MIT Industrial Performance Center
Innovation. Productivity. Competitiveness.

WORKING PAPER SERIES

From Resource Extraction to Knowledge Creation: Oil-Rich States, Oil Companies and the Promotion of Local R&D

Renato Lima-de-Oliveira, PhD
Assistant Professor of Management, Asia School of Business (ASB)
Research Affiliate, MIT-IPC
rlima@mit.edu

Timothy Sturgeon
Senior Researcher, MIT IPC
sturgeon@mit.edu

MIT-IPC Working Paper 17-003

September 2017

ACCELERATING INNOVATION in BRAZIL

400 Main Street, E19-733, Cambridge, MA 02139
ipc.mit.edu

From resource extraction to knowledge creation: oil-rich states, oil companies and the promotion of local R&D

Renato Lima-de-Oliveira and Timothy Sturgeon

ABSTRACT

The increasing technological and operational requirements associated with unconventional oil and gas (O&G) reserves have created new challenges for oil companies and brought new opportunities for states to use the O&G industry itself — not just revenues from O&G — to drive industrial upgrading and high skilled employment. This paper identifies the role of firms and governments in the technological development of the oil industry. It provides a typology that connects firm-level business strategy to public policy priorities in the natural resource sector, and makes predictions about which scenarios can lead to local knowledge creation and spillovers. It characterizes the main actors in the oil value chain according to their role in new knowledge creation and highlights the collaborative nature of R&D in this industry. The paper also highlights the importance of geological challenges in shaping firms' R&D strategies and for influencing the potential for public policies to promote spillovers. Effective public policies leverage the collaborative nature of innovation in the oil industry to promote linkages with local knowledge institutions and suppliers as a way to maximize the indirect, knowledge-based, benefits of O&G production.

Introduction

Oil and gas (O&G) is among the world's biggest industries. For example, it is the largest consumer of steel (Bret-Rouzaut and Favennec 2011), and traded value of crude oil is the highest of any commodity (Aguilera and Radetzki, 2016; Brooks and Kurtz, 2016). Despite the absolute growth in renewable energy production, the share of oil, coal and natural gas in the global energy mix — about 80% of primary energy demand — has remained stable over the past 25 years (IEA 2016, p. 32). Because energy transitions tend to be slow, notwithstanding environmental concerns having to do with the effects of carbon emissions on human induced climate change, most professional forecasters predict that hydrocarbons will continue to be the dominant source of the world's energy into the foreseeable future (IEA, 2016; BP, 2017).

Surprisingly, given its importance, the O&G industry has a poor reputation as a driver of economic development. As an extractive industry with high capital expenditure (CAPEX) requirements, innovation, technological learning, and new firm formation have been weak.[1] Employment generation has been modest, at best. Value chains are dominated by a small number of very large firms. Because states own mineral rights, it has been up to government agencies to use revenues in ways that can diversify the industrial base into sectors that are more dynamic in terms of employment and technology development. Most states have failed in this regard. Rents, however high, tend to be captured by elites, and oil wealth forestalls the need to focus on more innovative sectors. This pattern is common enough in extractive, resource-based industries to be have been dubbed "the resource curse."

However, as world energy consumption continues to grow, new reserves have been added to keep the oil flowing. Not all places with oil reserves have favorable geological profiles, and newer reserves tend to be more challenging and expensive to develop. "Unconventional" reserves from deep offshore, tar sands and shale are gradually replacing low-cost onshore O&G, and as production goes from good ore to bad and from bad to worse, more ingenuity is needed to locate and develop new reserves. As MIT energy economist M.A. Adelman put it, these additional reserves "were no gift of nature. They were a growth of knowledge, paid for by heavy investment" (Adelman, 1995, p. 17).

[1] This profile is similar to construction.

With increasing technological and operational requirements associated with unconventional reserves, new opportunities are opening up for states to use the O&G industry itself — not just revenues from O&G — to drive technological learning, industrial upgrading and high skilled employment. However, the literature on how innovation happens in the oil industry is scarce, and further, little attention has been paid to how public policies have been used to maximize the knowledge spillovers from oil production. This paper seeks to address these gaps by exploring the following questions: a) how does innovation happen in the O&G industry; b) what roles are played by the main actors in value chain: state oil companies, international oil companies, oilfield services suppliers, and universities; c) what policies have oil-rich countries used to capture R&D spillovers, and d) how do these policies interact with firms' corporate strategies? The objective of this paper is to characterize how knowledge is created in the oil industry, and identify how public policies can promote spillovers that go beyond the generation of rents from oil extraction.

This paper is organized as follows. After this introduction, Section 2 characterizes the drivers of innovation in O&G and proposes a typology that links firms' R&D strategies in O&G to the public policy approach taken by oil-rich states. Section 3 analyzes the role played by the main actors in the O&G value chain and public policies enacted by selected countries. Section 4 presents a case study of Brazil's innovation and regulatory system. It starts by analyzing a particular R&D project in Brazil, the Flatfish Autonomous Underwater Vehicle (AUV), documenting the public policy-driven interactions between oil companies, suppliers, and research institutions; and ends with a subsection on recent regulatory changes in Brazil's oil industry, its impact in the country's business and innovation environment for the sector, and the implications of these changes for the network of innovation institutes recently established by SENAI.[2] Section 5 concludes with policy recommendations and areas for further research.

We use a variety of sources and methods, drawing from academic and trade literatures, companies' annual reports, and primary data collected through fieldwork that includes opportunistic, semi-structured interviews with various industry stakeholders, including university researchers, corporate R&D managers, and state regulators.

---

[2] SENAI, which stands for Serviço Nacional de Aprendizagem Industrial (Industrial National Service for Industrial Training), is a private sector non-profit organization focused on secondary level professional training. It is part of Brazil's umbrella industrial association, the Brazilian Confederation of Industry.

The Heterogeneous O&G Industry: Value Chain Actors and Drivers of Innovation

Despite enormous quantities of fuel already burned since the beginning of the "age of oil" (Maugeri, 2006), production capacity, consumption, and known reserves have been rising over the years.[3] Extraction of conventional oil can generate high profits due to the wide difference between production cost and its selling price, which has frequently been multiple times more than the cost of production, especially from giant fields in the Middle East.[4]

The key factor generating high returns to resource-owners (governments and oil companies) is access to a favorable geology. In these cases, it takes little effort (and cost) to extract O&G, meaning high rents when sold in international markets. The history of the O&G industry has been marked by a constant tension between states and oil companies over the division of such rents. Governments have used a variety of mechanisms to capture oil wealth, including fees, royalties, income and windfall profit taxes collected from oil companies as well as payments in kind (see, for example, Grunstein, 2010 and Tordo et al., 2010).[5] Nevertheless, extractive industries, and oil in particular, have occupied an odd place in debates about development and technology, particularly after the rise of the resource curse literature, which brought attention to the frequent negative economic and social effects associated with oil abundance (see Ross, 2015 for a review). Part of this literature is based on the idea that positive economic development requires structural change. Countries need to move towards more complex activities that embed more knowledge, and pumping oil out of the ground would be one of the activities least likely to promote the development of new knowledge.

What this standard image misses is the increasing geological heterogeneity of oil reserves and the industry's growing technological intensity. New techniques such as remote imaging and robotics are key to identifying, characterizing, developing, and maintaining unconventional resources. Unlike conventional oil, unconventional resources can have production costs that

---

[3] By the end of 2014, the world had enough reserves to sustain current levels of consumption for 52 years (Lima-de-Oliveira, 2017).

[4] Per barrel oil prices varied widely, from a minimum of $10.25 to a maximum of $145.31 between 1986 and 2017 (EIA, 2017), but production costs can be less than $5 per barrel from oil fields in the OPEC countries (Aguilera, 2014).

[5] Other ways to capture oil rent have been the direct production through National Oil Companies (NOCs) and the cartelization of production through output quotas within members of the Organization of the Petroleum Exporting Countries (OPEC). Sovereign economic expropriation of oil production infrastructure also results in the capture of value, but because of its temporary nature is more appropriately classified as a quasi-rent.

allow only marginal profitability unless high technological hurdles can be overcome, even in periods of high oil prices.[6]

Therefore, while less profitable, production from unconventional sources can create substantive positive spillovers as it triggers demand for technological innovation across a range of goods and services that serve as inputs to discovery, assessment, and exploitation of new oil reserves. Any societal benefits that come from oil exploitation are shaped by decisions taken by both firms and governments. We provide a stylized typology of how these decisions interact and can either reinforce a path towards maximizing the indirect, knowledge-based benefits of oil production, or conform to the standard image of the oil industry as a pure generator of rents for governments and oil companies with few positive spillovers.

In building our typology, we start from Bret-Rouzaut and Thom's (2005) categorization of oil company technology strategy as being either predominantly about efficiency or about growth. Because growth business strategies require exploration in frontier areas, they typically include an explicit technology strategy and high R&D spending levels, resulting in high patent counts. Efficiency strategies, because they require less exploration for new reserves, are characterized by low levels of spending on R&D and fewer patents granted. Companies explore less, because favorable geology renders it unnecessary. When technology is needed, these companies tend to buy from suppliers.

To this strategic dichotomy we add a public policy dimension. Following Lima-de-Oliveira (2017), we categorize O&G public policies as either rent-taking (maximizing taxes that accrue to governments) or rent-creating (promoting spillovers and developing Schumpeterian/innovation rents by channeling resources to R&D, training, and supplier development programs). In Figure 1, we associate a set predicted outcomes with each of the four combinations in the typology. However, we find that if public policies are oriented towards rent capture, firms are unlikely to adopt growth strategies, leaving three possible outcomes.

[6] There is no universal definition for unconventional oil and many different types of formations can be called so, such as deep offshore, oil sands and shale. What they have in common, according to Yergin (2011), is that "their development depends on the advance of technology" (Yergin, 2011, p. 243).

Figure 1. Interaction of business strategy and public policies in the O&G industry

BUSINESS STRATEGY	PUBLIC POLICY: Rent Capture	PUBLIC POLICY: Rent Creation
EFFICIENCY: firms do not face technical challenges to produce oil but can invest in cost reduction	1) Residual R&D - No spillover	2) Low R&D - Low spillover
GROWTH: firms invest in new technologies to find and produce oil in frontier areas and reduce costs	unlikely to occur	4) High R&D - High spillover

The upper left quadrant combines an efficiency strategy with a rent capture policy, leading to a residual level of R&D with no spillover. This is typical of places with easy geology, where governments can easily set high taxation levels (also known as government take), and firms do not face technical challenges to produce oil but may invest to improve operational efficiency.[7] The upper right quadrant combines an efficiency strategy with rent creation policies, resulting in low R&D investment levels with little spillover. Finally, the bottom right quadrant, which combines growth strategy with rent creation policies, is the sweet spot for innovation and knowledge transfer. This can occur when companies adopt growth strategies in the context of challenging geologies, and the country's public policies both support their efforts and incentivize R&D to be carried out locally.

[7] Government take is defined as "government receipts from royalties, taxes, bonuses, production or profit sharing and Government participation divided by cash flow" (Johnston, 2008, p. 52). It varies from as low as 25% to as high as 98%, depending on geological risk, type of resource (natural gas, light oil, heavy oil), and institutional risk (Van Meurs, 2008).

The Role of Oil Operators, Suppliers and Public Policies in O&G Innovation

> "…the question for an oil company is not so much which technologies to develop but which technologies to influence and gain access to and the best route for this, from many available." (Bret-Rouzaut and Thom, 2005, p. 6)

This section examines the role of the main actors of the O&G value chain in regard to innovation: oil operators, oilfield services providers (OSPs), governments, and host country universities and research and technology organizations (RTOs). It is illustrated by examples derived from an analysis of a selected group of international oil companies (IOCs), national oil companies (NOCs) and by specific policies enacted by oil-rich governments.

In the O&G sector, one can find companies with highly skilled human resources deploying cutting-edge technologies and investing heavily in R&D, competing with inefficient firms staffed by patronage appointments that engage in little R&D. In contrast to most industries, both groups can be highly profitable, depending on the geology of their operational assets. In general terms, oil operators working in easy geologies have little incentive to invest in R&D and technology development.

Based on the analyses of companies' annual reports and financial disclosures, interviews with specialists and executives of the sector, and specialized scholarly and trade literature, we summarize the main channels through which innovation in this industry takes place. The stages and actors in the oil and gas value chain are depicted in Figure 2. Our analysis focuses on the upstream segment of the chain.

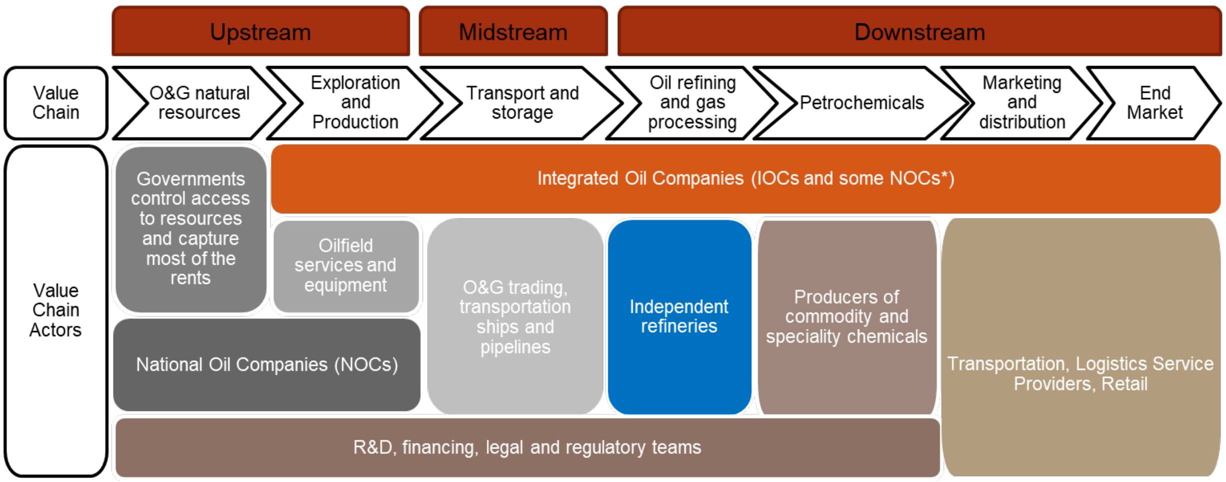
1.1 Oil Companies

This group of firms is predominantly composed of the national oil companies (NOCs) of oil-rich states, which control about 90% of the world's reserves (Victor et al., 2012). These organizations have a competitive advantage derived from state ownership of (typically) easy and plentiful geology. Oil companies left with less-than-good acreage, mainly IOCs and a few NOCs such as Petrobras (Brazil) and Statoil (Norway), have to invest to overcome technical challenges associated with high-cost reserves such as deep offshore, oil sands, and shale.[8] Because we are interested in how states can harness spillovers from innovation, this paper focuses on the

[8] In terms of global value chain (GVC) theory, the O&G industry can be said to be "bi-polar" in regard to lead firms (Ponte and Sturgeon, 2014).

strategies and practices of oil companies (and their suppliers) engaged in identifying and developing unconventional, technically challenging reserves.

Figure 2. The Oil and Gas Value Chain



* NOCs that went beyond their privileged access to resources and developed integrated downstream operations
Source: Lima-de-Oliveira (2016)

As oil demand continues to grow and the best, low-cost, reservoirs are increasingly restricted to the NOCs of oil-rich countries, IOCs and a select group of NOCs have had to ramp up their technology investment to build reserves. Most importantly, heavy investments have been made to increase the knowledge of the earth's subsurface with new evaluation and extraction techniques. These advanced techniques and technologies tend to be used in frontier areas such as deep offshore and shale O&G rather than the prolific and easy-to-access fields in the Middle East. In addition, how much of this knowledge is created and retained by local scientists and suppliers and how much is imported is a function of both the geological challenges that influence oil companies' business strategies, the extant capabilities in the local supply base, and public policies that incentivize oil companies to invest more in R&D, sometimes in partnerships with local organizations.

Oil companies' most important asset in the upstream segment of the production chain is access to reserves. Without acreage to explore, an oil company cannot proceed. Given the high CAPEX nature of oilfield development and long time horizons, access to capital is also critical. Projects frequently have a long lead times – meaning that a considerable amount of time is incurred, and money invested, before a project can start generating positive cash flow. For instance, while a typical onshore project can come on stream in about a year, a deep offshore prospect can take up to a decade and more than a billion dollars of investment before it can begin commercial-scale operations and generate positive cash flow (Victor et al., 2012; Lima-de-Oliveira, 2017). In such circumstances, companies must integrate bundles of technologies to find and develop resources in frontier geologies, and because geological and operational risks are higher, have to do business under strict financial discipline. Under these conditions, integration of technologies requires dynamic capabilities that are deployed during the different stages of project development (Garcia et al., 2014). In sum, financial and technological capabilities are the key success factors for companies that have to compete on the basis of developing new reserves.

Since the 1970s, oil companies have outsourced most of their operations, including many aspects of technology development, to oilfield services and equipment providers (OSPs), concentrating on core areas, particularly the ability to find resources and manage project portfolios.[9] The steps involved in oil production, and their technological challenges, can be summarized as follows. After the acquisition of exploratory rights of an acreage from a resource-owner (such as a government), an oil company will gradually invest in activities that reduce the uncertainty about whether a commercial discovery can be made. During this exploration phase, seismic surveys and other indirect analyses are conducted. If results are promising, as well as sometimes forced by contractual obligations, an oil operator starts a drilling campaign that can include several exploration wells. If discoveries are made, an appraisal phase begins, requiring new wells to be drilled to delineate and characterize the field. After a field is characterized in terms of its extension and production potential, the project enters into its development phase, where the long-term production infrastructure is built. The firms that conduct the seismic, drilling, and sometimes even the oil production itself can be OSPs working under directions from the oil company (which are also called the operators). Key success factors, from the point of view of oil companies (IOCs and NOCs with difficult geology), are the determination of which blocks of land to buy/lease, how much to pay for them, and where to drill.

For these reasons, oil companies have concentrated their R&D activities in technologies aimed at discovering, characterizing and optimizing oil fields. Since the mid-1980s, product development, in terms of specific operational technologies and equipment, has largely been outsourced to OSPs and other suppliers (Perrons, 2014 and interviews). In fact, oil companies

[9] Currently, from 70% to 95% of all expenditures made by oil companies in the upstream segment are outsourced (Raymond and Leffler, 2006; Bain & Company and Tozzini Freire, 2009).

slashed their R&D investments following the long period of low oil prices from 1986 up to mid-2000s while OSPs increased their investment. However, because of the rising importance of unconventional reserves, thanks to high oil prices, oil companies returned to invest heavily in R&D after the mid-2000s. For instance, data provided by Bret-Rouzaut and Thom (2005) show that the R&D spending for the top 6 US IOCs plus BP was of $2.2b in 1985, $2.3b in 1991 and only $1.2b for the period 2000-2001. These figures are dwarfed by more recent data, even taking into account a year of crisis and adaptation such as 2015, when crude oil prices plummeted. Table 1 presents key indicators of the 5 main IOCs (ExxonMobil, Chevron, Total, Shell, BP) and 5 NOCs selected as benchmarks (Statoil, Petrobras, Pemex, Petronas, Saudi Aramco).

The first thing to notice in Table 1 is that just this group of companies invested over $5.2 billion in R&D in 2015. IOCs continue to invest more in R&D than NOCs, with companies like Shell, Total, and ExxonMobil investing each over a $1 billion per year. The IOCs in the group invested $4.18 billion in R&D, while the NOCs only $1.04 billion – with the caveat that Saudi Aramco's amount is not disclosed. Taking into account the R&D investment share of total revenues, the average for IOC is 0.6% while for NOCs amount half, with 0.34%. While IOCs, on average, invest at nearly double the rate of NOCs, the industry as a whole has very low rates of R&D investment relative to most other industries, where large companies routinely spend from 4% - 10% of revenues on R&D (Price Waterhouse Coopers, 2017).

Total 2015 production by the IOCs in Table 1 is 15.2 million barrels per day (mb/d), while NOCs account for 20.3 mb/d – with half of that amount accounted for by Saudi Arabia. Among NOCs, Petrobras led investments in R&D with $630 million in 2015, or 0.65% of revenues, placing it ahead of all companies in Table 1 except for BP and Total. In fact, between 2010 to 2015, Petrobras invested about a $1 billion per year, on average. The 2015 figure is closer to what had been registered in 2009 ($685), when currency devaluation in Brazil and low oil prices led the company to reduce its investment in R&D.