Contractual Responses to the Common Pool: Prorationing of Crude Oil Production

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> Overproduction is like the weather, everyone talks about it, but no one has ever really done anything about it.
> [*Oil Weekly*, May 20, 1927]

There is growing interest in the role of bargaining costs in inhibiting voluntary contracts (Victor Goldberg, 1976; Oliver Williamson, 1979). The theoretical work stresses the problems of heterogeneous firms, asymmetrical information, and sequential adjustment as economic conditions change. There has, however, been little empirical work on the impact of the number and heterogeneity of parties on contracting success.[1] This paper addresses that issue by isolating firm differences that lead to differing bargaining positions, and by showing the high degree of concentration necessary to complete contracts. We analyze firm bargaining to mitigate rent dissipation from competitive production on five common oil pools where contracting success varied sharply. On some fields, agreements were quickly reached and effectively enforced, while on others compliance was never achieved. We show the firm heterogeneities that led to different bargaining positions, and calculate the level of concentration necessary for private contracting success. We measure concentration both by the inverse of the Herfindahl index and by the absolute number of firms.[2]

Three contractual solutions were considered to the common pool problem: lease consolidation, unitization of production under a single firm, and prorationing of field output among oil firms. In general, agreements for consolidation or unitization were not reached, and prorationing emerged as the dominant solution. Our analysis of prorationing contracts focuses on Oklahoma and Texas from 1926–35, a period when private and state controls were first implemented. The five largest fields discovered during that period are examined. The fields, their discovery dates, and 1949 cumulative U.S. production rankings were East Texas (1930, 1st); Oklahoma City (1928, 4th); Seminole District, OK (1926, 5th); Yates, TX (1926, 14th); and Hendrick, TX (1926, 22nd).[3] On Yates, consensus for prorationing was reached early, and dissipation margins were sequentially closed as they appeared. On Oklahoma City, Seminole, and Hendrick, there were partial agreements, and firm shares of the fixed field total were based on the number of wells; hence, dissipation occurred as firms drilled additional wells, and agreements broke down after short periods. On East Texas, field output limits were only effective during military occupation of the field in 1931 and under NIRA controls in 1933. Where private con-

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[1]Available empirical evidence on related issues is in Ronald Johnson and Libecap, 1982; Vernon Smith and Arlington Williams, 1981a, b; and Mark Isaac and Charles Plott, 1981.

[2]These measures of concentration emphasize different aspects of concentration on these fields. The absolute number of firms gives the number of parties in an agreement; the inverse of the Herfindahl index shows the degree of large firm control, but is insensitive to large numbers of small firms. The inverse of the Herfindahl index is the numbers equivalent of equal-sized firms (Morris Adelman, 1969). For example, a Herfindahl index of .33 gives a number equivalent of three equal-sized firms.

[3]Seminole District includes Seminole City, Earlsboro, Bowlegs, and Little River. See American Petroleum Institute, 1951, pp. 156–71.

tracting failed, firms lobbied for state enforcement, but again firm heterogeneities molded the final outcome.

Other studies of prorationing have criticized the rules for encouraging costly overcapitalization, nonoptimal pumping rates, and small firm biases (Morris Adelman, 1964, pp. 104–05; Melvin de Chazeau and A. H. Kahn, 1959, pp. 150–66; and James McKie and S. L. McDonald, 1962, pp. 113–16). These treatments have focused solely on production efficiency. We show that prorationing quotas were chosen to bring all firms into broad agreement, rather than to achieve minimum physical production cost. To achieve consensus for control of the most costly sources of rent depletion, concessions permitting less extensive dissipation along other margins were made. The provisions of the negotiated contract, then, while prohibiting particular activities by firms, set the lines along which some rent dissipation could occur. While the costs of the regulatory arrangement were high, our examination explains these rules as optimizing responses to achieve at least some control of rent dissipation.

In developing our argument, we first describe the options considered by firms to mitigate common pool conditions to show why prorationing was chosen. Section II provides a brief theoretical discussion to derive implications for the empirical analysis in Section III.

I. The Common Pool Problem and Potential Solutions

In this section we outline the characteristics of common oil pools and their impact on contracting: Part A describes the nature of the common pool and the costs of competitive extraction; Part B shows the link between fragmented surface ownership and the concentration of production, the key determinant of contracting success; and Part C examines the failure of consolidation and unitization.

A. *Characteristics of the Common Pool and Costs of Competitive Extraction*

Typically, oil reservoirs are compressed between an upper layer of natural gas and a lower layer of water. The two layers, as well as gas dissolved in the oil, drive the oil to the surface when the surrounding formation is punctured by a well. Oil migrates to the well, draining neighboring areas. The extent of migration depends upon subsurface pressures, oil viscosity, and the porosity of the rock. Reservoirs are not uniform; these characteristics differ across the field, generating inherent variation in well productivity. As a firm drills additional wells oil migrates more rapidly into the created low pressure zone, raising the firm's share of field output. Increases in the rate of production, however, reduce ultimate oil recovery. With high withdrawal rates, the ratio of natural gas and water to oil produced increases, leading to a greater loss in subsurface pressure. Pockets of oil became trapped, and retrievable only with high extraction costs.

Oil reservoirs are commonly found below numerous, independently owned surface tracts. The surface landowners initially hold the mineral rights, but transfer them to firms through mineral leases. By this process, multiple firms gain access to the pool. Under the rule of capture, property rights to crude oil are assigned only upon extraction (Robert Hardwicke, 1935). Given migratory oil and fragmented surface holdings, each producing firm has incentive to drill and drain. Rent dissipation follows with high capital costs—duplicate wells and surface storage—and with reduced total oil recovery. Discussions of unrestrained oil production in the 1920's and early 1930's emphasized extraordinary wastes (George Stocking, 1925; John Ise, 1926). The Federal Oil Conservation Board (1926, p. 30; 1929, p. 10) estimated recovery rates of only 20–25 percent with competitive extraction, while 85–90 percent was possible with controlled withdrawal. Excessive capital costs are indicated by the following data for the Hendrick field of West Texas. Discovered in June 1927, exploitation was essentially unrestricted until May 1928. During that time, competitive drilling by oil firms led to one well per 10 acres at a cost of $57,000 a well when, given porous geologic conditions, only one well per 80 acres would have rapidly drained the reservoir. The associated loss in underground pressure forced premature oil pumping at a marginal cost of

TABLE 1—CONCENTRATION OF LANDOWNERSHIP AND OPERATING FIRMS BY ACREAGE

Field	Numbers Equivalent		Absolute Number	
	Landownership	Operating Firms	Landownership	Operating Firms
Yates	1.3	3.2	2	16
Hendrick	2.1	7.5	3	18
Seminole[a]	120.0	15.0	127	40
Oklahoma City	20.0	2.0	42	7

Source: Oil Weekly, Oil and Gas Journal
[a]Seminole City pool

$.10 per barrel. Moderate withdrawal would have maintained pressure and allowed oil to flow without pumping until late in the field's life (*Oil Weekly*, March 23, 1928; April 13, 1928). Competition for rents necessitated large surface storage. During the first five months of 1928, storage capacity on Hendrick rose from 5,251,000 barrels to 10,987,000 barrels at a cost of $3,842,300. By contrast, on the neighboring Yates field where private controls limited production, storage was only 783,000 barrels and cost $274,000. This was despite a larger potential and greater ultimate oil recovery on Yates (*Oil Weekly*, February 24, 1928; March 23, 1928; May 25, 1928).

B. *Fragmented Land Ownership and the Concentration of Production*

The rent dissipation associated with common oil pools provides firms with clear incentives to restrict output. As we show, the number and heterogeneity of firms, however, limited the agreements that could be reached. The concentration of production was largely determined by surface landownership. In general, more fragmented surface holdings led to a lower concentration of operating firms on a field due to the leasing strategies of landowners and firms, an issue that is generally beyond the focus of this paper.[4] An important characterization of this process, however, linking surface holdings and firm concentration, is that large landowners fear drainage to neighboring areas, while small landowners seek oil migration to their lands. Accordingly, all landowners prefer *not* to lease to firms operating on adjacent tracts. Landowners also protect themselves by using short-term leases that expire if production does not occur rapidly. Additional incentive to drill is provided by granting firms up to 90 percent of the oil produced. The impact of fragmented land holdings on the concentration of production is shown in Table 1, where the absolute number and numbers equivalent of landowners and operating firms for Yates, Hendrick, Seminole, and Oklahoma City are presented. The concentration measures are calculated by acreage for the first date when such data are available. The data reveal that lower concentration of surface ownership generally leads to lower concentration of operating firms.[5] As we show below, the relationship described by the data in Table 1 is not sensitive to the stage of field development.

C. *Information Costs and Contractual Solutions to the Common Pool*

Three contractual possibilities are available to firms to mitigate rent dissipation: consolidation of production rights through purchase, unitization, and prorationing. Under unitization, production rights to the field are delegated to one operator with costs and revenues allocated among the firms based on their contribution to the unit. Consolidation

[4]This phenomena is observed on maps of the five fields in the *Oil Weekly* and *Oil and Gas Journal*, that show both surface ownership and operating firms. See *Oil and Gas Journal*, August 4, 1927, for the Seminole City field. Leonard Logan (1930, pp. 52–54) discusses leasing strategies.

[5]Oklahoma City is an exception because the Indian Territory Illuminating Oil Company (ITIO) acquired production rights to the area before there was indication of productive reserves (*Oil Weekly*, December 14, 1928).

and unitization assign production to a single firm, which then has the incentive to maximize field rents. Such agreements, however, are difficult to achieve because relative or absolute tract values for each firm must be determined, before production rights can be transferred. This requires estimates of oil in place, recoverability, and drainage. Given inherently high information costs, the importance of oil migration for small tracts, and variation in field characteristics, these estimates are costly and subject to large error.[6] Hence, it is difficult to estimate tract values and to determine whether the contract would make all parties better off. These problems limited unitization and consolidation, as shown by the following empirical data. By 1947, only 12 of some 3,000 fields in the United States were fully unitized (Joe Bain, 1947, p. 29).[7] For consolidation, Table 2 reports the numbers equivalent measures of concentration across time for the five fields in our sample. The dates selected in the table are based on available data. The data show that consolidation was not a general response to common pool conditions.[8] Indeed, the data reveal that the fields (except for East Texas) became less concentrated over time as new firms began producing on previously undeveloped land. For example, while there were 6 firms on the Yates field in September 1927, by July 1928 there were 20 (*Oil Weekly*, September 9, 1927; July 6, 1928).

TABLE 2—CONCENTRATION OF PRODUCTION OVER TIME

Field	Numbers Equivalent	
Yates	1.9	5.9
	September 1927	July 1928
Hendrick	10.0	13.2
	September 1927	July 1928
Seminole City	11.2	15.7
	May 1929	August 1929
Oklahoma City	5.0	6.3
	December 1929	December 1932
East Texas	64.6	35.3
	March 1931	February 1933

Source: Oil Weekly.
Note: Numbers equivalents for all fields except Seminole City are calculated by well ownership. For Seminole City, continuous well data were unavailable and output data were used.

The third option, prorationing, is a less complete but more flexible solution, which allowed agreements to be reached. Under prorationing, all parties are maintained on the field, and their output is controlled through simple quota assignments. Accordingly, once and for all tract values need not be estimated since no transfer of production rights occurs. Shares are automatically adjusted as production continues; some leases are flooded by water, and production declines on others due to pressure loss. Such adjustments are difficult to achieve with unitization and consolidation because both alter the pattern of development from what would occur with multiple producers. Prorationing allocation rules will be chosen to achieve consensus among the multiple firms exploiting the pool, and not all margins for dissipation will be controlled. The types of rent dissipation are determined by the quota arrangements. These arguments briefly explain why prorationing emerged instead of tract consolidation or field-wide unitization. The rest of the paper analyzes the determinants of the quota rules and impact of particular prorationing contracts.

II. Firm Size and the Incentive to Restrict Output

To clearly develop testable implications for the empirical analysis, we briefly summarize the common pool problem when firm sizes differ. We apply a variation of the dominant firm model to a common property resource. This approach illustrates how firm size affects both the willingness to enter agreements to control output and preferences for particular quota arrangements. Firm i's profit function is

$$\pi_i = pq_i - C_i(q_i, q_i^-)q_i, \tag{1}$$

[6]For example, a recent study of federal leasing showed that second place bids often ran 50 percent lower than the winning bid (E. C. Capen et al., 1971).

[7]Elsewhere (1983a) we examine the contracting problems that limited unitization.

[8]For Table 2 and throughout the paper, except as noted, we calculate concentration on the basis of well ownership, since acreage or production data are not consistently reported in the *Oil Weekly* or *Oil and Gas Journal*.

where p = the parametric market price, q_i = firms i's output, $q_{\bar{i}}$ = output of other firms on the field, and $C_i(q_i, q_{\bar{i}})$ = firm i's average cost function.[9]

Oil migration leads to cost interdependence. Differentiating (1), yields the noncollusive profit maximizing output:[10]

$$(2) \quad p = C_i(q_i, q_{\bar{i}}) + (\partial C_i / \partial q_i) q_i$$
$$= C_i(q_i, q_{\bar{i}}) + (\partial C_i / \partial q_i) S_i Q,$$

where $Q = q_i + q_{\bar{i}}$, and $S_i = q_i / Q$. The firm optimum is where price equals marginal extraction cost, which includes both the direct cost of additional output and the increased cost of inframarginal production. As S_i gets arbitrarily small, holding Q constant, inframarginal cost effects are completely external, and the firm produces where $p = C_i(q_i, q_{\bar{i}})$. As a firm's share increases, however, there is incentive to restrict output below $p = C_i(q_i, q_{\bar{i}})$.[11] Additionally, as shares increase, firms internalize more of the cost increases from rival production.

$$(3) \quad \partial C_i / \partial q_{\bar{i}} = (\partial C_i(q_i, q_{\bar{i}}) / \partial q_{\bar{i}}) S_i Q > 0.$$

The cross-unit cost effects from common pool production show why large firms seek to limit field output; however, if they unilaterally reduce production, small firms will expand output. Thus, as large firms cut production, they must prevent expansion by small firms. These efforts to restrict output are further complicated by oil drainage. Any firm's output depends both upon oil in place below its lease and drainage from neighboring areas. Because of limited oil in place, small operators necessarily rely more heavily on drainage.[12] Drainage increases substantially with higher output rates, and, accordingly, small firms are reluctant to enter agreements to restrict output, despite reduced aggregate production costs and potential increases in ultimate recovery.

These arguments demonstrate the importance of firm size in determining positions on output controls. To obtain the support of small firms in restraining production, large firms will offer small firms quota concessions. Of the available options, only per well quotas provide gains to small firms to entice them into agreements, since they can drill additional wells to increase their share of output. An alternative allocation rule is acreage, but this clearly favors large firms by eliminating drainage. A similar disadvantage exists for quotas based upon past output, which do not allow small firms to increase their share of field production under regulation.

A number of testable implications directly follows. First, greater concentration of operating firms on a field will lead to more rapid and complete agreements, since greater concentration of production implies more large and fewer small firms. Second, per well allocations will be used on unconcentrated fields, while on concentrated fields acreage quotas will be used. Third, per well quotas will lead small firms to drill more densely than large firms to increase their share of field production. Finally, small firms are more likely to violate prorationing quotas. The differing incentives of firms to support prorationing and the corresponding bargaining concessions mean that prorationing will bring only partial controls on rent dissipation. The extent of uncontrolled dissipation will vary systematically across fields with operator concentration. We now turn to the empirical examination of bargaining for prorationing on the Yates, Hendrick, Seminole, Oklahoma City, and East Texas fields.

[9]The model is a static one with the primary characterization, cost interdependence. For dynamic considerations, see Paul Davidson (1963). While there are price effects associated with unconstrained output on the sample fields, those effects do not change the arguments presented here. For discussion see our (1983b) paper.

[10]We assume that firms follow a Cournot decision rule under conditions of free entry.

[11]Nonetheless, large firms will have lower direct production cost ($C(q_i, q_{\bar{i}})$) for any level of output ($q_i^*, q_{\bar{i}}^*$). With more acreage and given that oil is not perfectly migratory, each well draws upon a larger effective pool, implying lower cost at any output level.

[12]This technological effect is repeatedly described in the literature. For example, see Joseph Pogue, 1921, p. 32; *Oil Weekly* April 20, 1928; *Oil and Gas Journal*, July 28, 1927.

TABLE 3—CONCENTRATION AND CONTRACTING SUCCESS ON FIVE OKLAHOMA AND TEXAS OIL FIELDS

	Yates	Oklahoma City	Seminole	Hendrick	East Texas
Discovery Date:	July 1927	December 1928	July 1926	June 1927	October 1930
Numbers Equivalent of Firms Based on Well Ownership:[a]	1.9 (6) (September 1927)	5.0 (18) (December 1929)	14.0 (27) (May 1927)	10.0 (18) (September 1927)	64.6 (147) (March 1931)
Time from Discovery to Private Contract Agreement:	2 months	1 month	none completed	none completed	none completed
Time from Discovery to State Regulation:		1 year	1 year	10 months	7 months
Effectiveness of Output Controls:	Full compliance under private agreement	Early compliance, with small lot drilling violations increased and state regulations were necessary	Full compliance only with state control	Full compliance only with state control	No compliance except during military occupation in 1931 and the NIRA in 1933
Primary Allocation Rule:	Acreage under private agreement	Under state regulation, per well	Per well[b]	50% acreage 50% per well[b]	Per well

Source: Oil Weekly, selected issues.
[a] *n*, absolute number of firms shown in parentheses.
[b] The Hendrick and Seminole allocations were based on production potential, which could only be increased by drilling additional wells.

III. Contracting for Production Controls

A. *Field Concentration and Contracting Success*

Table 3 outlines the concentration of production and contracting success for the five fields. The concentration entries in the table, measured by the numbers equivalent, $1/H$, and the absolute number of firms, n, are for the first period when well ownership data are available. The table reveals a close relationship between the degree of concentration and contracting success. On the most concentrated field, Yates ($1/H=1.9$; $n=6$), agreements on well spacing, total production, and firm quotas were completed within two months of discovery. The initial quotas, based on a per well formula, soon led to overdrilling. The quota arrangement was then changed to productive acreage, and the margin was closed (*Oil Weekly*, September 9, 1927; December 2, 1927). An umpire was hired by the operators to monitor compliance and to arbitrate disputes. After the Texas Railroad Commission intervened in neighboring Hendrick, Yates operators requested state enforcement of their contract, a request based on fear of antitrust prosecution of the private agreement rather than its failure (*Oil Weekly*, June 15, 1928). At the initial agreement, there were 6 firms with completed wells, and one, the Mid Kansas Oil Company, had 71 percent of the field's 17 wells. A year later, Mid Kansas remained the dominant producer with 35 percent of the 203 wells on the field, and concentration remained high with $1/H$ equal to 5.9. Under the Yates plan, daily output was held below 150,000 barrels, even though the field's daily potential reached 4,000,000 barrels in

October 1928.[13] That restraint was despite low drilling costs associated with the field's shallow 1,000 foot depth ($15,000 per well compared with $57,000 on neighboring Hendrick: *Oil Weekly*, November 11, 1927; March 23, 1928). Moreover, Yates had the smallest surface storage investment of the five fields.

Oklahoma City, the next most concentrated field, had the next most successful early private contracting record. Bargaining began in December 1928, when the Indian Territory Illuminating Oil Company (ITIO) held 67 percent of the acreage (*Oil Weekly*, December 14, 1928). By December 1929 the field was still concentrated ($1/H = 5.0$, $n = 10$), and ITIO had 35 percent of the completed wells (*Oil and Gas Journal*, December 5, 1929). The first agreement limited the number of wells. The field's depth, 6,400 feet, led to high drilling costs of $155,000 per well (*Oil Weekly*, January 10, 1930); hence, the incentive to restrict drilling. Further, wells were closed for fixed intervals to reduce production. The field began southeast of Oklahoma City, but continued exploration extended the field into the city. Much smaller surface tracts (town lots) led to rapid entry by small firms and declining concentration. Between December 1929 and February 1932, the number of firms rose by 57, and 45 of the new entrants had fewer than 5 wells each. By contrast, 6 of the 10 early producers had over 20 wells each, and the largest, ITIO, had 293 (*Oil Weekly*, December 5, 1929; February 12, 1932). As the number and diversity of firms on the field increased, a consensus on private output restrictions could not be maintained and the larger operators petitioned the Oklahoma Corporation Commission to restrict output and prorate production (*Oil and Gas Journal*, September 19, 1929).

A per well allocation rule was chosen by the state in the face of large numbers of small firms. As with Yates, the resort to output limits helped to restrain early Oklahoma City production and to limit storage (*Oil Weekly*, August 23, 1929). Daily output remained stable at under 200,000 barrels from December 1929 through June 1933, despite a potential of over 3,000,000 barrels (*Oil Weekly*, November 17, 1930). The entry of small firms led to increased violation of production quotas, and output rose, peaking at 324,000 barrels in August 1933 (*Oil Weekly*, February 6, 1933; March 13, 1933).

Seminole and Hendrick were less concentrated than either Yates or Oklahoma City and had similar concentration and contracting records ($1/H = 14.0$, $n = 27$ for Seminole and $1/H = 10.0$, $n = 18$ for Hendrick). Neither field achieved successful private prorationing restrictions. At Seminole's peak output of 514,000 barrels per day in July 1927, all firms were producing at capacity (*Oil and Gas Journal*, July 28, 1927). Moreover, near its peak, Seminole had a storage capacity of 3,000,000 barrels, over three times that of the larger Yates field (*Oil Weekly*, March 4, 1927). No constraints were implemented on Hendrick and Seminole until the Texas Railroad Commission and the Oklahoma Corporation Commission intervened at the operators' request. State prorationing began in the Hendrick field in May 1928. On Seminole, formal controls appear not to have been in place until August 1928, nearly a year after the first petition to the Corporation Commission (*Oil Weekly*, July 8, 1927; August 10, 1928). As implied by the theory, prorationing rules in both fields relied upon per well allocations.

Table 3 shows that East Texas had both the least concentration and the least success in restricting output through private or government controls. Discovered in October 1930, the shallow field (3,500 feet) had low drilling costs (approximately $26,000 per well) and diffuse surface ownership that led to rapid entry by small firms and competitive drilling (*Oil Weekly*, March 6, 1931). By March 1931, the numbers equivalent based on well ownership was 64.6.[14] By early 1933,

[13] *Oil Weekly*, October 12, 1928. Field potential estimates for all fields are overstated because they were based on wide-open production by each well for selected short periods. If all wells were run continually, pressures would have dropped and reduced field production.

[14] Because of rapid drilling on the field, the concentration was calculated on the basis of ownership of both completed wells and wells being drilled. During early development, there were almost no dry holes on East Texas.

there were over 1,000 firms and 10,000 wells on the field. East Texas production reached 738,035 barrels a day in August 1931 and peaked in May 1933 at 1,074,180 barrels. Rapid extraction reduced subsurface pressure, and lowered total recovery. Despite the costs of unrestrained production, no private prorationing contracts were completed. The Railroad Commission intervened with little success beginning in April 1931. The failure of these efforts led the Texas governor to close the field twice under martial law in August 1931 and in December 1932. State-imposed quotas were violated and numerous successful court challenges to government prorationing were initiated. Except during military occupation, the field remained uncontrolled until the NIRA codes were implemented and federal limits on interstate shipment of hot oil (oil produced above quotas) were imposed. This failure occurred despite exclusive use of a per well allocation rule by the Railroad Commission.

The most important feature in the success or failure of contracting was the degree of concentration on each field; other factors were not systematically related with bargaining outcomes: the two fields with the lowest drilling costs, Yates ($15,000) and East Texas ($26,000), had opposite contracting results; Oklahoma City with drilling costs of $155,000 had early production agreements, while on Hendrick, where costs were $57,000 per well, controls were implemented relatively late and only with state support. Moreover, size of field was unrelated. Oklahoma City and East Texas were the largest fields in terms of production, but their contracting patterns were similar only when concentration declined in Oklahoma City with development on fragmented surface plots.

B. *Firm Size and Support for Prorationing*

The theory implies that large firms will support prorationing and small firms will resist. The concentration data support this implication, but we also have more detailed evidence of the position of firms on prorationing. Support for prorationing is evidenced by joining private agreements to restrict output, by complying with state prorationing rules, by promoting prorationing through testimony before regulatory agencies and legislatures, or membership in advisory bodies for implementing controls. Opposition to prorationing is evidenced by failure to comply with private or state restrictions, initiation of court challenges of prorationing, or testimony before regulatory agencies and legislatures against constraints.

On the Seminole field, there are published lists of the votes of firms on early prorationing controls. In May 1927, a meeting of 20 Seminole operators was held to restrain drilling. The 16 operators listed in favor held 73 percent of the wells on the field, and 12 of those were among the 15 largest firms by well ownership (*Oil Weekly*, May 20, 27, 1927). Barnsdall, the eighth largest firm, voted against the particular rule under discussion, but the firm was active in other prorationing efforts. The remaining three opposing votes were by firms with only 2 of the 447 completed wells on the field. A prorationing advisory committee of 5 firms was established in August 1927 to restrict exploratory wells; the members were all top 10 firms by well ownership (*Oil Weekly*, May 27, 1927; August 5, 1927). Later in 1928, 7 firms agreed to limit drilling on their leases. Six were ranked in the top 10 on the field (*Oil Weekly*, May 27, 1927; February 17, 1928). In 1929, 17 firms (of 34) voluntarily closed operations on Sundays to supplement formal controls; that included 7 of the largest 10 firms on Seminole (*Oil Weekly*, February 22, 1929; March 1, 1929; *Oil and Gas Journal*, January 19, 1928).

On the Oklahoma City field, the initial drilling restriction of December 1928 was promoted by the field's largest firm, ITIO, a leading advocate of prorationing. Once controls were in place, large firms voluntarily cut production below their authorized quotas. In July 1931, 365 wells, nearly half the wells of the field, were voluntarily closed to reduce output; 212 of those were owned by 5 of the largest 10 firms (*Oil Weekly*, July 24, 1931; February 12, 1932). By September 1931, voluntary underproduction by large firms totalled 3,600,000 barrels; 71 percent was by ITIO, Slick (2nd largest number of wells on the field), Phillips (3rd), Franklin (5th) and Skelly (8th) (*Oil Weekly*, September 25, 1931; February 12, 1932). The record for small operators is sharply different. Between September 1930 and September 1932, published sources list 16 firms, all small, as challenging or violating Oklahoma City prorationing rules. Of those, only 2 had as many as 10 wells, and the rest had 5 or fewer wells.[15] Through 1935, none of the 10 largest firms on the Oklahoma City field initiated court suits or was identified as producing beyond quotas.

In East Texas, the division between large and small firms was similar. When the Railroad Commission began to regulate the field in April 1931, an umpire was chosen to set and police quotas; costs were covered through firm assessments, but only large firms paid (Texas Senate *Journal*, 1931, pp. 15–23). In testimony before the Legislature, 4 of the largest 24 operators on the field (Gulf, Texas Company, Arkansas Fuel, and Sinclair) offered to support *any* prorationing bill, regardless of its quota structure (*Oil Weekly*, July 3, 1931). Humble and Gulf, the largest firms on East Texas, attempted private enforcement of prorationing rules by offering higher prices to firms that complied with quotas and by refusing to purchase oil produced in excess of quotas (*Oil Weekly*, April 24, 1931; May 29, 1931). By contrast, small firms opposed prorationing through lobby efforts in the Legislature, failure to comply with quota, and court suits. Their opposition to East Texas controls continued despite the use of per well quotas that allowed them to drill additional wells (*Oil Weekly*, July 3, 1931). Of more than 50 firms identified between 1931 and 1933 in court suits against Texas Railroad Commission's prorationing rules, or listed as violators, only one was among the top 24 firms on East Texas.[16] Small firm opposition is illustrated by one case involving 7 firms with combined holdings of only 94 acres, but daily production of 50,000 barrels. Their production of approximately 500 barrels per acre per day far exceeded the field average of 10 barrels per acre, and was due largely to drainage. They challenged Railroad Commission quotas that would have reduced their strategic advantage (*Oil Weekly*, July 31, 1931; June 5, 1931).

C. *Concessions on Quotas and their Impact on Behavior*

While small firms prefer per well quotas because they permit them to expand production, such quotas lead to the overdrilling documented by Adelman and others. The role of quota concessions is clearly shown in the negotiations on Hendrick, Yates, and East Texas. During initial contracting on Hendrick, there were more wells on tracts operated by small firms than on those held by large firms: the numbers equivalent based upon acreage was 7.4, while for wells it was 10.5. A major opponent of prorationing was Cranfill, a small firm with only 5 percent of the acreage, but 9 percent of the field's output (*Oil Weekly*, April 20, 1928). To reduce opposition by small firms, a quota was adopted based on 50 percent wells and 50 percent acreage. Six months after the quotas were installed, additional drilling by small firms reduced well ownership concentration to 13.3 (*Oil Weekly*, April 20, 1928; July 6, 1928; November 1, 1928). On Yates, the limited opposition to acreage quotas came from one small firm (*Oil Weekly*, December 9, 1927). The firm, Simms, had 9 percent of the field's production potential, because of wells located strategically for drainage, but only 6 percent of the acreage (*Oil Weekly*, December 23, 1927; January 27, 1928). Opposition by Simms did not lead to a breakdown of private controls, but when state regulation was instituted, a 50 percent well, 50 percent acreage quota was adopted. The change from acreage allocations immediately led to the drilling of 51 new wells at a cost of $750,000 (*Oil Weekly*, May 25, 1928). In East Texas, there were no effective controls until martial law was declared by the Texas governor in August 1931, because of opposition by small firms who held 85 percent of

[15] Violators of prorationing rules were listed in the *Oil and Gas Journal*, January 2, 9, 1931 and the *Oil Weekly*, September 12, 1930; January 22, 1932; September 12, 19, 1932; October 16, 1932. See also American Bar Association (1938, pp. 175–211).

[16] The *Oil Weekly* from April 1931 through December 1932 contains articles on court suits. Articles with lists of parties can be found in the issues of May 22, 1931; June 5, 1931; March 4, 1932 and May 16, 1932. Some lists of court injunctions against violators are reported in the *Oil Weekly*, January 9, 16, 23, 1932, and February 13, 1932.

the leases on the field (Texas Senate *Journal*, 1931, p. 291).

We have additional evidence from East Texas that per well quotas lead small firms to drill more densely than large firms. The quota adopted by the Railroad Commission in September 1931 granted 225 barrels per day per well. Under that rule, small firms drilled additional wells and large firms held back. For the next year and a half, an average of 110 wells were sunk each week (*Oil Weekly*, January 30, 1933). By February 1933, the 24 largest firms on the East Texas field had an average of one well per 14 acres, while smaller firms averaged one well per 9 acres (*Oil Weekly*, February 27, 1933). The Cole Committee (U.S. House of Representatives, 1939, p. 503) reported that prorationing rules in East Texas contributed to the drilling of 23,000 unnecessary wells at a per well cost of $26,000.[17] As the number of wells rose, quotas were reduced to maintain targeted field output levels. They fell from 225 barrels per well in September 1931 to 37 barrels by December 1932 (J. H. Marshall and N. L. Meyers, 1933, p. 717). Texas law, however, gave special quotas of 40 barrels to high-cost pumping wells, more than the quota available to free-flowing wells in East Texas. Accordingly, firms placed pumping units on their wells at a cost of $3,500 per well to qualify for the larger allocation (*Oil Weekly*, January 23, 1933; February 27, 1933; *Railroad Commission of Texas v. Rowan and Nichols*, 107 Fed 2nd 70).

IV. Concluding Remarks

This paper has examined bargaining among firms to mitigate rent dissipation. Because of high bargaining costs, more complete solutions, consolidation and unitization, were not chosen. Instead, firms resorted to prorationing, and success varied. On Yates and Oklahoma City, where initial concentration of output was high, early agreements were reached. Private efforts failed on the less concentrated Seminole and Hendrick fields, though sufficient agreement was mustered to request state intervention to enforce compliance. On East Texas, with hundreds of small firms, no consensus could be reached on either private or government controls. Indeed, a major finding of the research is the high degree of concentration necessary to achieve successful coordination. Private agreements were completed when the numbers equivalent was less than 5; state enforcement brought compliance when it was approximately 10–12; but when concentration was less, state intervention could not control production without the use of troops. This is new empirical evidence on the contracting process among heterogeneous firms and the importance of concentration levels on the outcome.

The analysis of contracting also shows why prorationing took the form it did. Adelman and others have criticized prorationing for encouraging unnecessary wells and have called for oil field unitization. Adelman (1964, p. 107) estimated that prorationing raised production costs $4 billion annually. To require that regulatory policies fully close all margins for dissipation fails to recognize the high contracting costs for reaching agreement. We show that concessions, such as per well quotas, were required to draw in small operators and that the quotas led to predictable responses regarding rent dissipation. Nevertheless, given Adelman's figures, it is extraordinary how much waste was embodied in the regulatory outcome.

Despite those costs, prorationing controlled total field production and costs. Further, prorationing controls conserved natural reservoir energies and lengthened field life. On Seminole, state-enforced prorationing may have reduced early output by as much as 50 percent (*Oil Weekly*, February 17, 1930). Available data indicate that lower withdrawal rates increased ultimate recovery and lengthened the productive life of oil fields. The prorationing regulations examined in this paper followed the major oil discoveries of 1926–35, which increased both the magnitude of the technological losses from common pool production and the gains from contracting to limit output. When private agreements failed, the parties success-

[17]Engineers testified before the Cole Committee that 3,000 wells could have drained the field. While interest rates and expected price changes influence optimal extraction, they would not explain the drilling of 23,000 additional wells. Clearly, competitive extraction was a driving force in the decision to drill.

fully appealed for state enforcement, and a permanent regulatory structure was established. Erich Zimmermann (1957, pp. 286–88) compared the productive life of 20 fields in Arkansas, Louisiana, Oklahoma, and Texas, 10 discovered prior to formal regulation and 10 discovered after regulation.[18] After 15 years, output from the earlier group had declined to an average of 8.6 percent of peak output, while the latter group produced an average of 73.9 percent of peak production. The sampled fields in this paper are transitional fields where production occurred under both uncontrolled and controlled conditions. For Yates, Hendrick, Seminole, Oklahoma City, and East Texas, fifteenth-year production was 28 percent of peak output.[19] In the late 1940's, industry sources cited by Zimmermann (p. 281) estimated that prorationing rules in Texas, Louisiana, New Mexico, and Mississippi annually saved the drilling of 100,000 unnecessary wells at an average per well cost of $100,000, a saving of roughly $10 billion. Thus, we see that prorationing was an effective partial solution to rent dissipation.

Our examination of contracting has major implications for the general analysis of regulatory institutions. Without recognition of the heterogeneities among firms and their impact on contracting efforts to increase rents, the observed prorationing arrangements that emerged in Oklahoma and Texas cannot be explained. Similar heterogeneities influence regulations elsewhere in the economy. Accordingly, detailed analysis of bargaining among firms is essential for insight into the emergence of various institutional forms.

[18]Arkansas and Louisiana adopted formal regulation during the same period as Oklahoma and Texas (Stephen McDonald, 1971, p. 40).

[19]Calculations for the ratio of fifteenth-year (from discovery) production to peak production were based on field output data from the *Minerals Yearbook*, U.S. Department of the Interior.

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[1] **Contracting Problems and Regulation: The Case of the Fishery**
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[2] **Comment on the "H" Concentration Measure as a Numbers-Equivalent**
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