the burden of compromise. Within primary and secondary groups there is little at hand to guide our judgment on this. However, within mixed groups it seems likely that large firms will dominate group behavior. There are several ways to put the supporting argument. Large firms, by virtue of size, have less to gain by the formation of the group than do small firms. The alternative value of bidding individually is higher for large firms than for small firms. Consequently, the range of acceptable compromise will be smaller for

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[14] We do not explore the selection of a particular bid amount here. The factors which influence this choice depend upon the appraised valuation of the petroleum resource and upon strategic factors related to the context of the auction. The solution to this optimization problem is the subject of a separate literature. See, for example, the studies by Keith Brown; Michael Rothhopf (1969), (1977); Smith; and the recent bibliography compiled by Robert Stark and Michael Rothhopf. It is sufficient for our purpose to note that profitability of the venture's bid is related to the amount tendered.

the large firms; they would be driven from the group by lesser provocations. Apart from a greater propensity to leave the group, the large firms are also likely to command greater bargaining strength due to their greater contribution to the profitability of the group. Recall that the presence of each large firm eliminates t_1/t_2 times as many potential competitors as does the presence of each small firm. Consequently, the threat value of large firm withdrawal is more significant than that of small firms.

In light of the need to arbitrate disagreements which arise within the venture group, concessions regarding the amount to be tendered constitute a natural conveyance for the "side payments" which sustain the group. Therefore, the discussion of side payments which has run throughout this paper need not imply that the viability of mixed ventures rests on overt monetary transfers. More subtle forms of accommodation and compromise that are likely to arise among venture partners in any event may serve this purpose equally well.

Conclusions

In this paper, our conception of the motive for joint bidding is simple but germane. Firms are confronted with the opportunity to circumvent competition by combining with the opposition. The only restraint on cooperative action is the cost of establishing and maintaining alliances. We have interpreted this constraint quite broadly to embrace implicit anti-trust penalties and the loss of public goodwill. Each firm's objective is to identify and attempt to initiate those particular ventures which best advance its interests.

The behavior patterns that are likely to emerge from this process are complex. We can develop a coherent understanding of the outcome only through abstraction--by focusng attention on the more significant aspects of the situation. Under circumstances that conform reasonably well to the reality of offshore lease auctions, joint bidding can be shown to have a minimal impact on the degree of competition for tracts. The average number of bidders per tract is unlikely to be influenced perceptibly by the occurrence of joint bidding. The major impact of joint bidding is to equalize the degree of competition over all tracts offered in the sale. By this we mean that joint bidding prevents the clustering of many bids on just a few tracts while other tracts receive less attention. At the same time, the fraction of offered tracts which are neglected entirely is reduced by the occurrence of joint bidding. In short, the effect of joint bidding is to induce a more uniform pattern of competition in the lease sale, rather than to reduce the average level of competition.

The model of venture formation also highlights the strategic differences between small- and large-firm participation in joint ventures. A central difficulty in maintaining a venture group of heterogeneous members (e.g., large and small firms) appears to lie in establishing a viable distribution of joint venture profits. A distribution based on the working interest shares of member firms is an obvious possibility, but we have shown that alternative distributions, perhaps entailing some form of side payments, may be preferred. These side payments need not involve overt monetary transfers among the venture partners, but rather might take the form of fairly subtle operating or managerial concessions written into the working agreement which defines and governs the group.

APPENDIX

A. Market Outcomes and Bid Clustering

The expected number of bids (x) on a generic tract, given that it is active, is given by:

$$\text{(A.1)} \qquad E[x|\text{active}] = \sum_{x=0}^{J_0 \cdot t_0 + J_1 \cdot t_1} x \cdot \text{prob}(x|\text{active}) \ .$$

To evaluate this expression we use:

$$\text{(A.2)} \qquad \text{prob}(x|\text{active}) = \frac{\text{prob}(\text{active}|x) \cdot \text{prob}(x)}{\text{prob}(\text{active})}$$

$$= \begin{cases} \dfrac{\text{prob}(x)}{\text{prob}(\text{active})} , & \text{for } x > 0 \ ; \\ 0 \ , & \text{for } x = 0 \ . \end{cases}$$

Also: $\text{prob}(\text{active}) = 1 - \text{prob}(\text{not active})$

$$\text{(A.3)} \qquad = 1 - [1 - \frac{m_0 \cdot t_0}{T}]^{J_0/m_0} \cdot [1 - \frac{m_1 \cdot t_1}{T}]^{J_1/m_1} \ .$$

Substituting from Equation (A.2) and (A.3) into (A.1), we have:

$$\text{(A.4)} \qquad E[x|\text{active}] = \frac{1}{1 - [1 - \frac{m_0 \cdot t_0}{T}]^{J_0/m_0} \cdot [1 - \frac{m_1 \cdot t_1}{T}]^{J_1/m_1}} \cdot \sum_{x=1}^{J_0 \cdot t_0 + J_1 \cdot t_1} x \cdot \text{prob}(x) .$$

Equivalently:

$$\text{(A.5)} \qquad E[x|\text{active}] = \frac{n_c}{1 - [1 - \frac{m_1 \cdot t_1}{T}]^{J_1/m_1} \cdot [1 - \frac{m_2 \cdot t_2}{T}]^{J_2/m_2}} \ .$$

Equation (A.5) corresponds to Equation (22) in the text.

To compute the expected fraction of neglected tracts, we first determine the probability that a generic tract receives no bids:

$$\text{(A.6)} \qquad \text{prob(no bids)} = [1 - \frac{m_0 \cdot t_0}{T}]^{J_0/m_0} \cdot [1 - \frac{m_1 \cdot t_1}{T}]^{J_1/m_1} .$$

The probability that exactly t tracts out of T receive no bids is then the binomial:

$$\text{(A.7)} \qquad \text{prob(t receive no bids)}$$

$$= \binom{T}{t} \cdot [\text{prob(no bids)}]^t \cdot [1 - \text{prob(no bids)}]^{T-t} .$$

The expected number of neglected tracts is then:

$$\text{(A.8)} \qquad \text{E[number neglected]}$$

$$= \sum_{t=0}^{T} t \cdot \binom{T}{t} \cdot [\text{prob(no bids)}]^t \cdot [1 - \text{prob(no bids)}]^{T-t}$$

$$= T \cdot \text{prob(no bids)} .$$

Finally, the expected fraction of neglected tracts is:

$$\text{(A.9)} \qquad \text{E[fraction neglected]} = \frac{\text{E[number neglected]}}{T} = \text{prob(no bids)}$$

$$= [1 - \frac{m_1 \cdot t_1}{T}]^{J_1/m_1} \cdot [1 - \frac{m_2 \cdot t_2}{T}]^{J_2/m_2} ;$$

... where we have substituted from Equation (A.6) in Equation (A.9), which then corresponds to Equation (23) in the text.

B. Maximal Large-Firm Participation in Mixed Ventures

We assume the expected rent (ER) captured by the optimal bid to be related to the number of competitors, n, by the following:

$$(B.1) \qquad n = \alpha - \beta \cdot ER - \gamma \cdot ER^2 \ .$$

Equivalently:

$$(B.2) \qquad ER(n) = \frac{-\beta + [\beta^2 - 4\cdot\gamma\cdot(n-\alpha)]^{.5}}{2\gamma} \ .$$

We assume that organizational costs are proportional to the size of the group. The cost to a group of class k of reducing the degree of competition to the level n is then given by [see Equation (30) of text]:

$$(B.3) \qquad \mathrm{cost}(n|\mathrm{class}\ k) = a \cdot \frac{T}{t_k} \cdot (n_c - n) \ .$$

The optimal size of the group (and optimal degree of competition, n*) is determined by equating the marginal costs and marginal gains of reducing competition:

$$(B.4) \qquad -[\beta^2 - 4\gamma(n^* - \alpha)]^{-0.5} = \frac{\partial}{\partial n} ER(n) \equiv \frac{\partial}{\partial n} \mathrm{cost}(n|k) = -a \cdot T/t_k \ .$$

Equivalently:

$$(B.5) \qquad [\beta^2 - 4\gamma(n^* - \alpha)]^{-0.5} \equiv a \cdot T/t_k \ .$$

Equation (B.5) can be solved explicitly for n^*:

$$(B.6) \qquad n^* = \alpha + [\beta^2 - (\frac{t_k}{aT})^2]/4\gamma \ .$$

For convenience, we now assume that the expected rent function is symmetric about the abscissa; i.e., $\beta=0$. Equation (B.6) then becomes:

$$n^* = \alpha - \left(\frac{t_k}{aT}\right)^2 / 4\gamma \quad . \tag{B.7}$$

Expected profitability of the optimal group is given by:

$$\pi_k = ER(n^*) - \text{cost}(n^* | k) \tag{B.8}$$

$$= \frac{t_k}{2\gamma aT} - \frac{aT}{t_k} \cdot (n_c - n^*)$$

$$= \frac{t_k}{2\gamma aT} - \frac{aTn_c}{t_k} + \frac{aT}{t_k} \left[\alpha - \left(\frac{t_k}{aT}\right)^2 / 4\gamma\right]$$

$$= \frac{t_k}{2\gamma aT} - \frac{aTn_c}{t_k} + \frac{aT\alpha}{t_k} - \frac{t_k}{4\gamma aT} \quad . \tag{B.9}$$

Now, if the industry is one that would be competitive in the absence of joint bidding, we must have $n_c = \alpha$. That is, we require:

$$ER(n_c) = \frac{[-4\gamma(n_c - \alpha)]^{.5}}{2\gamma} = 0 \quad ; \tag{B.10}$$

... which implies $n_c = \alpha$, as stated.

Making this substitution in (B.9), the equation is reduced to:

$$\pi_k = \frac{t_k}{2\gamma aT} - \frac{t_k}{4\gamma aT} = \frac{t_k}{4\gamma aT} \quad . \tag{B.11}$$

This expression corresponds to Equation (34) in the text.

Substituting this value of π_k in Equation (32) of the text:

$$\text{(B.12)} \qquad \frac{1}{4\gamma} \cdot \frac{t_k}{aT} = s_1 \cdot m_1 \cdot \frac{1}{4\gamma} \cdot \frac{t_1}{aT} + s_2 \cdot m_2 \cdot \frac{1}{4\gamma} \cdot \frac{t_2}{aT} \quad .$$

We substitute again, using: $s_2 = (1-s_1 \cdot m_1)/m_2$ ... from Equation (31);

and: $m_2 = m_1 \cdot (1-k)/k$ ... from Equation (24).

The resulting version of Equation (B.12) appears, after simplification:

$$\text{(B.13)} \qquad t_k = s_1 \cdot m_1 \cdot t_1 + (1-s_1 \cdot m_1) \cdot t_2 \quad .$$

Solving this equation for s_1 yields:

$$\text{(B.14)} \qquad s_1 = \frac{1}{m_1} \cdot \frac{t_k - t_2}{t_1 - t_2} = \frac{k}{m_1} = \frac{1-k}{m_2} \quad .$$

Substituting for $(1-k)/m_2$ from Equation (29), we have:

$$\text{(B.15)} \qquad s_1 = \frac{1}{m_1 + m_2} \quad ;$$

... which corresponds to Equation (35) of the text.

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