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INDUSTRIAL ORGANIZATION OF THE MARITIME SEISMIC ACQUISITION MARKET

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Abstract

In this article, we analyze the industrial organization of the Maritime Seismic Acquisition Market (MSAM). Their firms are process, science, and technologyintensive and provide geophysical information for oil companies operating in the upstream offshore segment. Our objective is to find the determinants of price changes and their relationships with market structures, firms conduct, and performance (SCP), considering the effect of oil price volatility on MSAM demand. To achieve this objective, we use a theoretical framework of the Industrial Organization (IO) to analyze the empirical data of MSAM at a global database between 2006 and 2019. The research is structured to calculate the SCP and the New Empirical IO (NEIO) parameters related to concentration, market power, and competition. We can verify the hypothesis about market power or collusion from empirical demand and cost models. We found that the concentration levels and the supplier's profit in MSAM decrease to an increase in demand, for which positive fluctuations are supplied by firms in the market fringe, generating pressure on the average costs of the industry, an essential factor to explain the price increase during periods of market heating. Although MSAM has a concentration, its firms have low levels of market power and markups with a high degree of competition, configuring itself as a Competitive Oligopoly.

Keywords: *Maritime Seismic Acquisition, Industrial Organization, New Empirical Industrial Organization, Oligopolies.*

1. INTRODUCTION

This article analyzes the Maritime Seismic Acquisition Market (MSAM) industrial organization, whose firms are intensive in process, science, and technology and provide geophysical-information services for oil companies operating in the upstream offshore segment [1]. This activity is performed by service companies that present a high level of specialization[2]that leads to a concentrated market structure. Just four companies have had between 60% and 90% of market share in the 2006-2019 period.

The economic relevance of this market can be seen through the estimated annual investments of the MSAM activities of around USD 19 billion at its peak in the year 2013. The seismic data supplied by the highly specialized firms of this market are one of the main inputs in the exploration of petroleum reserves, and therefore the results obtained from the use of this information affect the entire industry supply chain. On the other hand, demand for seismic information directly affects the price and demand of the final product of the oil industry. Thus, we think that this study can be relevant to empirical industrial-organization research due to the complex dynamics of price formation in this specific market, the importance of this service in the industry supply-chain in terms of investment volume and its crucial supply position, and because it is an unexplored empirical area in industrial organization theory.

Our initial research hypotheses are that the oligopolistic structure and technological characteristics of MSAM explain both its low level of competition and profit-rate differences between leading companies and those on the fringe of the market. To verify these hypotheses, we apply the microeconomic theory of price formation using a Bertrand-Russel equilibrium through the model of price decomposition in costs and markup to understand the reaction of firms to demand shocks and the market structure itself. From this model, prices in MSAM oscillate over time due to variations in costs and firms' price strategies. Cost variations come from changes in inputs prices, some of which are highly dependent on the level of market heating (for example, the charter costs of vessels depend on the price of oil that is one of the most volatile exogenous parameters) and the evolution of the firms' technical dimensions (efficiency gains through technological advances). At the same time, markup varies according to market conditions, such as the level of concentration of the industry and demand for seismic data from the oil and gas companies (O&GC). Therefore, endogenous and exogenous factors affect both costs and markup. To separate the two components, we use the technique proposed by Rosse (1970) and Scherer and Ross (1990) and applied by Bresnahan and Reiss (1991) and Nevo (2001), which calculates the cost and mark-up components from market share and price variations. With the markup information, we can analyze the relationships between market structures and performance at the aggregate level as proposed by Mason (1939, 1948) and at the firm level as proposed by Bain (1956). We perform the markup regressions using the traditional explanatory variables of structure like the concentration parameters (*CR*, *HHI*), the market size (*MS*), and the market turnover factor by year (*DMS* - the firstorder variation of *MS*); and conduct variables, like expenditures with research and development (*R&D*) and salles effort (*SE*).

The following results are relevant from the regression models. The MSAM structure for *C*8 remains practically unchanged over the years, while *C*4 fluctuates with significant margins. The performance regressions show that profit margins vary in time and between firms and with the market's concentration and size. After this analysis of structure and performance, we estimate the conduct parameters of firms using two techniques: the Lerner index (θ) (Lerner, 1973) and the NEIO conduct parameter (λ) (Bresnahan, 1989). The results indicate a low level of collusion for both parameters. Finally, we evaluate the competitiveness parameter (*RPD*) proposed by Boone (2008), which shows a good level of competition in MSAM. With these measures of structure, conduct and performance, we analyze the results and present the conclusions of the work.

Beyond this introduction, the article consists of three sections, including the conclusions. Section 2 briefly presents an overview of the maritime seismic data acquisition market. In section 3, we present the theoretical reference, the methodology, and the data used. In this section, we evaluate the demand and supply conditions in the MSAM to investigate the mechanisms of demand generation by O&GC, and we estimate the size of MSAM. Also, in this section, we depict the physical and governance structures of MSAM firms, which allows us to model their cost functions. At the end of section 3, we display the analysis of cost and markup structures and the market power of MSAM firms, applying consolidated techniques from IO and NEIO. Finally, in section 4, we analyze the results and present the conclusions.

2. The Maritime Seismic Acquisition Market

Several scientific methods are used in the investigation of sedimentary basins for mineral exploration purposes, as can be seen in Gaci and Hachay (2017) and Kearey et al. (2002). Sedimentary basin information can be obtained directly from outcrops and boreholes rock samples or indirectly from geophysical methods. The latter method has become a fundamental element in petroleum exploration, as noted in numerous references, such as Haldar (2018), Gadallah and Fisher (2008) and Durrheim et al. (2020). Geophysical methods use the physical principles of classical mechanics and

[1] We emphasize that this work is strictly academic research. The information presented here is the responsibility of the author. For the SeismicBase by IHS Markit, we preserve the original data, and we present only aggregate values.

[2] The process to obtain seismic data is complex in operational terms, involves a wide range of tasks, for example, towing a set of cables at sea with lengths that can exceed ten kilometers, for which only a limited number of firms are capable. The field of operation of seismic data acquisition companies is global, reflecting the demand behavior from oil companies investigating sedimentary basins on all continents. The great diversity of geographic, cultural, and legal conditions influences the organizational form that the seismic companies adopt, impacting their strategies technically, operationally, and business, also impacting their cost structures.

electromagnetism to infer the physical properties of the earth. Among the known geophysical methods, the seismic method is the most applied in the oil exploration activity (for more information, see Appendix A.).

2.1. Seismic Products

The product generated by MSAM firms is a set of digitized data stored in media that can be transferred and manipulated in specific software. This data set can have 2*D*, 3*D*, and 4*D* dimensions, the 2*D* dataset are used to generate images in parallel sections, the 3*D* to generate a seismic cube where it is possible to extract sections in any direction, while the 4*D* refers to the difference between two 3*D* cubes, which are used for reservoir management. Each product serves different phases in the exploration chain and has different cost ranges. These products are specifically used to imaging large areas, so they are only used commercially by companies that exploit natural resources such as minerals and oil. We can observe the use of this data for other purposes, such as ocean floor studies by governments or private companies in other sectors, but this type of use has a minimal share in generating demand for MSAM, which is why its demand stays limited to oil companies. On the other side, seismic data have no substitutes. This combination of product specificity and non-substitutability generates a rigid supply and demand relationship, where variations in supply-demand behavior directly impact the market.

The seismic method combines unique properties of imaging resolution of geological layers that other geophysical methods cannot achieve. This method has established itself as the primary input in the oil-industry exploratory process in its early stages, being the MSAM firms' suppliers of one of the critical inputs in the O&G upstream chain. Specifically, the 3*D* data is the product focalized by our analysis since it is used by O&GC for reserve characterization, certifying estimates of the amount of oil in each reservoir. From these estimates, it is possible to evaluate the economic viability of the exploration investment in the target area [3].

2.2. Market Structure and Behavior

The market concentration of seismic equipment manufacturers is even higher, being ION and SERCEL two leading firms. Ship and equipment control technologies greatly influence the final product quality, and each company develops its technology with a reasonable degree of product homogeneity. Horizontal differentiation is present, although product variety is limited by contractual modalities and the phases within the exploration. For vertical differentiation, it is even more restricted since quality differentiation depends more on the quality and supervision of the contracts by the buyers than on the conduct of the suppliers themselves.

The MSAM is a market where the processes of mergers and acquisitions are frequent [4] given the small number of suppliers, being a market defensive behavior to preserve the sector's human and physical capital. For example, Fugro (5^{th} place in rank) was acquired by CGG (1^{th} place in rank) in 2012, and WesternGeco (WTG,3^{th} place in rank) ended its operational activities in 2018 selling its vessels to Shearwater GeoServices, which was not a top-ten company. Taking WTG's place, this entrant's market share jumped from 2% in 2016 to 28% in 2019. In Table 1 we present the summary about this market for top-ten firms from the demand and supply side[4].

Regarding MSAM governance, the different types of contracts and operational strategies lead to some degree of heterogeneity, resulting in different governance modes that affect governance modes of firms that in turn affect the SCP parameters.

Table 1: Number of projects by demand, supply, and market, to top-ten MSAM's firms in the period from 2006 to 2019.

Demand				Supply			Market		
#	O&GC	np	%	Firm	np	%	country	np	%
1	CNOOC	158	3.5	CGG	804	17.7	Norway	444	9.8
2	Total	102	2.2	PGS	699	15.4	China	232	5.1
3	Shell	99	2.2	WTG	633	13.9	Australia	199	4.4
4	Statoil*	98	2.2	COSL	327	7.2	UK	195	4.3
5	BP	67	1.5	FGO*	220	4.8	USA	104	2.3
6	ONGC	58	1.3	TGS	196	4.3	India	96	2.1
7	Chevron	48	1.1	POL	191	4.2	Malaysia	90	2.0
8	Eni*	47	1,0	SBD*	184	4.1	Brazil	83	1.8
9	Petrobras	43	1.0	BGP	121	2.7	Indonesia	71	1.6
10	Exxon*	40	0.9	DPH*	101	2.2	Angola	70	1.5
	Σ	760	16.7		3476	76.5		1584	34.9

[3] The use of plants to 4*D* data surveys is relatively recent, starting in the 1990s and increasing from the 2000s. Companies now have one more possibility for plant allocation and a new source of demand, given that investments in 4*D* come from a link in the oil industry chain that holds more resources, which is production. For 4*D* designs, the effect of vertical differentiation could be more remarkable. However, it is somewhat of a consensus that for these products, Ocean Bottom Sensor (OBS) technology is predominant because of the higher quality of the sensors (4*C*) in terms of positioning, noise levels, azimuthal contributions, and repeatability. For now, this market (high-end) is still tiny with the prospect of capturing resources from a link up the chain of exploitation, i.e., bringing resources from production and increasing its size compared to 3*D* (mid-end). There is a convergence concerning the geophysical data quality on the supply side when comparing similar types of acquisitions. [4]see cap.3 of Barros Junior´

[4] More details of Table 1 can be found in Appendix A.

*We abbreviate the names of Eni Petroleum, ExxonMobil, Fugro(FGO), SeaBird (SBD), Dolphin(DPH) and Statoil (Equinor). Note. For these statistics we consider the two contractual modalities, proprietary and multi-client and all technologies with a total of 4544 projects, with the data for the year 2019 until the third quarter. Information compiled from SeismicBase by IHS Markit.

The different modes of governance are characterized by: i) Ownership of Vessels (owned or chartered); ii) Product Portfolio (operation in other segments or not, and data technologies); iii) Contractual Modalities Served (focus on owner or multi-client); iv) Public or Private Companies (stock market listing); v) Performance in R&D (whether in-house R&D or not); vi) Markets (regional or global). This characteristic separates the three leaders from the followers operating on the market fringes. Leaders' advantages come from product differentiation by R&D investments and operational flexibility based on proprietary or multi-client contract models, which allow optimizing vessels' allocation and, thus, reducing production downtime costs[5].

In Table 2 we summarize the characteristics and governance types of the top five firms {*CGG, PGS, WTG, COSL, POL, RES*} and the fringe firms RES. The market leaders that present a similar governance model g_1. The first three companies $\{f_1, f_2$ and $f_3\}$ are the market leaders of this oligopoly, with marketshare above 60% and similar cost structures. Although there are particularities[6]regarding the unit prices of inputs, operational efficiency, and fixed costs (as discussed later). These firms have similarities regarding the fleet of owned vessels, number of employees, number of offices, investments in R&D. The fourth company f_4 out of the top three is a local-market player in the process of internationalization. Having a different governance model (g_2), its lower comparative costs represent the main threat to entry into the world market. The fifth firm f_5 is a market entrant, with the governance parameters g_3. In the fringes, representative firm f_6 operates by chartering vessels on short-term contracts, mobilizing and demobilizing teams according to demand, with governance parameter g_4. In summary, this set representing the possible governance modes ($G = \{g_1,g_2,g_3,g_4\}$) will be used to modeling cost functions of the MSAM.

Table 2: Characteristics of firms and types of governance.

Firm	Contract*	Vessels	R&D	SE	PD **	Market	G
f_1	P&M	Own	Yes	Yes	V&H	Global	g_1
f_2	P&M	Own	Yes	Yes	V&H	Global	g_1
f_3	P&M	Own	Yes	Yes	V&H	Global	g_1
f_4	P&M	Own	No	No	ND	Regional	g_2
f_5	P&M	Own	Yes	Yes	V	Global	g_3
f_6	P	Charter	No	No	ND	Global	g_4

* *P* represent a propretary projects and *M* the Munticlient projects.
** *V* represent a vertical, *H* horizontal and *ND* no differentiation of products.

3. Theoretical and Empirical Basis
This section will present the database, the methodology, and the theoretical background.

3.1. Database
The database is built on different sources. We gather companies' data from the demand side, including proven annual reserves and annual production. Additionally, we use some external variables, such as annual oil demand and average annual Brent-oil price per barrel. From the supply side, we gather MSAM companies' annual selling, annual market share, fleet information[7]. To process data, we use R statistical software R Core Team (2019), to make tables and graphs and to apply the econometric regressions.

3.2. Methodology
We follow the New Empirical Industrial Organization (NEIO) general approach to build up our methodological tools Shepherd (1990), taking into account the structural market arrangement, the internal organization of firms, and the firms' outcomes from metrics that are specified from an equilibrium model. Each path presents interpretations and results that can be complementary. Based on the available data, we can apply different methodologies, and due to the lack of an

[5] IAGC website: The Multi-Client Data Licensing Business Model – Fact Sheet, Aug 2016 – IAGC – International Association of Geophysical Contractors.
[6] Furthermore, we classified the firms according to their plants, calculating the efficiency based on the equipment in the plants (parameter α that we will explain in section 3.1). We also collected information on profits, occupancy rate, number of employees, investments in R&D, and sales expenses. The coefficients are used to classify firms for the calculation of competitiveness by the RPD index (Boone, 2008).
[7] We found this information in the 20*F* annual reports of the companies listed on the stock exchange. For prices and market share, we used information from a worldwide database, SeismicBase by IHS Markit in https://login.ods-petrodata.com, and the fleets data we found in https://www.marinetraffic.com.

analysis of MSAM in the literature, we chose to estimate the study's parameters from complementary theoretical approaches and bring the results together aiming a broader analysis[8]. Thus, our tools are based on IO empirical studies, specially: Einav and Levin (2010), Schmalensee (2012) and Pakes (2017). These empirical studies undertake analysis of case studies, cross-section and longitudinal analysis, barriers to entry studies, and finally, regression problems of endogeneity and identification.

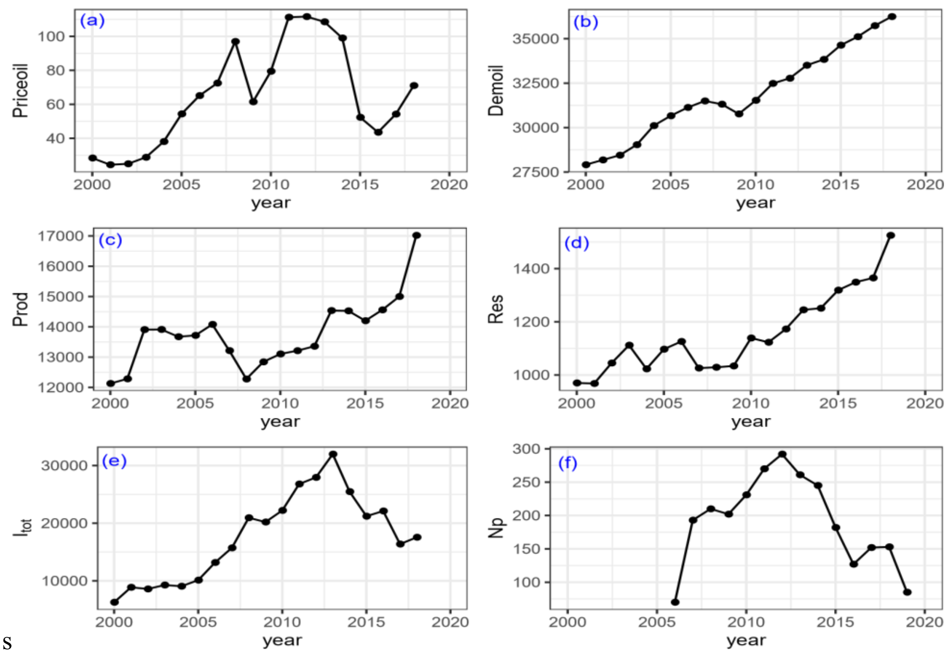
3.3. Demand for MSAM Products

In our model, the O&G firm's objective is to maximize profit π given the budget constraint. Demand by seismic (a product with a low degree of heterogeneity and no substitute goods in a market with few buyers and few suppliers) is limited by the amount of investment available (I_{total}).Our model for the demands functions derives, with adjusts, from the example for utility function found in Pakes (2017). The demand for seismic products D is a function of some of the endogenous and exogenous variables that compose the determinants of I_{total}, according to the equation 1:

$$D(I_{seismic}) = f(I_{total}) = f(Priceoil, Demoil, Prod, Res, \eta) \quad (1)$$

Where I_{tot} is the total investment in millions of dollars of O&GC, *Priceoil* is brent's annual average USD price, *Demoil* is the annual global demand of oil in billion barrels of oil equivalent (*BBOE*), *Res* is the value of yearly (December) proven reserves in a million barrel of oil equivalent (*MBOE*), and *Prod* is the annual production of O&GC specified as an endogenous variable[9]. Figure 1 shows the aggregate values for each demand variables: *Priceoil* (a), *Demoil*(b), *Prod* (c), *Res* (d), I_{tot} (e); and we have also added the number of seismic projects per year (f) starting in 2006. The parameter η represents other features affecting MSAM investments, such as the level of current O&GC knowledge about the sedimentary basin and the availability of exploration area auctions by the national regulatory agencies. As these variables are difficult to measure, we will consider them as a stochastic variable founded in the regressions' error parameters.

Figure 1: MSAM Demand Variables between 2000 and 2018 (annual average of top-ten O&GC demand for MSAM products) - (a) price of Brent oil (b) global oil demand (c) oil production (d) proved reserves (e) investments and (f) total yearly projects.



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In the oil industry, investments are made based on strategic plans with a horizon of five years. This extended period is due to the long-term service contracts of this industry regarding technical and regulatory complexities of oil exploration[10]. The O&GCs in these multi-year plans allocate their total investment amounts for the following years and the distribution among segments and activities, including MSAM activities. Thus, demand for seismic information is conditioned on

[8] How write Shephered (1990) "Rather than replace mainstream Industrial Organization, "new IO theory" is a complement to it"

[9] The data for these four parameters were compiled between the years 2000 and 2018 for the rank in table 1. However, in the end, the sample base is complete for nine companies from 2004 to 2018. Figure 1 we present the values between 2000 and 2018 considering extrapolation and interpolation for some samples. A more in-depth analysis can be seen in Barros Junior.´

[10] A seismic project, between the identification of the need for information and the delivery of processed seismic data for geological interpretation, can take between 2 and 5 years, depending on the regulation involving contractual and environmental licensing issues, the size of the area, the operational complexity, the processing technique used.

planned investments of O&GCs. We assume that each O&GC knows its optimal level of investment considering the investment model variables. That is, from seismic information and other technical relevant knowledge, O&GCs seek profit maximization given market conditions.

The aggregate level of total investment (I_{total}) is divided between the upstream and downstream segments ($I_{total} = I_{up} + I_{down}$). At upstream resources are divided between exploration and production ($I_{up} = I_{exp} + I_{prod}$), and within exploration, it is possible to estimate the portion related to direct information from wells and indirect information from seismic ($I_{exp} = I_{well} + I_{seismic}$). Thus, our model (1) represents total O&GC investment, it is specified empirically in equation 2 in which depends on the four variables of market conditions:

$$\log(I_{tot}) = \beta_0 + \beta_1 \log(Priceoil) + \beta_2 \log(Demoil) \quad (2)$$
$$+\beta_3 \log(Prod) + \beta_4 \log(Res) + \varepsilon$$

Where ε is the error associated with each measure in the regression with the application of log function to get around the problem of different orders of magnitudes and sizes of the variables. We will use lower case letters to represent the log of each variable ($x_i = \log(X_i)$). Thus, equation 2 can be written as:

$$i_{tot} = \beta_0 + \beta_1 priceoil + \beta_2 demoil + \beta_3 prod + \beta_4 res + \varepsilon \quad (3)$$

We consider two other models, (2) which replaces production and proven reserve variables by *log*(*Res/Prod*), and (3) that includes a dummy variable differentiating national and international O&GCs. We run the regression at the firm level with degrees of freedom above one hundred for these three models. We also run models (4) and (5) considering industry-level aggregate annual data, aiming to significantly reduce dispersion compared to individual-firm analyses, despite the expected reduction of the degree of freedom. Table 3 summarizes the econometric results.

Table 3: Econometric results for Oil&Gas total investment.

Level Model	Firm			Industry	
	(1)	(2)	(3)	(4)	(5)
(Intercept)	−18.57**	−22.79**	−20.87**	−8.64	−8.73
	(6.04)	(7.47)	(6.73)	(8.67)	(8.25)
priceoil	0.72***	0.75***	0.77***	0.82***	0.81***
	(0.09)	(0.11)	(0.10)	(0.15)	(0.14)
demoil	2.08***	3.03***	2.77***	2.19*	2.16*
	(0.60)	(0.73)	(0.66)	(0.92)	(0.79)
prod	1.41***			2.74*	
	(0.14)			(1.05)	
res	−0.62***			−2.78*	
	(0.11)			(1.26)	
Res/ prod		−0.75***	−0.62***		−2.73*
		(0.14)	(0.13)		(1.01)
dummy			−0.45***		
			(0.09)		
R^2	0.71	0.55	0.64	0.85	0.85
Adj.R^2	0.70	0.53	0.62	0.81	0.82
Num. obs.	110	110	110	19	19

$***p < 0.001$; $**p < 0.01$; $*p < 0.05$

The results for the three models at the firm's level are highly significant with relatively high adjusted R^2 and low residual error. Since the oil production and reserves series are pretty similar, it seems that the best fitting and mitigates endogeneity/correlation is the model (3), which incorporates the res/prod ratio and a dummy variable for the nature of the O&G company. The negative sign of their coefficients means that: (i) any reduction of *res/prod* ratio induces increases in investments of O&GCs; (ii) IOCs have higher investment levels than NOCs. It is consistent with the expected standard commodity large-corporation behavior. Its planned investments tend to react to supply constraints coming from relatively decreases in proven reserves and be more significant if it operates internationally.

Models (4) and (5) show very close results. Apart from oil prices, all other variables have low significance signaling the degree of freedom problem of just 19 observations. The best-fitting is model (5) with *res/prod* variable showing the expected sign.

Applying the estimated values of the independent variables from the end of 2018, we estimate a total investment of USD 250 billion for the set of ten companies. As observed earlier, they represent about 40% of the global demand, so the global market for 2018 is estimated at USD 625 billion. The estimated value per year is about USD 40 billion per firm at peak investments, which results in USD 400 billion for 40% of the market, or USD 1 trillion for the entire market. On average, global investments are around USD 500 billion per year.

We now turn to the breakdown of the total investment between two segments and upstream between exploration and production. The data for exploration, upstream, and total investments are correlated. However, the regression is not intended to create a structural model of explanatory variables but only to obtain the linear relationships between the different levels of investment. In a simple model, we describe that the equations establishing relationships among total, upstream, and exploration investments as:

$$Iup = \alpha 0 + \alpha 1 Itot + \varepsilon\alpha$$
$$Iexp = \gamma 0 + \gamma 1 Iup + \varepsilon\gamma \qquad (4)$$
$$Iexp = \theta 0 + \theta 1 Itot + \varepsilon\theta$$

As before, we define different models to estimate equation 4, three at the firm level and three at industry level, as shown in Table 4. As expected, the results for all models are highly significant.

For a total investment estimated at USD 625 billion (for the year 2018), upstream investment is estimated to be USD 430 billion. For exploration investment, the value found was about USD 60 billion, and for geophysics, USD 11.5 billion. In the pick of market heating, in 2013, our models' total estimated O&GC investments are about USD 1 trillion, so upstream investments of the order of USD 700 billion and exploration USD 100 billion. The estimated resources for geophysics are USD 19 billion. We find that exploration investments are between 11% and

Table 4: Econometric results for linear models relating i_{tot},i_{up} and i_{exp} .

Level	Firm			Industry		
Model	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	363.85	231.97	−349.40	−582.62	−88.01	−275.27
	(890.05)	(229.38)	(204.05)	(814.05)	(224.33)	(182.65)
inv	0.74***		0.11***	0.79***		0.11***
	(0.04)		(0.01)	(0.04)		(0.01)
invup		0.11***			0.13***	
		(0.01)			(0.01)	
R^2	0.78	0.41	0.60	0.96	0.84	0.91
Adj. R^2	0.78	0.40	0.59	0.96	0.84	0.90
Num. obs.	110	110	110	19	19	19

$***p < 0.001$; $**p < 0.01$; $*p < 0.05$

13% of upstream investments from the regressions. Resources for geophysical activities are average on 19% of exploration investments. With the values of resources directed to geophysical activities and the average value per project, we can estimate the demand for seismic vessels and compare it with the available fleet.
As a comparison between our results and the market information, we organized the data declared in the COSL and CGG annual reports [11] which cites specialized consulting firms for investment forecasts by the oil companies, and the summarized information is available in Table 5.

Table 5: Comparison results of I_{up} from consultancy and $\hat{I}_{up}$ estimated.

year	consultancy	I_{up}(USD billion)	$\hat{I}_{up}$(USD billion)	ratio($I_{up}/\hat{I}_{up}$)
2006	CitiBank	271	315	1.16
2007	CitiBank	300	344	1.15
2008	L&B	331	386	1.17
2009	Int*	399	296	0.74
2010	Int	466	451	0.97
2011	Int	532	519	0.98
2012**	Barclays	600	561	0.94
2013	Barclays	682	584	0.86
2014	Barclays	723	583	0.81
2015	Barclays	557	459	0.82
2016	Barclays	429	406	0.95
2017	Int	565	384	0.68
2018	Barclays	698	464	0.66

* Int = interpolated data from previous and next years.
** For geophysical services, Spears estimated USD 15.4 billion in 2012. Note. We use model (5) from Table 3 to estimate $\hat{I}_{up}$.

[11] See in the COSL Annual Report 2007, 2011, 2013, and 2014; Report Global 2018 E&P spending outlook and CGG Annual Report 2017.

In 2013, a reduction in demand in the geophysics sector is observed, starting in the second half of the year, due to O&GC's decisions to cut investments in exploration and production projects to improve short-term cash flow. This movement continues in 2014 with a 10% reduction in the seismic sector. The price of Brent crude suffered a 59% drop-in 2015 from USD 115 per barrel to USD 47 per barrel, resulting in a 23% drop in exploration and production investments the marine seismic sector having the same amount of reduction. In 2016, the drop in the price of Brent crude is maintained, and cuts continue in O&GC's investments, with a 23% reduction in upstream investments compared to 2015. Our estimate for the 2018 year was USD 700 billion, a 3% deviation from Barclays' estimate. Comparing the forecasts informed by several consultants in the analyzed period and the results of the regressions, applying for each year the four parameters chosen in the modeling of the O&GC investments, we found the convergence of the values so that the model employed was validated.

3.4. Supply of MSAM Products

This section will present the main supply-side variables in the MSAM represented in the cost models. We have two ways to estimate firms' costs in the MSAM: (i) directly determining costs from the sum of the costs of each input added the fixed costs for different modes of firm governance; (ii) indirectly using the information of price and market share variations. These two ways of estimating MSAM firm costs will provide different conduct measures and crossvalidation of the estimated values.

3.4.1. Costs Functions

The cost functions of the firms in MSAM are dependent on the type of governance adopted. We consider in this topic the attendance of the proprietary, contractual modality and the acquisition technology or 3D/4D products. The costforming elements can follow two distinct models: i) owned vessels; ii) chartered vessels. In the first model, the vessel-related costs must consider depreciation, insurance, and amortization, which depend on the purchase prices of the vessels, while in the second model, these costs are paid as rent to the vessel-owning companies. We will only use the term charter and cite the governance model for simplification. The other cost items are common to both models. We will now present the main cost items in order of importance: charter, fuel, personnel costs, taxes and fees, and management costs. The total cost of a product/project is a function of the unit costs mentioned above, plus the project completion required time and the risks included in the project proposals. The risks are a gray area between operational costs and the markup because in this highly specialized service market based on fierce competition, companies can assume the risks without transferring them to oligopsony prices as a strategy to win the project. Thus, the cost function is given by:

$$cij = cfij + \alpha ij \text{ X} wijtij \qquad (5)$$

Where cf_{ij} is the project fixed costs, depending on the characteristics of each project and each firm. The fixed costs directly related to the project are onetime events to operate, such as costs of environmental licensing, mobilization and demobilization, and port and customs fees. Additionally, project direct fix costs include local-standard compliance costs and user's demand specifications. Project fixed costs related to firms are overhead costs to cover office expenses, sales efforts, R&D, and bureaucratic expenses. In the next topic, we will detail these costs. These two types of fixed costs have, respectively, denotations type 1 for firm costs ($cf1_i$) and type 2 for project costs ($cf2_i$).

The term α_i is related to the operational efficiency of each firm, taking into account variables such as the size of the vessels, quantities of seismic equipment, and fleet age, providing the cost model with aspects regarding technology features. This relationship is represented by the expression $\alpha_i = g(ns_i, bhp_i, dwt_i, loa_i^{idf_i})$. The terms w_{ij} are the unit prices of the production inputs that form the variable costs: daily charter rate of all vessels in the fleet, the daily fuel consumption of the fleet, wages of all crew converted to per diems, food costs, crew change costs. Since there is an endogenous cost component carrying the firms' internal decisions (α_i), except for the governance type (g_i, i = 1,2,3 or 4), one can write the unit costs of the inputs varying from the exogenous cost component related to the 'state' of the market, which we identified in section 2 with the demand generating mechanism by exploration investments (I_{exp}), then we can write $wij = f(ti, Iexp, gi)$. A variable cost with a high impact on this industry's productivity is transittime cost, related to type 2 costs. Due to the global demand, the vessels work on several continents. Vessels' origin and destination mobilization to attend projects in different regions depending on their availability. The transit-time cost escalates to a maximum of 25 days, depending on the location of the vessel's origin and destination. If it is added custom and port stopped time, displacement time to the operation area, and pre-operational equipment preparation, vessels can reach up to a month without effective production. Due to scale economies, this item is critical to a firm's performance in this industry. Accordingly, intelligent fleet distribution by MSAM service company is a crucial competition element of comparative advantage. If a company performs concise projects, of 1 to 3 months, in distinct geological basins, which is common in the typical firm's portfolio, this transit time can represent up to 25% of the annual time of a seismic vessel. In summary, fixed costs are given by:

$$cf_i = cf1_i + cf2_i \qquad (6)$$

$$cf1_i = \begin{cases} \exp(\sigma_0 + \sigma_1 ne_i + \sigma_2 n_i) & if \quad G\imath \ = \ 1 \\ 0 & if \quad G\imath \ = \ 2,3 \quad and \quad 4 \end{cases} \qquad (7)$$

$$cf2_i = mob + initial\ expenses \qquad (8)$$

Observed figures of fixed costs show that *cf*1 corresponds to a maximum of 2.5% of the project cost and *cf*2 has an average mobilization time of 25 days corresponding to an average cost of about USD 5 million, and the initial expenses of about USD 1 million.

Regarding variable costs, they function the operation time and unit costs of inputs. The operation time of a maritime seismic project takes into account a large number of variables, especially project area, trace density (which represents the level of resolution that is intended to be achieved), location, weather conditions, presence of obstructions in the project area, diving activities (usually to perform maintenance on platforms), environmental issues (greater or lesser presence of cetaceans). In exploratory regions, the geophysical survey areas are usually large, leading to a longer duration. However, the trace density can be more sparse, reducing the average duration. Considering a single time for all inputs we have:

$$c_i = cf_i + \alpha_i t^{X} w_{ij} = cf_i + t\alpha_i w_i \qquad (9)$$

Where $w_i = {}^{P}w_{ij}$, is the total price of inputs and $\alpha_i = g(ns_i, bhp_i, dwt_i, loa_i, idf_i)$ can be obtained by:

$$\alpha_i = \exp\left(\delta_1 + \delta_2 \frac{ns_i}{\max(ns_i)} - \delta_3 \frac{idf_i}{\max(idf_i)} + \delta_4 \triangle i\right)$$

$$\triangle_i = \frac{1}{3}\left(\frac{bhp_i}{\max(bhp)} + \frac{dwt_i}{\max(dwt)} + \frac{loa_i}{\max(loa)}\right) \qquad (10)(11)$$

The parameter δ is used to normalize so that α_i equals unity when the other dependent variables assume the average values considering the whole industry.

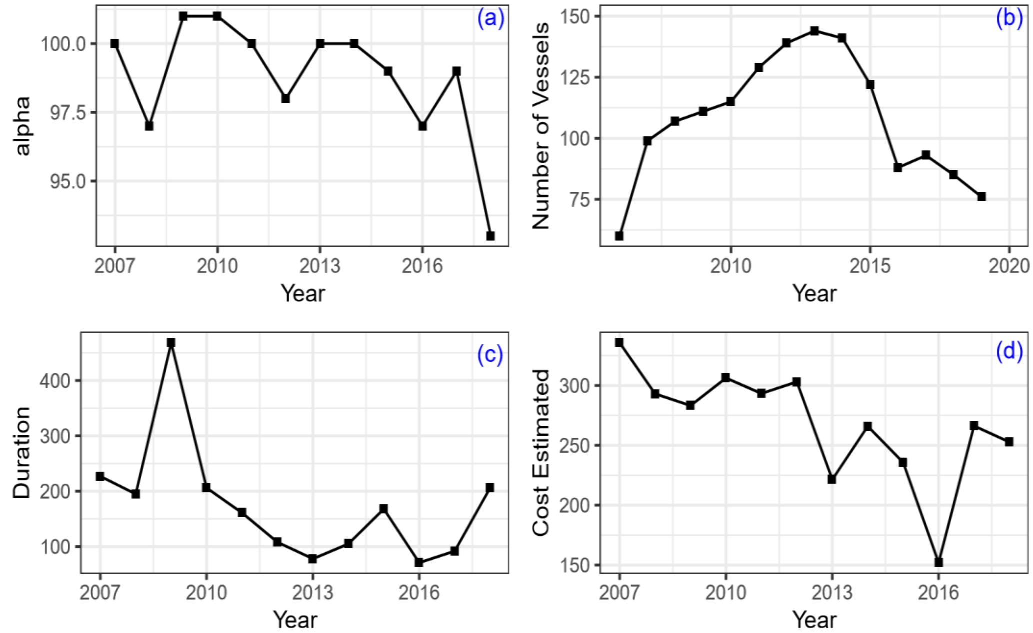
The results are summarized in Table 6 and in the Figure 2.

Table 6: Physical characteristics of the plants of MSAM firms: minimum, average and maximum observed values of α_i.

Firm	$\overline{bhp}$	$\overline{dwt}$	$\overline{loa}$	$\overline{nms}$	$\overline{age}$	$\min\alpha$	$\bar{\alpha}$	$\max\alpha$
f_1	14029	3218	105	11	25	0.87	1.04	1.19
f_2	17734	4658	89	18	21	0.69	0.93	1.18
f_3	13308	3878	89	13	11	0.95	0.96	1.00
f_4	5384	2314	84	6	31	1.18	1.18	1.18
f_5	15500	5150	84	8	8	0.97	0.97	0.97
f_6	13166	3821	95	12	18	0.69	1.00	1.20

Note. For the firms f_4 and f_5, the calculations are based on a representative vessel, thus α is a constant.

Figure 2: Costs for six firms between 2007 and 2019 annual aggregate:(a) α that represents the technical level of firms (b) number of vessels available as firm's plants(c) value of duration by year and (d) estimated price from observed demand and amount of investments.



3.4.2. Price Formation, Costs, and Mark-Up

Our framework to pricing and its relations to market structure will follow the standard theoretical literature used to empirical works[12]. Thus, we assume that price formation in MSAM firms comprises costs and mark up: $P = C + \mu$. To estimate the costs indirectly we will use the profit function as:

$$\pi = \sum \pi_i = \sum (s_i \times (p_i - cm_i) - CF_i) \tag{12}$$

$$\pi = s_i \times (p_i - cm_i) \times S - CF \tag{13}$$

$$\mu_i = p_i - cm_i \tag{14}$$

Where i refers to the of the ith MSAM firm, s_i is the market-share, S is the market size given by the total number of projects, μ_i is the markup, cm_i is the marginal cost, p_i is the price of seismic service, CF_i is firm's fixed costs, and CF is the total fixed costs of industry. The observed values of s_i and p_i are shown in Table 7 from our database. Considering the price competition strategy (BertrandNash equilibrium) and that prices are all positive, then the equilibrium condition can be expressed as:

$$\frac{\partial \pi}{\partial p_i} = \frac{\partial}{\partial p_i} \sum [s_i \times (p_i - cm_i) \times S - CF_i] = 0 \tag{15}$$

resulting in,

$$s_i + \sum (p_j - cm_j) \frac{\partial s_j}{\partial p_i} = 0, \qquad com\ j \neq i \tag{16}$$

defining,

$$\Omega = \Omega_{ij} = -\frac{\partial s_j}{\partial p_i} \quad and \quad \mu_j = p_j - cm_j \tag{17}$$

we find,

$$si - \mu j\ \Omega ij = 0 \quad \rightarrow \quad s = \Omega\ \mu \tag{18}$$

therefore,

$$\mu = p - cm = \Omega^{-1} s \quad \rightarrow \quad cm = p - \Omega^{-1} s \tag{19}$$

The equation 19 relates firms' markups to market share and price changes and will be used to estimate a firm's price split between markup and marginal costs.

The estimated results are shown in 8.

Table 7: Market Share and prices per MSAM firm per year from 2006 to 2019.

$year$	s_1	p_1	s_2	p_2	s_3	p_3	s_4	p_4	s_5	p_5	s_6	p_6	$\bar{p}$
2006	16.4	220	24.1	220	25.0	292	27.6	250	6.9	185	0.0	0	233
2007	23.2	200	25.8	230	16.3	280	26.8	300	7.9	200	0.0	0	242
2008	25.3	240	23.1	300	25.3	310	21.3	249	5.0	250	0.0	0	270
2009	22.3	250	34.5	240	18.9	175	16.0	200	8.3	200	0.0	0	213
2010	28.6	150	21.2	250	20.8	155	20.0	250	4.9	195	4.5	210	202
2011	28.9	230	16.2	240	19.7	165	20.4	300	6.3	200	8.5	241	229
2012	31.5	205	18.4	235	15.7	220	17.0	270	6.6	205	10.8	295	238
2013	25.3	155	24.1	305	16.1	400	19.5	264	6.5	200	8.4	280	267
2014	28.1	175	22.8	270	11.4	230	16.3	260	10.2	195	11.4	210	223
2015	28.0	100	20.6	240	20.1	105	11.6	255	9.0	200	10.6	103	167
2016	21.5	95	11.5	210	25.4	170	15.4	250	13.9	195	12.3	160	180
2017	23.9	100	13.8	180	25.8	180	13.2	255	12.0	200	11.3	150	178
2018	25.2	110	17.2	195	20.5	190	8.6	257	15.2	195	13.3	140	181
2019	47.2	121	11.1	210	22.2	200	0.0	260	8.3	200	11.1	159	192
avg	26.6	164	21.0	238	19.4	219	17.6	259	8.1	201	7.2	195	215

Note. The firm f_6 enter in the market only in 2011.

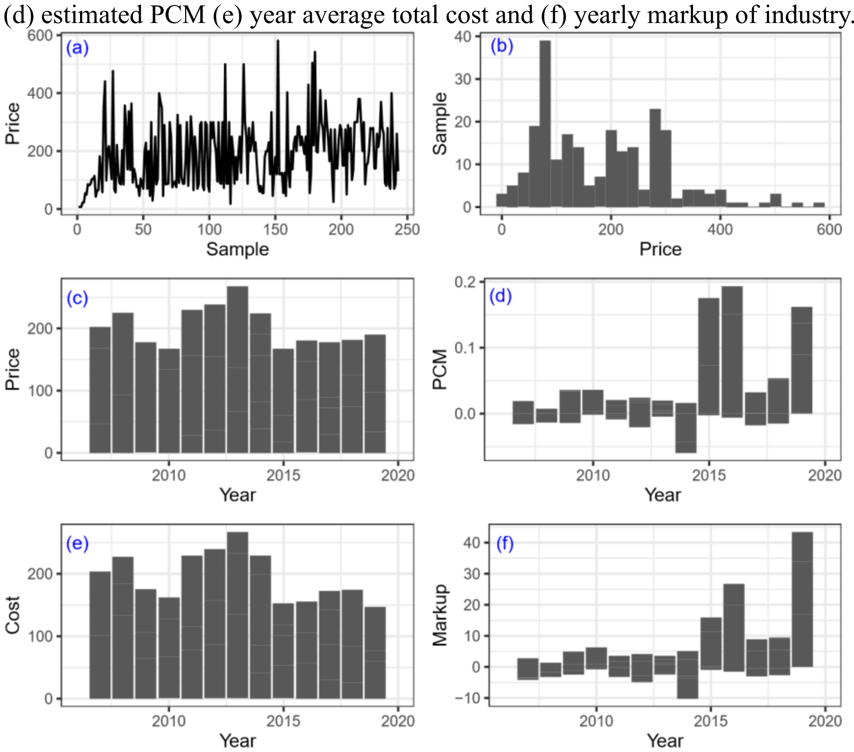
[12] Hall and Hitch (1939), Chamberlin (1949), Mason (1939), Bain (1942, 1949, 1952, 1956, 1983), and Stigler and Kindahl (1970).

Table 8 shows the estimated results of costs and markups of MSAM companies between 2007 and 2019. For years 2009, 2010, and from 2015 onwards, costs are comparatively lower than in other years of the time series, and 2013 the year of greater demand, it has the highest costs for the MSAM companies. Thus, price fluctuations in this market of MSAM services are strongly linked to cost variation due to varying service demand from O&G companies. From 2015 onward, costs have decreased sharply and grew slower since then. Worth remarking that we observe some convergence in the comparison between both methods to obtain costs that validate the values estimated.

Table 8: Estimated mark up and cost values per firm per year from 2007 to 2019.

year	c_1	m_1	c_2	m_2	c_3	m_3	c_4	m_4	c_5	m_5	c_6	m_6	$\bar{c}$	$\bar{m}$
2007	184	16	232	−2	302	−22	300	0	199	1	0	0	243	−1
2008	238	2	305	−5	304	6	260	−11	254	−4	0	0	272	−2
2009	246	4	219	21	182	−7	207	−7	196	4	0	0	210	3
2010	147	3	219	31	153	2	251	−1	199	−4	0	0	194	6
2011	220	10	229	11	167	−2	301	−1	207	−7	250	−9	229	0
2012	194	11	231	4	238	−18	281	−11	206	−1	286	9	239	−1
2013	149	6	298	7	396	4	261	3	202	−2	293	−13	267	1
2014	195	−20	290	−20	248	−18	264	−4	179	16	196	14	229	−5
2015	72	28	213	27	67	38	252	3	203	−3	104	−1	152	15
2016	68	27	220	−10	120	50	225	25	155	40	143	17	155	25
2017	103	−3	195	−15	180	0	237	18	178	22	138	12	172	6
2018	105	5	197	−2	157	33	240	17	193	2	153	−13	174	7
2019	101	20	146	64	187	13	172	88	144	56	130	29	147	45
avg	156	8	230	9	208	6	250	9	193	9	188	5	206	8

Figure 3: Estimated prices, costs, and mark ups of MSAM. (a) prices of 235 seismic projects (b) price histogram (c) yearly average price (d) estimated PCM (e) year average total cost and (f) yearly markup of industry.



3.5. Measures of SCP

This subsection will present the primary measures used in the empirical analysis and its theoretical foundation. We will start with the pricing model that will allow us to extract information on expenditures, revenues, and profits, the latter being used as a performance measure. Next, we will treat the concentration measures applied in analyzing market structures and a performance summary. Finally, we will present measures of conduct.

3.5.1. Structure and Performance

There are two concentration indexes commonly used in the literature, as seen in Lee (2007), which are the concentration ratio (*CR*) and the Herfindahl - Hirschman Index (*HHI*), see (Herfindahl, 1950)), calculated from each firm's market share according to equations 20 and 21: *N*

$$CR = \sum_{i=1}^{N} s_i \tag{20}$$

$$HHI = \sum_{i=1}^{N} s_i^2 \tag{21}$$

Table 9 shows the values of $C4$, $C8$, $HHI4$ and $HHI8$ for MSAM. We observe that $C4$ concentration level oscillates, falling significantly in the period of increasing demand (it reached a low of 0.6 in 2012) and rising at the time of contracting demand (it reached a value of 0.79 in 2016). The $C8$ index oscillates in a narrower range between 0.89 and 0.97, averaging 0.93. The $HHI4$ and $HHI8$ are in the band between 0.10 and 0.24, corroborating the results of $C4$, the market is in the band between moderately and highly concentrated[13].

Based on the model specified in equation 22, we run regressions using combinations of variables regarding concentration, market size, and profit. The results indicate that the significant variables are $C8$, market size (MS), and yearly market-size variation (DMS). The value of R^2 was 0.82. When we add the brent price into the model, R^2 rises to 0.85, but the adjusted R^2 remains the same, indicating that this variable has little influence due to its high correlation with MS(0.88).

$$\pi = l_0 + l_1C4 + l_2C8 + l_3SM + l_4DSM + l_5RD + l_6SE + \varepsilon \tag{22}$$

The equation 22 contains the terms $C4$ and $C8$ that present correlation, and therefore the specified model presents endogeneity. However, despite the correlation between the concentration variables, these variables are correlated only in part of the analyzed period, and therefore we understand that they reflect different

Table 9: SCP Measures from MSAM per year from 2006 to 2019.

year	$C4$	$C8$	$HHI4$	$HHI8$	MS	DMS	$R\&D$	SE	π
2006	0.91	0.97	0.24	0.24	116	−	67	328	−
2007	0.81	0.92	0.19	0.20	190	0.64	80	421	−1
2008	0.78	0.90	0.18	0.19	211	0.11	84	372	−2
2009	0.82	0.95	0.21	0.22	206	−0.02	146	349	3
2010	0.71	0.95	0.15	0.18	245	0.19	130	375	6
2011	0.66	0.95	0.12	0.15	283	0.16	135	360	0
2012	0.60	0.91	0.10	0.13	305	0.08	175	386	−1
2013	0.71	0.91	0.15	0.16	255	−0.16	193	448	1
2014	0.64	0.89	0.11	0.13	244	−0.04	185	457	5
2015	0.69	0.94	0.13	0.15	180	−0.26	119	446	15
2016	0.79	0.96	0.17	0.19	121	−0.33	44	488	25
2017	0.74	0.91	0.16	0.17	157	0.30	46	394	6
2018	0.78	0.95	0.16	0.17	142	−0.10	66	370	7
2019	0.78	0.94	0.18	0.20	70	−0.51	18	364	45
avg	0.74	0.93	0.16	0.18	195	0.00	106	397	8

Note. The variables of structure are concentration levels $C4$, $C8$, $HHI4$, $HHI8$, market size (MS) and MS variation, DMS; conduct variables are $R\&D$ spending and sales effort SE and performance variable is the average MSAM profits π per year.

momentum. While $C4$ captures cyclical effects, $C8$ captures the structural effects of MSAM. A similar idea occurs for $HHI4$ and $HHI8$. Therefore, we consider a model (1) with all four concentration variables to analyze the significance level of each term in table 10. Next, we present the models considering a concentration index concentration (2) for CN and (3) for HHIN. In (4), we consider only the concentration index $HHI8$. In (5) and (6), we omit the parameter of spending on $R\&D$ and spending on $R\&D$ and SE, respectively.

In the (2), showed in table 10 below, the coefficients founded for $C4$, MS and DMS are negative (−61.44,−29.25,−9.50) and for $C8$ was positive (+80.98). Thus, demand increases from O&G companies stimulate competitive pricing pressure

[13] The HHI values are in percentage terms, so one must multiply by 10,000. According to Hall and Hitch (1939) markets are considered low concentration if $HHI < 1000$, moderately concentrated for $1000 < HHI < 1800$ and highly concentrated if $HHI > 1800$.

on MSAM suppliers, resulting in a decreased profit. This fact occurs because O&GCs define the market size each year in advance, and MSAM firms compete to capture maximum resources established by O&GCs' budgets. The governance model of the leaders makes it difficult for them to modify their plant size at the same speed as fringe firms, which can charter ships and form teams quickly. In this case, it is not new entrants that supply the incremental demand, but firms on the market fringe tend to grow their share at any demand increases.

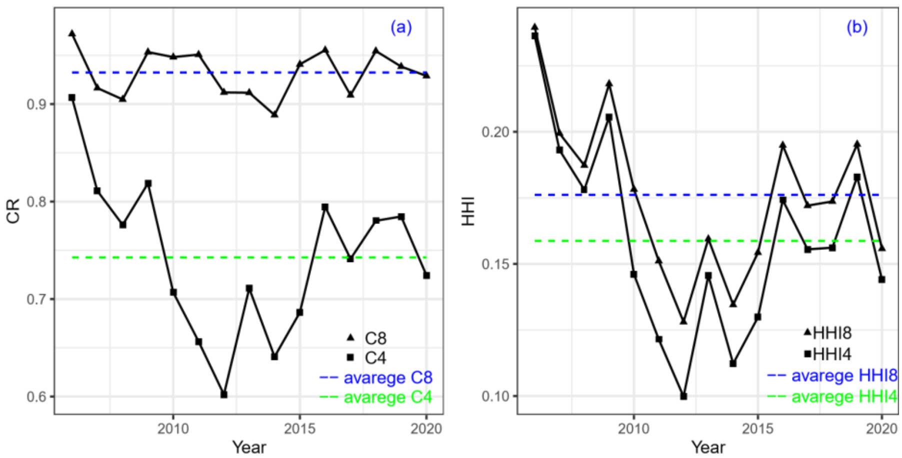
To sum up, as demand increases, the leaders increase their supply but proportionally more minor than the marginal firms. As the idleness of the vessels reduces, charter costs tend to increase. The leading suppliers have some room to select projects and choose the most profitable ones without fixing prices for the whole industry. This room for the MSAM leaders to project selection is possible since time and quality of service are critical to O&GCs.

Table 10: Regression models of profit (π) at MSAM.

Models	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	137.83	100.90	82.48	141.59	53.79	136.35***
	(54.44)	(154.53)	(78.95)	(141.27)	(59.95)	(22.28)
C4	−146.11*	−61.44				
	(51.21)	(32.98)				
C8	1.62	80.98				
	(42.89)	(71.49)				
HHI4	−266.39		−603.64**	−71.30	−574.77**	−526.88**
	(194.27)		(134.17)	(70.41)	(119.42)	(122.91)
HHI8	566.72*		640.14**		616.83**	543.90**
	(142.93)		(154.48)		(142.55)	(142.95)
Log(MS)	−37.87**	−29.25	−32.70*	−22.67	−26.38***	−26.76***
	(6.06)	(18.08)	(11.00)	(19.52)	(3.10)	(3.31)
DMS	−7.28	−9.50	−9.49	−14.77	−11.71*	−12.37*
	(2.93)	(8.90)	(5.31)	(9.38)	(3.65)	(3.87)
Log(RD)	3.42	−0.58	3.14	−2.30		
	(2.98)	(8.29)	(5.23)	(9.21)		
Log(SE)	17.09*	5.52	11.02	1.16	12.58	
	(5.66)	(14.71)	(9.36)	(16.47)	(8.57)	
R^2	1.00	0.93	0.97	0.90	0.97	0.96
Adj. R^2	0.99	0.86	0.95	0.83	0.95	0.95
Num. obs.	13	13	13	13	13	13

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Figure 4: Measures of Structure - a) Values by year and average of C4 and C8; b)Values by year and average of HHI4 and HHI8.



3.5.2. Conduct

In this topic, we estimate the firms' conduct in two ways: through the Lerner index θ_i, given by the product between the price elasticity of demand and the price-cost margin (*PCM*) divided by the market share; and through the conduct parameter λ_i, calculated from the two-step regression of the simultaneous equations of demand curves and supply relations, according to the NEIO modeling can be seen in Bresnahan (1989).

3.5.3. The Lerner Index

This conduct index θ_{ij} of firm i in year j varies between 0 (perfect competition) and 1 (collusion). Its calculation development can be seen in Lerner (1973) and summarized in following the equations:

Firm i profit function in year j,

$$\pi_{ij} = r_{ij} - c_{ij} \qquad (23)$$

$$\frac{\partial \pi_{ij}}{\partial q_i} = mr_{ij} - mc_{ij} = 0 \qquad (24)$$

Where, *mr* is marginal revenue and *mc* is marginal cost. Marginal revenue of firm i in year j, including the parameter θ_{ij} as in Lerner (1973),

$$mr_{ij} = p_{ij} + \frac{\partial p_{ij}}{\partial q_{ij}} q_{ij}\theta_{ij} \qquad (25)$$

Marginal cost equals marginal revenue equation,

$$mc_j = p_j + \frac{\partial p_i}{\partial q_j} q_{ij}\theta_{ij} \qquad (26)$$

Price elasticity of demand,

$$\varepsilon_{ij} = \frac{\partial q_{ij}}{\partial p_{ij}} \frac{p_{ij}}{q_{ij}} \qquad (27)$$

Market share by signature *i* in year *j*,

$$s_i = \frac{q_{ij}}{q_j} \qquad (28)$$

Simplifying the marginal cost equation we have,

$$\frac{p_{ij} - cm_{ij}}{p_{ij}} = -\frac{\partial p_{ij}}{\partial q_{ij}} \frac{q_j}{p_j} \frac{q_{ij}}{q_j} \theta_{ij} = -\frac{s_i \theta_{ij}}{\varepsilon_{ij}} \qquad (29)$$

Thus,

$$\theta_{ij} = -\frac{\varepsilon_{ij}}{s_i} \left(\frac{p_{ij} - cm_{ij}}{p_{ij}} \right) \qquad (30)$$

The actual values obtained for θ_{ij} from 2007 to 2019 are shown in Table 11.

Table 11: Annual θ values for firms and industrial (Σ) levels from 2007 to 2019.

year	f_1	f_2	f_3	f_4	f_5	f_6	Σ
2007	0.04	−0.04	0.00	0.00	−	0.1	0.1
2008	0.00	0.01	0.00	−0.03	−	0.00	−0.02
2009	0.01	0.01	0.02	0.02	−	0.04	0.10
2010	0.67	0.01	0.00	0.75	−	0.00	1.43
2011	−0.05	0.00	0.00	0.06	0.14	0.00	0.15
2012	−0.10	−0.03	0.02	−0.08	−0.04	0.01	−0.22
2013	0.01	0.00	0.01	0.01	0.33	0.00	0.36
2014	0.01	0.03	−0.12	0.03	0.03	0.02	0.00
2015	−0.02	0.02	−0.68	−0.27	0.00	0.00	−0.95
2016	0.28	0.01	−0.03	0.01	0.01	−0.28	0.00
2017	−0.06	0.00	−0.04	−0.07	0.05	−0.02	−0.14
2018	−0.02	0.08	−0.47	−0.17	−0.01	−0.01	−0.6
2019	0.32	−0.02	−	1.36	0.11	−0.04	1.73
avg	0.08	0.01	−0.10	0.12	0.05	−0.01	0.15

3.5.4. NEIO Conduct Parameter

In the classical IO methodology, the analysis of firms' conduct has a theoretical focus, based on regressions between structure and performance parameters. At the end of the 1980s, there was a shift in the focus from theoretical to empirical analyses, differing from the classical analyses in three aspects: i)data improvement; ii) use of formal theory applied to econometric method; iii) the firm is the main element of the analysis, and not the industry. In this movement, Bresnahan (1989) coined the term New Empirical Industrial Organization. Under this connection, Sutton (2007), shows that a firm's conduct based on game theory models is helpful for problems with a well-defined control of variables. This theoretical approach has provided wide-range options for firm-level analysis. For industry cross-section analysis, controlling measures are more complex. Expressly, one can adopt either simultaneous entry or sequential entry models to evaluate entry behavior. One can use the Bertrand (Nash equilibrium in price) or Cournot (Nash equilibrium in quantity) models to analyze post-entry competitiveness. As highlighted by Einav and Levin (2010), state of the art in OI theory encompasses the transition from intra-industry models to studies " focused on a single industry or market, considering specific institutional issues, measures of critical variables, and econometric identification."

This methodology brings together the clarity provided by theory with empirical measures, enabling a better understanding of the competitive mechanisms. Demand models, as Nevo (2001), indicate, can be obtained with individual consumption data or price and market share aggregates. The estimation is done based on price and demand variations. In our market reference, the MSAM industry, demand change is almost wholly dependent on the cyclical economic conditions which define the investment behavior of oil and gas companies. The shocks usually have a well-defined direction, demand varies, and price variations occur. One can use variation in market size next to long-run equilibrium and analyze whether there may be a relationship between profitability and market size. Variations in market size can provide inference about the level of competition Bresnahan and Reiss (1991). As Sutton (2007) explains, market structures present empirical regularities that seem to arise from some economic mechanism that has general validity. In OI theory, this "mechanism" has two aspects: 1) the relationship between competitive prices and the level of market concentration; 2) firms invest in R&D and advertising (to encourage and capture consumers) or in reducing variable costs in production. In the NEIO methodology, to extract the degree of collusion, indicative of the firms' non-competitive behavior, we need information on demand and costs, which are exogenous to the firms, rely on some costs in the MSAM depends on the oil price, and on quantities and prices that are endogenous, according to the method developed by Bresnahan (1982, 1989). We define the model from the following equation 31 of supply and demand at the MSAM industry level:

$$S(P_j, W_j, A_j, \lambda) = D(P_j, Z_j) \qquad (31)$$

Where the parameter P_j is MSAM prices set at year j, $D(P_j,Z_j) = Q_j = {}^{P}q_{ij}$ is the total quantity Q of entire industry supplied by firms i in year j, W_j is an exogenous supply-displacing variable (cost of chartering), Z_j is an exogenous demand-displacing variable (exploration investment i_{exp} calculated previously in section 3.3), A_j is an operational technical cost variable (α calculated in section 3.4), and λ is a industry's conduct variable to be estimated.

The supply and demand equations in the proposed model are determined simultaneously. To solve endogeneity problems, the exogenous variable in the demands equation cannot be related to price, and the exogenous variable in the price equation cannot be related to quantity. This assumption is used to observe how the dependent variable shifts from an external shock to an independent variable. If an exogenous variable affects both equations terms, we cannot isolate its effect in one of the terms. Once the exogenous terms are defined either in Q and P equations, two-stage SLS can be applied, an econometric procedure frequent in NEIO modeling, such as in Zeidan and Resende (2009). First, to check the OLS validity, we apply a Wo-Hausman Test for only one instrumental variable (IV) for each side demand and supply (Z and W), which results for both in p-value above 0.9, which means a rejection of the null hypothesis, implying in a correlation between regressors and the error terms. [14]. In this case, the random-effects model is more suitable than fixed effects. We define the demand curves and supply ratio through structural equations 32 and 33 (the model is of log-log type for all parameters) below:

$$log(Q) = \alpha_0 + \alpha_1 log(P) + \alpha_2 log(Z) + \varepsilon_Q \qquad (32)$$

$$log(P) = \beta_0 + \beta_1 log(Q) + \beta_2 log(W) + \beta_3 log(A) + \varepsilon_P \qquad (33)$$

We check correlations between Q and P (quantity and price) and the exogenous variables for this model. In general, the correlation shows a good consistency of the model, where $corr(Q,P)$ and $corr(Q,Z)$ are relatively high (0.77 and 0.69), which indicates P and Z as good endogenous and exogenous variables, respectively, explanatory of Q. The low correlation (0.25) between P and Z corroborates this consistency. The high correlation of P with W (charter costs) of 0.68 and the low correlation between Q and W (0.29) indicates that W is a good exogenous explanatory variable for P. Furthermore, for this model, we have a second exogenous variable of P, A, which negatively correlates with W and has low correlations with P and Q. This last variable A will have its significance and endogeneity assessed in the statistical diagnostics to decide whether to keep it in the model or not.

Running the first model, we calculated the residuals of Q and P (for $\alpha_2 = \beta_2 = \beta_3 = 0$) and then calculated the correlations with the error terms. When this correlation is high, we indicate an endogeneity problem. The value found for the structural equation was 0.64. Including the other parameters, we obtain the correlation value with the residuals of 0.36, a significant reduction in the endogeneity problem, but still present. The correlation of the error with the instrumental variables (VI) found values almost zero, a necessary result for the correct use of a variable as instrumental. Since the endogeneity problem is present, the instrumental variables method is applied to solve the two-step equations. The instrumental variables are the exogenous variables unrelated to each other, where we apply Sargan's Test to the case with two-plus IVs

[14] See Gujarati (2011) and TIRYAKI and ANDRADE (2017)

for the supply-side (W and A) that presets similar results to the Hausmans Test. For the price equation 35, the exogenous cost variable W represents the prices of inputs, and demand variable Z is the annual values of exploration investments, and A is the operational efficiency parameter. The equations in reduced form (we use lowercase to omit the log) are given by:

$$q = \gamma_0 + \gamma_1 q + \gamma_2 z + \varepsilon_Q \quad (34)$$
$$p = \tau_0 + \tau_1 z + \tau_2 w + \tau_3 a + \varepsilon_P \quad (35)$$

Performing the regression for equation 35 for two models: (1) including variable A and (2) not includes A in regression. In this two-stage regression, we have added an intermediate step $(1.5)^{st}$ to remove the error influences of one stage in the next. In the first stage, we obtain $\hat{p} = p - \varepsilon_P$ and replace it into equation 34, then we toward to the one a half stage, where we find $q = \gamma_0+\gamma_1\hat{p}+\gamma_2 z+\varepsilon_Q$, and then calculate $\hat{q} = q - \varepsilon_Q$. Finally, in the second stage, substituting it in equation 34 we obtain $p = \beta_0 + \beta_1\hat{q} + \beta_2 w + \beta_3 a + \varepsilon'_P$. The results of the regressions are listed below in table 12. The first-stage regression results provide an F-statistic with a value above 10 (10.88), a criterion for which the null hypothesis, which is essential that we have weak instruments, is rejected; that is, the instruments chosen are suitable. As expected, the variable Z is statistically insignificant for the P supply model. The highest weighted variable in 35 is W with an elasticity of approximately 0.413 and with statistical significance for a confidence level of 0.001.

The value of $\lambda = \alpha_1\beta_1$ is obtained from the structural equation (32 and 33), and the value found was $\lambda = 0.27$, indicating that this market is closer to a competitive market than to a monopoly where this parameter is unity. A discussion of this result will be made in conclusion in conjunction with the other metrics employed for the competition and competitiveness assessment of MSAM.

Table 12: Results of the 2SLS regressions for estimating the conduct parameter λ.

Model	(1)			(2)		
Stage	1^{st}	$(1.5)^{st}$	2^{nd}	1^{st}	$(1.5)^{st}$	2^{nd}
(Intercept)	5.85*	−13.87***	7.43***	4.52	−13.87***	7.37***
	(2.04)	(2.66)	(0.76)	(2.69)	(2.66)	(0.84)
log(P)		0.91***				
		(0.19)				
log(Q)			0.29*			
			(0.12)			
log(Z)	0.17	0.65**		0.32	0.65**	
	(0.15)	(0.16)		(0.18)	(0.16)	
log(W)	0.41***		0.31**	0.37**		0.25**
	(0.08)		(0.08)	(0.11)		(0.07)
log(A)	4.26*		2.57			
	(1.46)		(1.50)			
log($\hat{P}$)					0.91***	
					(0.19)	
log($\hat{Q}$)						0.43**
						(0.11)
R^2	0.80	0.85	0.86	0.59	0.85	0.81
Adj. R^2	0.73	0.82	0.81	0.50	0.82	0.77
Num. obs.	12	12	12	12	12	12

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

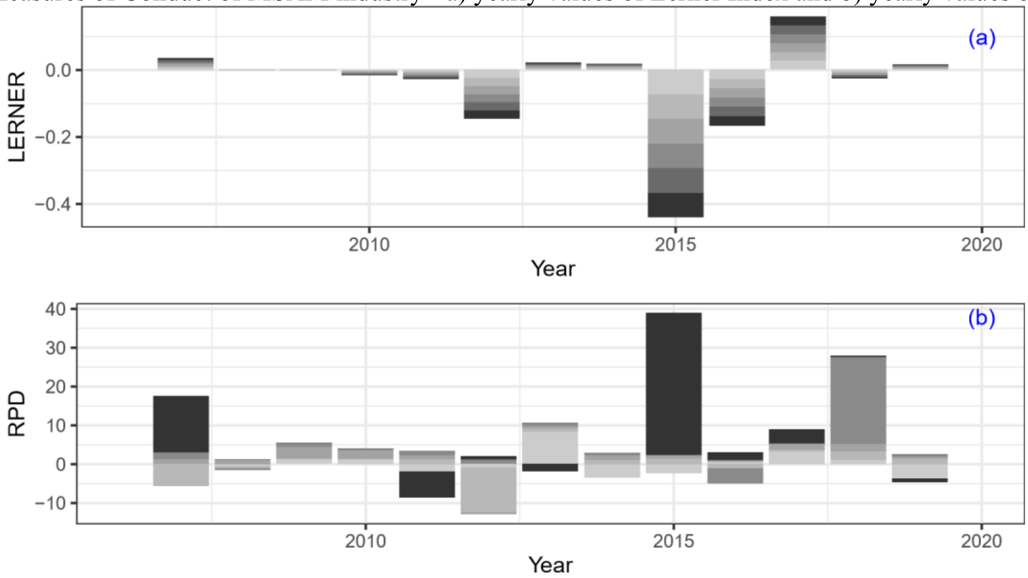
3.5.5. Measure of Competitiveness - RPD

We can perform direct measures of competitiveness through the price-cost margin (PCM), which is the markup (μ) ratio and the price to operational costs. We present a measure of competitiveness proposed by Boone (2008). His measure proposal of competitiveness is the "relative profit differences" (*RPD*), which is defined by:

$$RPD = \frac{\pi'' - \pi'}{\pi'' - \pi} \quad (36)$$

Where π'', is the profit of the most efficient firm, π' of the second most efficient firm, and π of the third most efficient firm. The *RPD* calculation can run over all firms, considering a window of three samples, starting from the first to the second and to the third firm and so far. This measure works as a dimensionless ruler to measure distances between profits and nearest neighbors for technical efficiencies. If there is a constant, positive difference between profits, the value of *RPD* will be two. The *RPD* approaches zero if $(\pi' - \pi) \ll (\pi' - \pi)$, meaning a higher degree of competitiveness. Negative *RPD* represents firms that have lower efficiency but obtain higher profits. These negative values can occur due to efficiency misclassification since this dynamic element varies over time, or it can represent some strategic movement of the firms. For example, expansion processes can reduce profits or even bring losses while they occur. The criterion for ranking firms to efficiency must be clear. Otherwise, the interpretation of the results is compromised. Equation 36 can present problems if profits of two firms that are neighbors in the ordering of the efficiencies are equal. However, the author highlights this situation, arguing that the economic system is complex and that two firms rarely have equal profit.

Figure 5: Measures of Conduct of MSAM industry - a) yearly values of Lerner Index and b) yearly values of *RPD*.



4. Conclusions

Data analysis O&GC reports have allowed us to understand the Maritime Seismic Acquisition Market (MSAM). As we have shown, it includes the mechanism for replacing reserves, investment strategies of O&GC in oil and gas exploration, oil brent prices, levels of demand and production, and proven reserves. These data have enabled us to estimate the worldwide demand for maritime seismic data, considered a highly specialized market niche. We validated the model by comparing our forecasts with information from specialized consultants in the sector. In particular, a relevant conclusion is related to the negative effect of proven reserves on exploration investments. It validates market knowledge that if reserves increase, the need to incorporate new oil fields decreases, reducing exploration investments and, thus, demand on MSAM services.

The MSAM industry is an offshore activity with have its birthplace in the geological basins of the North Sea and the Gulf of Mexico, which pioneered offshore oi exploration in the technological transition trajectory, from land to shallow waters in the 1970*s*. From 1970*s* onwards has taken momentum, going to deep waters in the 80*s*, and reaching the current frontier takin place in deep and ultradeep waters.

To sum up, our study provides the main features of MSAM's industrial organization. First, Mergers and acquisitions are frequent since there are few bankruptcies. Bankruptcy losses in this market can go far beyond the financial dimension since lost tacit knowledge may never be recovered.

Second, the operational physical aspects are critical to incumbent firms' cost, productivity, and competitiveness. Information from vessels provided estimates of the cost function, separating the effects of team productivity variation from the parameter of technical efficiency.

Third, internal heterogeneity among firms is relatively straightforward, which corroborates Steindl and Penrose's idea that there is no optimal firm size. Instead, each firm has its characteristics according to its operational scale, competing for market space within its conditions. Thus, scale variables are critical, such as the coexistence of companies of different fleet sizes, vessel dimensions, seismic equipment quantities, and highly specialized employees. In this regard, the market structure resembles Steindl's "competitive oligopoly", cohabiting a core of leading firms with a relatively high number of small firms in the market fringes. As was seen, the leading firms follow a similar governance model: they owe the vessels, although only the top three (PGS, CGG, and WesternGeco), have quite convergent behavior, acting strategically on sales efforts, R&D investments, and horizontal and vertical product differentiation.

Fourth, price variations occur due to fluctuations in absolute costs and markup of leading firms. Absolute costs vary due to differences among the customized projects, team productivity, and variation in input prices. The different project parameterizations directly affect the fixed costs of type 2, which are associated with economies of scale. The markup is associated with leading firms' strategies and can fluctuate from positive to null or negative, depending on market conditions. In particular, the results indicated a substantial negative markup in 2014, when there was a drastic reduction in O&GC investments, concomitant with an increase in fleets, due to a maturing lag between decision and construction, which generated idle capacity quickly and sharply. According to our estimates, the three market leaders made losses at similar rates. In 2015 and 2016, there is a reversal, and the average annual markups of some companies reach values twice above the average.

Fifth, we have observed a negative correlation between profit and market growth. Our starting premise was that leaders earned higher profits during heating periods due to their market power and their type of governance, which could reduce charter costs. However, in the empirical analysis, we observed that profits reduced with market expansion. Our findings suggest that cost and competitive pressures have worked opposite to constraint markup increases by the leading firms even under demand scaling up. The indicators of firms' conduct show that MSAM operates most of the time under competitive conditions. The NEIO-based conduct parameter indicates a market with a relatively low level of collusion, which validates MSAM the degree of competition observed in the other two competitiveness indices (Lerner and Boone). It was possible to observe that RPD's values between 2011 and 2016 indicated a high degree of industry competitiveness. The years 2008−2010 and 2017−2018 had higher values of RPD, indicating lower market competition.

Our findings show the stability of market structures in the long term in a more comprehensive view. $C8$ is practically constant throughout the period analyzed. The high degree of specialization of MSAM's process-intensive activities presents substantial barriers to entry and exit. The growth of the fringe firms occurs mainly due to technological development with productivity gains through process improvement, based on innovation sustained by both R&D investments mergers and acquisitions. In parallel, the firm's growth in this industry is due to gradual scarcity of discoveries of large onshore reserves with low extraction costs, the so-called "big fields", which have directed exploratory research from the 90*s* onwards to offshore, causing substantial displacement in demand for maritime seismic data.

Additionally, in this industry's trend, we should consider the importance of firms' governance models related to fleet occupation strategies in the cyclical adjustment of supply and demand, where small-sized-fringe firms have much less room for maneuver. We have seen substantial price fluctuations in the short term that are explained not by cyclical demand changes but by the rigidity of fixed costs, which is typically an industry's structural variable among those we have studied. Evidence has shown that a firm's strategy of modifying fixed cost structures in the cycle can generate drastic and disastrous changes in market structures.

It is especially sensible when the cycle has great intensity and speed of change with the sudden variation of external variables, such as oil prices. This movement has recently transformed the MSAM, with the collapse of two of the three giants of this oligopoly. Another market structure movement, by the technological route, is approaching, and it can deepen these changes. Thus, further market structure disruption can occur by the increasing adoption of Ocean Bottom Sensor (OBS) that has a considerable impact on absolute fixed costs due to the differences in equipment, vessels type, and size. We concluded that MSAM is a Competitive Oligopoly, with the dynamics of its market structure dependent on brent prices, exploration investments, and process technology changes. Firms' conduct reflects low market power, which tends to vary in a narrow band. This industry has a price-competition oligopolistic market, and despite being concentrated, presents a high degree of competition.

Finally, in future work, we can expand NEIO's tooling to deepen the study of technological paradigm change in MASM, using the Schumpeterian line linked to hiring strategies for both market players and bid and demanders, using Contract Theory. This work focuses on streamer technology, where the demand mechanism is relatively restricted to the first exploratory phases. The market is undergoing a recent change, with the increasing presence of OBS technologies, advancing more and more in the production phase, bringing new resources to the market. Updating future work with data on firms that employ these background technologies may bring new results and a new understanding of MSAM. Another possibility of advancement is to employ our methodology in the other links of the upstream chain, such as, for example, in the well drilling activity.

Appendix A. Seismic Acquisition Activity

This method consists of recording in a seismograph the acoustic waves that propagate in the physical environment of the rocks and fluids in the basins studied. The seismic reflection method application in the petroleum industry dates from the beginning of the 20th century for the terrestrial environment and the late 1950*s* decade to the aqueous environment. The classical equipment of seismography in onshore exploration is the geophone, a device stuck in the ground and sensitive to displacements of particles in the ground. When an acoustic wave propagates on the ground, the different layers of rock generate reflections recorded by geophones, and the processing of this data generates an image that contains information of the contrasts between layers of rock underground. In the aqueous environment, the equipment to register seismic waves is the hydrophone[15]. The hydrophone is sensitive to pressure variations in water and records the P component of the wave that propagates in a fluid environment. The signal recorded in the hydrophones can be from passive or active sources. In

[15] The seismic method using hydrophones to oil industry occurs at least 1958. See in the CGG website: https://www.cgg.com/en/Who-We-Are/Company-Profile/Our-History.

the first case, the environment itself generates the acoustic waves, while in the second case, energy pulse came from a vibrating system or explosives in the case of the terrestrial environment and from air cannons in the case of the sea. Air cannons, known in the maritime seismic industry as air-guns, airtight chambers where an amount of air is injected at high pressure, and the air is released quickly to generate an energy pulse that propagates in the form of a wave in the water Dondurur (2018).

The equipment of register and source to seismic-data gathering is towed by vessels in the under investigation place. The size of the vessels and quantity of equipment depends on the parameters of the project demanded by O&GC. The set of vessels with the registration and source equipment configure the production plant of the MSAM firms. Seismic vessels vary in size according to the type of project they will serve and can reach 100 meters in length and more than 50 meters in width [16].This composition of vessels and equipment to form the plant (seismic team) that will serve a specific project enables a diversity of arrangements depending on the strategy of each firm, given that teams with larger plants (number and size of vessels and amount of equipment) have higher costs that can be offset by productivity gains, depending on the project.

To better understand MSAM, we summarize database information departure of the quantity of 3*D* projects [17]which was around 2700 in total, with an average of 200 projects per year and maximum and minimum quantities of 300 and 100 projects in the years 2012 and 2016 respectively. We observed about 70 firms that operated about 170 different vessels on the supply side. The three leaders have used over 60% of these vessels, of which about 20 vessels have executed over 30 projects (+600) in total. On the demand side, we observe many oil and gas companies, more than 400 firms, however less than 3% show at least 2 projects per year. In table 1 we present the number of total projects (*np*) distributed by demand, supply, and markets with the most significant participation up to the tenth position.

Norway has the most significant number of projects in terms of regions, and Statoil (now Equinor), the national company, accounts for a 1⁄4 less share of Norway's projects, highlighting greater competition in exploring the North Sea reserves. China has CNOOC, the national offshore company, with almost 70% share of total Chinese projects demand. COSL, a subsidiary of CNOOC, has completed almost the totality of 158 projects in the holding company, creating a pole out of place from the rest of the market's demand and supply. COSL's other projects are mainly in the African basins. The firm BGP, also Chinese, has a lower demand than COSL due to its greater focus on the onshore segment but has relevance in serving projects outside the Chinese market, even for Chinese clients, placing itself as a competitive firm in a global market. We observe that although the USA is in the fifth position, it has some leadership in the amounts of investments in geophysics because it is a world pole of seismic processing technology and technological vanguard along with Norway. Another aspect to observe is the duration of the project. The countries with larger exploratory areas and where the oil fields are more developed have a more significant number of obstructions, and due to environmental and climatic issues, the duration can increase significantly.

For example, Petrobras is ninth of rank in terms of projects and third if the criteria are total duration.

References

[1]. Bain, J.S., 1942. Market classifications in modern price theory. The Quarterly Journal of Economics 56, 560–574.
[2]. Bain, J.S., 1949. A note on pricing in monopoly and oligopoly. The American Economic Review , 448–464.
[3]. Bain, J.S., 1952. Industrial pricing and market practices.
[4]. Bain, J.S., 1956. Barriers to new competition: The character and consequences in manufacturing industries. Harvard University Press.
[5]. Bain, J.S., 1983. Price leaders, barometers and kinks. J. Reprints Antitrust L. & Econ. 13, 767.

[16] The types of main vessels can be: Streamer Vessel or Master Vessel (MV) that tows the hydrophones cables and sources; Source Vessels that tows only sources; and Multi-purpose Vessels (MVP) that has a Remote Operated Vehicles (ROV) used in Ocean Bottom Sensor (OBS) technology. In addition to seismic vessels, there are other vessels teams to give support during the execution of a survey: Supply Vessel or Support Vessel (SPV) that is responsible for food and fuel supply of the fleet and the Chase Vessel (CV), which performs the function of escorting the main vessels that have low mobility. For a Streamer Team, the plant has formed by a set of three vessels {MV, SPV, CV} or four vessels {MV, SV, SPV, CV} in projects that include the undershooting technique in obstructed areas and OBS Team by a set of four vessels {MVP, SV, SPV, CV}. In this article, we only address the market for Streamer technology.

[17] The database shows more than 4500 projects (2*D*,3*D* and 4*D*) from 2006 to 2019, which more than 1⁄4 are multi-client and 3⁄4 proprietary. We have almost 2700 samples of projects 3*D* for proprietary and multi-client contracts in the database. By type, the proprietary projects have almost 1250 projects 2*D*, 2300 are 3*D* and more minor than 200 projects 4*D*. By technology, the MSAM is a majority in the Streamer projects ($< 95\%$), has a few projects of Ocean Bottom Sensor (OBS)($> 5\%$), with 200 projects divided between Ocean Bottom Cable (OBC) and Ocean Botton Nodes (OBN) projects. In this set of samples, we observe 137 different vessels and 117 countries. 71 acquisition companies and 469 oil companies demanded the acquisition services. With more than 30 projects in the period, only 14 clients and 21 suppliers. Further information of data's source is seen in subsection 3.1 Database.

[6]. Barros Junior, P.R.d.M., . Formac¸´ ao de prec¸o em oligop˜ olios intensivos em pro-´ cessos: estudo do mercado mundial de aquisic¸ao s˜ ´ısmica mar´ıtima .
[7]. Boone, J., 2008. A new way to measure competition. The Economic Journal 118, 1245–1261.
[8]. Bresnahan, T.F., 1982. The oligopoly solution concept is identified. Economics Letters 10, 87–92.
[9]. Bresnahan, T.F., 1989. Empirical studies of industries with market power. Handbook of industrial organization 2, 1011–1057.
[10]. Bresnahan, T.F., Reiss, P.C., 1991. Entry and competition in concentrated markets. Journal of political economy 99, 977–1009.
[11]. Chamberlin, E.H., 1949. Theory of monopolistic competition: A re-orientation of the theory of value. Oxford University Press, London.
[12]. Dondurur, D., 2018. Acquisition and processing of marine seismic data. Elsevier.
[13]. Durrheim, R.J., Manzi, M.S., Webb, S.J., 2020. Exploration geophysics .
[14]. Einav, L., Levin, J., 2010. Empirical industrial organization: A progress report. Journal of Economic Perspectives 24, 145–62.
[15]. Gaci, S., Hachay, O., 2017. Oil and Gas Exploration: Methods and Application. volume 72. John Wiley & Sons.
[16]. Gadallah, M.R., Fisher, R., 2008. Exploration geophysics. Springer Science & Business Media.
[17]. Gujarati, D., 2011. Porter, dc basic econometrics.
[18]. Haldar, S.K., 2018. Chapter 6 - exploration geophysics, in: Haldar, S.K. (Ed.), Mineral Exploration (Second Edition). second edition ed.. Elsevier, pp. 103– 122.
[19]. Hall, R.L., Hitch, C.J., 1939. Price theory and business behaviour. Oxford economic papers , 12–45.
[20]. Herfindahl, O.C., 1950. Concentration in the steel industry. Ph.D. thesis. Columbia University New York.
[21]. Kearey, P., Brooks, M., Hill, I., 2002. An introduction to geophysical exploration. volume 4. John Wiley & Sons.
[22]. Lee, C., 2007. Scp, neio and beyond. Nottingham: Nottingham University Business School, Working Paper Series 2007, 05.
[23]. Lerner, A., 1973. The concept of monopoly and the measurement of monopoly power, in: Readings in Welfare Economics. Springer, pp. 1–19.
[24]. Mason, E.S., 1939. Price and production policies of large-scale enterprise. The American economic review 29, 61–74.
[25]. Mason, E.S., 1948. The current status of the monopoly problem in the united states. Harv. L. Rev. 62, 1265.
[26]. Nevo, A., 2001. Measuring market power in the ready-to-eat cereal industry. Econometrica 69, 307–342.
[27]. Pakes, A., 2017. Empirical tools and competition analysis: Past progress and current problems. International Journal of Industrial Organization 53, 241–266.
[28]. R Core Team, 2019. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. URL:
[29]. https://www.R-project.org/.
[30]. Rosse, J.N., 1970. Estimating cost function parameters without using cost data: Illustrated methodology. Econometrica: Journal of the Econometric Society , 256–275.
[31]. Scherer, F.M., Ross, D., 1990. Industrial market structure and economic performance. University of Illinois at Urbana-Champaign's Academy for entrepreneurial leadership historical research reference in entrepreneurship .
[32]. Schmalensee, R., 2012. "on a level with dentists?" reflections on the evolution of industrial organization. Review of Industrial Organization 41, 157–179.
[33]. Shepherd, W.G., 1990. Mainstream industrial organization and "new" schools. Revue economique , 453–480.
[34]. Stigler, G.J., Kindahl, J.K., 1970. Behavior of industrial prices .
[35]. Sutton, J., 2007. Market structure: theory and evidence. Handbook of industrial organization 3, 2301–2368.
[36]. TIRYAKI, G.F., ANDRADE, C., 2017. Econometria na pratica. Econometria na´ pratica .´
[37]. Zeidan, R.M., Resende, M., 2009. Measuring market conduct in the brazilian cement industry: a dynamic econometric investigation. Review of Industrial Organization 34, 231–244.