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Article (Accepted version)
(Refereed)

Original citation:
Mason, CF (2015) Concentration Trends in the Gulf of Mexico Oil and Gas Industry. Energy Journal, 36. ISSN 1944-9089
DOI: http://dx.doi.org/10.5547/01956574.36.SI1.cmas

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ABSTRACT

In this paper, I evaluate patterns of concentration in the Gulf of Mexico oil and gas industry, one of the most important sectors for US production over the past few decades. In the 1990s, production in the Gulf was quite concentrated, and was dominated by large oil companies. But over the past decade or so this concentration has eroded, with recent levels consistent with an unconcentrated industry. These patterns apply for drilling and leasing as well, and are relevant to both shallow and deep water. The overall picture is an industry with strong competition for leases, drilling and production.

Keywords: Petroleum Economics, Concentration, U.S. Gulf of Mexico, Oil exploration

http://dx.doi.org/10.5547/01956574.36.SI1.cmas

1. INTRODUCTION

During his illustrious career, Morris Adelman devoted considerable time and energy to thinking about the structure of oil markets, at both the international and national level.[1] A recurring theme in these analyses is the evolution of the oil market, and in particular the tendency towards greater competition over time.[2] As an illustration, Adelman (1977, pp. 1–2) notes that the share of the global oil market attributable to the four largest oil companies fell by nearly 20% between 1950 and 1969. Contemporary public policy was less optimistic about the trend towards greater competition; for example, the staff of the FTC described the petroleum industry as "characterized by high barriers to entry" (Erickson, 1977, p. 55).

The question of the potential impact of market power and concentration does not just apply to oil and gas production. To the extent that local or regional markets are characterized by high concentration, this can have implications for input markets. Adelman (1972, p. 201) anticipated this possibility, when he observed in reference to the oil service industry that "[t]he offshore drilling industry is perhaps the biggest single part of the complex." In this regard, a particularly important market segment for offshore oil and gas is the Gulf of Mexico: As Figure 1 illustrates, crude oil production from federal leases in the Gulf of Mexico has accounted for 15 and 30% of domestic US production over the past 20 years.[3] And while the share of US production attributable to the

1. See, for example, Adelman (1972). For a more regionally focused study, see Adelman et al. (1971).

2. See Table III-1 and Table III-2 on pages 80–81, as well as discussion on page 82 in Adelman (1972). This theme is also taken up by Verleger, Jr. (1987).

3. The data used to construct this figure is available at http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_m.htm.

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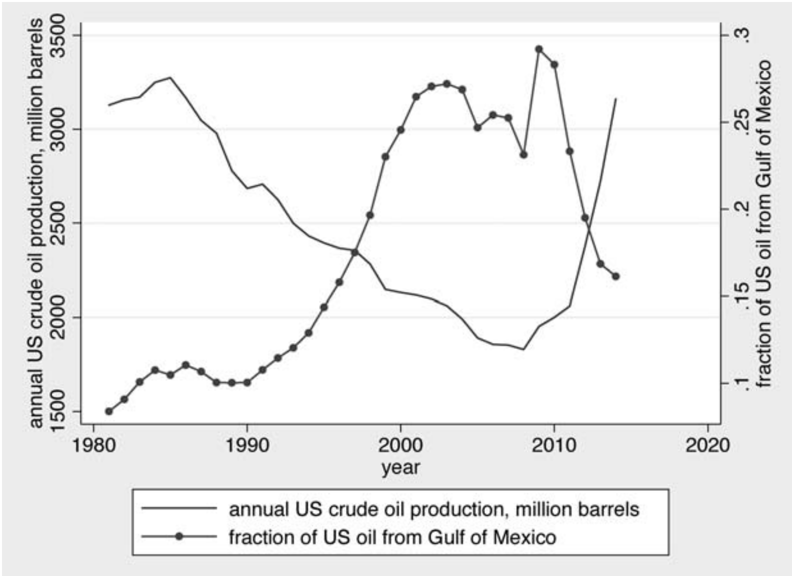
Figure 1: The role of Gulf of Mexico Crude Oil Production



Gulf of Mexico has fallen off in the past few years, its role remains important: this reduced share is almost surely the result of the recent boom in tight oil production, which is particularly light. Since US refineries are geared to process heavier crude slates, this new source of crude has to be blended with heavier crude, the most economic source thereof comes from the Gulf of Mexico.[4]

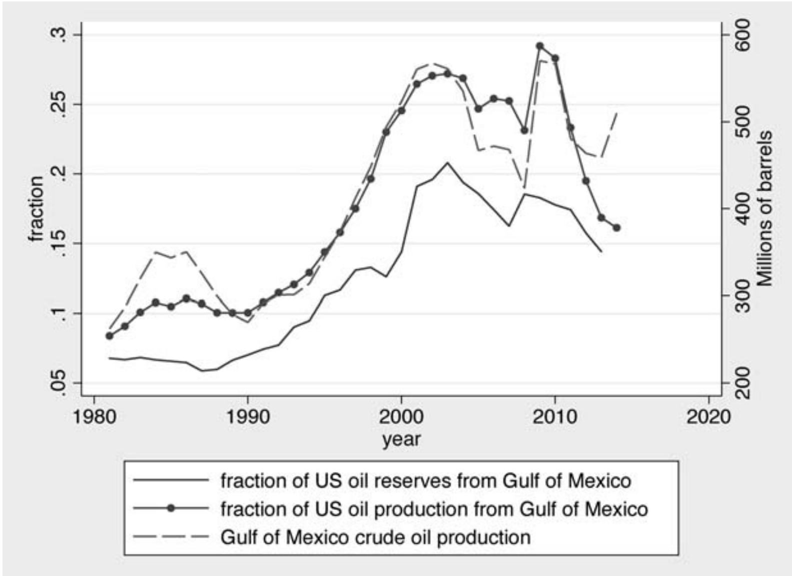
A second theme found in Adelman's work relates to the recurring push to capture oil companies' profits, either via a windfall profits tax or a move to force divestiture (Adelman, 1972, 1977). In his view, such efforts are ill-directed, in part because of the general trends towards increasing competition. Echoes of these issues are also present in the Gulf of Mexico oil and gas industry. There the share of output attributable to the so-called "Seven Sisters," firms that crafted the collusive Achnacarry agreement nearly 90 years ago, has fallen sharply over the past 20 years.[5] Early on, firms that were part of the Seven Sisters controlled a considerable fraction of oil production, in both shallow and deep water. The shares attributable to these firms in 1996 were roughly 50% in shallow water, and slightly more than 80% in deep water. However, these shares had eroded markedly by 2014, falling to about 20% in shallow water and 55% in deep water. The story is quite similar for gas. The upshot is that over time, the significance of these major oil and gas companies has diminished in the Gulf of Mexico, consistent with the overall portrait of emerging competition.

In this paper I flesh out these impressions, providing calculations of concentration statistics for multiple metrics of importance to the oil and gas industry in the Gulf of Mexico. I start by

4. See Brown et al. (2014) for a discussion of the mis-match between the new tight oil supplies and present US refinery configurations.

5. For discussion of the Seven Sisters, see Mason (2014); Yergin (2011). The firms in the original Seven Sisters were Standard Oil of California (i.e., Chevron), Texaco, BP, Gulf Oil, Royal Dutch Shell, Standard Oil of New Jersey (i.e., Exxon) and Standard Oil Company of New York (i.e., Mobil). Those firms that participated in the Gulf of Mexico during the past 20 years are Chevron, Texaco, BP, Shell, Exxon and Mobil; the first two have combined into the ChevronTexaco corporation, while the last two have combined into ExxonMobil.

Figure 2: Gulf of Mexico as a fraction of total US: Crude Oil



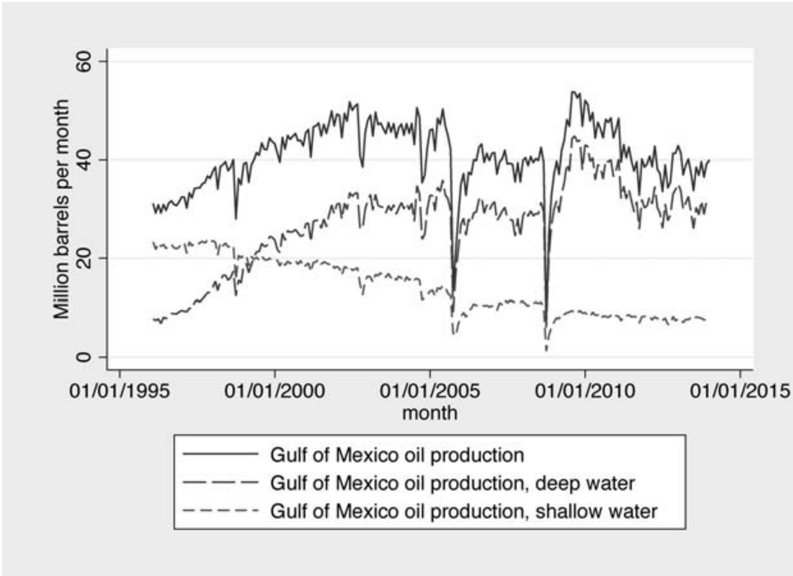
describing annual concentration levels in lease markets between 1954 and 2014. I then discuss trends in drilling, in both shallow water (between 2007 and 2013) and deep water (between 2009 and 2013). I then discuss concentration in oil and gas production, for the Gulf as a whole, as well as for both shallow and deep water. Here the data allows analysis of monthly statistics. In general, the evidence points towards decreasing concentration over time. Finally, using the monthly observations on concentration for oil and for gas production, I undertake a time series analysis. This latter inquiry allows me to estimate the long-run levels of concentration; for each segment, these long-run estimates fall in the range deemed to be "unconcentrated" by the U.S. Department of Justice.

I start the discussion in section 2, where I present an overview of the oil and gas industry in the Gulf of Mexico. I then proceed to a graphical examination of concentration patterns in section 3. I present results for three sectors in the Gulf of Mexico oil and gas industry: leasing, drilling and production. The latter data is sufficiently detailed as to allow a deeper empirical investigation, which I undertake in section 4. Here I evaluate the time series properties of these data, paying particular attention to the implied long-run level of concentration. In section 5 I offer a discussion of these results; here I offer some thoughts on the roots of declining concentration. Concluding remarks are offered in section 6.

2. AN OVERVIEW OF THE GULF OF MEXICO OIL AND GAS INDUSTRY

Oil and gas operations have been active in the Gulf of Mexico since the 1940s (Energy Information Administration, 2005). In the intervening years, exploration steadily increased; as indicated in Figure 2, crude oil production in the Gulf had reached 300 million barrels by the early 1980s. This pattern accelerated over the next few decades, with output levels exceeding 500 million barrels by the turn of the century. This rise in production was echoed by the increasing role played by Gulf oil production, as a share of total US output, with shares exceeding 20% by the late 1990s.

Figure 3: Gulf of Mexico Crude Oil Production

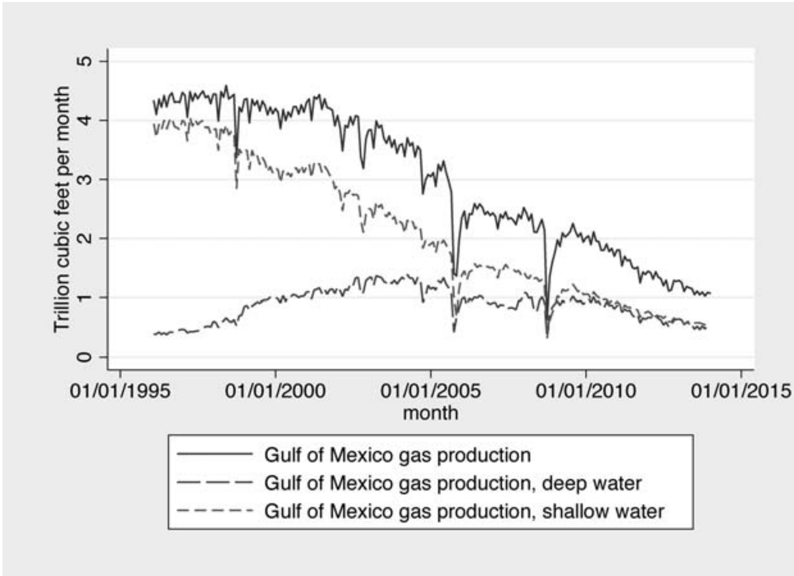


Referring back to Figure 1, this increase came at a time when total US production was declining fairly rapidly, underscoring the significance of the Gulf. The importance of Gulf of Mexico resources is also indicated by a comparison of the fraction of US production attributable to this basin. As with reserves, this fraction increased markedly after the mid-1990s, reaching roughly 20% by the early part of this century. It is also noteworthy that the fraction of US production arising from the Gulf of Mexico consistently exceeds the fraction of US reserves found in the Gulf; this implies that Gulf reserves are being extracted more rapidly than are onshore reserves.

During this period, there was a clear migration towards deeper waters. As illustrated by Figure 3, crude oil production from waters less than 600 feet in depth has fallen by about half over the past 20 years or so, with production from deeper waters rising steadily. This increase in production from deeper waters has been sufficient to outweigh the falloff in shallower water production, with the net effect that total production has remained roughly constant at about 40 million barrels per month—with the notable exceptions in August 2005, in the aftermath of Hurricane Rita, and in September 2008, following Hurricanes Gustav and Ike (Cruz and Krausmann, 2008; Kaiser and Yu, 2010). One observes a similar pattern with Natural Gas production. As Figure 4 illustrates, production from shallow waters has been steadily declining for the past 20 years, while production from deeper waters increased by roughly a factor of three between 1995 and 2005; by 2010, production levels from the two depth cohorts were quite similar. Overall production levels for gas have generally declined over the period, again with significant temporary reductions in August 2005 and September 2008.

The initial preference for shallower deposits can be explained by cost differences: while production in shallower waters can be readily accomplished by structures that are fixed to the sea floor; production from platforms in deeper waters "quickly becomes uneconomic" (U.S. Minerals Management Service, 1997, p. 12). However, technological gains lowered costs associated with production from deeper waters to the point that these deposits became economic to exploit over the

Figure 4: Gulf of Mexico Natural Gas Production



past 15 years (U.S. Minerals Management Service, 2001). These observations point to deep water resources as increasingly important.

Exploration and production in the Gulf of Mexico was initially dominated by large oil companies, with the Seven Sisters' shares of 1996 oil production roughly 50% in shallow water and 80% in deep water. One might interpret this data as indicating there were barriers to participation in oil and gas production in the Gulf of Mexico, which could then have implications for the performance of industries related to support services (such as drilling, or labor markets). It could also have implications for bidding for leases, in particular one might worry that winning bids were distorted downwards.

However, the market shares of the oil majors had eroded markedly by 2014, as Figures 5 and 6 illustrate. Figure 5 shows the fraction of Gulf of Mexico crude oil output produced by firms in the Seven Sisters, in both deep water (production from depths greater than 600 feet) and shallow water (production from depths no greater than 600 feet).[6] Evidently, the share of oil production attributable to these large oil companies had declined to about 20% in shallow water and 55% in deep water by 2014. The story is quite similar for gas. The upshot is that over time, the significance of these major oil and gas companies has diminished in the Gulf of Mexico, consistent with the overall portrait of emerging competition.

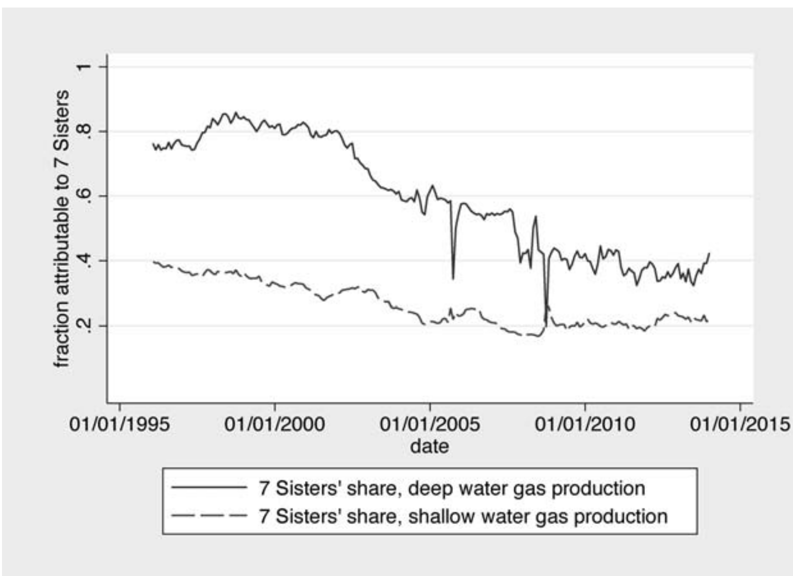
An indication of these trends is conveyed by the number of active participants in various sectors of the Gulf of Mexico oil and gas industry, as Table 1 illustrates. Here, I list the average, standard deviation, minimum and maximum number of firms for leasing, drilling and production in the Gulf of Mexico. For each of the three categories, I list the period on which I base the sample statistics, along with the frequency of the observations.[7] For leasing, I split the observations between

6. U.S. Minerals Management Service (2001) places the demarkation between shallow and deep water at 200 meters, which is slightly greater than 600 feet.

7. Detailed descriptions of the various data sources are provided in the next section.

Figure 5: Role of 7 Sisters, Gulf of Mexico Crude Oil Production

Figure 6: Role of 7 Sisters, Gulf of Mexico Natural Gas Production



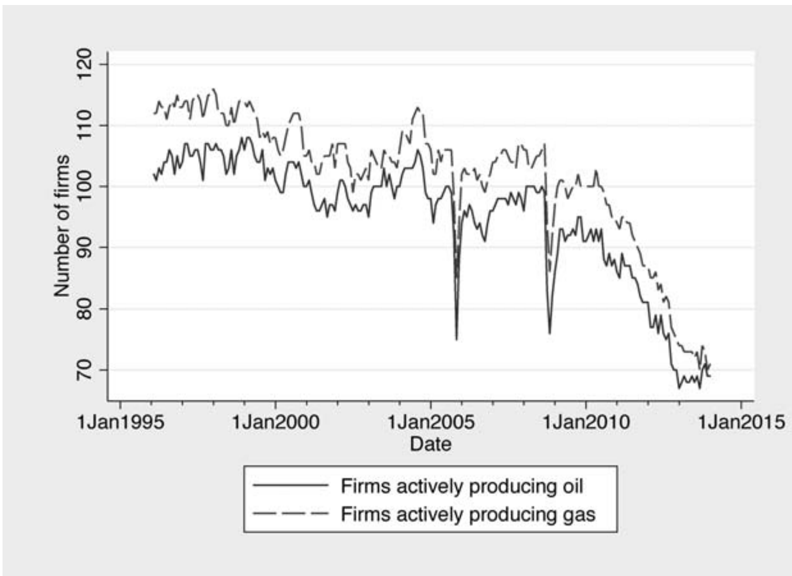
early data (taken from the Hendricks and Porter (1992) analysis of offshore leasing between 1947 and 1979, based on both state and federal leasing) and later observations (based on federal leases, taken from the Bureau of Ocean Energy Management, or BOEM). For drilling, I present information for all drilling as well as deep water drilling. For production, I split out observations for each of oil and gas production. In leasing after 1980, drilling as a whole, and both types of production, the

Table 1: Number of Firms in the Gulf of Mexico

	Leases		Drilling		Production	
	all	federal	all	deep water	oil	gas
period	1954–1979	1980–2014	2007–2013	2009–2013	1996–2014	1996–2013
frequency	annual*	annual	annual	annual	monthly	monthly
average	25.5	63.7	93.7	22.2	94.9	101.7
std. dev.	8.6	15.4	24.5	2.95	10.5	11.0
minimum	12	30	59	18	67	70
maximum	40	95	134	25	108	116

*: data in the 1950s and 1960s are less frequent (3 sales in the 1950s, 7 in the 1960s)

Figure 7: Number of Firms Extracting Oil and Gas in the Gulf of Mexico, by Month



average number of firms is substantial—ranging from the mid-60s to over 100. On the other hand, the industry size for early leasing and for deep water drilling is much smaller, in the 20s. This sense is also conveyed by the minimum observations (12 for early leasing and 18 for deep water drilling, as compared to 30 for all leasing and values in the range of 60 for the other categories). And while the number of firms producing hydrocarbons in the Gulf of Mexico has tended to be substantial, there seems to have been some shake-out in the industry during the past few years. As Figure 7 illustrates, there were over 100 firms actively producing oil, and over 110 firms actively producing gas, in the Gulf of Mexico during the mid-1990s. By 2014 the number of active firms had fallen to roughly 70 for both oil and gas; much of this reduction occurred after 2010. Despite this dramatic recent reduction, market concentration levels in the Gulf have remained low, as I demonstrate in the next section.

3. TRENDS IN CONCENTRATION

The graphical impressions offered in the previous section point to concerns that operations in the Gulf of Mexico might have been dominated by a handful of large companies, particularly in the 1990s. The pronounced role associated with these firms hints at potential barriers to participation in oil and gas production in the Gulf of Mexico. Such barriers, if they were present, would significantly decrease the competitiveness of the market for leases, and increase the degree of concentration in the market for leases. But as I noted above, these patterns eroded over time.

In this section, I elaborate on these patterns, focusing specifically on measures of market concentration in the Gulf. I discuss concentration patterns in three key layers of the industry: leasing, drilling and production. One can think of these layers as summarizing the nature of competition in the process of delivering hydrocarbons from the Gulf, as they comprise the stages of acquiring extraction rights, developing those rights via exploration and development, and then finally extracting the resources located on the leased properties. As shown below, the data reflect an unconcentrated and competitive market in all three of these phases.

To determine the competitiveness of each stage in the market, I look to a standard measure of market concentration, the Herfindahl-Hirschman Index (HHI).[8] This index is calculated by summing the squares of firms' shares over all firms in an industry. Letting s_i represent the share held by a firm i, the HHI is defined by:[9]

$$HHI = \sum_i s_i^2 . \tag{1}$$

This metric can be applied to any variable that describes an industry's structure. When market concentration is low, competition will tend to be vigorous; a market with a HHI of .15 or less can be described as unconcentrated.[10]

An alternative way to interpret the HHI is by constructing the "industry equivalent", which is the number of firms in a hypothetical industry with the HHI in question, and where all firms are of identical size.[11] For example, an industry with a HHI of .15 has an industry equivalent of roughly 6, while an industry with a HHI of .25 has an industry equivalent of 4.

3.1 Leasing in the Gulf of Mexico

I start my inquiry by evaluating the total number of leases newly acquired, on an annual basis.[12] Available data allow identification of the number of leases acquired by each firm, as well

8. For discussion of this measure, see Carlton and Perloff (2008).

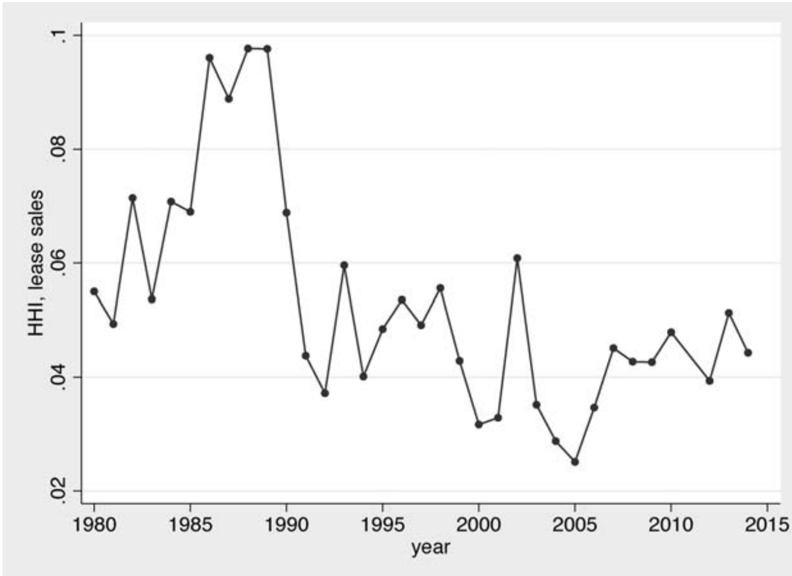
9. The HHI reaches a maximum value of 1 for a monopoly, since a single firm controls 100 percent of the market. At the other extreme, the HHI can approach zero in a purely competitive market in which a large number of firms each control a small share of the market. For example, in a market with 100 identically sized firms, each firm's share is .01, and so the HHI is $100(.01)^2 = .01$.

10. This is consistent with the current U.S. Department of Justice and Federal Trade Commission Horizontal Merger Guidelines (U.S. Department of Justice and Federal Trade Commission, 2010). By contrast, markets with a HHI above .25 are regarded as highly concentrated. The merger guidelines are calculated using basis points as opposed to market shares, e.g., a share of .1 corresponds to 10%, so its square is calculated as 100. In this way, the values constructed under the merger guidelines correspond to the HHI I calculate multiplied by 10,000 ($= 100^2$).

11. Adelman (1972, pp. 81–82) uses this interpretation in his Table III-2 and the supporting discussion.

12. Data for individual leases are available at www.data.boem.gov/homepg/data_center/leasing/leaseOwner/master.asp for all leases from 1996 to the present. There was a moratorium on leasing in much of 2011 following the Deepwater Horizon oil spill, and so I combine the small lease sale in early 2011 with the 2012 lease sales that followed the rescinding of the moratorium. The BOEM website also includes information on earlier leases, though this information is less detailed. Nevertheless, it provides sufficient information to ascertain concentration levels between 1980 and 1996. Finally, data from the Hendricks and Porter (1992) analysis of offshore leasing between 1947 and 1979 is available at http://capcp.psu.edu/data-and-software/outer-continental-shelf-ocs-auction-data; this data comprises all leases during this period, both federal

Figure 8: Concentration in Gulf of Mexico Leasing



as the distribution of ownership shares for these newly acquired leases, on an annual basis for 1980 to 2014.[13] Based on this information, I then determined the total number of leases acquired by any particular firm in a given year, allowing for fractional ownership. Summing over all firms then yields the number of leases awarded in that year; dividing the firm's total number of leases acquired by the total number awarded yields the firm's share, from which the HHI can be calculated using eq. (1).

Following this approach, I calculated the HHI for newly acquired leases for each year from 1980 to 2014. These values are graphed in Figure 8. While the market was a bit more concentrated in the 1980s, particularly in the period between 1986 and 1989, it generally has fallen into the unconcentrated range. In particular, the HHI has been roughly .05 during the past ten years; this corresponds to an industry equivalent size of around 20 in each year.

The implication of these data are clear: The market for leases in the Gulf of Mexico has been robustly competitive for at least 25 years, pointing to a lack of barriers to entry. There are plenty of bidders for every profitable lease, which in turn suggests there are likely to be many firms actively developing attractive resources.

3.2 Drilling in the Gulf of Mexico

To determine the level of concentration in the development of leases, I next turn to an analysis of concentration in drilling in the Gulf of Mexico. Here, I evaluate data showing the total number of days spent drilling for each firm operating in the Gulf, again on an annual basis.[14] The

and state. While the important leases were federal in more recent years, much of the leasing activity in the early years occurred in state waters; accordingly, I believe it is appropriate to include the state observations for this part of the analysis.

13. Because the Hendricks-Porter data does not identify the firms involved in the leases it is not possible to combine entities that are part of the same corporate structure, and so I do not report concentration statistics for years before 1980. The BOEM data does allow such combination, and so for the years from 1980 forward, I use the BOEM data.

14. These data are available from RigLogix (http://www.riglogix.com/).

Table 2: Concentration in Gulf of Mexico Drilling, 2007–2013

	Drilling Days			HHI		
	shallow	deep	all water	shallow	deep	all water
2007	34515.33	—	34515.33	0.0229	—	0.0229
2008	29712.17	—	29712.17	0.0313	—	0.0313
2009	10730.50	10189	20919.50	0.0359	0.104	0.0341
2010	11373.83	5029	16402.83	0.0579	0.0675	0.0342
2011	13539.33	6246	19785.33	0.0732	0.116	0.0459
2012	18095.67	18897	36992.67	0.0548	0.0929	0.0373
2013	12327.67	25353	37680.67	0.0761	0.114	0.0596

data includes information on the water depth of the drilling operation for some years, which allows me to contrast concentration in shallow and deep water. Using this information, I determined the number of drilling days in both shallow and deep water for each firm operating in the Gulf of Mexico in a given year, from which it is straightforward to calculate the firm's share in the drilling market.[15]

I summarize the information regarding drilling in Table 2. This table lists the total number of drilling days in waters less than 600 feet (column 2), waters deeper than 600 feet (column 3), and all waters (column 4); the available data allow determination of the first and last cohorts for each year from 2007 to 2013, while data for deep water is available for each year from 2009 to 2013. Overall, there is a clear movement away from shallower waters and into deeper waters, with the number of drilling days in shallow water falling by nearly 2/3 between 2007 and 2013. In contrast, with the exception of the period between 2009 and 2010, drilling days in deep water has grown every year. In particular, the number of drilling days in 2013 is more than double the number of drilling days in 2009; this run-up in deep water drilling was sufficient to more than offset the decline in shallow water drilling, so that total drilling increased slightly over the 7 year period. This migration into deep water underscores the emerging significance of deep water in the Gulf of Mexico; it also highlights the distinction between more recent observations and older observations, a point I return to below.

Concentration statistics for the three depth cohorts are presented in columns 5 through 7. The annual HHI statistics for drilling operations in less than 600 feet is listed in column 5, for waters deeper than 600 feet in column 6, and for all waters in column 7. The HHI statistics for drilling are all smaller than .15, generally by a fair degree. The overall conclusion to be drawn is that the market for drilling in the Gulf of Mexico has been, and continues to be, unconcentrated. This point corroborates the observation from the preceding sub-section.

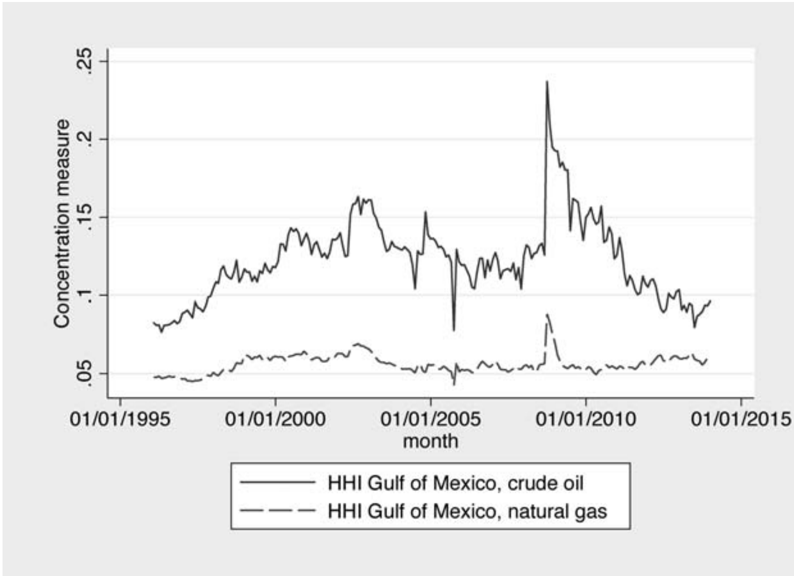
3.3 Production in the Gulf of Mexico

One might well take the position that production is the most important sector in which to assess the degree of competitiveness in the Gulf of Mexico oil and gas industry. To evaluate concentration levels in this sector, I obtained data on oil production from the BOEM database.[16] This database lists each operator's monthly output from January 1996 to December 2013, which corre-

15. As these firms generally contract out drilling operations, the shares can be interpreted as reflecting buyers' market power.

16. These data are available at http://www.data.boem.gov/homepg/pubinfo/repcat/product/Production-B.asp.

Figure 9: Concentration in Gulf of Mexico Oil and Gas Production



sponds to 216 months. Summing these values in any particular month gives the total industry oil production; then dividing an operator's production by the industry production gives that firm's share of production for that month. Using this information, I then calculated HHI values for each of the 216 months.

Figure 9 shows these levels of concentration for both oil and gas production. I observe that concentration levels are generally low for both hydrocarbon resources. With the exception of a brief period in late 2002, and in the aftermath of the 2008 Hurricanes, the HHI for oil production never exceeds .15, while the HHI for gas never exceeds .1 (and is generally considerably smaller). After the impacts from the 2008 Hurricanes had passed, the HHI for oil has fallen steadily. Overall, I conclude that the concentration indices for both oil and gas have fallen mainly within the unconcentrated range; in recent years, comfortably so.

In light of the emerging focus on deeper waters, it is interesting to compare patterns of concentration between shallow and deep water. Sorting the data set described above by water depth of operation, I formed two subsets of the data: one for operations in waters of depth no greater than 600 feet, and one for deeper water. Then, I calculated values of the HHI for each hydrocarbon resource, for each of the water depth cohorts. The results from this analysis are depicted in Figure 10 for oil and in Figure 11 for gas.

I note first that concentration levels are generally greater in deep water than in shallow water, for both oil and gas production, particularly in earlier months. This fact underscores the point that deep water production was initially dominated by the large oil and gas companies, as I noted above. But here as well this historic domination has eroded. Indeed, there was little difference between concentration levels in shallow and deep water oil production throughout the last year of the sample—both were in the range of .11, corresponding to an industry equivalent of around 9 firms. Similar patterns emerge in a comparison of shallow and deep water gas production, although here shallow water concentration levels remain smaller than deep water concentration levels throughout the sample.

Figure 10: Concentration in Gulf of Mexico Oil Production, Shallow vs. Deep Water

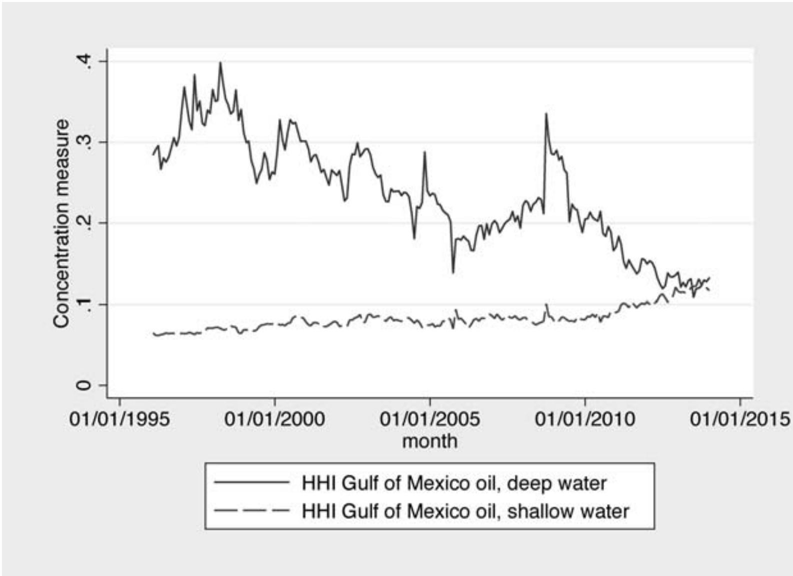
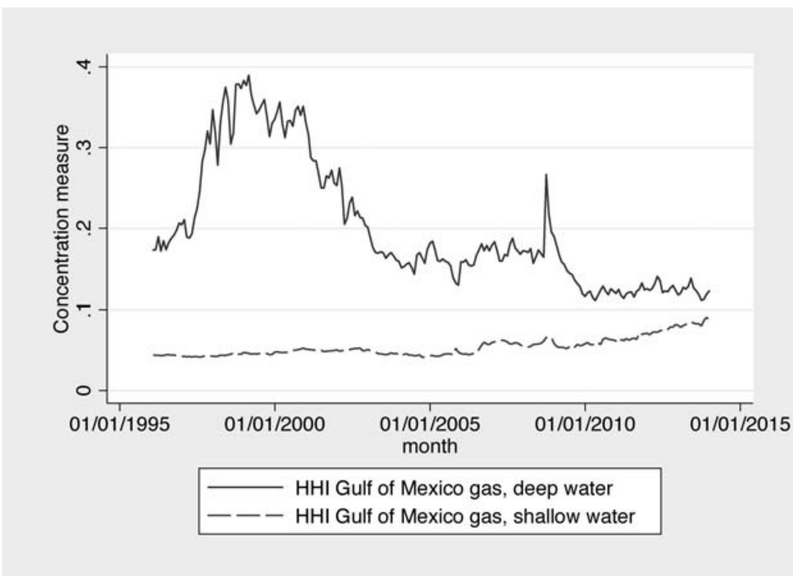


Figure 11: Concentration in Gulf of Mexico Gas Production, Shallow vs. Deep Water



Overall, the pattern displayed by this data is one of decreasing concentration, and increasing competition, over time. This pattern is particularly pronounced in the months following the major Hurricane events of 2008. Moreover, concentration levels were both markedly larger in deep water than in shallow water during the 1990s, and these larger levels were noticeably larger than the cutoff for an unconcentrated industry. But even here the early levels of concentration dissipated

Table 3: Optimal Lag Structure in HHI

lag	LL	LR	AIC	SBIC
		oil		
0	479.50		−4.514	−4.498
1	645.59	332.18	−6.072	−6.040
2	651.33	11.48	−6.116	−6.069*
3	653.78	4.89*	−6.130*	−6.067
4	653.96	0.37	−6.122	−6.043
		gas		
0	782.91		−7.377	−7.361
1	925.73	285.64*	−8.714*	−8.683*
2	925.90	0.35	−8.707	−8.659
3	925.91	0.01	−8.697	−8.634
4	926.03	0.24	−8.689	−8.610

*: optimal structure

over time, so that by the end of the sample period even deep water production was marked by relatively low levels of concentration.

4. TIME SERIES ANALYSIS OF CONCENTRATION IN PRODUCTION

While the pattern of falling concentration levels in oil and gas production echoes the patterns I observed in leasing and drilling, the production data are considerably richer. The greater number of observations, and the more granular nature of the data (monthly as opposed to annual), allows a more detailed empirical analysis. In particular, one can envision investigating the time series properties of this data, and the likely long-run levels of concentration consistent with that data. I undertake such an investigation in this section.

A simple way to summarize the time series properties of the concentration data is to view it as generated by an auto-regressive process, of the form

$$C_t = a_0 + \sum_{i=1}^{p} a_i C_{t-i} + u_t, \tag{2}$$

where C_s is the level of concentration in period s, p represents the auto-regressive order of the time series (i.e. , the number of lags in the process), and u_t is an error term that is assumed to be identically and independently distributed with mean 0.

The first step in the analysis is to determine the appropriate number of lags. To this end, one evaluates a measure related to the time series; three statistics that are typically evaluated in this regard are the Akaikie Information Criterion, the Schwartz-Bayesian Information Criterion, and the likeihood ratio test.[17] Table 3 presents the results from this part of the analysis, for both oil and gas concentration statistics. The first column lists the number of lags, the second column shows the

17. See Hamilton (1994) for discussion. The likelihood ratio test evaluates the hypothesis that adding a lag is statistically unimportant; thus, the test statistic is based on a comparison of the log-likelihood value for a model with a particular number of lags and the log-likelihood value for a model with one fewer lags.

Table 4: Analysis of Concentration: Oil

	all water depths		deep water	
coeff.	all observations	post-Ike	all observations	post-Ike
a_1	0.647***	0.620***	0.726***	0.654***
	(0.0873)	(0.144)	(0.0703)	(0.104)
a_2	0.126*	0.0064	0.114*	0.0883
	(0.0653)	(0.137)	(0.0645)	(0.116)
a_3	0.151***	0.281***	0.138**	0.175*
	(0.0377)	(0.105)	(0.0562)	(0.102)
a_0	0.0095***	0.0087*	0.0080*	0.0106*
	(0.0028)	(0.0045)	(0.0043)	(0.0061)
C^*	0.124***	0.0940***	0.188***	0.127***
	(0.0102)	(0.0118)	(0.0588)	(0.0202)
N	213	61	213	61
R^2	0.809	0.932	0.925	0.941

Standard errors in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

log-likelihood statistic, the third column presents the likelihood ratio test statistic, the fourth column lists the Akaikie Information Criterion, and the fifth column shows the Scwartz Bayesian Information Criterion. The optimal lag structure will maximize the evaluation criterion; alternatively, one can interpret the likelihood ratio test statistic as indicating whether adding an additional lag (corresponding to the number of lags indicated in the row) generates a statistically significant improvement. The optimal lag structure under each of the three metrics, taking all three criteria into account, is indicated by an asterisk.[18] The lag structure selected for the oil HHI is three lags, while the structure selected for the gas HHI is one lag.

Once the appropriate lag structure is determined, one can estimate the time series model in eq. (2). The results from such a procedure can be used to estimate the long-run level of concentration C^*; that is the level implied by setting $C_s = C^*$ for $s = t, \dots t-p$; using the notation above, the long-run level is:

$$C^* = \frac{a_0}{1 - \sum_{i=1}^{p} a_i}. \tag{3}$$

Table 4 displays the estimation results for oil concentration statistics. In this table, the first column lists the parameters that were estimated; I also include the estimated long-run value of concentration. I list estimates for all water depths in columns 2 and 3, and for deep water only in columns 4 and 5. Estimates based on the entire time series are given in columns 2 and 4. To provide a sense as to the distinction between recent patterns and patterns implied by the longer time frame,

18. If these three criterion agree on a particular structure, as with gas, that is the selected structure. For oil, two of the three criteria select three lags, and so I adopt that structure. To verify the appropriateness of the selected time series, I collected the residuals from each regression and checked for the presence of serial correlation using Durbin's test. Under the null hypothesis of white noise in the residuals, the resultant test statistic will be close to 2; this was true in each case: the test statistics for oil were 2.001 for all observations and 2.012 for deep water; the test statistics for gas were 2.075 for all observations and 2.059 for deep water. I conclude that all selected time series structures were appropriate.

Table 5: Analysis of Concentration: Gas

	all water depths		deep water	
coeff.	all observations	post-Ike	all observations	post-Ike
a_1	0.861***	0.770***	0.982***	0.740***
	(0.0336)	(0.0374)	(0.0153)	(0.0458)
a_0	0.0078***	0.0129***	0.0033	0.0322***
	(0.0019)	(0.0021)	(0.0027)	(0.0059)
C^*	0.0566***	.0558***	0.187***	0.124***
	(0.0015)	(0.0010)	(0.0554)	(0.0026)
N	215	63	215	63
R^2	0.746	0.892	0.961	0.929

Standard errors in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

I also present estimates based on observations for the period following the major Hurricane events in September 2008; these are listed in columns 3 and 5 (under the heading "'post-Ike"). I observe that the estimated long-run level of concentration for the full set of production sites is smaller than .15 for both the full sample of dates, and for the sub-sample following the Hurricane events; the estimated long-run concentration level based on observations following the Hurricane events is noticeably smaller than the estimate based on the full set of temporal observations. Moreover, for both time frames, the difference between .15 and the estimated long-run concentration level is statistically important. The industry equivalent size implied by the estimated long-run concentration level based on the full set of months is 8.1, while the industry equivalent size based on the more recent observations is 10.6. The estimated long-run concentration level for deep water production using the full list of dates is larger than .15 (though this difference is not statistically significant). This underscores the perception that production from deep water is more concentrated than in the Gulf as a whole. That said, the estimated long-run concentration level for deep water production based on observations following the Hurricane events is noticeably smaller than the estimate based on all months, though this estimate is not statistically different from .15. These estimated long-run concentration levels imply industry equivalent sizes of 5.3 (based on the full set of monthly observations) and 7.9 (based on the more recent observations alone). The impression based on these results is that concentration is falling over time, for deep water oil production and for Gulf of Mexico oil production as a whole, which echoes the pattern suggested by the visual presentation in Figures 9 and 10. For all four columns, the sum of the coefficients on lagged concentration levels is around .95, with the coefficients on terms farther in the past significantly smaller. The implication is that shocks to concentration die off slowly, meaning that there are prolonged periods where concentration moves in the same direction. Such periods could reflect epochs where concentration steadily increases, as in with the first eight years or so of the sample period for all Gulf oil production, and other periods where concentration steadily falls, as with the last seven years of the sample period for all Gulf oil production, as well as most of the sample period for all deepwater oil production.

Table 5 displays the estimation results for gas concentration statistics. Here again, the first column lists the parameters that were estimated, including the estimated long-run value of concentration; estimates for all water depths are listed in columns 2 and 3, while estimates for deep water only are given in columns 4 and 5. I show estimates based on the entire time series in columns 2 and 4; estimates based on observations for the period following the major Hurricane events in

September 2008 are listed in columns 3 and 5. As with oil, the estimated long-run level of concentration for the full set of production sites is smaller than .15 for both the full sample of dates, and for the sub-sample following the Hurricane events, and the difference between .15 and the estimated long-run concentration level is statistically important in both samples. The industry equivalent size here is slightly less than 18 for both sets of temporal observations: 17.7 based on the full set of monthly observations and 17.9 based on the more recent observations. The results generally indicate smaller levels of concentration in gas production than in oil production, although the estimated long-run concentration level for deep water production using the full list of dates is similar to the corresponding estimated level of concentration for oil—with both being larger than .15—though here again the difference is not statistically significant. Also as with oil, the estimated long-run concentration level for deep water production based on observations following the Hurricane events is smaller than the estimate based on all months; for deep water gas, this estimated long-run level of concentration is statistically smaller than .15. Based on these estimates, the implied industry equivalent size for deep water gas production is 5.3 (based on the full set of monthly observations) and 8.1 (based on the more recent observations alone). Parallel to the results for oil, these results indicate that concentration in deep water Gulf of Mexico gas production is falling over time, corroborating the visual presentation in Figure 11.

5. DISCUSSION

The results from the previous two sections point to a reduction in concentration over time in the Gulf of Mexico, suggesting relatively easy entry. To the extent this inference is valid, one would expect to see some turnover, particularly in leasing. This conjecture can be assessed using the two datasets I described in subsection 3.1 (the Hendricks-Porter dataset and the BOEM dataset). The Hendricks-Porter dataset provides information on the number of bids won, by firm, for 20 years between 1954 and 1979. This data set has information from 3 years in the 1950s (1954, 1955 and 1959), 7 years in the 1960s (1960, 1962, 1964, 1966, 1967, 1968 and 1969) and every year in the 1970s. Firms' names are not provided; instead firms are identified by a code number. The BOEM dataset provides information on the number of bids won, by firm, for every year between 1980 and 2014. Because there was a moratorium on leases for most of 2011 and early 2012, I combine these years in the following discussion. Firms are identified by a company code given by the former Minerals Management Service; a lookup utility at the BOEM website allows identification of the company associated with each code. As a result, it is possible to identify all codes corresponding to a particular company at any point in time; the results I discuss below aggregate information for each unique company. For some companies, multiple listings are given form virtually identical firm names (e.g., BP America and BP Exploration and Production); for others, mergers or acquisitions lead to a combination (e.g., Chevron and Texaco, or Exxon and Mobil). I use these two data sources to investigate the degree of turnover among top bidders over time. I offer two pieces of evidence. I first inquire as to the inertia from one lease year to the next among the top 10 bidders. To this end, I identified the top 10 bidders in each lease year, and then counted for each year the number of these top bidders that were in the top 10 for the preceding lease year. By "lease year" I mean the year corresponding to the observed lease sale. Because multiple firms can participate in a successful bid, I ascribe to each winning firm its share of the lease. So, for example, a firm that won 2 leases with 100% of the bid and 2 leases with one-third of the bid would be allocated 2.67 leases in my analysis. Figures 12 and 13 illustrate. Figure 12 shows the number of repeat top 10 bidders during the early years of the industry, between 1955 and 1979; here we see that in a typical year 6 or more firms were in the top 10 in consecutive lease years. Figure 13 shows the number of

Figure 12: Inertia in Top 10 Lease Winners, 1955–1979

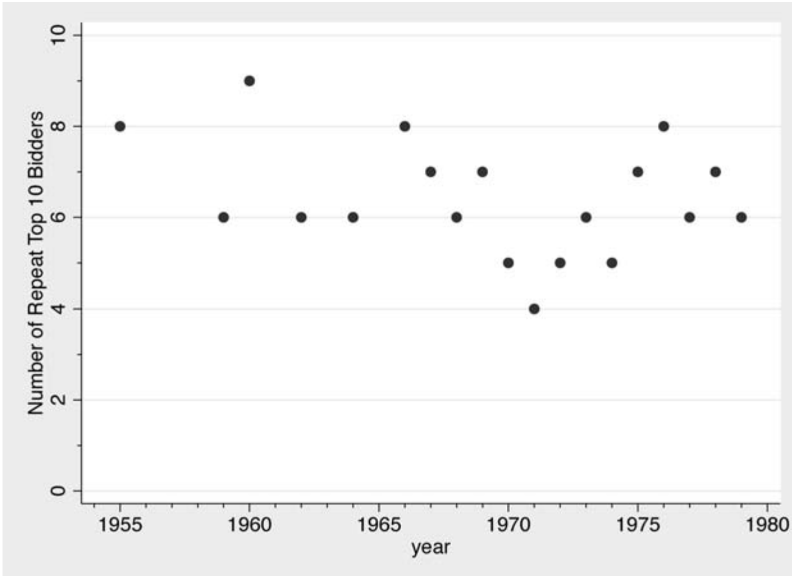
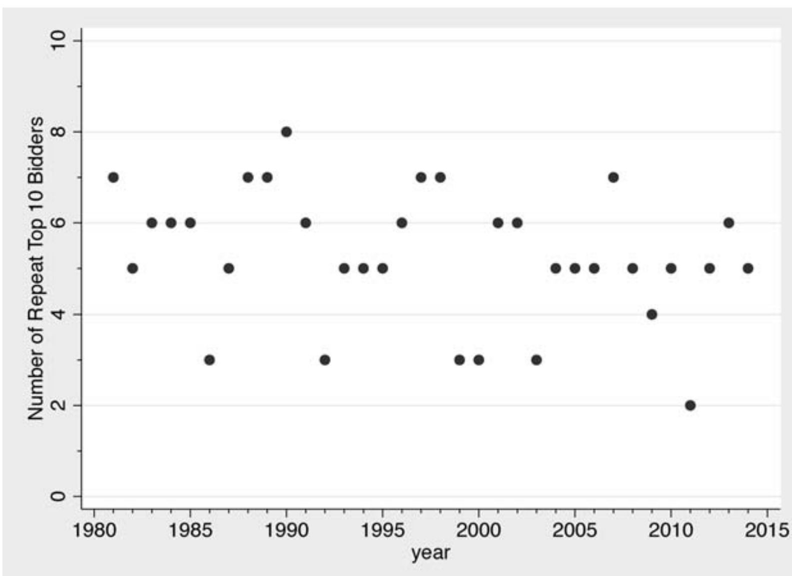


Figure 13: Inertia in Top 10 Lease Winners, 1981–2014



repeat top 10 bidders during more recent years, between 1981 and 2014; here we see that in a typical year 5 or fewer firms were in the top 10 in consecutive lease years. The general theme is that there has been more turnover in recent years. Indeed, with roughly half the firms falling from the top 10 between one year and the next, one senses there is a fair bit of turbulence at the top.

I also use the data on winning bids to assess the top 10 winners in each of the 7 decades (1950s, 1960s and 1970s for the Hendricks-Porter data, and 1980s, 1990s, 2000s and 2010s for the

Table 6: Top Winning Bidders by Decade

A. Hendricks-Porter Data

rank	*1950s*	*1960s*	*1970s*
1	1	30	30
2	30	1	8
3	3	3	5
4	168	5	**801**
5	5	8	3
6	2	14	**24**
7	7	15	1
8	4	9	9
9	16	2	17
10	15	17	**271**

B. BOEM Data

rank	*1980s*	*1990s*	*2000s*	*2010s*
1	689	689	2481	**56**
2	276	78	78	78
3	114	1138	689	2481
4	593	276	276	**2941**
5	1	1680	59	276
6	78	1	1207	689
7	967	3	2219	2277
8	81	771	981	**105**
9	771	114	2277	**2748**
10	2	59	2169	2219

BOEM data). These results are summarized in Table 6. I note first that a handful of firms are consistently in the top group of bidders: firms 1, 3, 5 and 30 in the Hendricks-Porter data; firms 78 (Chevron-Texaco), 267 (Exxon-Mobil) and 689 (Shell) in the BOEM data. But aside from these perennially important players, there is considerable fluctuation from one decade to the next. Indeed, the Hendricks and Porter data shows that 3 of the top 10 firms in the 1970s were previously not in the top 10—these are the bold-faced firms, 801, 24 and 271. From the BOEM data, one observes that 4 of the top 10 firms in the 2010s were not in the top 10 in the preceding 3 decades—these are the bold-faced firms 56 (ConocoPhillips), 2941 (Maersk), 105 (Apache) and 2481 (StatOil).

It is also interesting to consider the role of joint bidding in the evolution of the Gulf of Mexico oil and gas industry. In Figures 14 and 15, I plot the fraction of winning bids that had multiple bidders (the solid lines in each diagram, measured against the left-most y-axis), along with the number of different firms that were involved in these bids (the line with dots in each diagram, measured against the right-most y-axis). Focusing first on the earlier data, one sees that joint bidding was not important among winning bids through the end of the 1960s, with joint bids representing only about 20% of winning bids. Joint bidding became much more important in the 1970s; by the end of the decade roughly 60% of winning bids were joint. At the same time, the number of different firms that won bids more than doubled. Joint bidding remained important for the first part of the 1980s, with joint bids continuing to represent roughly 60% of winning bids through 1983. After that, the fraction dropped back to around 20%, where it has remained. In contrast to the period prior to 1970, however, the number of different firms winning bids remained high.

The nature of joint bidding also seems to have undergone a subtle change between the period before 1970 and the following decade, as Table 7 illustrates. There, I list the pairs of firms

Figure 14: Joint Bidding and the Number of Lease Winners, 1954–1979

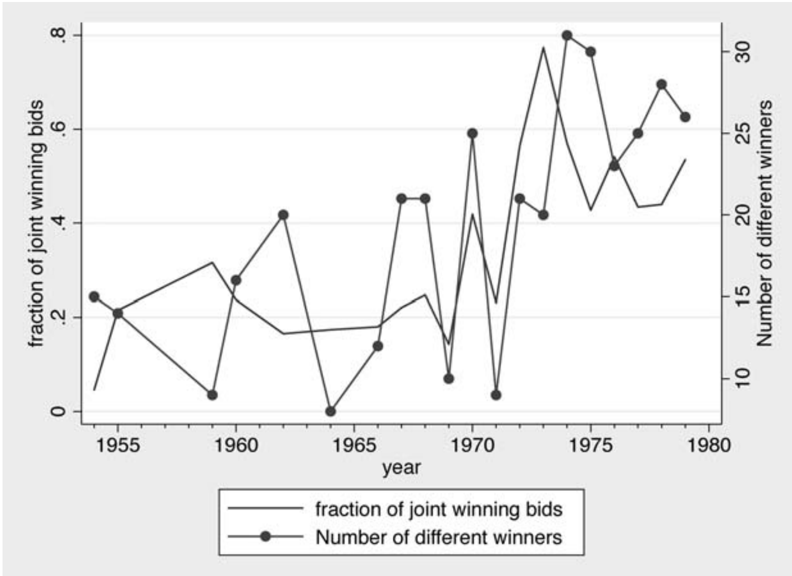
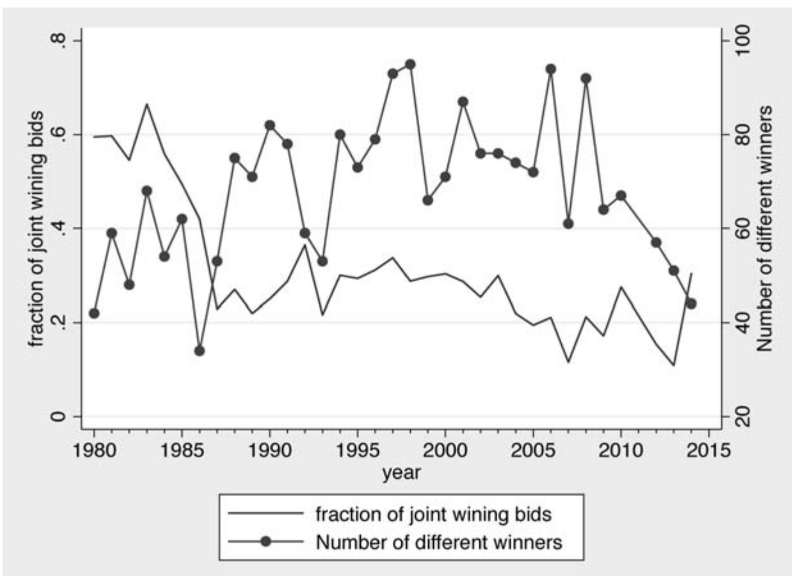


Figure 15: Joint Bidding and the Number of Lease Winners, 1980–2014



that undertake at least 10 winning joint bids during the period in question. For the period prior to 1970 there are only 8 such pairs. The most significant of these pairs is the combination of firms 2 and 15, with 46 successful joint bids. Firms 4, 16, 23 and 24 are also heavily involved in joint bidding, each with two different partners. In the following decade, there are twenty pairs of firms that won more than 10 joint bids, with several firms heavily involved, many with three or more

Table 7: Patterns of Joint Bidding, 1954–1979

A. 1954–1969			B. 1970–1979		
company 1	company 2	count	company 1	company 2	count
2	15	46	1	16	21
4	5	15	1	20	20
4	16	10	2	6	28
6	16	12	2	16	16
6	24	13	2	176	12
16	30	10	3	274	14
22	23	19	4	16	20
23	24	17	4	19	13
			6	14	16
			6	16	14
			6	18	10
			7	30	12
			14	18	12
			15	17	21
			16	21	18
			18	22	10
			18	24	26
			22	23	14
			23	24	36
			233	240	14

different partners. From this data it seems clear that a number of firms became interested in joint bidding towards the end of the period covered by the Hendricks-Porter data set.

While one might imagine a number of motivating factors driving the movement towards joint bidding in the 1970s, I believe two explanations are of particular significance. First, by participating in a joint bid firms can diversify their risk. As is true in many locations, exploration in the Gulf of Mexico was risky; indeed, the fraction of dry holes reported in the Hendricks-Porter data set is on the order of 55%. By entering into a joint bid, a firm can increase the number of draws in which it participates, thereby lowering the risk that it will come up completely empty. Second, by partnering with a more established firm, a smaller firm can acquire valuable information about the process of exploring and developing offshore prospects; this is an example of strategic learning (Pyka and Windrum, 2003; Walkup Jr., 2014). One important aspect of such learning is that it facilitates participation by the junior partner in future Gulf of Mexico ventures. As such, the increased importance of joint bidding in the 1970s could explain the increase in the number of winning bidders in the period from 1980 through 2010, which laid the foundation for declining concentration levels in oil and gas production I observed in the previous section.

6. CONCLUSION

Overall, the picture painted by the results I have presented in this paper indicates low concentration levels in the Gulf of Mexico, for both oil and gas. Concentration levels are larger in deep water than for the Gulf as a whole, but these levels have been declining over time. The implied long-run levels of concentration are generally smaller than the cutoff level of .15, which places the levels in the "unconcentrated" category. These results cover a wide range of market conditions, including periods of recession, booms and busts in oil markets, technological innovation and big mergers. Finally, the evidence suggests concentration is falling over time, particularly in deep water oil and gas production. Taken as a whole, these results are indicative of a robustly competitive industry.

One possible explanation for this downward trend in concentration is the emerging role played by non-majors in the market for leases in the Gulf of Mexico. The participation by these smaller firms increased sharply in the period from 1980 to 2010, perhaps as a result of an increased tendency towards joint bidding during the 1970s.

My findings have clear implications. There are substantial volumes of hydrocarbons in the Gulf of Mexico, for which there are a steady ongoing stream of leases. The key message of this paper is that there is every reason to believe there will be strong competition for these leases, drilling that develops the leases, and production based on those acquired leases.

ACKNOWLEDGMENTS

Some of the data/software used in this research was made available by the Center for the Study of Auctions, Procurements, and Competition Policy at Penn State with support from the Human Capital Foundation (http://www.hcfoundation.ru/en/). Thanks are due to Rémi Morin-Chassé and Gavin Roberts for able research assistance, and to two anonymous referees and Jim Smith for their constructive criticism, which has strengthened the paper. The usual disclaimer applies.

REFERENCES

Adelman, Morris A., Charles A. Norman, and Paul G. Bradley (1971). *Alaskan Oil: Constant Supply*. Praeger Publishers, New York, NY.

Adelman, Morris A. (1972). *The World Petroleum Market*. Johns Hopkins Press, Baltimore, MD.

Adelman, Morris A. (1977). The changing structure of big international oil. In *Oil, Divestiture and National Security*, pages 1–10. Crane, Russak & Company, Inc.

Brown, Stephen P.A., Charles F. Mason, Alan Krupnick, and Jan Mares (2014). Crude behavior: How lifting the export ban reduces gasoline prices in the united states. Technical report, Resources for the Future, Washington, D.C.. Issue Brief 14-03-REV.

Carlton, Dennis W., and Jeffrey M. Perloff (2008). *Modern Industrial Organization*. Addison Wesley, Boston, 5th edition.

Cruz, Ana M., and Elisabeth Krausmann (2008). Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: An overview. *Journal of Loss Prevention in the Process Industries* 21: 620–626. http://dx.doi.org/10.1016/j.jlp.2008.04.008.

Energy Information Administration (2005). Overview of U.S. Legislation and Regulations Affecting Offshore Natural Gas and Oil Activity. Technical report, Office of Oil and Gas.

Erickson, Edward W. (1977). "Charges of domestic energy monopoly: The dog in the manger of U.S. energy policy." *Oil, Divestiture and National Security* 41–55. Crane, Russak & Company, Inc..

Hamilton, James D. (1994). *Time Series Analysis*. Princeton University Press, Princeton, NJ.

Hendricks, Kenneth and Robert Porter (1992). "Joint bidding in federal OCS auctions." *American Economic Review* 82:506–511, 1992.

Kaiser, Mark J. and Yunke Yu (2010). "The impact of hurricanes Gustav and Ike on offshore oil and gas production in the Gulf of Mexico." *Applied Energy* 87(1): 284–297. http://dx.doi.org/10.1016/j.apenergy.2009.07.014.

Mason, Charles F. (2014). "The organization of the oil industry, past and present." *Foundations and Trends in Microeconomics* 10: 1–83. http://dx.doi.org/10.1561/0700000051.

Pyka, Andreas and Paul Windrum (2003). "The self-organisation of strategic alliances." *Economics of Innovation and New Technology* 12: 245–268. http://dx.doi.org/10.1080/10438590290025561.

U.S. Department of Justice and Federal Trade Commission. Horizontal Merger Guidelines, 2010. Available at http://www.justice.gov/atr/public/guidelines/hmg-2010.html.

U.S. Minerals Management Service. Deepwater in the Gulf of Mexico: America's New Energy Frontier. Technical report, U.S. Department of the Interior, 1997. OCS Report MMS 97-0004.

U.S. Minerals Management Service. The Promise of Deep Gas in the Gulf of Mexico. Technical report, U.S. Department of the Interior, 2001. OCS Report MMS 2001-00374.

Verleger, Jr., Philip K. (1987). "The evolution of oil as a commodity." In Richard L. Gordon, Henry D. Jacoby, and Martin B. Zimmerman, editors, *Energy: Markets and Regulation*, pages 161–186. MIT Press.

Walkup Jr., Gardner W. (2014). Evaluation of Potential Impacts on Non-Operators of a CWA Civil Penalty Against Non-operator Anadarko for the Macondo Incident. Expert Report. In RE: Oil Spill by the Oil Rig MDL No. 2179 "Deepwater Horizon" in the Gulf of Mexico, on April 20, 2010. At US_PP_EXP002268.

Yergin, D. (2011). *The Prize: The Epic Quest for Oil, Money & Power*. Free Press.