The Effect of Monopsony Power on Prorationing and Unitization Regulation of the Common Pool

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Abstract

For four decades beginning in the 1930s, the U.S. oil and gas industry was regulated by a quota-supported price-floor instrument known as prorationing. Most economists argue that unitization would have been a more efficient form of regulation. This paper studies how monopsony power held by integrated pipeline/refinery firms affects that conclusion. Absent regulation, the underproduction by monopsony dominates the overproduction from common property supply. Thus unitization, which forces producers to internalize costs, causes output to be further restricted. In contrast, prorationing severs the price-setting ability of the monopsonist, so can increase output to the first-best. Under prorationing, at the first-best output level, the marginal monopsony rents equal the Pigouvian output tax that solves the common property problem. Also discussed are the distribution of gains under prorationing and unitization as implemented.

Key words: Prorationing, unitization, monopsony, common property, oil & gas
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1 Introduction

In the depths of the Great Depression, with oil producers facing 4¢ per barrel oil, down from a dollar a barrel a year earlier, the Franklin D. Roosevelt administration decided to include oil in the National Industrial Recovery Act of 1933 (NIRA). The "oil code," section 9(c), vested control over production and prices in the U.S. oil and gas industry with the federal government. Following earlier state efforts in Texas and Oklahoma, NIRA implemented a nation-wide system of "prorationing" of oil. Under prorationing, a floor on the price paid to producers was supported using quota restrictions on production, with these quotas allocated *pro rata* across producing wells. After NIRA was rejected by the U.S. Supreme Court, prorationing continued under the auspices of the Intrastate Oil and Gas Compact Commission (IOGCC) between the producing states until the early 1970s.

Many observers[1] argued that a more effective regulatory mechanism would have been "unitization," whereby the owners of production on each field coordinated production so as to maximize the joint return from the field,[2] since unitization would directly address the problems due to common property ownership of the oil fields. These authors generally, though not universally (see German 1938, Hardwick 1938, Weaver 1986), viewed prorationing as a significant policy failure. Later authors such as Libecap and Wiggins (1984, 1985), Wiggins and Libecap (1985), Libecap and Smith (1999, 2001, 2002), argued that unitization was subject to significantly greater problems of implementation than prorationing. A more recent literature (Wiggins and Libecap 1987, Libecap 1989, Viscusi, Harrington, and Vernon 1995, Libecap and Smith 2002, and Smith 2005) has argued that prorationing prevailed over unitization in part because prorationing enabled the industry to effectively operate a government-run cartel which would become the model for OPEC years later.

This paper argues that prorationing, rather than unitization, arose in response to the perceived market power pipeline companies (many descendants of Standard Oil Company) held over producers. As a consequence of the economies of scale in pipelines, most oil fields were served by one or at most a couple of major pipelines (Johnson 1967). The pipelines were widely believed to exploit their monopsony power on the oil fields. Indeed, it was concern over the low prices being paid to producers that led to both state and federal government prorationing,

[1] Stocking 1925, Ise 1928, Logan 1930, Ely 1938, Bain 1947, Rostow 1948, Zimmerman 1957, Hardwicke 1961, Davidson 1963, Adelman 1964, and McDonald 1971

[2] Hardwicke (1961, p. 13) credits the idea for unitization to a 1916 Bureau of Mines report by Willam F. McMurray and James O. Lewis, and a 1918 publication by economists Chester E. Gilbert and Joseph E. Pogue. See Libecap and Wiggins (1985) and Libecap and Smith (1999, 2001, 2002) for detailed analysis of unitization.

this involvement capped nearly thirty years of federal and state legislative and administrative efforts to limit the power of pipelines (Stocking 1925, Ise 1926, Beard 1941, Johnson 1967). The prorationing clause, Section 9(c) of NIRA, for example, was subordinate to clauses 9(a) and 9(b) whose purpose was to control and enforce pipeline pricing. All of this suggests that monopsony power was foremost on the minds of regulators.

I derive a theoretical model to examine these issues. I show that when both common property and monopsony exist, production is less than is socially optimal. Because unitization forces producers to internalize costs that were external under common property, the price that producers need to be paid to bring the same output to market under unitization rises. Thus unitization reduces output relative to the common property equilibrium, which, since underproduction already occurs in the presence of monopsony power, makes society worse off. Prorationing, in contrast, by placing a price floor above the prevailing monopsony price, severs the monopsonist's ability to set the price. Hence output rises and welfare increases. Furthermore, even though prorationing controls only the producer price, there exists a prorationing price floor which yields the first-best outcome, since at the price that induces the socially optimal output, the monopsonist's marginal profits correspond to the Pigouvian tax on output that corrects the common property externality problem. Finally, though prorationing was potentially the optimal instrument, I show that the only group to benefit from a prorationing price high enough to require quotas to allocate excess supply are the mineral rights owners.

The argument that prorationing arose rather than unitization because of concerns over market power by the integrated pipeline/refinery companies is in stark contrast to much of the recent literature on prorationing and unitization. That literature, which ignores the early writers' concern with monopsony power,[3] attributes the failure to adopt unitization to high transaction costs, driven by large numbers of producers with heterogeneous interests and asymmetric information (Libecap

[3] Stocking (1925), Ise (1928), American Bar Association (1938, 1949), and Zimmermann (1957) on the waste of common property are cited in Libecap and Wiggins (1984, pp. 97-8, 1985, pp. 694, 709, and 711), Wiggins and Libecap (1987, p. 1), Libecap and Smith (2002, p. S592, *n.* 10). Bain's (1947) claim that only 12 of 3000 fields had been unitized is cited in Libecap and Wiggins (1984, p. 90), Wiggins and Libecap (1985, p. 365) and Libecap and Smith (1999, p. 528). But there are no citations to the concerns expressed by these same authors about the imbalance of market power between producers and pipelines. Yet, Stocking (1925), Ise (1926), and Bain (1947) each devote great portions of their books to concerns about the monopsony power held by owners of pipelines, and other sources such as Beard (1941), Rostow (1948), and Johnson (1967), which are concerned chiefly with the issue of controlling market power by pipelines, are not cited in any of the seven papers by Libecap and coauthors.

and Wiggins 1985, Wiggins and Libecap 1985, Libecap and Smith 1999, 2001, 2002).[4] Prorationing, by enlisting the coercive power of the state, was able to overcome some of these problems, but it too was subject to pressure to preserve rents to smaller producers by allocating quotas in part on the number of wells drilled, rather than surface areas (Libecap and Wiggins 1984). Since prorationing also enabled the industry to operate a government-run cartel, this literature argues that prorationing, not unitization, became the favored instrument (Libecap and Wiggins 1984, Wiggins and Libecap 1987, Libecap 1989, Viscusi, Harrington, and Vernon 1995, Smith 2005).

Like this paper, these authors argue that regulation arose in part to protect the interests of small producers. To identify whether the prorationing regulation arose in order to control monopsony, as claimed here, or to finding a way to create rents for the industry in the face of high transactions costs, as claimed by Libecap and coauthors, it is useful to consider the implications of the government run cartel theory versus the monopsony power theory. If the objective of prorationing were to sustain a cartel in oil, then consumer prices should increase. In contrast, if this were an attempt to constraint the monopsony power of pipelines, then producer prices should increase.

Table 1 presents data on petroleum prices during this period. Columns (1)-(4) present API data on the prices paid by consumers and to producers, both in nominal dollars and in inflation-adjusted prices [see column (5) for the CPI numbers used to create inflation-adjusted prices] relative to 1931 inflation-adjusted prices. Columns (6) and (7) contain data on the movements of the U.S. Bureau of Labor Statistics CPI for gasoline and fuel oil relative to the general CPI level, data which only goes back to 1935. If the cartel theory is correct, one should observe an increase in consumer prices relative to the 1931 minimum. To a certain extent, this is what happened, with 1932-41 inflation-adjusted gasoline prices rising about 20% relative to their 1931 minimum by the API data. Similarly, the BLS estimates of fuel oil prices rose by about 8% between 1935 and 1941, while gasoline prices fell by about 1% (comparable to the API estimate). During the same period, however, inflation-adjusted well-head crude oil prices—the prices paid to

[4] The early literature on prorationing and unitization (Stocking 1925, Ise 1928, Logan 1930, Ely 1938, Bain 1947, 1949, Rostow 1948, 1949, Zimmermann 1957, McKie and McDonald 1962, Davison 1963, Adelman 1964, and McDonald 1971) simply viewed prorationing as a policy failure, and pointed to unitization as the superior alternative. While Rostow (1948)—who advocated compulsory unitization along with strict enforcement of antitrust laws—understood intuitively that market power was central to the problem of regulating the oil industry, no serious attempts were made to model these issues. The subsequent literature, McKie and McDonald (1962), Davison (1963), Adelman (1964), and McDonald (1971), simply ignored market power issues by assuming perfect competition for the pipeline and refining sectors.

producers on the field—rose by 70% relative to their 1931 minimum. Furthermore, after World War II, when the state-run prorationing programs were at their peak, inflation-adjusted gasoline prices were actually *lower* than their 1931 level, while inflation-adjusted well-head prices continued to rise to more than double their 1931 level. Thus, the price data are consistent with the hypothesis that an important effect of prorationing was to redistribute rents within the industry to upstream producers from downstream pipeline and refining sectors.[5]

For the remainder of the paper, Section 2 reviews the historical evidence of how concerns with monopsony power affected unitization and prorationing. Section 3 sets out the model assumptions. Section 4 derives the laissez-faire equilibrium. Section 5 derives the effects of unitization in the presence of monopsony. Section 6 derives the effects prorationing in the presence of monopsony. Section 7 examines two brief extensions, and Section 8 concludes.

2 Historical Setting

Prior to prorationing, the common law 'rule of capture' was the prevailing legal authority in the U.S. on how producers might acquire ownership to oil or gas. As a consequence, oil and gas fields were subject to 'flush production,' where each producer, in an attempt to acquire as much oil or gas as possible from the common pool, drilled many wells in close proximity to one another and at the borders of his property to produce at the maximum rate at which he could store or transport to market. The oil industry, however, faced a second problem: the economies of scale in pipeline transportation, relative to rail and truck transportation, gave pipelines firms market power over producers.[6] This section shows that attempts to regulate the industry, first by common-carrier legislation on pipelines, and later by prorationing and unitization, all share a concern for the market power the integrated pipeline and refining firms held over producers.

[5]Cole and Ohanian (2004), who studied the cartelization of industry under the Roosevelt administration, report that more than 500 industries (p. 784) were organized in this way under NIRA. They use the CPI for the service sector to deflate prices, since that was one of the few sectors not covered under NIRA. With this index, they find that wholesale prices for petroleum products rose by 40 to 60 percent in the 1930s (p. 791), which the attribute to relaxed antitrust enforcement and to encouragement of labor unions.

[6]The only form of transport that was cost effective as pipelines was water transport, but this required transportation to the waterfront.

2.1 Pipelines and Monopsony Power

The refining and pipeline transportation sectors of the oil industry in the 1920s and 1930s were dominated by large, vertically integrated pipeline/refinery companies, many of whom were the descendants of the Standard Oil Company, which, prior to its dissolution, controlled over 90% of refining and pipeline transportation (Johnson 1967, p. 13, Table 4). The Interstate Commerce Commission (ICC), who regulated pipelines and rail roads, stated in 1907, "At the basis of the monopoly of the Standard Oil Company in the production and distribution of petroleum products rests the pipe line. The possession of these pipe lines enables the Standard to absolutely control the price which its competitor in each given locality shall pay" (*id.*, p. 55).

Following its 1911 dissolution, the resulting companies still controlled 68% of trunk-line pipelines as of 1918 (Stocking 1925, p. 25). By 1931, the U.S. had eighteen major trunk-line pipelines, with 58,571 miles of pipelines, sixteen of which were owned by integrated companies.[7] Rostow (1948, p. 58), and Bain (1949, p. 59) estimated that the twenty major oil companies owned 90% of trunk-line pipelines at the end of the 1930s.

Regulators first attempted to regulate oil pipelines using "common carrier" laws. The federal Hepburn Act (1906) required that interstate pipelines carry at non-discriminatory rates oil produced on the field by producers other than owner of the pipeline and to refineries other than those controlled by the owner of the pipeline. Most producing states also passed common carrier legislation.[8] The federal Mann-Elkins Act (1910) gave the ICC the power to initiate investigations as to whether pipeline rates were unreasonable. Between 1911 and 1912, however, fifteen major pipeline companies refused to comply with Hepburn Act requirements that they file tariff rates with the ICC, arguing that they did not carry oil other than oil they had purchased or produced themselves and were therefore not common carriers. The U.S. Supreme Court, however, rejected these arguments, stating, "those who are common carriers in substance do become so in form," *Pipeline Cases* (1914) 234 U.S. 548 (at pp. 561-62).[9]

[7]One of the exceptions, Prairie Oil Co., the Standard Oil company which was the first pipeline connecting the mid-continent fields in Oklahoma and Kansas to the east coast in 1900, was independent only because of Standard's 1905 decision to break its pipeline holdings into separate wholly within-state operations in an attempt to avoid the Hepburn Act (Johnson 1967, p. 70).

[8]For example, Kansas in 1905, Oklahoma in 1909, amended in 1915, California in 1913, Texas in 1917, amended in 1930, and Louisiana in 1918 (Stocking 1925, p. 25, Johnson 1967, pp. 189-95, McDonald 1971, p. 34).

[9]Only the Uncle Sam Pipeline Company, which ran a pipeline from Oklahoma to Kansas, and which carried only oil it had produced, was given an exemption (Johnson

Pipelines, however, continued to exploit their market power over independent producers and refineries by refusing to ship oil not owned by themselves, by requiring minimum shipments of 100,000 barrels (quantities in excess of nearly all producers' and even most refineries' annual usage levels), by requiring that shipments be received at only the terminal serving the pipeline's own refinery (Stocking 1925, pp. 97-99), or by charging all shippers a common high price for transport, but to itself rebating these costs in the form of dividends paid by the pipeline to its parent company (Beard 1941, p. 111, Weaver 1986, p. 41). In Wyoming, where two Standard Oil companies controlled 99% of pipeline mileage and operated 85% of refining, Ise (1928) claimed that the "general policy of the company has been to maintain a low price for crude, while selling gasoline at a highly remunerative price" (at p. 228). Rostow (1948, p. 53) quotes one independent Texas producer as saying, "In each field there is usually one predominant buyer and he sets the prices. We are subject to go along with it." Regulators shared these views. In testimony before Congress in 1934, Texas Railroad Commission (TRRC) chairman Ernest O. Thompson stated, "In most instances the company that owns the pipeline also purchases oil in the field. Through control of the pipeline [it] absolutely controls the production" (quoted in Johnson 1967, at p. 223). Thus there was widespread belief that the economies of scale in pipelines led to their owners exercising market power over producers and rivals.

These concerns led to a number of government inquiries, legislation, and court cases relating to market power by pipelines. In 1916 and 1922, the Federal Trade Commission (FTC) issued reports arguing that the margin between pipeline costs and rates was too high and that minimum tenders were too large (Johnson 1967, pp. 174-75). A June 2, 1920 complaint to the ICC over Prairie Pipe Line's 100,000 barrel minimum tender requirement led the ICC to rule against Prairie,[10] requiring only 10,000 barrel tenders, but because the ruling narrowly applied only to Mid-Continent crude shipped to the Franklin and Lacy Stations, Pennsylvania, no shipper, including the complainants, ever made use of the ruling (Johnson 1967, p. 206). Between August 1922 and February 1923, U.S. Senator Robert M. LaFollette chaired hearings on the issues of minimum tenders, high transport rates, and restricted delivery points.[11] In January 1931, hearings were held on Congressman

1967, pp. 71-72). Two other exemptions were later allowed, one for Tidewater in Illinois (*Tidewater Pipe Line Company v. Board of Review of Crawford County*, 311 Ill. 375; 143 N.E. 87 (1924)) and one for Associated in California (*Associated Pipe Line Company v. Railroad Commission of California*, 176 Cal. 518 (1917); 169 Pac. Rep. 62). In each case, it was determined that the carrying of other's oil was a small part of the business (Beard 1941, pp. 35-36).

[10] *Brundred Brothers vs. Prairie Pipe Line Company et al.*, 58 ICC 458 (1922).

[11] 67 Congress, 2 and 4 Sess., LaFollette Committee *Hearings*.

Homer Hoch's bill, H.R. 16695, which would have separated pipeline transportation ownership from production and refining. And in December 1931, Congressman Sam Rayburn, chair of the House Committee on Interstate and Foreign Commerce, appointed Walter W. M. Splawn, economist and President of the University of Texas, to investigate pipelines. Splawn's report concluded that regulation "would have to reach the owning or controlling corporations" (quoted in Johnson 1967, at p. 221).

By 1931, 21 states had enacted common carrier legislation (Johnson 1967, p. 189). These resulted in a number of legal challenges. In 1917, the California Supreme Court ruled that Associated Pipeline, which did not use eminent domain and did not move oil for anyone except its parent companies, was exempt from the common carrier statute.[12] Another California case reached the U.S. Supreme court, which ruled that the pipeline was subject to the state's common carrier legislation since it had used eminent domain to build the line and had carried oil for others (Johnson 1967, p. 190).[13] Oklahoma's 1909 common carrier statute was challenged by Champlain Refining Company, which had written contracts with producers that allowed Champlain the right to purchase the oil it transported. Champlain was ruled a common carrier on the basis that it carried oil for hire.[14] In Louisiana, from 1919-1926, Public Service Commission chairman Huey P. Long fought Louisiana Standard over its pipeline rates on the Caddo field (Johnson 1967, pp. 191-94). In Texas, the 1917 common carrier statute gave regulation of pipelines to the TRRC, which issued its first regulatory order, Oil and Gas Circular No. 10, in 1919. The order included minimum tender requirements of only 500 barrels, and it included a *pro rata* of allocation of space when pipeline capacity was exceeded (*id.*, p. 194). A 1930 Act allowed the TRRC to set pipeline tariff rates based on a "fair return" which the TRRC interpreted to mean an 8% return on investment (*id.*, pp. 215-6). Thus at both federal and state levels, the issue of market power by pipelines was central to efforts to regulate oil and gas.

2.2 Prorationing

The first attempt to proration output occurred in Oklahoma, when in 1914 production from the 500 million barrel Cushing and 350 million barrel Healdton fields, discovered in 1912 and 1913, respectively, exceeded Prairie Oil and Gas Company's pipeline capacity. In response to the threats of government action using the state's 1909 common carrier

[12] *Associated Pipe Line Company v. Railroad Commission of California*, 176 Cal. 518 (1917), 169 Pac. Rep. 62.

[13] *Producers' Transportation Company v. Railroad Commission of California*, 251 U.S. 228 (1920).

[14] *In re Champlain Refining Company*, 129 Oklahoma 166, 265 Pac. Rep. 160 (1927).

law, producers on the Cushing field reached an agreement with Prairie to *pro rata* allocate production across producers as a percentage of potential production. This was codified into an order by the Oklahoma Corporations Commission (OCC) in July, 1914 which also set the purchase price at $0.55 per barrel (German 1938, pp. 115-126), using the rationale that "as the pipeline companies still possessed a monopoly of marketing opportunity, the states power to prevent waste…could be exercised by fixing a *minimum* price for crude oil" (quoted in Daintith 2010, p. 200 [emphasis added]). But by the time the order was issued, negotiations between Prairie and producers broke down. In defiance, Prairie set the price at $0.40 per barrel. When the OCC launched an antitrust investigation of Prairie's actions, Prairie discontinued further shipments of oil from the fields (Ise 1928, p. 131). Producers, unable to sell their oil, accepted Prairie's price, ending the first attempt at prorationing.

The next attempt occurred when, with the 1925 discovery of the Seminole field, Oklahoma's oil production increased to 277 million barrels in 1927 from 179 million barrels in 1926. Again facing pipeline constraints, a voluntary prorationing scheme was adopted in 1927 and, as in 1914, was codified into a OCC order, which prorated on lease potential. In December 1928, the 800 million barrel Oklahoma City field was discovered. OCC order 4882, issued December 23, 1929, prorationed its output at 40% of potential production, using the rationale that "the gas pressure would be unduly and disproportionately dissipated" (German 1938, p. 159). Production from town-lot units, as the field was found to extend into Oklahoma City, forced the OCC to reduce quotas to $1/6^{\text{th}}$ of potential production. To enforce the order, Governor William H. Murray declared martial law and shut down production on the field from August 5 to October 10, 1931 (*id.*, p. 180). Oklahoma's prorationing orders were upheld in federal courts on the basis of conservation of oil and gas in *Champlin Refining Co. v. OCC*, 51 Fed.(2) 823 (1931), U.S. 210, 76 (1932).

In Texas, Humble Oil and Refinery Company, a subsidiary of Standard Oil of New Jersey, convinced producers on the 1.9 billion barrel Yates field, discovered in 1927, to proration production on the basis of acreage, using as its model the Sugarland field in Texas, on which the leases were owned entirely by Humble (Weaver 1986, p. 45). Humble, the only pipeline serving west Texas, secured this agreement by telling producers it would only build a pipeline to the field if production shares were agreed to be allocated by acreage. However, negotiations to proration the 500 million barrel Hendrick field failed. Ten months after its discovery in 1927, the TRRC ordered prorationing, with output allocated 50% on acreage and 50% on number of wells (Libecap and Wiggins 1984, p. 92), using as its legal basis the waste provisions of a 1919 act. In August 1930, the TRRC issued its first statewide prorationing order, restricting state output to 750,000 barrels per day (b/d), a reduction of 50,000 b/d from 1929 (Johnson 1967, p. 213).

Upon the October 1930 discovery of the 5.4 billion barrel East Texas field, Humble attempted to accomplish a rationalization of production. Humble advocated 20-acre well-spacing units, telling producers,

> "The size and location of the Humble Company's holdings in this area [16% of acreage] justify the extension of its pipeline to serve its properties. This extension will be made. In the event a program of orderly development and production with proration along the lines above set forth is worked out by the Railroad Commission, this Company will undertake to provide a market for such quantities of crude produced in the area as it can use itself or for which it can find a market demand; and in such event it will run the oil of other producers along with its own production on the basis of the proration schedules so established. In the absence of an orderly program of development and production, it would be foolish for the Humble Company to attempt to serve the area generally." (quoted in Weaver 1986, p. 47)

Thus, Humble was effectively attempting to unitize field production, since the 20-acre well spacing requirement would prevent over-drilling. But instead of facing the 16 producers on Yates, on East Texas there were 147 producing firms in March 1931 (Libecap and Wiggins 1984, p. 92) and over 600 by August 1931 (Ely 1938). When, in face of the worsening economic conditions, Humble lowered its well-head price, producers accused Humble of exploiting its market power, ending attempts at private contracting on the East Texas field (Weaver 1986, pp. 55-57) . In April 1931, the TRRC issued a prorationing order for the East Texas field restricting production to 325,000 b/d. This was enforced by Governor Ross Sterling's declaration of martial law on the East Texas field on August 17, 1931 (Johnson 1967, p. 213).

In February 1932, the TRRC's state-wide prorationing order was struck down by state courts in *Danciger v. TRRC*, 49 S.W. (2nd) 837 (1932), on the basis that the order was attempting to limit "economic waste," and Governor Stirling's martial law was declared an invalid use of police power in *McMillan v. TRRC*, 51 Fed.(2) 400 (1931) (Hardwicke 1938, p. 220). In a special session, the Texas legislature in 1932 wrote an act which prevented physical waste. This act was finally upheld in the courts in *Amazon v. TRRC*, 5 F. Supp. 633 (1934).

The producing states, however, faced the problem that without federal support they could not control out-of-state shipments of oil. Illegal shipments of 'hot oil' caused the East Texas field price to drop from $0.98 per barrel in March 1932, when martial law was in effect, to $0.04 per barrel in May 1933 (Yergin 1991, p. 252). This led the newly elected Roosevelt Administration to include federal prorationing in NIRA. The Roosevelt administration implemented nation-wide prorationing in September 1933, with the prohibition of interstate transportation of oil in excess of state prorationing orders. The prorationing section 9(c), however, was subsidiary to sections 9(a), which required "reasonable, compensatory [pipeline] rates," and section 9(b), which threatened to separate pipeline ownership from integrated firms if "unfair practices or exorbitant rates" occurred (Johnson 1967, p. 223). The effectiveness of NIRA was evidenced by the 60-80% reduction in the number of East Texas field refineries following its implementation; these firms apparently subsisted upon 'hot oil' (*id*, p. 224).

The oil code section of NIRA, however, was declared unconstitutional by the U.S. Supreme Court in January 1935 (*Panama Refining v. Ryan*, 293 U.S. 388). In response, the major oil producing states formed the Interstate Oil and Gas Compact Commission (IOGCC), which for the next four decades coordinated state prorationing. The federal government supported state prorationing by providing demand estimates through the Bureau of Mines and, more importantly, by prohibiting interstate sales in excess of the state proration quotas through the Connally Hot Oil Act of 1935.[15] With the exception of World War II, when the federal government again controlled oil production, state "market demand" prorationing remained in effect in Texas, Oklahoma, California, Louisiana, Kansas, and New Mexico (who together accounted for between 80% to 90% of U.S. production over this period) until 1972, when the quotas were finally set at 100% of potential. By 1960s, however, Adelman (1964) estimated that the waste due to excessive drilling under prorationing, as producers expanded capacity to capture the higher prices, was as high as four billion dollars per year, which equalled nearly half of industry revenues.

2.3 Unitization

Unitization statutes created rules under which a minimum percentage of owners in a private bargain could coerce the remaining owners of surface rights on a field into an agreement over how the field was to be operated.[16] The first compulsory unitization statute was in the federal Minerals Leasing Act of 1930, which gave incentives for unitization agreements to be reached prior to exploration (Libecap and Wiggins 1985).[17] While voluntary unitization was allowed in California and

[15] In addition, oil import quotas advocated by the IOGCC were also used to sustain the prorationing prices (see Libecap 1989 and Viscusi, Harrington and Vernon 1995).

[16] The states varied in the percentage of owners who were required to agree before the minority could be forced to accept unitization, ranging from 50% in Tennessee to 85% in Mississippi, generally weighted by surface acreage (Eckman 1973, Table I, pp. 384-85).

[17] The Kettleman Hills field in California was the first to be unitized under federal law. Interestingly, Kettleman Hills was a gas-cap field and unitization failed to control the

New Mexico as early as 1929, and in Texas as early as 1935 for natural gas, Louisiana was the first state to pass a compulsory unitization statute when in 1940 it allowed unitization on natural gas condensate fields if at least 75% of the producers agreed to it. The first state unitization statute for oil fields occurred in Oklahoma in 1945. By the 1970s, with the important exception of Texas, most states had passed compulsory unitization laws, although the terms under which compulsion could be enforced varied across states (Eckman 1973).

Bain (1947, p. 29) reported that only 12 of 3,000 fields in the U.S. had been fully unitized by 1947. However, Holloway (1948, p. 49) found that 18 unit agreements had been reached in California between 1929 and 1942, mostly under the federal Minerals Leasing Act. Williams (1952, p. 1173, n. 74) found that by 1951 there were 181 federal unitization agreements covering 2,623,261 acres and that by 1949, 53% of oil and 75% of gas on federal lands came from unitized leases. A 1964 IOGCC report found that production on unitized fields in the U.S. had risen from 50 million barrels per year in 1948 (2.5% of U.S. production) to 400 million barrels per year in 1962 (15% of U.S. production) (Weaver 1986, p. 418). Over 1,000 unitization agreements were reached in Texas between 1949 and 1979, accounting for 56% of the largest fields (*id.*, pp. 369-70). These agreements were reached in part because the TRRC applyied a "doctrine of equal coercion," forcing opponents to show cause as to why a unitization agreement should not proceed (*id.*, p. 150). Nevertheless, unitization was a lengthy process. In Texas, the average time to reach a unitization agreement was 18 years (*id.*, p. 318). Thus, by the time a field was unitized, rent-dissipation due to excessive drilling of wells had already occurred. Libecap and Smith (1999, 2001, 2002) found that many unitization agreements were subject to litigation and renegotiation.

2.4 Post-NIRA Anti-Trust Regulation of Pipelines

The Connolly Act did not end federal involvement in the regulation of the major oil firms. In 1934, while federal prorationing was still in effect, the ICC began investigations of pipeline rate structures and minimum tender sizes. A 1936 ICC report recommended that minimum tenders of greater than 10,000 barrels be declared unreasonable, and that pipeline firms be required to show cause if rates exceeded 65% of the rates in December 1933 (Johnson 1967, pp. 242-44). By 1940, the ICC, following the Texas TRRC, issued an order that pipelines be restricted to an 8% rate of return. In 1936, the U.S. Justice Department sued 18 major oil companies for violations of the Sherman Antitrust Act for actions the companies claimed was a continuation of

dissipation of the drive from the gas cap (Holloway 1948).

policies that the Federal Government had implemented under NIRA. The oil companies were found guilty of antitrust violations by the U.S. Supreme Court in 1940 in *United States v. Socony-Vacuum Oil Co. et al.* 310 U.S. 150. This was followed in September, 1940 by a new Justice Department indictment of 22 oil companies in the "Mother Hubbard" case (*id.*, p. 284). That suit was settled by a consent decree on December 17, 1941, which capped pipeline profits at 7% return on investment (*id* at p. 300).

3 Theoretical Model

The remainder of the paper analyzes an economic model of the effects of unitization and prorationing. This section develops assumptions about supply under common property and then about demand.

3.1 Field Production

Field production depends upon the total number of wells, w, drilled on the field according to the production function

$$q = f(w) \equiv w^{\alpha}, \qquad \text{where} \qquad 0 < \alpha < 1. \tag{1}$$

This production function exhibits diminishing marginal productivity to wells throughout its domain, which implies that the average product of a well, $f(w)/w = w^{\alpha-1}$, is greater than the marginal product of a well, $f'(w) = \alpha w^{\alpha-1}$. This gives rise to congestion externalities when there are multiple producers on a field.

Suppose there are $n \geq 1$ producers, holding the rights to produce from the subsurface minerals on a common pool. I assume that n is exogenous. Increasing n increases the degree of the common pool problem, since each player ignores the effect his production has upon the $n-1$ other producers. The case where $n = 1$ corresponds to unitization. With n producers, mineral rents per producer are[18]

$$R^i = \frac{w^i}{w}\left[pf(w) - w\right], \qquad i = 1, \ldots, n, \tag{2}$$

where p is the price of oil relative to the cost of drilling a well (which is normalized to one), w^i is the wells drilled by producer i, and $w = \sum_{i=1}^{n} w^i$ is the total number of wells drilled on the field.

Stating producer profits in this way makes several assumptions. First, each well drilled on the field has the same average productivity, $f(w)/w = w^{\alpha-1}$, for all $i = 1, \ldots, n$. Heterogeneity of producers, however, complicates both prorationing and unitization in similar

[18] With free-entry in production, these rents accrue to the original mineral rights owners.

ways (Libecap and Wiggins 1984, 1985). Second, dynamics relating to production on a particular field and the discovery of new fields are each ignored. Both prorationing and unitization reduced the stock externality by restricting output, but they had very different effects on the congestion externality from drilling of wells.[19] I therefore focus on these differences. Third, differences between old and new fields are ignored.[20] Since the interesting counterfactual is what would have happened had unitization been implemented rather than prorationing, I let the equilibrium number of wells on each field depend upon the expectation of prices under each form of regulation. This focuses attention on the magnitude and distribution of the rents under each regulatory regime. Finally, because the marginal product of an additional well never becomes negative, the supply function is always increasing in price, so there is no "backwards-bending" of the supply curve (Copes 1970). Nevertheless, because both the unitization and all monopsony equilibria occur on the upwards sloping part of supply, all of the results regarding prorationing and unitization, including the important Lemma 1, follow even with a backwards bending supply curve.[21]

3.2 Common Property Supply

Taking the well-head price paid to producers, p, as given, producers choose w^i to maximize (2). In the symmetric Nash equilibrium, the total number of wells drilled on a field satisfies

$$\frac{\partial R^i}{\partial w^i} = p\left[\frac{1}{n}f'(w) + \left(1 - \frac{1}{n}\right)\frac{f(w)}{w}\right] - 1 = 0, \qquad i = 1, \ldots, n, \quad (3)$$

where $w^i/w = 1/n$ when firms are symmetric. The equilibrium number of wells drilled on a field, therefore, equates a weighted average of the value of the marginal product of a well, $pf'(w)$, and the value of the average product of a well, $pf(w)/w$, with the cost of an additional well. When $n = 1$, the weight on the average product vanishes, so the value

[19] The reserves-to-production ratio remained steady at between 12 and 15 years during the prorationing era. This is because disincentives for exploration were a key component of prorationing. In Texas, new fields became subject to prorationing once six wells were drilled on the field (Weaver 1986). Oklahoma required that newly drilled wells remain inactive for 65 days upon completion (German 1938, p. 126). In addition, Zimmermann (1957) found that fields discovered during the prorationing era were producing at 73.8% of their maximum production fifteen years into production, while fields prior to prorationing were producing only 8.6% of their maximum production in their fifteenth year.

[20] This ignores that property rights may have changed hands (so rents may be earned by original mineral rights owners, not producers).

[21] When supply is backwards bending, for sufficiently high demand, relative to the social optimum, there may be *underproduction* in the common property equilibrium, rather than overproduction. This does not, however, appear to be the empirically relevant case.

of the marginal product of a well equals the cost of an additional well, but as $n \to \infty$, the weight on the marginal product vanishes so that the value of the average product equals cost of an additional well.

For a given price p, solving (3) for the equilibrium number of wells and using (1) to obtain the implied field production yields

$$w_n(p) = (pA_n)^{\frac{1}{1-\alpha}}, \qquad \text{and} \qquad q_n(p) = (pA_n)^{\frac{\alpha}{1-\alpha}}, \quad \text{where} \quad A_n \equiv \tfrac{\alpha+n-1}{n} \in [\alpha, 1). \tag{4}$$

The subscript 'n' on a variable indicates that its value also depends upon the extent of the common property problem, as measured by the parameter n. The well-head price p appears in parentheses to indicate that its equilibrium value is yet to be determined. Thus, both production and the number of wells drilled on a field are increasing in p. The expression A_n is bounded between $A_1 = \alpha$ and $lim_{n\to\infty} A_n = 1$, and is increasing in n. Therefore, holding p constant, an increase in n causes the total number of wells and output to increase.

Let $R = \sum_{i=1}^{n} R^i$ denote the total rents earned by the mineral rights owners on a field. From (4), at well-head price p, the total rents to mineral rights owners equal

$$R_n(p) = p\big[w_n(p)\big]^{\alpha} - w_n(p) = \left(\frac{1-\alpha}{n}\right) p^{1/(1-\alpha)} A_n^{\alpha/(1-\alpha)}. \tag{5}$$

Thus, rents are increasing in p. Holding p constant, rents are decreasing in n, and in the limit as $n \to \infty$, rents vanish for all finite p.

Let there be k identical fields, where k is exogenously determined. Thus, for a given price, p, the aggregate quantity supplied is given by

$$Q_n(p) = k\,(pA_n)^{\frac{\alpha}{1-\alpha}}. \tag{6}$$

Inverting this yields the (inverse) common property supply curve:

$$p = S_n(Q) = A_n^{-1}(Q/k)^{\frac{1-\alpha}{\alpha}}. \tag{7}$$

For a given Q, an increase in n causes the inverse supply curve to shift downwards as n increases, since A_n is increasing in n.[22] Thus, the price required to bring quantity Q to market decreases as n increases. This occurs because under common property, each producer ignores the costs he imposes upon other $n-1$ producers by way of congestion on the field. Thus, as the common property problem worsens, i.e., as

[22]McKie and McDonald (1962) and McDonald (1971, p. 106) claimed that the marginal cost under unitization was lower than under common property. These authors appear to have assumed that since social costs are higher under common property, so too were private costs. Davidson (1963), however, correctly finds that $S_n(Q)$ is below $S_1(Q)$.

n increases, a larger share of these costs become external, the price required to bring that quantity to market declines.

When $n = 1$, the supply curve is:

$$p = S_1(Q) = \alpha^{-1}(Q/k)^{\frac{1-\alpha}{\alpha}}. \tag{8}$$

The supply curve $S_1(Q)$ measures the social marginal cost of production. The vertical difference between the social marginal cost, $S_1(Q)$, and the private marginal cost, $S_n(Q)$, is the marginal external cost additional production imposes upon other producers. Under common property, the aggregate quantity supplied at price p is $Q_n(p)$. But because producers ignore the costs they impose upon others, the producers' surplus at a given price p, $PS_n(p) = pQ_n(p) - \int_0^{Q_n(p)} S_n(Q)\mathrm{d}Q$, over-states the welfare contribution, since social costs are given by $S_1(Q)$, not $S_n(Q)$. It follows that at production level $Q_n(p)$, the true measure of producers' surplus is the rents earned by the mineral rights owners on the k fields:

$$PS(p) = pQ_n(p) - \int_0^{Q_n(p)} S_1(Q)\,\mathrm{d}Q = kR_n(p). \tag{9}$$

3.3 Demand

Oil is purchased at the field by the pipeline, who pays price p for the oil and then transports and refines the oil to sell the refined product to consumers at price $\hat{p}$. Pipeline demand for oil is derived from the consumer demand for refined products. Facing prices $\hat{p}$, consumer demand is:

$$Q = D(\hat{p}) = \begin{cases} \hat{p}^{-\epsilon} & \hat{p} \leq \bar{p} \\ 0 & \hat{p} > \bar{p} \end{cases} \tag{10}$$

where ϵ is the absolute value of the elasticity of demand. This yields the inverse demand function, $\hat{p} = P(Q) \equiv D^{-1}(Q) = Q^{-1/\epsilon}$ for $\hat{p} < \bar{p}$. A finite choke price, $\bar{p}$, ensures that consumer's surplus is a bounded when demand is inelastic. I assume, however, that $\bar{p}$ is high enough to not affect the equilibrium outcome, and so $\bar{p}$ plays no further role.[23] Given (10), consumer's surplus is

$$CS(\hat{p}) = \begin{cases} \int_{\hat{p}}^{\bar{p}} z^{-\epsilon}\,\mathrm{d}z = \frac{1}{1-\epsilon}\left(\bar{p}^{1-\epsilon} - \hat{p}^{1-\epsilon}\right) & \text{if } \hat{p} \leq \bar{p} \\ 0 & \text{if } \hat{p} > \bar{p} \end{cases}, \tag{11}$$

which is decreasing in the consumer price, $\hat{p}$.

Oil demand in the 1930s, as today, was inelastic. Thus, $0 < \epsilon < 1$. The most compelling evidence for this is from the East Texas field, dis-

[23] A simple interpretation of $\bar{p}$ is that it is the cost to transport oil by less efficient means, such as by truck or rail road.

covered in October 1930, which remained the largest field in the U.S. until the 1968 discovery of Prudhoe Bay field in Alaska. When production on the East Texas field began, the price of oil was a dollar per barrel. By May 1931, the East Texas field was producing a million barrels a day, equivalent to 1/3 of U.S. production, and the price dropped to $0.10 per barrel by August, 1931. That this was driven by a supply shock and not the general deteriorating economic conditions of the Great Depression was evidenced when Texas Governor Ross Sterling imposed martial law on August 17, 1931, which shut down production on the East Texas field, and prices rose back to a dollar a barrel by March 1932 (Yergin 1991, p. 251). Furthermore, after the courts ruled Governor Stirling's martial law to be illegal, prices again dropped to less than ten cents per barrel by May 1933 (*id.*, at p. 252). This suggests an elasticity of demand on the order of $\frac{\%\Delta Q}{\%\Delta P} = \frac{1/3}{-9/10} = -10/27$, which is comparable to demand elasticity estimates in the literature.[24]

3.4 Pipeline Profits

Consumers pay $\hat{p} = P(Q)$ for each unit of oil. The pipeline faces "iceberg costs," so that if it purchases Q units from oil producers, it sells $\hat{Q} = (1-\beta)Q < Q$ units to consumers, where $0 \leq \beta < 1$. Iceberg costs, unlike constant unit costs, allow analytical solutions when demand and supply are each iso-elastic.

Thus, pipeline profits are

$$\Pi_n(Q) = P[(1-\beta)Q](1-\beta)Q - S_n(Q)Q. \qquad (12)$$

pipeline profits depend upon n because the quantity supplied at each price depends upon n.

3.5 Marginal Factor Costs

Given the supply curve $S_n(Q)$, the marginal factor cost of obtaining oil to a price setting pipeline is given by

$$MFC_n(Q) = \frac{d}{dQ}\left[S_n(Q)Q\right] = S_n(Q) + QS_n'(Q) = \frac{1}{\alpha}S_n(Q). \qquad (13)$$

The marginal factor cost curve, $MFC_n(Q)$, lies at or above the average factor cost curve, $S_n(Q)$, since the price required to bring a larger supply to market is increasing in output. Both the marginal and average factor cost curves shift down as n increases.

[24] Hamilton (2009) uses the supply shock of the Iranian revolution in 1979 to obtain an demand elasticity estimate around $-5/16$.

Lemma 1 shows the relationship between the marginal factor cost curve with n common property competitors and the supply curve when there is only one supplier:

Lemma 1. *For the production function given in* (1)*, the marginal factor cost curve $MFC_n(Q)$ lies above the supply curve $S_1(Q)$ for all finite n, and* $\lim_{n\to\infty} MFC_n(Q) = S_1(Q)$.

Proof. From (8), $S_1(Q) = A_1^{-1}(Q/k)^{\frac{1-\alpha}{\alpha}}$. From (13), $MFC_n(Q) = \frac{1}{\alpha}S_n(Q) = \alpha^{-1}A_n^{-1}(Q/k)^{\frac{1-\alpha}{\alpha}}$. Thus, $MFC_n(Q)/S_1(Q) = \alpha^{-1}A_n^{-1}/A_1^{-1} = A_n^{-1} \geq 1$, with the equality only occurring only as $n \to \infty$. □

The intuition for this result is as follows. Moving from the supply curve to the marginal factor cost curve for a given number of suppliers is changing the number of demanders from (effectively) an infinite number (perfect competition) to only one (monopsony). With linear curves, we know that this results in a doubling of the slope of the marginal factor cost relative to the average factor cost, resulting in a halving of input demand for a constant output value. Conversely, if the value of average and marginal product curves were linear, to get a doubling of inputs would require a move from sole ownership ($n = 1$) to open access ($n \to \infty$). That this intuition works here can be seen by noting that $S_1(Q) = Q^{(1-\alpha)/\alpha}/\alpha$ while $MFC_n(Q) = Q^{(1-\alpha)/\alpha}n/(\alpha + n - 1)$, so that only in the limit as $n \to \infty$ does $MFC_n(Q)$ equal $S_1(Q)$.

Lemma 1 also shares features with the literature on the optimal number of competitors in the commons (e.g., Cornes, Mason and Sandler 1986). There, market power in the output market causes the sole owner ($n = 1$) to under-produce relative to the social optimum in order to capture monopoly profits in the output market even though he internalizes all of the externalities in production. Conversely, when $n \to \infty$, there is over-production because producers become price taking open-access competitors. In that case, the single parameter n affects competition at both the output and input level. Here, the shift from $S_n(Q)$ to $MFC_n(Q)$ results from effectively changing the number of buyers b from many ($b \to \infty$) price-takers to one ($b = 1$) price-setter, while the shift from $S_n(Q)$ to $S_1(Q)$ is the result of moving from a few ($n > 1$) common-property producers to one ($n = 1$) sole-owner producer. Thus, unlike the optimal commons literature, two parameters change when comparing $S_1(Q)$ with $MFC_n(Q)$.[25]

[25]The relationship between $S_1(Q)$ and $MFC_n(Q)$ in Lemma 1 can be shown to hold for the upwards sloping part of the supply curve for the quadratic production function, $f(w) = w(a-w)$, even though the supply curve for that production function is backwards bending for sufficiently high prices.

4 Laissez-Faire Equilibria

To measure the gains from regulation, I now derive social optimum and compare that with the laissez-faire equilibria first under assumption of a competitive pipeline and then under assumption of a monopsony pipeline.

4.1 The Social Optimum

The social marginal benefit of oil is given by $P[(1-\beta)Q](1-\beta)$. To see this, observe that given social marginal costs of $S_1(Q)$, the social planner chooses Q to maximize

$$W(Q) = \int_0^{(1-\beta)Q} P(z)\,\mathrm{d}z - \int_0^{Q} S_1(z)\,\mathrm{d}z.$$

Therefore, by Leibnitz's rule, the social optimum production satisfies $S_1(Q^*) = (1-\beta)P[(1-\beta)Q^*]$. When $\beta = 0$, so that the quantity produced equals the quantity consumed, this occurs at the intersection of the unitized supply curve $S_1(Q)$ and the demand curve $P(Q)$. But when $\beta > 0$, the social marginal benefit curve becomes $P[(1-\beta)Q](1-\beta) = (1-\beta)^{(\epsilon-1)/\epsilon}P(Q)$, which, for $\epsilon < 1$ and $0 < \beta < 1$, lies above $P(Q)$. For example, for $\beta = 1/2$ and $\epsilon = 1/4$, $(1-\beta)^{(\epsilon-1)/\epsilon} = 8$. Because the diagrams for social welfare are much simpler to see when $\beta = 0$, for the remainder of the text, the figures are drawn only for the case where $\beta = 0$, although the calculations allow for $\beta > 0$. (The case with $0 < \beta < 1$ is analyzed in Appendix A.)

Fig. 1 shows the relationship between the various functions when $\beta = 0$. The demand curve $P(Q)$ represents the social marginal value of additional output when $\beta = 0$. Also shown are the supply curves $S_1(Q)$ and $S_n(Q)$ and the corresponding marginal factor cost curves $MFC_1(Q)$ and $MFC_n(Q)$. The supply curve $S_1(Q)$ lies above the supply curve $S_n(Q)$ since along $S_n(Q)$, part of producers' costs are external costs borne by their competitors. The $MFC_1(Q)$ function lies above the $MFC_n(Q)$ function since $S_1(Q) > S_n(Q)$, and finally $MFC_n(Q) > S_1(Q)$ by Lemma 1.

4.2 Competitive Common-Property Equilibrium

When the pipeline market is competitive in both sales to consumers and purchases from producers, the only market failure is due to common-property supply. Thus the market clearing prices p_n^c and $\hat{p}_n^c$ and production Q_n^c (where equilibrium values are denoted by a superscript-subscript combination, where the superscript indicates the competitiveness of the pipeline price ('c' = competitive, 'm' = monopsonistic)

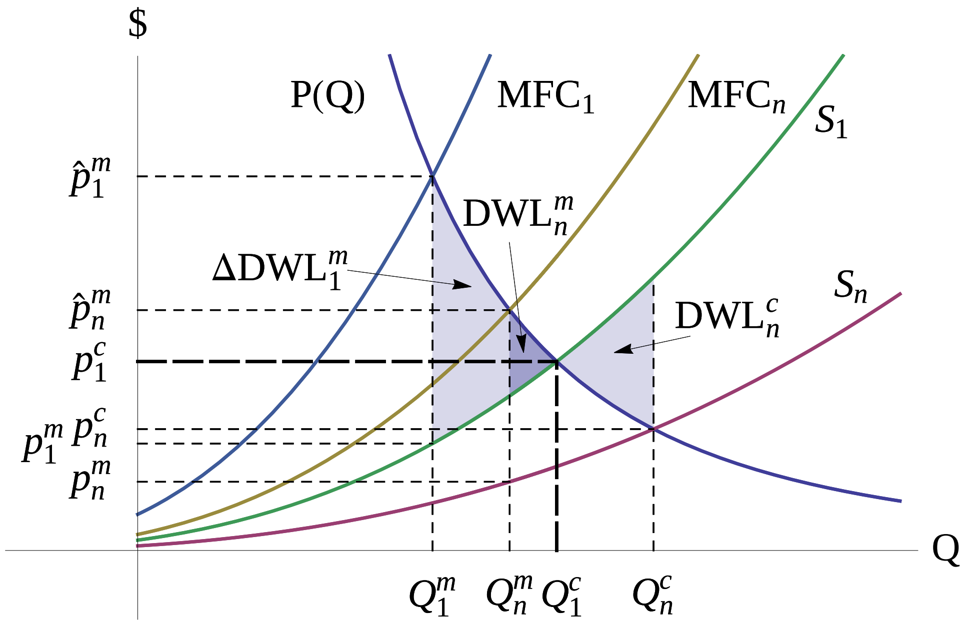

Figure 1: Monopsony and Competitive Common-Property and Unitization Equilibria ($\beta = 0$).

and the subscript 'n' again indicates the extent of the common property problem, as indexed by the number of producers, n.) satisfy:[26]

$$S_n(Q_n^c) = (1-\beta)P[(1-\beta)Q_n^c], \; p_n^c = S_n(Q_n^c), \; \& \; \hat{p}_n^c = P[(1-\beta)Q_n^c]. \tag{14}$$

Since in the first equation, the right-hand-side is the social marginal benefit of oil, while the left-hand side is the private marginal cost of oil, the common-property production level is too high:[27]

Proposition 1. *When supply is everywhere increasing in price, output in the competitive common property equilibrium, Q_n^c is greater than the socially optimal output level, Q_1^c for all $n > 1$.*

In Fig. 1, the laissez-faire competitive common-property equilibrium, output is Q_n^c. Producers are paid p_n^c, which, since $\beta = 0$, equals the price consumers pay $\hat{p}_n^c = p_n^c$. The rectangle $p_n^c Q_n^c$ is the pipeline

[26]The solutions: $Q_n^c = (1-\beta)^{(\epsilon-1)\alpha\psi}(A_n/k)^{\alpha\epsilon\psi}$, $p_n^c = (1-\beta)^{(\epsilon-1)(1-\alpha)\psi}(A_n/k)^{-\alpha\psi}$, $\hat{Q}_n^c = (1-\beta)^{\epsilon\psi}(A_n)^{\alpha\epsilon\psi}$, and $\hat{p}_n^c = (1-\beta)^{-\psi}(A_n/k)^{\alpha\epsilon\psi}$, where $\psi = \frac{1}{(1-\alpha)\epsilon+\alpha}$.

[27]If, however, the production function exhibits a range where the marginal product is negative, so that the supply curve may be backwards-bending, output in the common property equilibrium may be less than output in the social optimum.

total purchasing costs. Consumers' surplus is the area between the inverse demand function $P(Q)$ and the competitive consumer price $\hat{p}_n^c$. Producers' surplus, which equals rents, is the area between the producer price and the social marginal cost curve, $S_1(Q)$. The dead-weight-loss triangle in the competitive common-property equilibrium is the area labelled DWL_n^c. Relative to the social optimum, over-production occurs because producers ignore the costs they impose upon other producers when making their choice of the number of wells to drill upon the field. Since the supply curve $S_n(Q)$ shifts down as n increases, this dead-weight-loss is increasing in the number of producers.

4.3 Monopsony Common-Property Equilibrium

When the pipeline has monopsony power (but remains a price taker in the output market), the equilibrium output is determined by equating the value of the marginal product, $(1-\beta)P[(1-\beta)Q]$, with the marginal factor cost of additional crude oil, $MFC_n(Q)$, and setting the well-head price equal to the price that causes that quantity to be supplied:[28]

$$MFC_n(Q_n^m) = (1-\beta)P[(1-\beta)Q_n^m],\ p_n^m = S_n(Q_n^m),\ \&\ \hat{p}_n^m = P[(1-\beta)Q_n^m]. \tag{15}$$

The monopsony common-property equilibrium has output $Q_n^m < Q_n^c$. The monopsonist restricts output relative to the competitive equilibrium in an effort to reduce his costs of purchasing the raw input. The equilibrium price paid to producers, p_n^m, is the minimum price required to bring Q_n^m to market, given that to producers $S_n(Q)$ is the private marginal cost of supplying output. The consumer price, $\hat{p}_n^m$, is the maximum willingness-to-pay by consumers at quantity $\hat{Q}_n^m$. Pipeline crude oil purchasing costs are given by $Q_n^m p_n^m$; and pipeline profits are given by $[\hat{p}_n^m(1-\beta) - p_n^m]\, Q_n^m$. Consumers' surplus is the area between the inverse demand curve $P(Q)$ and the consumer price $\hat{p}_n^m$ over the region $[0, Q_n^m]$. Total rents to mineral rights owners' equal the difference between the total value of purchases and the costs evaluated at $S_1(Q)$ over the interval $[0, Q_n^m]$. Since the monopsony producer price is less than the competitive producer price, aggregate and field production, wells drilled, and mineral rights owners' rents are lower than in the competitive common-property equilibrium. Refiner's profits, however, are positive, since there is now a wedge between the value of the marginal product of additional output, $(1-\beta)\hat{p}_n^m$, and the price paid to producers, p_n^m.

The next result establishes that $Q_n^m \leq Q_1^c$:

[28] These have solutions: $Q_n^m = \alpha^{\alpha\epsilon\psi} Q_n^c$, $p_n^c = \alpha^{(1-\alpha)\epsilon\psi} p_n^c$, $\hat{Q}_n^m = \alpha^{\alpha\epsilon\psi}\hat{Q}_n^c$, and $\hat{p}_n^c = \alpha^{-\alpha\psi}\hat{p}_n^c$, where the competitive solutions are given in *n.* 26, *supra*.

Proposition 2. *For the production function* (1)*, output in the monopsonistic common-property equilibrium,* Q_n^m*, is strictly less than the socially optimal output level,* Q_1^c *for all* $n < \infty$*, and* $Q_n^m = Q_1^c$ *as* $n \to \infty$*.*

Proof. The monopsonist equates the value of the marginal product of crude inputs, $(1-\beta)P[(1-\beta)Q]$, with $MFC_n(Q)$, while the social optimum equates the value of the marginal product of output with the social marginal cost function, $S_1(Q)$. Since the value of the marginal product is decreasing in output, the proof depends upon whether $S_1(Q)$ is greater or less than $MFC_n(Q)$. By Lemma 1, the production function 1 implies that $MFC_n(Q) \geq S_1(Q)$ for all $n \leq \infty$ and strictly so for $n < \infty$, which implies that $Q_n^m \leq Q_1^c$, and strictly so for $n < \infty$. □

Thus, when both the monopsony power and common-property supply problems are present, the reduction in output from monopsony is greater than the increase in output from common-property for all $n < \infty$.[29] Intuitively, Proposition 2 occurs because a monopsonist, like a monopolist, has a large effect on the quantity produced relative to the competitive equilibrium, while the effect of a worsening of the common property problem is incremental. The effect of monopsony is exactly offset by common property only as $n \to \infty$.

5 Unitization Equilibria

Under unitization, the field is effectively operated as though there were a single owner, where production shares are allocated according to an agreed upon formula.[30] In principle, unitization agreements may be made at any stage in the production process. Here, however, I consider only the counterfactual where the unitization agreement is made in advance of drilling and there are no heterogeneities such as a gas cap or water drive affecting the field.

[29]Unlike Proposition 1, which requires the supply function $S_n(Q)$ to be everywhere upwards sloping, this result can be shown to hold when $q = w(a-w)$, so that the supply curve is backwards-bending, since the marginal factor cost is positive in value only when the supply curve is upwards sloping.

[30]In complicated environments, such as gas cap fields, unitization agreements often specify the conditions under which the transition from oil to gas production begins (Libecap and Smith 1999, 2001, 2002).

5.1 Competitive Unitization Equilibrium

The competitive unitization equilibrium satisfies[31]

$$S_1(Q_1^c) = (1-\beta)P[(1-\beta)Q_1^c],\ p_1^c = S_1(Q_1^c),\ \&\ \hat{p}_1^c = P[(1-\beta)Q_1^c]. \tag{16}$$

Since $S_1(Q)$ measures social marginal costs and $(1-\beta)P[(1-\beta)Q]$ measures social marginal benefits, the competitive unitization equilibrium maximizes social welfare. Quantity Q_1^c is produced, producers receive price p_1^c, which equals the social marginal cost of production, and consumers consume $\hat{Q}_1^c = (1-\beta)Q_1^c$ and pay $\hat{p}_1^c = P[(1-\beta)Q]$.

5.2 Monopsony Unitization Equilibrium

Now consider unitization in the face of monopsony power. The monopsony unitization equilibrium satisfies

$$MFC_1(Q_1^m) = (1-\beta)P[(1-\beta)Q_1^m],\ p_1^m = S_1(Q_1^m),\ \&\ \hat{p}_1^m = P[(1-\beta)Q_1^c]. \tag{17}$$

The effect of unitization is to shift the inverse supply curve to the left from $S_n(Q)$ to $S_1(Q)$. By (13), this also shifts up the marginal factor cost curve from $MFC_n(Q)$ to $MFC_1(Q)$. This causes the equilibrium quantity demanded by the monopsonist to decrease to Q_1^m from Q_n^m, because both marginal and average factor cost are now higher. Thus, given Proposition 2, we may state the following:

Proposition 3. *When production is given by* (1)*, under monopsony, unitization causes output Q_1^m to decrease relative to Q_n^m, which, because $Q_n^m \leq Q_1^c$, implies that social welfare is reduced.*

Since production declines as n decreases under unitization, the number of wells drilled on each field decline in the monopsony unitization equilibrium relative to the monopsony common property equilibrium, since unitization forces costs which were external under common property to be internalized.

Contemporary participants in the debate over whether to adopt unitization or prorationing were well aware that market power might undo the good of unitization.[32] Indeed, on the Yates field, where Humble Oil had convinced producers to engage in de facto unitization in 1927, Humble requested that the Texas Railroad Commission issue an order codifying the agreement that had been privately reached specifically because they were concerned that their private agreement might

[31] Both the competitive and monopsonistic unitization equilibria are written as in n.'s 28 and 30, respectively, replacing A_n with $A_1 = \alpha$.

[32] Rostow's (1948), for example, proposed a version of the first-best in which fields were forced to unitize and market power was restricted by a *per se* rule in which antitrust violations occurred as soon as a firm was sufficiently large.

be undone by antitrust authorities. Proposition 3 suggests these worries were well grounded.

5.3 Distributional Effects of Unitization

Since $Q_1^m < Q_n^m$, the monopsonistic consumer price, $\hat{p}_1^m > \hat{p}_n^m$, is higher under monopsony unitization than under monopsony common property (see Fig. 1). The effect of unitization on the price paid to producers, however, is composed of two offsetting effects. Unitization shifts the supply curve from $S_n(Q)$ to $S_1(Q)$, which, holding output constant, raises the price paid to producers. But as the marginal factor cost curve also shifts up to $MFC_1(Q)$ from $MFC_n(Q)$ under unitization, the quantity demanded decreases along $S_1(Q)$, causing the price paid to producers to decline. Differentiating p_n^m with respect to n reveals the net effect of unitization on the producer price:

$$\frac{dp_n^m}{dn} = -\frac{\alpha}{(1-\alpha)\epsilon + \alpha}\left(\frac{p_n^m}{A_n}\right)\frac{dA_n}{dn} < 0,$$

where the inequality follows from $dA_n/dn > 0$. Thus, unitization, which effectively reduces n, increases the equilibrium producer price.

Using (12), we can now see how monopsony profits change when unitization is imposed:

$$\begin{aligned}
\frac{\Pi_n^m}{\Pi_1^m} &= \frac{(1-\beta)^{(\epsilon-1)/\epsilon}\left(Q_n^m\right)^{(\epsilon-1)/\epsilon} - (A_n)^{-1}\left(Q_n^m/k\right)^{(1-\alpha)/\alpha} Q_n^m}{(1-\beta)^{(\epsilon-1)/\epsilon}\left(Q_1^m\right)^{(\epsilon-1)/\epsilon}(\alpha)^{-1}\left(Q_n^m/k\right)^{(1-\alpha)/\alpha} Q_1^m} \\
&= \frac{\left[(1-\beta)^{(\epsilon-1)/\epsilon} - (A_n)^{-1}k^{-(1-\alpha)/\alpha}\left(Q_n^m\right)^{\alpha\epsilon\psi}\right]\left(Q_n^m\right)^{(\epsilon-1)/\epsilon}}{\left[(1-\beta)^{(\epsilon-1)/\epsilon} - (\alpha)^{-1}k^{-(1-\alpha)/\alpha}\left(Q_n^m\right)^{\alpha)\epsilon\psi}\right]\left(Q_1^m\right)^{(\epsilon-1)/\epsilon}} \\
&= \frac{(1-\beta)^{(\epsilon-1)/\epsilon}(1-\alpha)\left[\alpha A_n(1-\beta)^{(\epsilon-1)/\epsilon}k^{(1-\alpha)/\alpha}\right]^{\alpha(\epsilon-1)\psi}}{(1-\beta)^{(\epsilon-1)/\epsilon}(1-\alpha)\left[\alpha^2(1-\beta)^{(\epsilon-1)/\epsilon}k^{(1-\alpha)/\alpha}\right]^{\alpha(\epsilon-1)\psi}} \\
&= \left(\frac{\alpha}{A_n}\right)^{(1-\epsilon)\alpha\psi} < 1,
\end{aligned}$$

where $\psi = 1/[(1-\alpha)\epsilon + \alpha]$, and where the second equality pulls out a common $(Q)^{(\epsilon-1)/\epsilon}$, with $Q = Q_n^m$ in the numerator and $Q = Q_1^m$ in the denominator; the third equality substitutes for the appropriate Q in the numerator and denominator; and the fourth equality cancels all common terms. This shows that monopsony profits rise when unitization is imposed.

Since unitization effectively reduces n, monopsony profits rise relative to the monopsony common property equilibrium. In Fig. 1 this can be seen as being due to the rise in consumer price being large enough to offset both the increase in the price paid to producers and the reduction in output. This occurs because consumer demand is inelastic, so the increase in revenues due to the reduction in output is greater than the increase in the price that must be paid to producers. The examples from the Yates and East Texas fields suggest that Humble recognized this fact: in both cases Humble was keen to proration output on a per acreage basis. Since a per acreage basis for prorationing output is all-but-in-name unitization, these efforts may be seen as the rational response by firms holding market power.

The effect of unitization on mineral rents can be seen by using (5) to show how mineral rights vary as unitization is imposed upon the monopsony common-property equilibrium:

$$\frac{R_n(p_n^m)}{R_1(p_1^m)} = \frac{\left(\frac{1-\alpha}{n}\right)(p_n^m)^{1/(1-\alpha)}(A_n)^{\alpha/(1-\alpha)}}{(1-\alpha)(p_1^m)^{1/(1-\alpha)}(\alpha)^{\alpha/(1-\alpha)}} = \frac{1}{n}\left(\frac{\alpha}{A_n}\right)^{\alpha(1-\epsilon)\psi} < 1,$$

where $\psi = 1/[(1-\alpha)\epsilon+\alpha]$, and the second equality uses the relationship that $p_1^m = (\alpha/A_n)^{-\alpha\psi}p_n^m$. This expression is less than one since $1/n < 1$ for $n > 1$ and $0 < \alpha < A_n$ and $\epsilon < 1$. Therefore rents rise under unitization when facing monopsony.

Only consumers, who now face higher prices since output declines, are made worse off under unitization. Nevertheless, by Proposition 3, the costs to consumers is higher than the gain to mineral rights owners' and to the monopsonist, as can be seen by the increase in dead-weight-loss, denoted $\uparrow DWL_1^m$, in Fig. 1, caused by the reduction in Q_1^m relative to Q_n^m.

6 Prorationing

Under prorationing, the regulator chose a well-head price floor, $\underline{p} > p_n^m$, then surveyed refineries to determine the demand at that price. In the event of excess supply, a quota was used to allocate the demand across producers. While many different schemes of allocating quotas were used, with homogeneous symmetric firms, allocation on a per well basis captures the potential for over-drilling which characterized prorationing (Adelman 1964).[33]

[33]The courts threw out several early prorationing attempts on the basis that a per well quota allocation was arbitrary. Producers holding more productive wells argued that they should obtain a larger quota share. Many of the problems from prorationing arose, however, because the courts, especially in Texas, ruled that small producers could not be prevented from producing a share sufficient to ensure their economic viability (Ely 1938 and Hardwicke 1938).

6.1 Prorationing Supply and Marginal Factor Costs

With common-property supply, when the price floor, $\underline{p}$, is less than the competitive price, p_n^c, there is excess demand. Thus, output is determined by the quantity supplied at price $\underline{p}$, and each producer sells all of what he brings to market. But when the price floor is above the competitive price, p_n^c, there is excess capacity, so each producer is only able to sell proportion $s(\underline{p}) < 1$ of what he could potentially bring to market. In Appendix B, I show that this causes the rationed (inverse) supply curve, $\bar{S}_n(Q)$, to become less price elastic relative to $S_n(Q)$, since sellers know that they will be rationed on what they can sell. Thus the supply curve becomes

$$\hat{S}_n(Q) = \begin{cases} S_n(Q) & \text{for} \quad Q \leq Q_n^c \\ \bar{S}_n(Q) & \text{for} \quad Q > Q_n^c \end{cases} . \tag{18}$$

Prorationing has two effects upon the refiner's marginal factor cost of acquiring crude oil when the prorationing price $\underline{p}$ is greater than the monopsony price, p_n^m. If the pipeline purchases a quantity less or equal to the competitive supply, $Q_n(\underline{p})$, at price $\underline{p}$, the monopsonist's marginal factor cost equals $\underline{p}$ since he cannot offer a lower price. This creates a discontinuity in the marginal factor cost curve at $Q_n(\underline{p})$. For quantities between $Q_n(\underline{p})$ and Q_n^c, which only exists when $\underline{p} < p_n^c$, the monopsonist must pay the price given by the supply curve $S_n(Q)$. Therefore, the marginal factor cost is $MFC_n(Q)$. Thus, the marginal factor cost the monopsonist faces has a jump at $Q_n(\underline{p})$. But once output exceeds Q_n^c, the relevant supply curve becomes $\bar{S}_n(Q)$, which is less elastic than $S_n(Q)$ since producers are rationed; this causes the second discontinuity in the marginal factor cost faced by the monopsonist. Therefore, the monopsonists' marginal factor cost when facing common property supply is

$$\widehat{MFC}_n(Q) = \begin{cases} \underline{p} & & Q < Q_n(\underline{p}) \\ MFC_n(Q) & \text{for} & Q_n(\underline{p}) < Q \leq Q_n^c \\ M\bar{F}C_n(Q) & & Q > Q_n^c \end{cases} , \tag{19}$$

where $MFC_n(Q)$ is the marginal factor cost derived above in (13) for the case where the price floor is not binding and $M\bar{F}C_n(Q)$ is the implied marginal factor cost curve when the inverse supply is $\bar{S}_n(Q)$.

These supply and marginal factor cost curves are shown in Fig. 2, with the dashed lines showing the continuation of $S_n(Q)$ and $MFC_n(Q)$ beyond Q_n^c and with the solid curves $\widehat{S}_n(Q)$ and $\widehat{MFC}_n(Q)$ showing the inverse supply (18) and marginal factor cost curve (19).

Now, consider the problem of the monopsonist whose value of marginal product for crude oil is given by $(1-\beta)P[(1-\beta)Q]$, and who faces

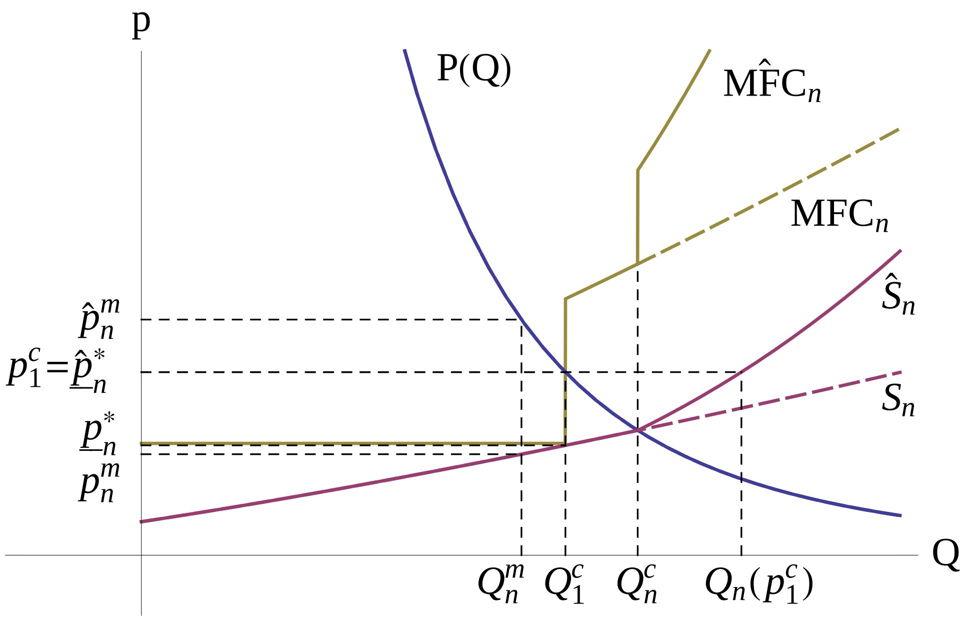

Figure 2: The Effect of a Prorationing Price Floor on Equilibrium Output ($\beta = 0$).

the marginal factor cost curve (19). If the prorationing price floor is less than p_n^m, the monopsonist is unconstrained, so the equilibrium is as before. When the prorationing price-floor is in the range $p_n^m \leq \underline{p} < p_n^c$, the monopsonist demands quantity $Q_n(\underline{p})$, since the value of the marginal product of crude oil is greater than $\underline{p}$ for all $Q < Q_n(\underline{p})$, but is less than the $MFC_n\left[Q_n(\underline{p})\right]$ for $Q \geq Q_n(\underline{p})$. In contrast, when $\underline{p} > p_n^c$, the quantity potentially supplied, $Q_n(\underline{p})$ is greater than Q_n^c. Thus, the equilibrium quantity is determined by the pipeline's demand at price $\underline{p}$.

Therefore, at any prorationing price greater than p_n^m the market clearing quantity is the quantity demanded by the pipeline. Thus, requesting demand by the refineries at given price was incentive compatible, which explains why Rostow (1948, pp. 27-28) found that the agencies responsible for allocating quotas seldom deviated from Bureau of Mines estimates of demand obtained by surveying refinery demand at price $\underline{p}$. Of course, when $\underline{p} > p_n^c$ under common property (or $\underline{p} > p_1^c$ under unitization), quotas must be implemented to allocate the excess supply.

6.2 Optimal Prorationing

Now, consider how the regulator would set the prorationing price if her objective were to maximize social welfare, but she was constrained to use only a price floor plus a quota to allocate excess supply. Then, the optimal prorationing price satisfies the following:

Proposition 4. *With field production* (1) *and common property supply, the optimal price floor is* $\underline{p}_n^*$*, which just induces production equal to* $Q_n(\underline{p}_n^*) = Q_1^c$*; at this price the marginal monopsony profits,* $\hat{p}_1^c(1-\beta) - \underline{p}_n^c$*, just equals the Pigouvian tax that forces producers to internalize the external costs they impose upon other producers Thus, this price floor achieves the socially optimal outcome with no excess capacity.*

Proof. Let $\underline{p}_n^*$ be the price floor that induces output Q_1^c along supply curve $S_n(Q)$. Then $\underline{p}_n^* = S_n(Q_1^c)$. At this output, the consumer price is $\hat{\underline{p}}_n^* = \hat{p}_1^c$, and the net price received by the monopsonist is $\hat{p}_1^c(1-\beta)$, which equals p_1^c. Thus, marginal profits are $\hat{p}_1^c(1-\beta) - \underline{p}_n^* = S_1(Q_1^c) - S_n(Q_1^c)$, which equals the Pigouvian tax the government would choose if it used a tax on output to achieve the social optimum. □

Since $Q_n^m \leq Q_1^c$ by Proposition 2, a price floor that raises aggregate output to Q_1^c causes both production and the number of wells drilled to increase relative to the laissez-faire monopsony common-property equilibrium. Pipeline profits fall since demand is inelastic and the producer price is rising in $\underline{p}$. At output Q_1^c, the consumer price equals $\hat{p}_1^c$. Since $\underline{p}_n^*$ just induces the socially optimal output level, it follows that the difference in the consumer net price and the well-head price, $\hat{p}_1^c(1-\beta) - \underline{p}_n^*$, is equal to the difference between the supply curves, $S_1(Q_1^c)$ and $S_n(Q_1^c)$, and as $S_1(Q_1^c) - S_n(Q_1^c)$ measures the marginal external cost producers impose upon one another at quantity Q_1^c, $\hat{p}_1^c(1-\beta) - \underline{p}_n^*$ equals the Pigouvian tax the government would charge producers if it had both instruments and used a price floor equal to p_1^c. Thus, even though the government only has one instrument, a price floor on producer prices, it may use the monopsonist's incentive to maximize profit to force producers to internalize the common property costs they impose upon one another. The conclusion, therefore, is that in choosing prorationing over unitization, the government chose what was *potentially* the optimal policy instrument. Whether it was used that way is a separate question, which I turn to in the next section.

There is an second way to obtain the socially optimal outcome:

Proposition 5. *If output is produced under unitized production, so the supply curve is* $S_1(Q)$*, the price floor* $\underline{p}_1^* = p_1^c$ *just induces output* $Q_1(\underline{p}_1^*) = Q_1^c$*. The consumer price is* $\hat{p}_1^c$*; therefore, producers earn price* $\hat{p}_1^c(1-\beta) = p_1^c$*, and the monopsonist earns zero profits. This outcome equals the social optimum.*

Proof. Under unitized supply, $S_1(Q)$ for $\underline{p} < p_1^c$ and $\bar{S}_1(Q)$ for $\underline{p} \geq p_1^c$, where the later reflects the fact that there will be excess supply at prices above p_1^c. The marginal factor cost is $\underline{p}_1^*$ for $Q < Q_1^c$, and is $M\bar{F}C_1(Q)$ for $Q \geq Q_1^c$. Therefore, under unitization, the monopsonist chooses quantity Q_1^c and pays producers $\underline{p}_1^* = p_1^c$. Consumers pay $\hat{p}_1^c$, and the monopsonist earns zero economic profits. □

Given that production is produced under unitization, setting the price floor at $\underline{p}_1^* = p_1^c$ forces the monopsonist to purchase Q_1^c output, earning zero marginal profits on each unit purchased. In this case, the production externality is internalized through unitization, rather than marginal profits acting as a Pigouvian tax. This solution, however, requires two instruments, while the price floor $\underline{p}_n^*$ required only one.

6.3 Non-Optimal of Prorationing

McDonald (1971, p. 164, Table 15) showed that between 1954-1967 the *pro rata* quota shares averaged 40% of capacity in the major producing states, and Adelman (1964) estimated that the cost of the excess drilling could have been as high as half of industry revenues. Under the optimal prorationing price $\underline{p}_n^*$, however, there is no excess capacity. Thus, as implemented, prorationing was not optimal. This section shows that only mineral rents owners gained from a prorationing price floor which induces excess supply, how efforts to alleviate the problems of excess supply through unitization and well-spacing requirements affected mineral rents, and offers a tentative explanation of why the federal government added prorationing after adopting unitization.

First, consider prorationing price floors when the price floor is in the range $p_n^m < \underline{p} \leq p_n^c$. In this case, output is increasing in $\underline{p}$ since the equilibrium quantity equals $Q_n(\underline{p})$. Therefore, consumers' surplus is increasing in $\underline{p}$ and mineral rents are increasing in the prorationing price by (5). Pipeline profits, however, are falling since marginal revenue is negative when demand is inelastic and marginal factor costs are rising. Indeed, total industry rents (monopsony plus mineral) are falling as the prorationing price floor rises, since demand is inelastic. Welfare is rising in $\underline{p}$ for $\underline{p} \leq \underline{p}_n^*$, and then falling for $\underline{p} > \underline{p}_n^*$.

But once the prorationing price rises above p_n^c, excess capacity exists. For $\underline{p} > p_n^c$, monopsony profits are driven to zero, and as the prorationing price continues to rise, consumers' surplus falls (output falls and the consumer price rises). Mineral rents rise (see (B.7)) because demand is inelastic. This rise in mineral rents occurs in spite of the dead-weight-loss due to excess drilling that occurs when $\underline{p} > p_n^c$.[34]

[34]These effects of prorationing hold also when fields have been unitized (as long as unitization does not cause $p_1^m > \underline{p}$). For $\underline{p} \leq p_1^c$, mineral rents and consumers' surplus are

Thus, the only group to unambiguously gain from a prorationing price floor above the competitive common-property output are the mineral rights owners. Furthermore, unlike unitization, where rents are bounded at R_1^m, mineral rents under prorationing are bounded only by the the choke price on consumer demand. To the owners of mineral rights, this would have been an important advantage of prorationing over unitization. Of course, for $\underline{p} > p_n^c$, the capacity under prorationing is in excess of the market demand at price $\underline{p}$, which cuts into the rents earned by producers.

The next result shows how the mineral rents when the prorationing price is just equal to the competitive common-property price compare to the mineral rents under monopsony unitization:

Proposition 6. *When production is given by* (1)*, for all prorationing prices less than or equal to* p_n^c*, mineral rents under monopsony prorationing are lower than the mineral rents under monopsony unitization.*

Proof. We know by (5) that mineral rents are increasing in $\underline{p}$ for $\underline{p} < p_n^c$. Thus, we need to show that mineral rents at the prorationing price $\underline{p} = p_n^c$ are less than mineral rents under monopsony unitization. By (5), ratio of mineral rents at the optimal prorationing price to mineral rents under monopsony unitization is given by

$$\frac{R_n(p_n^c)}{R_1^m} = \frac{\left(\frac{1-\alpha}{n}\right)\left[A_n^{-1}\left(Q_n^c/k\right)^{(1-\alpha)/\alpha}\right]^{1/(1-\alpha)}}{(1-\alpha)\left[\alpha^{-1}\left(Q_1^m/k\right)^{(1-\alpha)/\alpha}\right]^{1/(1-\alpha)}} = \frac{1}{n}\left(\frac{A_n}{\alpha}\right)^{\alpha\epsilon\psi-1}\alpha^{\epsilon\psi} < 1,$$

where $\psi = 1/[(1-\alpha)\epsilon+\alpha]$, and the second equality uses $Q_n^m = \alpha^{\alpha\epsilon\psi}Q_n^c$ and $Q_m^1 = (A_n/\alpha)^{\alpha\epsilon\psi}Q_n^m$. The terms $1/n$ and $\alpha^{\alpha\epsilon\psi}$ are each less than one in value. Since $A_n > \alpha$, the second term is less than one only if $\alpha\epsilon\psi < 1$. But $\alpha(\epsilon-1) < (1-\alpha)\epsilon$, since demand is inelastic. Adding α to each side reveals that $\alpha\epsilon\psi < 1$. □

This shows that if the objective were to raise mineral rents, then to raise rents higher than could be attained under unitization requires that the prorationing price be high enough to induce excess capacity.

Next, consider the subsequent efforts to reduce the dissipation of rents due to the excess capacity. Beginning with Louisiana in 1940 for natural gas, and followed by Oklahoma in 1945 for oil and gas,

increasing and monopsony rents and total industry rents are decreasing in the prorationing price. But for $\underline{p} > p_1^c$, monopsony rents are zero, consumers' surplus is decreasing, and mineral rents are increasing in the prorationing price.

the state legislatures of the producing states adopted or relaxed compulsory unitization rules (Eckman 1973). The states also encouraged larger minimum well-spacing by giving higher quotas to fields using larger spacing of wells (McDonald 1971). Both of these have the effect of reducing the number of competitors on a field. The next result shows the effect this had upon mineral rents, consumer's surplus, and monopsony rents:

Proposition 7. *When production is given by* (1)*, for a prorationing price* $\underline{p} > p_n^c$*, imposing unitization on top of prorationing increases mineral rights owner's rents, decreases consumers' surplus, and increases monopsony rents if* $\underline{p} < p_1^c$ *and has no effect otherwise.*

Proof. Holding $\underline{p}$ fixed, differentiating mineral rents (B.7) with respect to n yields

$$\frac{dR_n^S(\underline{p})}{dn} = -R_n^S(\underline{p})\left[\frac{n-1}{n^2 A_n}\right] < 0.$$

Thus, mineral rents increase as n decreases. Consumers are made worse off, since $Q_1(\underline{p}) < Q_n(\underline{p})$ for all $n > 1$. If the prorationing price still binds, there is no effect upon monopsony rents, which are zero both with and without unitization. If $p_n^c < \underline{p} < p_1^c$, however, imposing unitization causes monopsony rents to become positive. □

Thus the adoption of unitization statutes and increasing well-spacing requirements by the states subsequent to prorationing increased mineral rents.

Finally, recall that the federal government adopted unitization on federal leases in 1930, yet it subsequently added prorationing with NIRA. Libecap and Wiggins (1985) and Wiggins and Libecap (1985) attributed this difference to fact that the Congress, unlike the state legislatures, was the residual claimant on federal oil and gas leases on federal lands. Wiggins and Libecap (1987), Libecap (1989), Viscusi, Harrington, and Vernon (1995), and Smith (2005), in contrast, argued that the purpose of NIRA and the subsequent prorationing regulation was to act as a government-run cartel for the oil industry as a whole. I have argued that prorationing as operated was an attempt to raise mineral rents. How, then, to explain the adoption of prorationing on top of unitization?

Under unitization, for values of $p_n^m < \underline{p} \leq p_1^c$, total welfare, consumers' surplus, and mineral rents are each increasing in the prorationing price, while monopsony rents and total industry rents are decreasing in the prorationing price. Thus, one argument may have simply been that the government recognized the welfare gain from prorationing. But, the fact that there was excess capacity suggests that regulators' primary focus was upon creating rents to mineral rights owners, since, again, for values of $\underline{p} > p_1^c$, only mineral rents are increasing in the prorationing price, while consumers' surplus and total welfare are each decreasing in the prorationing price and monopsony rents remain at zero.

7 Extensions

Finally, I consider two extensions of the model. The first examines what happens if unitization creates a bilateral monopoly between the pipeline and the producers, and the second relaxes the assumption leading to Lemma 1 and Proposition 2.

7.1 If Unitization Creates a Bilateral Monopoly

Because unitization causes producers to act as a single unit in production, what would happen if that caused them to recognize that they too have market power vis-à-vis the monopsonist? In this case, a bargaining situation arises in which the pipeline and the producers bargain over a (p_B, Q_B) combination. All such price-output combinations must maximize the joint monopsony plus mineral rents. This implies:

Proposition 8. *If the monopsony buyer and producers behave as a bilateral monopoly with both groups treating the consumer price as given, then the bilateral equilibrium involves production of $Q_B = Q_1^c$ and prices $p_B = p_1^c$ and $\hat{p}_B = \hat{p}_1^c$ This outcome maximizes social welfare.*

Proof. In this case, the buyer's profits are $\Pi_B = P[(1-\beta)Q](1-\beta)Q - pQ$ and the mineral rents are $R_B = pQ - \int_0^Q S_1(z)\,\mathrm{d}z$. The equilibrium must maximize the sum $R_B + \Pi_B$. Thus, the iso-profit and iso-rent curves must be tangent at an equilibrium:

$$\left.\frac{dp}{dQ}\right|_{d\Pi_B=0} \equiv \frac{P[Q(1-\beta)](1-\beta)-p}{Q} = \frac{S_1(Q)-p}{Q} \equiv \left.\frac{dp}{dQ}\right|_{dR_B=0}.$$

This implies that Q_B solves $P[(1-\beta)Q_B](1-\beta) = S_1(Q_B)$, or that $Q_B = Q_1^c$. Thus, the equilibrium producer price is $p_B = p_1^c$ and the equilibrium consumer price is $\hat{p}_B = \hat{p}_1^c$. □

Thus, if unitization creates a bilateral monopoly between the pipeline and producers, the only possible negotiated outcome (when the two together remain price takers in the output market) is the efficient solution, since that is what maximizes the joint rents.[35] Hence, the inefficiency of unitization in Proposition 3 is attenuated in this case.

[35] The case where the two recognize their market power in the output market, however, is substantially different. In that case, marginal revenue equals $\bar{p}(1-\beta)$ for the quantities where the consumer price is $\bar{p}$, and is negative thereafter, since demand is inelastic.

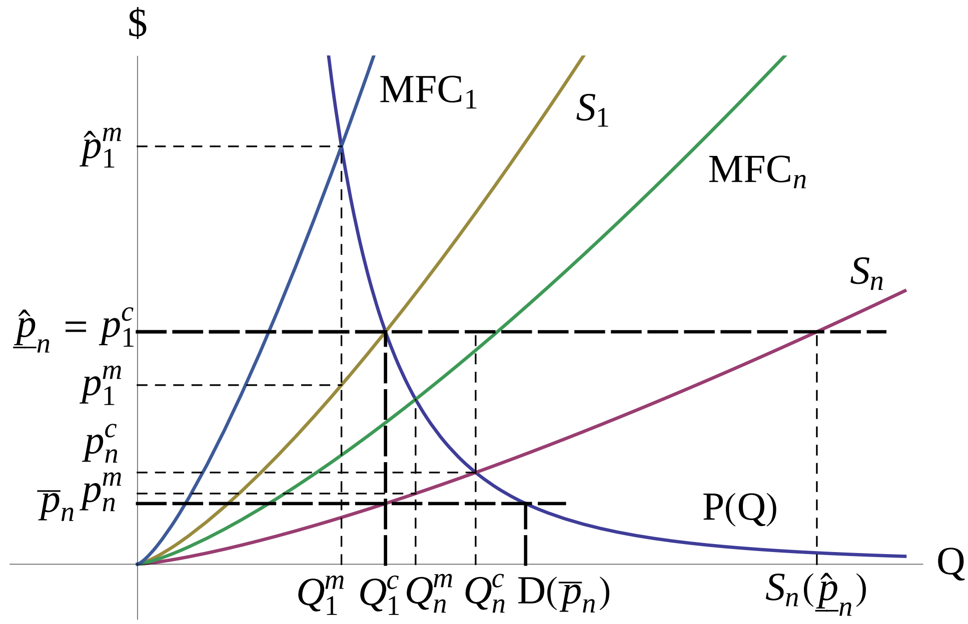

Figure 3: The Effect of a Prorationing Price Floor on Equilibrium Output when $S_1(Q) > MFC_n(Q)$ ($\beta = 0$).

7.2 Prorationing and Unitization if $S_1(Q) > MFC_n(Q)$.

The analysis has proceeded under the assumption that $S_1(Q) < MFC_n(Q)$, which I showed in Lemma 1 to be true for the assumed functional form for production. But what if the true production function yields $S_1(Q) \geq MFC_n(Q)$?

Fig. 3 shows this case, again drawn for $\beta = 0$.[36] The social optimum again occurs at output Q_1^c. Clearly, competitive unitization would achieve this optimum. But now, $Q_n^m \geq Q_1^c$. Thus, there is over-production in the monopsony common-property equilibrium, rather than under-production. It continues to be the case, however, that monopsony unitization causes under-production, since the social optimum occurs at Q_1^c, and $MFC_1(Q) > S_1(Q)$, so that $Q_1^m < Q_1^c$. Thus, the conclusion in Proposition 3 that unitization fails to achieve the first best in the presence of monopsony is robust to this change,

Hence, the only outcome possible in all equilibria is that Q_B occurs at the discontinuity in marginal revenue, and the producer price is indeterminate. I ignore this case, because it can be shown that *neither* unitization nor prorationing have any effect upon the equilibrium output.

[36]The figure also ignores the issues of supply elasticity when output is rationed.

although the conclusion in Proposition 2 that the unregulated monopsony common-property equilibrium under-produces relative to the social optimum is not.

But what about prorationing? Now, $Q_1^c < Q_n^m < Q_n^c$, so that optimal prorationing must *reduce* output relative to both the monopsony and competitive common-property equilibria. The only way to achieve the first best with price controls enforced by quotas is to set a price *ceiling* on the well-head price at $\bar{p}_n < p_n^m$ such that the quantity supplied just equals Q_1^c. A price floor at $\bar{p}_n$ would be ineffective since $p_n^m > \bar{p}_n$. At this price ceiling, there is excess demand, since $D(\bar{p}_n) > Q_1^c$. Therefore, the optimal prorationing result Proposition 4 would not hold. A price ceiling, however, is exactly opposite to what regulators attempted to do. Raising producer prices explicitly occurred in NIRA[37] and also was the objective on the Cushing, Oklahoma field in 1914 and the effect when martial law enforced prorationing on the East Texas field in 1931-1932. It is also contrary to the evidence from Table 1 that well-head prices rose, rather than fell, under prorationing.

Finally, consider a price floor that is greater than or equal to $\hat{\underline{p}}_n > p_n^c$ in Fig. 3. Then, the analysis is identical to the analysis of non-optimal prorationing above, and it is consistent with the observed excess capacity, since $S_n(\hat{\underline{p}}_n) > Q_1^c$.

8 Discussion

This paper examines why, when trying to solve the common pool problem in the oil and gas industry, the U.S. came to be regulated by the price-floor mechanism prorationing, rather than by unitization. I argue that prorationing arose in part as a response to the monopsony power held by the integrated pipeline/refinery companies.

I also show that while unitization solves the common pool problem, it does nothing to solve the monopsony power problem, and indeed exacerbates it if implemented absent prorationing. Prorationing, in contrast, by setting the price floor above the monopsony price, directly severs the price-setting ability of the monopsony. Indeed, at the producer price which just brings the socially optimal level of output to market, the monopsonist's marginal profit just equals the Pigouvian tax a regulator would place on output to solve the common property problem. Thus, prorationing had potential to be the optimal instrument. In practice, however, prorationing fell short of the ideal. I argue that the evidence of excess capacity suggests that the policy was designed to increase the rents to mineral rents owners, and that relative

[37] Cole and Ohanian (2004, p. 784) state, "Most [NIRA] industry codes included trade practice arrangements that limited competition, including *minimum prices*, restrictions on production..." (emphasis added).

to unitization, may have yielded higher mineral rents.

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A Iceberg Equilibria, $\beta > 0$.

Fig. 4 shows the corresponding equilibria from Fig. 1 for the case where the iceberg costs are positive. When $\beta > 0$, the value of additional production is given by $(1-\beta)P[(1-\beta)Q] = (1-\beta)^{(\epsilon-1)/\epsilon}P(Q)$. Since $0 < \beta < 1$ and $0 < \epsilon < 1$, this curve lies above the demand curve $P(Q)$. Thus, field production in the four equilibria are determined by the intersection of the $(1-\beta)P[(1-\beta)Q]$ function and the respective supply or marginal factor cost curves. For a given output Q, consumption is $\hat{Q} = (1-\beta)Q$. In the competitive equilibria, total revenues from consumers equal total payments to producers, so that $p = (1-\beta)\hat{p}$ and $\hat{Q} = (1-\beta)Q$. The dashed curves represent the zero level iso-profit curves for the pipeline (which have an elasticity of -1). Consumer prices in the monopsony cases are higher than the break-even price. Also shown in Fig. 4 are the the value-in-use (the area under the demand curve $P(Q)$ to quantity $\hat{Q}$) and the total producer costs (the area under the $S_1(Q)$ supply curve) for the social optimum.

There are two things to note about Fig. 4. First, the relative positions of the equilibria are identical to those in Fig. 1. Second, instead of simple dead-weight-loss triangles, the welfare comparisons require a comparison of the gain or loss to consumers with the gain or loss to producers. Qualitatively, however, the the analysis is identical to that in Fig. 1. Table 2 presents a numerical simulation of the equilibrium values for parameters: $n = 2$, $\beta = 1/2$, $\epsilon = 1/3$, $\alpha = 2/7$, and $\bar{p} = 15$. The optimal prorationing price is $\underline{p}_n^* = 1.65$. This results in rents of $R(\underline{p}_n^*) = 0.60$ and monopsony profits of $\Pi(\underline{p}_n^*) = 2.12$, which sum to the mineral rents at the competitive unitization equilibrium. The row "Minimal Prorationing" displays the minimum price such that prorationing rents equal rents under monopsony unitization.

B Prorationing Equilibrium when $\underline{p} > p_n^c$.

When the prorationing price floor $\underline{p}$ is greater than the competitive common property price p_n^c, there is excess capacity, resulting in each producer being allowed to produce only $0 < s < 1$ of what they are capable of producing. Thus, each producer's rents are

$$R^i = \frac{w^i}{w}\left[\underline{p}sf(w) - w\right] \qquad \text{for} \qquad \underline{p} \geq p_n^c. \tag{B.1}$$

Taking s and $\underline{p}$ as given, the symmetric equilibrium wells satisfies

$$\frac{\partial R^i}{\partial w^i} = s\underline{p}\left[\left(\frac{1}{n}\right)f'(w) + \left(\frac{n-1}{n}\right)\frac{f(w)}{w}\right] - 1 = 0, \qquad i = 1, \ldots, n. \tag{B.2}$$

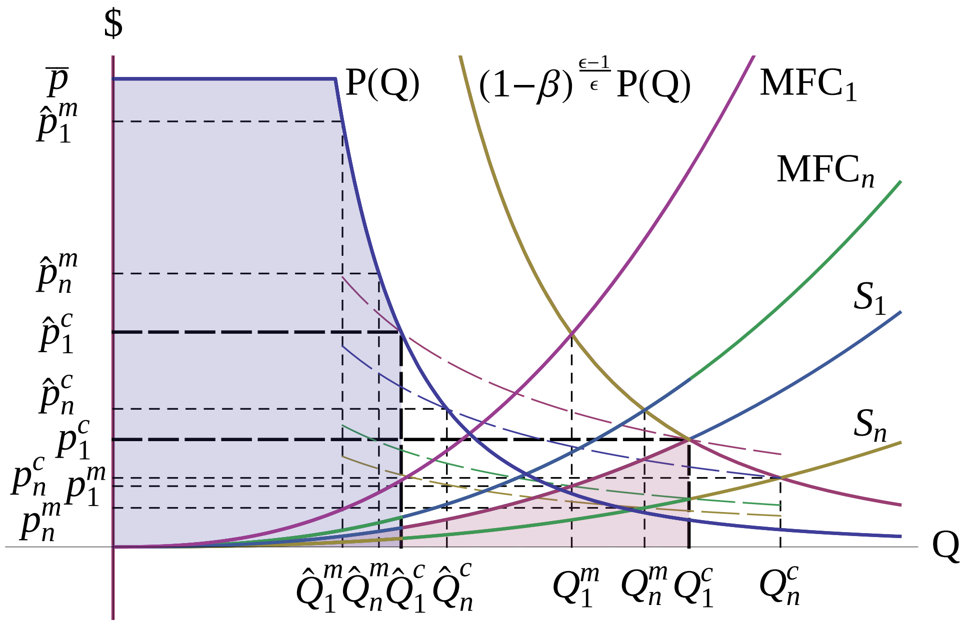

Figure 4: Monopsony and Competitive Common-Property and Unitization Equilibria ($\beta > 0$).

The equilibrium number wells drilled, potential field and aggregate production, and field rents are thus

$$q_n^D(s\underline{p}) = \left(s\underline{p}A_n\right)^{\frac{\alpha}{1-\alpha}}, \qquad Q_n^D(s\underline{p}) = k\left(s\underline{p}A_n\right)^{\frac{\alpha}{1-\alpha}},$$
$$w_n^D(s\underline{p}) = \left(s\underline{p}A_n\right)^{\frac{1}{1-\alpha}}, \qquad \text{and} \qquad R_n^D(s\underline{p}) = \left(\frac{1-\alpha}{n}\right)\left(s\underline{p}\right)^{\frac{1}{1-\alpha}} A_n^{\frac{\alpha}{1-\alpha}}, \tag{B.3}$$

where the superscript 'D' indicates that output is determined by the monopsonist's demand. As in (4), the number of wells, potential field and aggregate production, and field rents are each increasing in $s\underline{p}$.

The pro rata share is derived from the market clearing condition that the quantity demanded equals s times the quantity supplied:

$$(1-\beta)P\left[(1-\beta)sQ_n^D(s\underline{p})\right] = \underline{p}. \tag{B.4}$$

Solving this for s yields the equilibrium prorationing quota share:

$$s_n^D(\underline{p}) = \underline{p}^{-[(1-\alpha)\epsilon+\alpha]}A_n^{-\alpha}k^{-(1-\alpha)}(1-\beta)^{(1-\alpha)(\epsilon-1)}. \tag{B.5}$$

The pro rata share is decreasing in $\underline{p}$, since an increase in $\underline{p}$ lowers the quantity demanded and raises the quantity supplied. Substituting for $s_n^D(\underline{p})$ into (B.3) yields the prorationing equilibrium production for a price floor in excess of the competitive price:

$$Q_n^D(\underline{p}) = (1-\beta)^{(\epsilon-1)\alpha} k^{1-\alpha} (A_n)^\alpha \underline{p}^{(1-\epsilon)\alpha}. \tag{B.6}$$

Supply is less elastic when $\underline{p}$ is greater than the competitive price because $\frac{dQ}{dp}\frac{p}{Q} = \frac{dq}{dp}\frac{p}{q} = (1-\epsilon)\alpha < \alpha$ in (B.6), while when $\underline{p}$ is less than the competitive price in (6), $\frac{dQ}{dp}\frac{p}{Q} = \frac{dq}{dp}\frac{p}{q} = \frac{\alpha}{1-\alpha} > \alpha$. The kink in $S_n(Q)$ at Q_n^c therefore causes the discontinuity in $MFC_n(Q)$ at Q_n^c.

Finally, mineral rents on each field rise rise as the prorationed price floor increases:

$$R_n^D(\underline{p}) = \left(\frac{1-\alpha}{n}\right)(1-\beta)^{\epsilon-1} k^{-1} \underline{p}^{1-\epsilon}. \tag{B.7}$$

Table 1: Effects of Prorationing on Gasoline and Well-Head Prices

	Nominal Prices		Real Prices (1931=1)		Consumer Price Indices		
	Gasoline	Well-Head	Gasoline	Well-Head	All Items	Gasoline/All	Fuel Oil/All
Year	($/Gal.)	($/bbl.)	($/Gal.)	($/bbl.)	(2009=100)	(1935=1)	(1935=1)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1921-30 Mean	0.223	1.46	1.16	1.98	8.04	–	–
1931	0.170	0.65	1.00	1.00	7.10	–	–
1932	0.179	0.87	1.18	1.49	6.37	–	–
1933	0.178	0.67	1.23	1.21	6.04	–	–
1934	0.189	1.00	1.26	1.75	6.24	–	–
1935	0.188	0.97	1.23	1.66	6.40	1.00	1.00
1936	0.195	1.09	1.26	1.84	6.46	1.03	1.02
1937	0.200	1.18	1.25	1.93	6.70	1.03	1.14
1938	0.195	1.13	1.24	1.88	6.57	1.02	1.11
1939	0.188	1.02	1.21	1.72	6.48	0.97	1.02
1940	0.184	1.02	1.18	1.70	6.54	0.95	1.05
1941	0.192	1.14	1.17	1.81	6.87	0.91	1.08
1932-41 Mean	0.189	1.01	1.22	1.70	6.47	0.99	1.06
1947-58 Mean	0.279	2.65	0.96	2.38	12.11	0.83	1.14
1959-71 Mean	0.319	2.97	0.87	2.12	15.38	0.82	1.11
1932-71 Mean	0.260	2.17	1.01	2.04	11.28	0.86	1.10

Notes: The gasoline price is the 50-city U.S. average nominal price per gallon for regular gasoline. The well-head price is the U.S. average nominal well-head price per 42-gallon barrel. The real price indexes for gasoline and well-head prices convert the nominal prices into inflation-adjusted prices using the consumer price index and then divide these inflation-adjusted prices by the 1931 inflation-adjusted price so that 1931 equals 1.00. The CPI indexes for gasoline and fuel oil are the CPI for those items divided by the CPI for all items, and normalized so that the index equals 1.00 in 1935 (the earliest year the data is available). All data, except columns (6) and (7), are from American Petroleum Institute: 1921-58: *Petroleum Facts and Figures, Centennial Edition 1959*, 1959-71: *API Basic Petroleum Data Book*. The relative CPI data in columns (6) and (7) are from U.S. Bureau of Labor Statistics.

	Producer Quantity	Producer Price	Consumer Price	Mineral Rents	Refiner Profits	Consumers' Surplus	Total Welfare
Equilibrium	Q	p	$\hat{p}$	R	Π	CS	W
Competitive Common-Property	1.18	2.38	4.71	1.01	0	4.86	5.88
Monopsony Common-Property	0.94	1.35	9.46	0.45	3.19	2.41	6.06
Competitive Unitization (Social Optimum)	1.02	3.71	7.43	2.72	0	3.40	6.12
Monopsony Unitization	0.86	2.10	14.73	1.22	4.29	0.11	5.62
Optimal Prorationing	1.02	1.65	7.43	0.60	2.12	3.40	6.12
Minimal Prorationing	1.07	3.18	6.36	1.22	0	3.97	5.19

Table 2: Numerical Example when $\beta > 0$.