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WHY IS PATENT PRODUCTION SO COMPARATIVELY LOW AT PETROBRAS?

DISSERTAÇÃO APRESENTADA À ESCOLA BRASILEIRA DE ADMINISTRAÇÃO PÚBLICA E DE EMPRESAS PARA OBTENÇÃO DO GRAU DE MESTRE

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WHY IS PATENT PRODUCTION SO COMPARATIVELY LOW AT PETROBRAS?

ABSTRACT

As a latecomer firm, Petrobras' innovation progress has previously been measured in terms of its productive capacity, capability accumulation, and more recently in terms of its strategic R&D and new product development. Patents are an acceptable proxy for innovation, especially for complex innovations such as biofuels and deepwater oil exploration & production, and this study evaluates Petrobras' patent intensity relative to Shell and ExxonMobil for the years 2008–2012. The study found that while Petrobras may be a world-leader in deepwater E&P, its patent activities and portfolio are not competitive with its peers. This low patent intensity (and, by proxy, innovation) of Petrobras' is explained by past and present institutional, cultural, and firm-specific factors.

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1. INTRODUCTION

Petrobras is the national oil company of Brazil, and a "national champion" that has received, and continues to receive, considerable governmental support to improve its capabilities and global competitiveness. Over 40 years, Petrobras invested in its organizational capabilities to support a growing innovation capability. It built a firm-centric knowledge network to support strategic innovation capabilities, and accumulated the technological capabilities to conduct world-leading research at the "innovation frontier" [16, 17, 5].

At the innovation frontier, patent production is an excellent measurement of innovation; however, the Companys patent production is significantly lower than its peers. Compared to its peers the Company's patent intensity is anemic (see Table 1).

	USPTO		WIPO PCT		EPO	
	5 Years 2008–2012	10 Years 2003–2012	5 Years 2008–2012	10 Years 2003–2012	5 Years 2008–2012	10 Years 2003–2012
Petrobras	35	87	42	67	60	91
Shell	307	1072	471	541	141	248
ExxonMobil	699	2201	1452	2805	979	1989

[66, 25, 81]

Table 1: *Patents by Key Venue*

As a latecomer industrial company, the process to accumulate organizational innovation capabilities at Petrobras is well documented and studied however, no research has considered the efficacy of the Companys capabilities now that it is at the innovation frontier. This research project proposes to specifically analyze the reasons for Petrobras patent production disparity relative to its peers. It builds upon prior case studies and research regarding Petrobras. The hypothesis of this study is that Petrobras' innovation is negatively affected by cultural and institutional factors.

1.1. LATECOMERS AND THE TECHNOLOGY FRONTIER

A "latecomer" firm is one whose late entrance to industrialization is historically determined, has some initial low-cost advantages (e.g. labor, natural resources), is isolated/removed from the technology sources and advantages of developed markets, and intends to catch up to its competitors [5]. Latecomer firms must acquire and develop the organizational capabilities for innovation. Key to the acquisition and maturation of these capabilities is both internal and external learning. Innovation has a degree of novelty: it is new to the firm, new to the market, or new to the world [62]. Nevertheless, innovation should not be confused with complexity.

Bell & Figueiredo [5] defined 4 levels of innovative activity for latecomer firms: basic, incremental, advanced, and world-leading. At the latter level, a latecomer firm has "arrived" at the international frontier of innovation for products, production, and organizational processes and systems. Such a firm has the human capital and technology needed to compete globally.

Similarly, the authors defined 3 organizational dimensions: specialization and differentiation, integration and coordination, and strategic dynamic orchestration. A simple specialized organization, for instance, may only have the ability to produce. As it matures to an integrated organization, it may add a quality assurance department and administrative departments. Finally, as it reaches strategic maturity, the firm may have all the organizational capabilities (admin, QA, production, marketing, finance, etc.) to exploit a sophisticated technology innovation.

The path of a latecomer firm's maturation is correlated to both its increasing technology innovation sophistication (innovation levels, from basic to world-leading) and its organizational sophistication and orchestration. Technological capability must be matched with organizational capabilities. For instance, some companies do leading R&D but fail to bring their innovative products to market due to a lack of organizational maturity.

Figueiredo [31] describes that latecomers are "climbing a ladder" to catchup to the global leaders. It is a technological, not economic, catch-up. As companies climb the ladder by accumulating capabilities, they grow from accumulating production capabilities to accumulating innovation capabilities. Latecomers typically cross in the production capabilities threshold in +10 years, the incremental line in +20 years, and the radical line is approached in +30 years.

Key to the path of innovation maturation of latecomer firms is the coordination of processes. Informal and formal processes are needed to coordinate physical capital, human capital, products/services, and processes/routines. "Innovation is a process involving a long process of activities" [31].

1.2. PATENTS AS A MEASURE OF INNOVATION

Measuring innovation is a challenge. It is difficult to quantify. Innovation involves transforming an invention for market acceptance and delivery. Stated differently, innovation is adaption. Derived from the Latin root for "change," innovation should have a degree of novelty: an innovation is new to a firm, new to the economy, or new to the world.

Innovation has been traditionally measured by R&D expenditure, individual qualifications, patents, gross domestic R&D expenditure (a national view), and investments in R&D personnel. However, these indicators are proxies and only measure late-stage innovation of products at the product innovation frontier.

To address the weaknesses of the traditional three classes of innovation indicators (R&D, patents, and bibliometric data), Smith [75] suggests the use of product performance data ("technometric"); synthetic indicators, mainly used by consultants; and, specialty research databases and surveys. He strongly cautions against reliance upon traditional indicators, since they don't directly measure innovation.

Within emerging/developing latecomer companies, engineering and manufacturing innovations are best measured with a process view. Measuring processes is best done with a a survey approach. Accumulating capabilities capability building for latecomer process and product firms can be found in Figueiredo's 2003 steel study and 2014 pulp paper study [29, 30].

Figueiredo [31] mapped innovation activities on a continuum, a linear line of capability accumulation, from simple to complex. The continuum is illustrated below in Figure 1. In

terms of complexity, patents are the penultimate activity and R&D is the ultimate activity.

Patents provide a wealth of data, over a long history; however, they are artifacts of a legal process. Patents suffer from a few weakness: first, they do not directly measure innovation, but rather legal preservation of invention. Stated differently, the absence of patents does not necessarily correlate to an absence of innovation. Second, patents are not widely used.

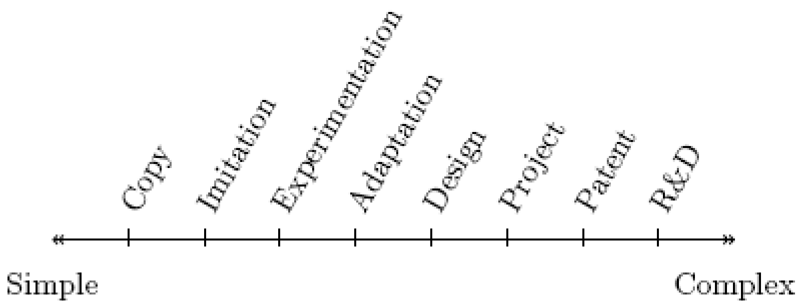

Figure 1: *Innovation Activities Line - Source:* [31]

Simply put, the patent process is expensive and sophisticated. It requires a commitment of resources and time that is beyond the capabilities of most firms. Drafting and filing a patent is only the beginning of a multi-year prosecution effort(the administrative effort of receiving a patent grant from the patent office). Once granted, additional work to protect a patent may be necessary (e.g. litigation).

Griliches [42]concluded that patents are correlated with R&D expenditures, and thus are a suitable proxy for innovation: “Patents are a good indicator of differences in inventive activity across different firms. While the propensity to patent differs significantly across industries, the relationship between R&D and patents is close to proportional, especially for firms above a minimal size.”

Patent law confers a limited commercial monopoly for inventions that are both useful and novel, to promote the public goods of commerce and invention. Patents follow a fairly standardized process: 1) a patent application is filed with the invention disclosure; and if found meritorious, 2) the patent application is granted with its constituent claims. In general, priority of claims is based on first to file rather than first to invent. One can track an application by its application serial number, and a patent by its patent number.

Energy is an international business, and energy patents have economic value in more than one national jurisdiction. Assuming that an invention needs protection in multiple nations, an inventor can seek protection in one of three ways:

1. Filing simultaneously in all desired national jurisdictions;

2. Filing a patent in a Paris Convention country to establish the priority date, followed within 12 months of the filing date with applications to every other Paris Convention country in which patent protection is sought; and,

3. Filing a single Patent Cooperation Treaty (PCT) patent application at the World Intellectual Property Organization.

Brazil is served by the Instituto Nacional da Propriedade Industrial (INPI); the European Union by the European Patent Office (EPO); and, the United States by the U.S. Patent and

Trademark Office (USPTO). All of the EU countries, the US, and Brazil are PCT members.

2. RELEVANCY

The oil & gas sector's innovation progress in deepwater oil countries is well documented. Silvestre & Dalcol's [21] studied Brazil's innovation cluster in oil & gas. Engen investigated Norway's deepwater oil & gas sector and the associated innovation at Statoil and other firms [24]. (As a fellow latecomer oil & gas industrial nation, Norway is arguably the nearest analogue to Brazil.)

The firm-level rise of Petrobras to the "technology frontier," with its accumulated innovation capabilities, has been well studied. Furtado et al [35] documented the Company's "catchup strategy" through cooperative R&D. Antunes el al [1] similarly reported on a successful Petrobras joint venture. Dantas (2006) [15] studied the firm-centered knowledge networks at Petrobras, and applied it more broadly to latecomer firms in emerging economies. Dantas & Bell (2009) [16] found that the Company acquired the capabilities to compete and innovate strategically, and as such had grown out of its latecomer status to compete at the global innovation frontier. Following their earlier work, Dantas & Bell (2011) [17] looked at the linkage between the evolution of Petrobras' knowledge network (from passive learning to strategic innovation) and its capability accumulation. The study was novel because it was dynamic, rather than static, and it applied a new framework for measuring innovation. It evaluated network-based innovation, rather than firm-based. This collaboration with vendors, universities, and joint industry teams was "open innovation."

Most recently,Joia [52] studied knowledge transfer at the Company's sales and marketing department.

To evaluate the effect of culture upon firms, this study will use the works of Hofstede [45, 46, 47] and the GLOBE study [48]. Their works on culture and its influences provide a foundation to identify key differences, and related effects on firm-level beliefs and behaviors.

National institutions can also affect firm-level decisions. Therefore, this study will also look to the institution-based view as proposed by Peng [67]. It will also consider the government's role in innovation, as proposed by Mahmood [56].

This study is relevant be because it applies both cultural and institutional perspectives to a firm-level innovation question: *"Why is Patent Production so Comparatively Low at Petrobras?"*.

3. STUDY DESIGN

Designed as a comparison of Petrobras relative to two peer companies, Exxon-Mobil and Shell, the study has both a quantitative and qualitative component. The rationale for the sample selection of ExxonMobil and Shell is addressed Section 4.1 below.

Commencing with a literature review, the study then progressed to gathering historical data on Petrobras. With a firm understanding of the Company's past and present, patent statistics were collected for the five-years 2008–2012, using the Patenscope database. This data analysis constituted the quantitative portion of the study.

Academic literature was then utilized to help explain the quantitative results, and this portion of the study comprised the qualitative element. No surveys were performed. The qualitative component of this study is limited to the review, and application of, academic literature for explanatory value of the quantitative results.

For those eager to read ahead, the interpretation of the quantitative and qualitative analysis can be found in the Conclusion.

3.1. SAMPLE SELECTION

Comparing every major oil production company is too large a task for this research effort. Therefore, the sample was limited to three companies. Petrobras is obviously the focus of this study, so its inclusion dictates the selection of the the other two companies for peer comparison.

First, the population was limited by seeking companies of equivalent size and capabilities. Petrobras is a major, multinational oil company. Major oil companies are global and have the financial resources to self-finance entire energy projects from start to finish. Size alone is insufficient to qualify as a "major": organization capabilities are a classification requirement. Major oil companies are also vertically integrated and responsible for all aspects of oil production: exploration, drilling and development, production, refining, and distribution. Specifically, every major oil company has R&D capabilities and produces world-leading innovation, where innovation is measured by patent production. The publicly traded "major" oil companies are: ExxonMobil, Chevron, BP, Royal Dutch Shell, Total, ConocoPhillips, Lukoil, and Eni. Every other top 25 producing oil company has greater than 50% government ownership.

The population is defined as the top oil producing companies, which is listed below in Table 2.

Rank	Company	MMb/d	Country	State Ownership
1	Saudi Aramco	12.5	Saudia Arabia	100%
2	Gazprom	9.7	Russia	51%
3	National Iranian Oil Co.	6.4	Iran	100%
4	ExxonMobil	5.3	US	0%
5	PetroChina	4.4	China	100%
6	BP	4.1	UK	0%
7	Royal Dutch Shell	3.7	UK/Netherlands	0%
8	Pemex	3.6	Mexioc	100%
9	Chevron	3.5	US	0%
10	Kuwait Petroleum Corp	3.2	Kuwait	100%
11	Abu Dhabi National Oil Co.	2.9	UAE	100%
12	Sonatrach	2.7	Algeria	100%
13	Total	2.7	France	0%
14	Petrobras	2.6	Brazil	32.2%
15	Rosneft	2.6	Russia	75%
16	Iraqi Oil Ministry	2.3	Iraq	100%
17	Qatar Petroleum	2.3	Qatar	100%
18	Lukoil	2.2	Russia	0%
19	Eni	2.1	Italy	30%
20	Statoil	2.1	Norway	67%
21	ConocoPhillips	2.0	US	0%
22	Petroleos de Venezuaela	1.9	Venezuela	100%
23	Sinopec	1.6	China	72%
24	Nigerian National Petroleum	1.4	Nigeria	100%
25	Petronas	1.4	Malaysia	100%

Table 2: *Top 25 Oil Companies by Production, 2012 - Rank Company MMb/d Country State Ownership Source: [34]*

Second, the companies in the sample study should not be majority controlled by the state, and publicly traded. This limits the population to 9 companies: ExxonMobil, Chevron, BP, Royal Dutch Shell, Total, Petrobras, ConocoPhillips, Lukoil, and Eni. Publicly traded companies publish financial statements with considerable detail, including headcount, R&D expenditures, and various asset/revenue measurements. These details may later prove useful for creating relative measurements in the comparative analysis of oil company patent production.

Third, the sample size of institutions was restricted to only 3 companies, as a practical measure, to limit the scope of the research project.

Fourth, cultural – rather than institutional – factors might explain variances in patent production (the chosen indicator for world-leading innovation). Therefore, it would be less useful to compare Brazilian Petrobras to two US Companies such as Exxon and Chevron. Each company in the sample should have a unique cultural heritage. In choosing between major oil companies from the same cultural domicile, preference was given to the larger company.

ExxonMobil is included over the other Anglo companies (Chevron, BP, ConocoPhillips) because of size. ExxonMobil is the largest private oil producer by both volume of production and by market capitalization.

Royal Dutch Shell was selected over BP, Chevron, and ConocoPhilips because in a sample of only three companies the addition of another Anglo (by culture) company was ill-favored. Shell was favored over Eni and Total for its offshore exploration & production

capabilities, size, and internationalism
– it is, arguably, the most international oil company. It has operations in 70 countries and is itself the product of an international merger of a Dutch company and a British company.

A sample with US., Dutch/British, and Brazilian firm cultures may yield useful insights, since differences in culture may have explanatory value.

The resulting proposed sample is 3 companies: Petrobras, Royal Dutch Shell, and ExxonMobil. Petrobras is Brazilian; Shell is an Anglo-Dutch company whose real institutional heritage is centered in both Southeast Asia and London, and historically possessed a unique dual-CEO management structure; ExxonMobil is a U.S. company, and the leading oil company in the world by profits. The selected sample of ExxonMobil, Shell, and Petrobras is given an overview comparison in Table 3.

Table 3 above illustrates that the chosen sample is very close to parity by Assets. The chosen companies are also each traded on the public markets. Finally, all three companies are similar in their employee count.

3.2. SCOPE LIMITATIONS

1. This study is not assessing any innovation variable other than patents.

	ExxonMobil	Shell	Petrobras
Market Capitalization, in US$	385,920,000,000	219,660,000,000	189,240,000,000
Assets, in US$	333,795,000,000	360,325,000,000	331,645,000,000
Revenue, in US$	482,295,000,000	467,153,000,000	144,103,000,000
Net Income, in US$	44,880,000,000	27,178,000,000	16,900,000,000
Employees	76,900	87,000	85,065
Countries with Operations	47	70	22
Revenue per Employee, in US$	6,271,717	5,369,575	1,694,034
Income per Employee, in US$	583,615	312,391	198,672
Revenue/Asset Ratio	1.44	1.30	0.43
Nationality	U.S.	Netherlands/U.K.	Brazil
Ownership	Public	Public	Government

Table 3: *Company Statistics as of EOY 2012 - ExxonMobil Shell Petrobras*
Source: [69, 74, 27]

2. Comparing every major oil production company is too large a task for this research effort. Therefore, the sample was limited to three companies: Petrobras, ExxonMobil, and Shell.
3. Global companies control many legal entities, each of which can be the named assignee for a patent. Resolving the complex legal hierarchies of global companies, to find a patent's ultimate parent company and owner, is beyond the scope of this study. ExxonMobil has 193 known subsidiaries, Shell 266, and Petrobras 43 [9]. For instance, among the many names used by ExxonMobil are: Exxon Mobil, Mobil Oil Corporation, Exxon Research And Engineering Company, Exxon Chemical Patents Inc., Nalco Exxon Energy Chem Lp, Exxon Production Research Company, Exxonmobil Chem

Patents Inc, and Exxonmobil Upstream Research Company.

4. Classification systems differ across jurisdictions (USPTO, EPO, and WIPO). For instance, the EPO uses the European CLAssification (ECLA) and the USPTO uses the United States Patent Classification (USPC). While the joint Cooperative Patent Classification (CPC) project was started in 2010 between the EPO and USPTO, at the time of this study there is no single, harmonized, patent classification system [12]. WIPO uses the International Patent Classification ("IPC") system, as established under the Strasbourg Agreement 1971 [79]. Therefore, the classification was not used as a query term in the searches.
5. This study does not include the development of patents through licensing.
6. Evaluating the quality of patent claims is beyond the scope of this research.
7. Evaluating the quantity of pending patents (applications not yet granted or otherwise in the prosecution stage) is beyond the scope of this research.
8. Comparing the relative patent production across market segments, such as oil operating companies versus oil service companies, is beyond the scope of this research.
9. The author is not fluent in Portuguese; only English language materials and databases were considered in this research.
10. Public query access to the WIPO Patentscope database is severely limited. The author did not have full relational query access, so some analyses were impossible. For instance, it would be interesting to see a full distribution of patents by named inventors, per company. Such an analysis is presently impossible given Patentscope's crippled query interface.
11. Access to the EPO PATSTAT database for global records was unavailable (Only the European data was publicly available).
12. The PatentVest database for patent quality is limited to USPTO filings.
13. No corporate surveys were performed. The qualitative component of this study is limited to the review, and application of, academic literature for explanatory value.

4. PETROBRAS' BACKGROUND

Petróleo Brasileiro ("Petrobras") was established in 1953, by Brazil's President Getúlio Vargas, pursuant to Law no. 2.004. The law created a national oil policy, a national petroleum council, and Petrobras [38]. At the time, the nation was engaged in its Import Substitution Industrialization (ISI) program and various exchange controls, and sought to improve its national balance of payments by spurring domestic oil production [3].

Petrobras was a "latecomer" industrial company far from the innovation frontier [16, 17, 5]. Industrialization in Brazil began late (relative to other leading economies), but the nation was rich in natural resources. The government actively formed "Petrobras" and directed the national oil company to build a national industrial capability [56]. Its charter was to increase production, and production capabilities.

Funding and initial capitalization was provided by the State, and the Company was given a national monopoly for the exploration, production, refining, and transportation of oil, oil shale, and gas. A transition from a government monopoly to government concessions occurred in 1997 with Law no. 9.478 [20, 39]. This market liberalization and reform ended the monopoly of this national oil champion, and allowed competitors to develop Brazil's energy resources.

4.1. DEEPWATER E&P LEADERSHIP

By the 1990s, Petrobras began to lead the world with its deepwater exploration and production (E&P) of the Bacia de Campos ("Campos Basin") reservoirs. Furtado et al [35] argued that the challenges of offshore and deepwater E&P forced Petrobras to become "an organization able to conceive its own technological solutions." To adapt, the Company moved from external technology acquisition to cooperative technology development, especially for subsea boosting systems. It used joint industry projects, technology cooperation agreements, and research projects with universities to innovate the necessary deepwater technologies. Cooperative research and development allowed the Company to lower technological barriers by sharing the risks and rewards of innovation. As the Company's capabilities matured, and its direct investments in the research projects increased, it sought to restructure some cooperative agreements to reflect its larger role. In one example, regarding a subsea separation system ("SSS"), the technology was too early/risky for a technology cooperation agreement or joint industry project. Petrobras therefore partnered with the University of Campinas (Universidade Estadual de Campinas, "Unicamp"). The Petrobras-Unicamp partnership resulted in 2 patents, and a successful SSS that was utilized in the deepwater operations.

Founded to create oil independence, Petrobras delivered national oil self-sufficiency in 2007 with a production record of 2.2 million barrels of oil per day. The Campos Basin P-54 platform set a "daily production record, at upwards of 2 MMb/d of oil, [and] is an absolutely extraordinary feat," according to E&P director Guilherme Estrella. "This mark puts Petrobras among the world's biggest companies. We have now surpassed the self-sufficiency level that is fundamental to Brazil [63]."

Two years later in 2009, Campos Basin was the site of another achievement: the P-51 platform is the first semi-submersible platform built entirely in Brazil [72].

4.2. MATURING KNOWLEDGE NETWORK

Dantas and Bell [16] found that the needs of offshore and deepwater development impelled the Company from the 1960s to the 2000s from a "passive learning network" to a "strategic innovation network." Their taxonomy provides a means of viewing a latecomer firm's knowledge network development over time. In their taxonomy, a firm has four progressive network classifications: passive learning, active learning, innovation, and strategic innovation networks:

1. Passive learning network, late 1960s-1984, characterized by acquiring technology to meet immediate needs; assimilating operational knowledge; and uni-directional flows of information, from the external suppliers to Petrobras.
2. Active learning network, 1985-1991, Petrobras characterized by the formation of its own S&T capabilities; and, a progression from pure supply acquisition into design and design modifications of supplied technologies. An example is the technology licensing and transfer process of custom catalysts from Akzo Chemie to Petrobras, as studied by Antunes et al [1]. Seven legal agreements governed the technology transfer process. Petrobras retained all intellectual property (patent) rights to the fruits of the partnership, which eventually yielded 20 patents registered at the Brazilian patent office (INPI). The training of Brazilian staff at Akzo's Amsterdam facility was deemed essential to the

project's success, by transferring the tacit knowledge from Akzo experts to the Brazilian team.

3. Innovation network, 1992-1996, characterized by endogenous S&T capabilities; and, bi-directional flows of information.
4. Strategic innovation network, 1997-2000s, characterized by active innovation of novel technology solutions; transferring technology to outside partners; collaboration with multiple partners; omni-directional communication; and, the innovation is focused on long-term (strategic) needs rather than immediate production needs. "The most striking shift during this last period was the increasing use of new forms of relationships with other organizations concerned with reverse technology transfers in which Petrobras itself was the main source of unidirectional flows of complex S&T knowledge to partners, thus reversing the direction of the earlier one-way flows[16]."

4.3. PUBLIC SHARE OFFERING

To fund its future investments in ultra-deep oil exploration, the Company raised US$ 70 billion in a September 2010 offering, on the BM&F Bovespa Stock Exchange. While the Company was already publicly-traded, this 2010 offering constituted the largest share offering in history to date [58].

In its prospectus, the Company extolled its global leadership, especially for deepwater exploration and production related to the Campos Basin. The following statement speaks to its accumulation of capabilities over the past five decades, and its confidence in its innovative capacity: "We are the leaders in exploration and production of oil in deep and ultra-deep waters, accounting for approximately 20.0% of the world's deep and ultra-deep water production in 2009, according to PFC Energy. We believe that our leading position results from our advanced knowledge of drilling techniques, exploration and production in deep and ultra-deep waters that we have acquired over the last 38 years, as we have continually developed technologies and procedures to expand our business in the deep seas, including innovative technology to explore wells over 3,000 meters (9,843 feet) deep. Our expertise has resulted in high productivity and allowed us to reduce our lifting costs" [70].

After the 2010 share sale, Petrobras was the fourth-biggest company in the world, by market capitalization. The offering was a financial and public relations success. PFC Energy, an investment bank, ranked the Company as the no. 3 energy company in its 2011 rankings, commenting: "Petrobras, this year no. 3 at $228.9 billion, was no. 27 on our first list in 1999; its market cap has grown from $13.5 billion – a 27% compound annual rate. The effect of the 23% 2010 share price decline was more than offset by a $67 billion new offering" [23]. Many observers claimed the 2010 sale was a "reverse privatization" which served only to increase State control, and would increase policy-making influence over the company [57]. President Luiz Inacio Lula da Silva fed this speculation when he stated Brazil was relying on the countrys oil wealth to help raise the nations 192 million people out of poverty.

4.4. GOVERNMENT CONTROLLED

Subsequent to the share offering, the Brazilian federal government and its affiliates

BNDESPAR and BNDS together control 60.4% majority of Petrobras common stock, 27% minority of the preferred stock, and an overall 46% of total stock (common plus preferred). In the extreme event of a bankruptcy or special dividend, the preferred shares vote[70, 71]. With control of the common stock and its voting rights, the federal government controls Petrobras but the company is listed on the public stock exchanges and shareholders own a majority of the economic interest.

Some effects of government voting control are apparent. For instance, key leadership appointments must be approved by the government, and Petrobras leadership appointments often precede or follow political office. President Lula appointed an experienced senator from his Workers' Party, to be the CEO. Dilma Rousseff, the current President of Brazil, is a former Director and Chairman of Petrobras. This politicization of the Company is used to support broader national policy agendas. For instance, Petrobras' consumer fuel sales are subject to price controls. "The main problem in the last 10 to 15 years has been the [politicization]: the company is being used to fulfill nationalistic missions," said John Forman, former director of the National Petroleum Agency (ANP) [60]. In regards to its sustainability investments, the social and cultural projects are too large relative to the environmental projects , especially since environmental projects are a better fit for an oil company [7].

4.5. PETROBRAS REACHES THE INNOVATION FRONTIER

As a strategic innovation network, Petrobras was on the innovation frontier. Dantas & Bell [16] found that the company had acquired the capabilities to compete and innovate strategically, and as such had grown out of its latecomer status to compete at the global innovation frontier.

Following their earlier work, in Dantas & Bell [17] looked at the linkage between the evolution of Petrobras' knowledge network (from passive learning to strategic innovation) and its capability accumulation. The study was novel because it was dynamic, rather than static, and it applied a new framework for measuring innovation. It evaluated network-based innovation, rather than firm-based. This collaboration with vendors, universities, and joint industry teams was "open innovation."

Dantas & Bell [17] found that as Petrobras accumulated capabilities and reached new maturity levels, these acquired capabilities acted as "entry tickets" to a corresponding knowledge network maturity level. For instance, to join an industry Joint Venture, Petrobras had to be a credible technological partner. As the company's capabilities increased, this stimulated demand for more and newer knowledge. Stated differently, for a latecomer firm such as Petrobras, capability accumulation corresponded to knowledge network maturation. The knowledge networks then helped the Company to consolidate its capabilities and scale them to a greater degree than could otherwise be possible in isolation. Dantas & Bell [17] defined four capability levels:

1. Assimilative, wherein the focus is upon acquiring and assimilating existing technologies;
2. Adaptive, wherein the focus is upon adapting existing technologies and designs;
3. Generative, wherein the Company is developing and generating its own technologies through R&D; and,
4. Strategic, wherein the Company is developing world-leading technology and is both intentional and strategic about its efforts.

By this framework, Petrobras reached the “Strategic Capabilities” level in 1997-2000s, “based on R&D activities driving innovation at the international technological frontier in 8 of the 10 technologies analyzed.” Most parts of Petrobras’ innovative capabilities are distributed around partners, not centralized at CENPES [15, 16, 17].

5. FINDINGS

5.1. R&D INVESTMENTS

Research and Development (“R&D”) is a broad investment category that can include basic research, and applied research. Done properly, R&D should result in knowledge creation for a firm. Applied R&D can include new services, products, incremental improvements for products/services, adaptations of external products, partnerships, production improvements, marketing improvements, etc. As an innovation indicator, R&D has a long history [75], but it only measures an input. A broad spectrum of simple-to-complex innovations can be funded through corporate R&D, only some of which may be patentable. Patents, and associated IP processes, are typically only a subset of the larger R&D investment within a firm. A firm can have a large R&D budget, create innovations, and file zero patents. Patenting activities are a legal process that occurs – optionally – subsequent to innovation. Innovation is loosely coupled with R&D investment, which in turn is only a rough proxy of patent efforts. Conversely, it is difficult to create new-to-the-world innovations and patent them without R&D funding.

	2008	2009	2010	2011	2012	Total
Shell	1,266	1,125	1,019	1,125	1,314	5,849
ExxonMobil	847	1,060	1,012	1,044	1,042	5,005
Petrobras	941	1,364	1,739	1,454	1,143	6,641

Table 4: *R&D investments for the five years 2008 – 2012, in million US$*
Source: [69, 74, 27]

Collecting annual R&D investment numbers from the respective corporate annual reports, it is evident that capital investment does not explain the patent production disparity. Petrobras’ research and development annual spend is comparable to Shell and ExxonMobil, and its cumulative 5year R&D investment exceeds both competitors. As a single indicator, the investment therefore fails to explain the patent disparity of Petrobras.

5.2. PATENT TO R&D RATIO

Another possible contributing factor for the patent disparity may be the efficiency of invested capital. Stated differently, how many patents are produced per US$ million of R&D investment? Considering the patent-to-R&D ratio as an indicator has a long history of use in

economics [53, 41].

To answer this question, the 5-year sum of patents was divided by the 5-year sum of R&D investment for each company, resulting in a ratio of patents produced per US$ investment. Please reference Table 5. WIPO's Patentscope includes patents for the USPTO, EPO, WIPO PCT, Brazil, and many other countries [82]. Therefore, the total patent count is supplied by Patentscope, to prevent double-counting. Finally, using Petrobras as the baseline, this ratio was compared to create a multiple per company. Exxon-Mobil's multiple is 19.5, meaning that it produces 19.5 times the patents of Petrobras per million of US$ in R&D. The conclusion is that ExxonMobil and Shell Oil are not only producing more patents on an absolute basis, they are also producing patents far more efficiently per dollar spent on R&D.

	Total Patents	R&D in millions US$	Patents per millions US$	Multiple Relative to Petrobras
ExxonMobil	6,318	5,005	1.26	19.5
Shell	1,322	5,849	0.23	3.5
Petrobras	431	6,641	0.06	1.0

Table 5*: R&D Patent Intensity 2008–2012*
Source: [69, 74, 27, 66, 25, 81]

5.3. VERTICAL INTEGRATION

The oil industry divides itself into "upstream" exploration and production ("E&P"), "midstream" pipelines for intra-and inter-national transit, and "downstream" refining and marketing. A vertically integrated oil company combines upstream and downstream capabilities: from finding, drilling, and producing oil, to its refining, transportation, marketing, and retailing. Opportunities for invention and innovation exist within every capability, so a vertically integrated company might have a patent production advantage relative to a a non-vertically integrated company.

Petrobras is vertically integrated, and divides itself into six business units: E&P; Refining, Transportation, and Marketing; Distribution; Gas and Power; Biofuel; and, International [69]. In addition to oil, the company has natural gas, liquefied natural gas ("LNG"), biofuel, and power generation capabilities.

Shell is vertically integrated, and manages itself as four business units: Upstream International, Upstream Americas, Downstream, Projects & Technology. Downstream oversees Shells interests in alternative energy (including biofuels but excluding wind) [74]. The Upstream Americas unit includes the wind power generation, and also includes the oil sands business.

Exxon Mobil is also vertically integrated, and has three primary business units: Upstream, Downstream, and Chemicals [27]. Exxon, like Shell, also has significant oil sands production and bitumen extraction capabilities.

All three companies do everything from finding oil and gas reserves, to selling it at the wholesale and retail level. Therefore, vertical integration – or lack thereof – does not explain the patent disparity.

5.4. ENVIRONMENTS

Exxon's upstream E&P operates in oil sands, deepwater, unconventional gas & oil (biofuels), conventional, LNG, arctic, and Acid/Sour environments. Similarly, Shell's upstream E&P includes oil sands, deepwater, biofuels, conventional, LNG, Sour gas, and Arctic environments. Petrobras does not operate in either oil sands or Arctic environments. Presently, Petrobras has no serious Acid/Sour gas operations, though it did previously. While Shell and ExxonMobil have large synthetic oil operations – extracting bitumen from oil sands, and refining the bitumen into synthetic oil – Petrobras has no comparable capability. Table 6 summarizes the comparative operational environments.

	Acid/Sour	Artic	Biofuels	Conventional	Deepwater	LNG	Oil Sands
ExxonMobil	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shell	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Petrobras	No	No	Yes	Yes	Yes	Yes	No

Table 6: *Operational Environments*
Source: [69, 74, 27]

5.5. PATENT JURISDICTION

Analyzing the search results further yields insights regarding jurisdiction, geography, and internationalization. Please reference Figure 2 for the graphical results, and Table 7 for the numbers.

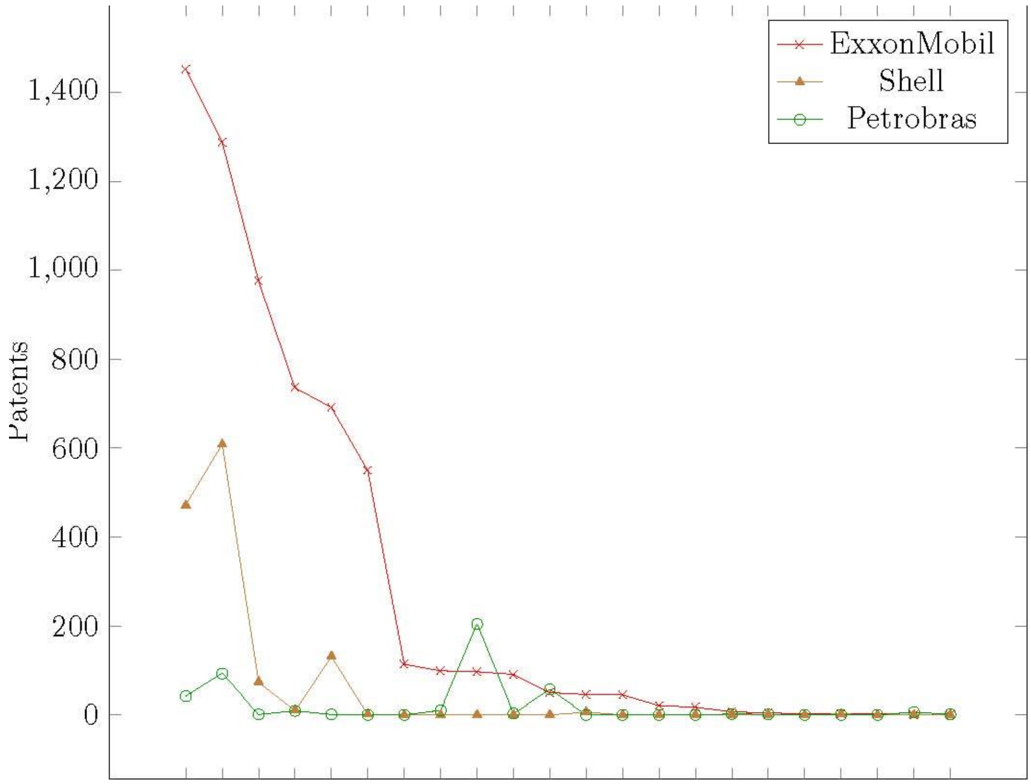

***Figure 2:** Patents 2008-2012 by Jurisdiction*
Source: [81]

Petrobras' patent portfolio is clearly regional, and not international. It leads its peers in patents for Brazil (204), Argentina (57), Columbia (6), and Cuba (1). The strong Brazilian portfolio is to be expected, given its history as a national champion. What is unexpected is the company's non-presence internationally outside of a modest modest US (93) and WIPO PCT (42) patent portfolio, and some token patents elsewhere. Petrobras does not use PCT filings as well as its competitors, and it is effectively absent in the European, Chinese, and Asian markets.

Shell's portfolio shows a far more robust PCT, US, and European effort than Petrobras. Of additional interest, Shell has created a strong Chinese position with 132 patents.

Yet the clear leader in breadth and depth of patents by jurisdiction is ExxonMobil. Its portfolio is truly global, and is simply in another league relative to Shell and Petrobras. ExxonMobil uses PCT filings aggressively (1452). Relative to Shell and Petrobras, the company has a dominating portfolio of European (976), Canadian (736) and Chinese (692) patents. It also has a large portfolio of patents in Singapore (555) – larger than Petrobras' entire portfolio for the examined period. Beyond these assets it also stands alone in its patent assets for Korea, Spain, Mexico, South Africa, the Eurasian Patent Office, Israel, and Japan.

A jurisdictional analysis of the patents illustrates that Petrobras and Shell are international patent companies, but only ExxonMobil is global. Petrobras is also well behind its peers in its use of WIPO PCT filings.

Code	Jurisdiction	ExxonMobil	Shell	Petrobras
WO	WIPO PCT	1452	471	42
US	United States	1288	608	93
EP	European Patent Office	976	74	1
CA	Canada	736	10	9
CN	China	692	132	1
SG	Singapore	550	1	0
KR	South Korea	114	0	0
ES	Spain	99	0	10
BR	Brazil	97	0	204
MX	Mexico	91	0	3
AR	Argentina	50	0	57
ZA	South Africa	46	6	0
EA	Eurasian Patent Office	45	0	0
IL	Israel	21	0	0
JP	Japan	17	0	0
MA	Morocco	7	0	2
JO	Jordan	4	0	1
VN	Vietnam	3	0	0
EG	Egypt	2	2	0
CL	Chile	2	0	0
CO	Columbia	0	0	6
CU	Cuba	0	0	1

Table 7: *Patents 2008-2012 by Jurisdiction*
Source: [81, 50]

5.6. PATENT CLASSIFICATION

Analyzing the results by classification shows that ExxonMobil and Shell greatly outstrip Petrobras in Sections B, C, E, and G. Querying the top 25 IPC classifications for each company, one can gain more detail on the comparative disparity. Please see Table 8) for the numerical results, and 3 for the graphical results. Appendix A provides the relevant IPC descriptions.

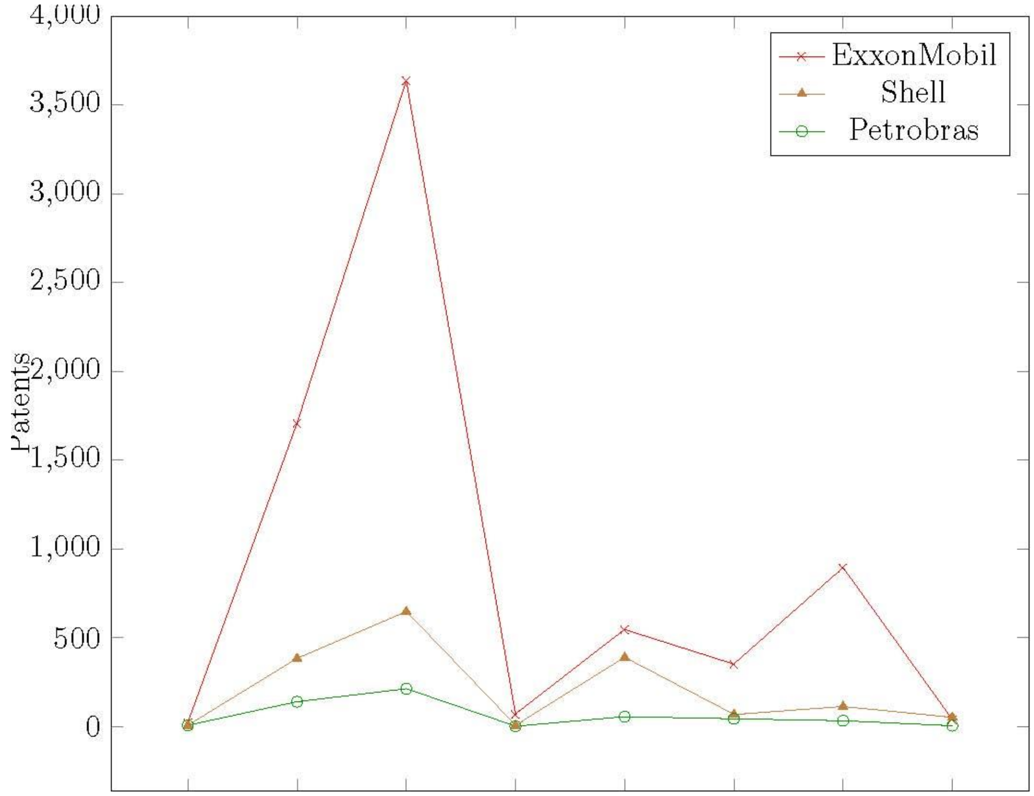

Figure 3: *Patents by IPC Section, 2008-2012*
Source: [81]

Section B governs process for physical operations and transport. Exxon-Mobil and Shell both have large patent portfolios for separation (B01D) and chemical or physical processes (B01J). ExxonMobil additionally has a sizable portfolio in layered products (B32B).

Section C governs chemistry. Both Shell and ExxonMobil posses large holdings n organic chemistry for acyclic or carbocyclic compounds (C07C), and cracking hydrocarbon oils (C10G). Additionally, ExxonMobil has a far larger portfolio across organic macromolecular compounds and related processes.

Section E governs fixed constructions (equipment and facilities) for drilling and extraction. Both Shell and Exxon Mobil have sizable portfolios.

Section G governs physics. ExxonMobil has a large portfolio of patents around measuring and testing flows, masses, and objects. This is highly related to the discovery, extraction, and management of natural resources. Furthermore, the company's portfolio includes extensive data processing and computing patents (G06).

While Petrobras has modest portfolio of patents related to shipment, pipes, and offshore equipment for deepwater E&P (17 patents for F16L, and 13 for B63B), the Company's patent disparity is explained by chemistry. The vast bulk of patents obtained by ExxonMobil and Shell are for chemistry: refining, cracking, processes, separation, compounds, etc.

Classification	ExxonMobil	Shell	Petrobras
B01D	413	119	27
B01F	26	14	5
B01J	892	202	78
B04C	6	3	9
B08B	22	9	5
B29C	54	2	2
B32B	219	0	0
B60C	71	0	0
B63B	26	32	13
C01B	278	75	12
C01G	16	26	6
C02F	17	2	9
C07D	43	55	2
C07C	999	203	39
C07F	91	15	2
C08F	563	10	4
C08J	158	1	4
C08K	223	8	2
C08L	526	16	11
C09K	60	49	11
C10B	35	0	10
C10C	31	6	6
C10G	1058	173	79
C10L	175	98	26
C10M	339	40	9
C10N	119	7	0
C11C	5	0	7
C12M	0	1	5
C12N	6	0	8
C12P	7	6	12
E21B	546	360	55
F02C	49	0	1
F16L	25	14	17
F25J	54	12	1
F28F	53	3	0
G01F	16	2	6
G01N	118	16	8
G01V	402	50	1
G06F	209	15	1
G06G	149	3	0

Table 8: *Union Set of Top 25 Patent Classifications, 2008-2012*
Source: [81]

5.7. PATENTS BY ENTITY

Petrobras and Shell both use a single legal entity as the main applicant for their patents (with a few exceptions for Shell). By contrast, ExxonMobil has four primary legal entities. In 2008–2012, ExxonMobil Research and Engineering is the applicant for approximately 37% of the 6318 patents; Exxon-Mobil Chemical Patents for approximately 37%; ExxonMobil Upstream Resources for approximately 24%, and ExxonMobil Oil Corporation for

approximately 2%.

5.8. PATENTS BY INVENTOR

Comparing the top 25 inventors from each company (see Table 9), it is evident that the individual productivity of inventors at Petrobras lags its peers. Petrobras' top inventors, as a group on average, produce one-sixth the patents of ExxonMobil and one-fourth that of Shell during a five-year period.

Measurement	ExxonMobil	Shell	Petrobras
Max	36	26	5
Min	14	6	2
Mean	18.6	10.3	2.7
Mode	14	7	2

Table 9: *Productivity of Top 25 Inventors, 2008-2012*
Source: [81]

5.9. PATENT QUALITY

An argument could be made that Petrobras patents less than its peers, but that the low volume is offset by high quality.

In assessing patent quality, one must ascribe a quantitative value to an intangible asset. There is, therefore, a great deal of controversy regarding patent quality measurements. Valuing patents, unlike other asset classes, has no standard accounting treatment (such as GAAP).

Most approaches to individual patent quality focus upon inbound and outbound citations [77, 44], bibliometric citations to scientific papers [59], the type of application [6], the number of claims, or the patent family size as a proxy for the value of the associated innovation. All of these approaches suffer from the weakness of a single indicator.

More recently, research on patent quality has focused on multiple indicators to form indexes of patent quality. Lanjouw et al [54] found multiple indicators results in higher quality. Furthermore, he found that market value is positively related to the stock of patents held by the firm (before any quality adjustment).

Guan et al [43] applied a bibliometric "h-index" to measure quality. Hu et al [49] applied network theory to patent citations, assessing the individual technology value of a patent with a multi-layered patent citation network. In effect, their work broadened citation approaches to indirectly cover multiple indicators. Taking a composite approach, Squicciarini et al [76] evaluated 12 factors to create a patent quality index, though the work was limited to national (rather than firm) comparisons.

For this study, the PatentVest database and its proprietary composite indicators were used to assess patent quality. PatentVest measures, scores and ranks over 4000 public and private companies, unifying over 4 million granted US patents and over 2 million US patent

applications on file [36]. The PatentVest database has two key limitations for this study. First, it is limited to USPTO filings, though the USPTO is the dominant global venue. Comparing the percentage of U.S. patents relative to the total portfolios (see Table 10), one can see that Petrobras and ExxonMobil are similar in the
U.S. percentage of granted patents, at 22% and 21% during the past 5 years. Shell utilized the U.S. for 47% of its granted patents.

Second, the PatentVest database is limited to all active patents for a firm. For example, a PatentVest report will analyze all the active patents for a company at the current point-in-time, rather than just all the active patents from 2008–2012. Since this particular study of Petrobras focuses on the patent activities from 2008–2012, one must suitably discount PatentVest data.

	Total Patents	U.S. Patents	U.S. Percentage
ExxonMobil	6318	1314	21%
Shell	1322	626	47%
Petrobras	431	94	22%

Table 10: *U.S. Patents as Percentage of Total Patents, 2008-2012*
Source: [81]

Metric	Petrobras Value	Petrobras Ranking	Petrobras Industry Ranking	Shell Value	Shell Ranking	Shell Industry Ranking	ExxonMobile Value	ExxonMobile Ranking	ExxonMobile Industry Ranking
Portfolio Score	1.49	1,269 / 5,201	8 / 24	2.53	193 / 5,201	1 / 24	2.36	273 / 5,201	2 / 24
Tech Score	0.72	3,929 / 5,201	17 / 24	0.87	2,322 / 5,201	8 / 24	0.73	3,798 / 5,201	14 / 24
Portfolio Depth	1.42	1,325 / 5,201	10 / 24	3.6	29 / 5,201	1 / 24	3.08	86 / 5,201	2 / 24
Tech Depth	0.68	3,629 / 5,201	20 / 24	1.24	165 / 5,201	1 / 24	0.95	936 / 5,201	5 / 24
Tech Isolation	7%	N/M	N/M	56%	N/M	N/M	28%	N/M	N/M
3yr App CAGR	7%	1,896 / 2,960	N/A	9%	1,354 / 2,960	N/A	9%	1,487 / 2,960	N/A
Avg App Distance Ratio	0.38	N/A	N/A	0.49	N/A	N/A	0.38	N/A	N/A
App Distance Ratio Coverage	40%	N/M	N/M	25%	N/M	N/M	18%	N/M	N/M

Table 11: *Patent Vest Reports*
Source: [9]

The PatentVest results are found in Table 11, and definitions for the metrics are found in Appendix C.

ExxonMobil’s and Shell’s portfolios are obviously larger, since they have been building their patent portfolios for a longer period than Petrobras. Therefore, the Portfolio Score metric is less instructive for this study due to its inclusion of overall portfolio size.

The Tech Score is calculated from the rate at which utility patents in a portfolio are being cited and normalized against a cohort group of patents selected by age. Please note that it only includes utility patents. It does not include design or plant patents. Tech Score does not depend on the absolute number of citations, and ignores self citations. The patent-by-patent analysis of external citations is adjusted for the marginal value of each citation and the remaining time to expiration of each patent. As an indicator, Tech Score therefore recognizes the weaknesses of using pure citation counts, the inflationary effects of self-citations. Since it

is calculated patent-by-patent, it also avoids the inflationary effect of portfolio size upon an individual patent's merit [36].

A high Tech Score score generally points to strong positioning of a patent portfolio in an important technology area. For a point of reference, the highest Tech Score is Medtronic at 1.17 (2014) [36]. Shell leads with a Tech Score of 0.87, but ExxonMobil and Petrobras trail close behind at 0.73 and 0.72. The conclusion is that Shell has a slightly higher quality patent portfolio, independent of overall portfolio size.

Tech Depth measures the degree of concentration or depth within an area of technology, and is indicative of an attempt to create a patent "thicket" around a key technology holding. It measures self-citations using patent-by-patent analysis adjusted for the marginal value of each citation and the remaining time to expiration of each patent. It does not reflect the size of a portfolio, and is therefore a better measure of Petrobras' young IP efforts relative to its peers. A high Tech Depth rating reflects a strong barrier to competitors' efforts to overcome the patent protection. Shell leads with a Tech Depth of 1.24, ExxonMobil is second at 0.95, and Petrobras trails far behind at 0.68. The conclusion is that Shell builds groups of patents ("families"), wherein the patents are highly inter-related, to protect novel technology – and that it does this better than its peers. Its portfolio is also reasonably youthful. Conversely, Petrobras patents but is more likely to patent narrowly and leave itself open to competitive patent avoidance. Petrobras does not build effective "thickets" of patents, and its patent portfolio quality is therefore lower than its peers.

PatentVest's Tech Isolation measures the degree of isolation or novelty of a companys technology relative to other companies. A higher score indicates greater novelty, or simply a lack of recognition. The median Tech Isolation value is approximately 4.7%; Petrobras' is 7%; Shell's 56%; and, ExxonMobil's 28%. Shell and ExxonMobil both build portfolio's of very novel and innovative patents, often in "greenfield" areas. By this indicator, the quality of Petrobras' portfolio is average.

All three companies have solid Compound Annual Growth Rates ("CAGR") in their patent efforts, indicating competitive relevance for all three. CAGR is the year-over-year compound annual growth rate of patent applications filed during the past three years. For a point of reference, the highest tracked CAGR is Adobe Systems at 28% (2014) [36].

Finally, in the PatentVest results, the App Distance Ratio and App Distance Ratio Coverage metrics are ignored for this study because the database is itself limited by the USPTO data restrictions. Thus, the results are biased and uninformative for purposes of comparing Petrobras, Shell, and Exxon-Mobil.

The overall conclusion of the PatentVest analysis is that Petrobras's patent quality is not above its peers, and it therefore cannot explain the total patent volume deficit.

6. DISCUSSION OF FINDINGS

The path of a latecomer firm's maturation is correlated to both its increasing technology innovation sophistication (innovation levels, from basic to world-leading) and its organizational sophistication and orchestration. Technological capability must be matched with organizational capabilities. For instance, some companies do leading R&D but fail to bring their innovative products to market due to a lack of organizational maturity.

Petrobras leads its peers in R&D Investment over the five-year period 2008–2012 with

US$6.6 billion invested; however, it significantly lags these same peers (Shell Oil and ExxonMobil) in both patent quality and patent quantity. Per invested $US million of R&D dollars, Shell produced 3.5x and ExxonMobil 19.5x the patents during the timeframe. The implication is that Exxon and Shell have far more efficient patent and invention processes.

This difference in firm-level efficiency coincides with the efficiency of individual inventors. Within the cadre of top-25 inventors, Exxon's average inventor creates 7 times the patents of Petrobras, and the average shell inventor creates 4 times the patents of Petrobras. Not only is Petrobras' firm-level patent production anemic, its stop inventors are far less prolific than peers at Shell and Exxon.

Petrobras's low patent intensity appears to be due to cultural factors, institutional factors, and firm-specific factors.

6.1. CULTURAL FACTORS

Hofstede [45, 47, 46] and the GLOBE study [48] provide a basis for understanding the differences in the Brazilian culture, relative to other cultures, and how it practically affects organizational management.

	Power Distance	Individualism	Masculinity	Uncertainty Avoidance	Pragmatism	Indulgence
U.S. [ExxonMobil]	40	91	62	46	26	68
U.K. [Shell]	35	89	66	35	51	69
Netherlands [Shell]	38	80	14	53	67	68
Brazil [Petrobras]	69	38	49	76	44	59

Table 12: *National Culture Comparisons*
Source: [10]

For the purposes of comparison, Table 12 above shows the six dimensional scores for national culture, as defined by Hofstede. Shell, as a company recently merged together from a British and a Dutch company, effectively reflects two national cultures. In this national culture comparison, there are a few outlier scores when comparing Brazil against the U.S., U.K., and the Netherlands. Of the four countries, Brazil is noteworthy for its high-power distance, low individualism, and high uncertainty avoidance.

Brazil is a high-power distance culture. It is hierarchical, with a great disparity in the distribution of power from the least-to most-powerful in the society. In contrast, the U.S., U.K., and Netherlands societies are low-power distance. Their cultures believe that inequalities amongst people should be minimized, and that people should – for the most part – be treated as equals.

Brazil is a communal culture, with a great degree of interdependence among its members. Family and personal networks are very important, and trust outside of these networks is low. The preferred communication is context-rich. The U.S., U.K., and Netherlands, contrastingly, are among the highest scores for individualism. To quote Hofstede, "In Individualist societies people are only supposed to look after themselves and their direct family. In Collectivist societies people belong to 'in groups' that take care of them in exchange for unquestioning loyalty" [10].

Brazil is also a culture with a very high uncertainty avoidance score. The higher the score, the more the culture actively tries to control its anxiety about future events, through the creation of beliefs and institutions. For example, a high desire to avoid uncertainty manifests itself in increased laws and bureaucracy. The U.S., U.K., and Netherlands all possess below average scores. In these three cultures: “there is a fair degree of acceptance for new ideas, innovative products and a willingness to try something new or different, whether it pertains to technology, business practices or food”[10].

In practice, Brazilian firms commonly have low-trust between organizational hierarchies (management layers), authoritarian leadership, and processes wherein the implicit context is more important than the explicit form. Long-term relationships are necessary within an organization to develop the trust for shared actions and experiences. Personal communication is essential for effective coordination. Most strikingly, the desire to avoid future uncertainty reduces the acceptance of new ideas and indirectly impedes innovation.

As the national oil company of Brazil, Petrobras likely shares the cultural predilection for bureaucracy, paperwork, implicit communication, and an unwillingness to try new ideas. A practical example of this firm-level impact of national-level culture, is the transfer of knowledge via shared networks.

Sharing knowledge often involves the transfer of tacit knowledge, and its later embodiment as codified knowledge. Codifed knowledge is explicitly documented: patents, designs, manuals, software, databases, and statements. Tacit knowledge, by contrast is “know-how” that is an intangible asset carried in the minds of a firm’s employees. While some of it can be codified, tacit knowledge is the information we implicitly rely upon for learning. As such, effective knowledge management is key to applying tacit knowledge to create innovative technology – and a patent is a codification of a world-leading innovative technology.

In a relevant study of the Company’s Sales and Marketing Division [52], the willingness to transfer knowledge at the Company was a function of the idiosyncratic traits of individuals, the Company’s knowledge management strategy, and the Company’s organizational structure. Employees’ mutual trust was the single strongest factor in explaining knowledge transfer variance. Similarly, the personal interactions, conversations and relationships seem more useful for tacit knowledge at Petrobras than the investments in formal information technology systems. Bureaucracy and hierarchy can impair the formation of informal networks and the consequent sharing of knowledge horizontally and vertically within the organization.

Innovation – and patenting – are difficult to accomplish without trust, communication, the willingness to try new ideas, and the sharing of knowledge. Relative to Anglo and Dutch cultures (ExxonMobil and Shell), Petrobras is at a cultural innovation disadvantage.

6.2. INSTITUTIONAL FACTORS

Another way of providing context to the findings, is to view them through the lens of its institutions and the history of those institutions. Informal and formal institutions can affect firm-level strategic outcomes [67]. For the purposes of this study, the institutions encouraging and protecting intellectual property are of especial interest.

Historically, patents are a rarity in Brazil. The patent regime in Brazil is relatively immature, despite the nation’s long history of participation with international intellectual

property agreements. It joined the Paris Convention in 1884, the Patent Cooperation Treaty in 1978, and the World Trade Organization in 1995 [78, 80, 84]. The latter involved all the provisions on TRIPs, the Trade Related Aspects of Intellectual Property Rights. Despite participating in the global trade and legal regime for patent law, the country only recently passed an Innovation Law modeled on the U.S. Bayh–Dole Act, to encourage public research university collaboration and licensing with private corporations[40]. Current patent policy debates in Brasilia seek to erode patent protections, especially around the pharmaceutical industry [11]. There is, therefore, some instability in the national position regarding patent rights.

Since the passage of the Innovation Law, the quantity of Brazilian PCT filings modestly improved from its low base; however, Brazil's national production remains anemic in comparison to other countries and its economy [33, 32, 65]. Brazil holds less than 0.3% of the patent applications in the world [11]. Domestic patent production in Brazil is dominated by a handful of institutions;Petrobras is the largest commercial filer of domestic patents in Brazil [14].

As of 2009, Brazil's patent quality slightly lagged the world average, while the U.K. was one of the leaders in patent quality, and the U.S. and Netherlands were both above average [76]. [Nevertheless, the national difference in patent quality for the four nations are insufficient for explanatory value in this firm-level analysis.]

In additional to the institutional challenges brought by the nascent patent regime, Brazil is still actively establishing the public-private networks for technology transfer and patent generation. Brazil lacks a history of "entrepreneurial universities" that not only provide technology transfers into commercial ventures, but which encourage entrepreneurship [26]. Ryan [73] found that Brazilian research universities were unfamiliar with patents, and the patent policies were relatively immature. Gimenez et al [37] concluded that the University of Campinas, the second largest patenter within Brazil, could better teach and promote intellectual property rights. Martins et al [2] similarly concluded Brazilian research institutions struggled with innovation due to cultural issues, conflicts in private-public partnership objectives, and poor utilization and knowledge of innovation management tools. Querido et al [18] also found university researchers confused and na¨ıve regarding patent creation and licensing processes. Furthermore, the patent production of Brazilian academia is clustered in the state of S˜ao Paulo (a "sub-national cluster"), and in only 2 universities: the University of Campinas, and the University of S˜ao Paulo [18] . Noticeably, the headquarters and CENPES research center of Petrobras is not inS˜ao Paulo, but rather Rio de Janeiro.

Contrastingly to Brazil, the U.S., Dutch, and British economies have strong institutional support for patents and R&D: there is a long tradition of patent rights; a legal and administrative framework for patent filing, prosecution, and disputes exists; all three nations have a history of entrepreneurial universities and sub-national clusters for innovation; and, national patent quality is higher than Brazil's.

6.3. FIRM-SPECIFIC FACTORS

To conclude the study's discussion of findings, several firm-level factors are considered. Petrobras' operating environment, government control, and immature patent strategy are all likely contributors to the Company's low patent intensity.

6.3.1. Operating Environment

One could argue that Petrobras is a product of its environment, and as such lacked the exposure, serendipitous partnerships, and creative circumstances to generate new inventions. To a degree this is correct. Petrobras has very limited or no experience in the Arctic, Sour gas, and Hydraulic fracturing. While the Company is vertically-integrated and possesses extensive refinery and chemical formulation capabilities, it lags far behind the large chemistry patent portfolios of its peers. A portion of this lack can be attributed to Petrobras' absence in the North American hydraulic fracturing and oil-tar sands markets. ExxonMobil has extensive chemistry patents related to Canadian oil-tar sands extraction, and both Shell and ExxonMobil have chemistry patent portfolios related to hydraulic-fracturing technologies.

6.3.2. Government Control

Petrobras is a national oil company, albeit one with significant global ambitions. It is, in many ways, more accountable to policymakers and popular opinion than it is accountable to shareholders and the market. For public opinion and policy, it is arguably easier to justify direct investments in employment and production, than investments in Intellectual property rights. The government control binds Petrobras closer to Brasilia than foreign shareholders.

6.3.3. Lack of Patent Sophistication

Finally, the Petrobras' low patent intensity is likely affected by its firm-level patent infrastructure and processes. Petrobras patent approach is unsophisticated.

Petrobras's patent strategy is principally domestic and regional, with limited international holdings. There appears to be a home-country bias. In contrast, its peers are executing global patent strategies.

Shell and ExxonMobil have dedicated legal entities to support invention and patent prosecution. This speaks to a corporate commitment for intellectual property development and prosecution. Petrobras does not appear to have a dedicated legal entity for technology R&D.

While Petrobras has extensive chemical and refining operations, it fails to patent with appropriate intensity for those classifications. If the Company is indeed creating new products and formulations, it is not protecting them well with patents.

Finally, Petrobras's patent quality is mediocre. Exxon and Shell produce portfolios with far better PatentVest Tech Isolation and Tech Depth, indicating both more novel innovations and larger families of patents ("thickets") around the innovations.

7. CONCLUSION

Innovation often comes from new combinations, new contacts, new resources, new knowledge, and new networks. Although innovation primarily occurs in firms, it is affected by an interactive process with external agents, the private sector, and the public sector. The history of a firm, and its context, affect its innovation. A firm's past affects its future. Thus, innovation is "pathdependent" [28].

Petrobras' path to its present patent intensity is – in part – a product of its national culture, weak intellectual property and innovation institutions, government control, bureaucracy, and a historic drive relentlessly focused on production (rather than innovation). This has culminated in firm-level patent strategies and processes that are unsophisticated.

While the Company is a peer to ExxonMobil and Shell when measured by assets, employees, capabilities, and oil production – it still has significant capabilities to develop before it is at patent parity. Petrobras has overcome its "latecomer" status in most areas, but is still in "catch-up" protecting its inventions with patents.

Petrobras is building a sizable patent portfolio, it is actively inventing. Prior authors and studies have confirmed its innovation capacity and progress to be a world-leading company on the "technology frontier." The question is therefore not whether or not Petrobras is innovating, the question is why is the Company not protecting its inventions and innovations at a pace comparable to its peers.

"Why is Patent Production so Comparatively Low at Petrobras?" In answer to the question, it is directly due to the firm's immature patent strategy and capabilities. This firm-level patent intensity seems to be negatively affected by both Brazilian institutional and cultural factors.

7.1. IMPLICATIONS FOR CORPORATE MANAGEMENT

A low patent intensity can result in competitive disadvantage, as key technologies are patented by competitors (the world's patent system is first-to-file, not first-to-invent). Competitors could then choose to block access to key technologies, or charge Petrobras rents (license fees). As a world leader in deepwater E&P, Petrobras could conceivably innovate valuable solutions only to be charged by competitors and partnering oil service firms to use its own deepwater inventions. Low patent intensity can also result in opportunity costs: missed opportunities to block competitors with patents, or to grow revenues by licensing/renting patents to them.

Petrobras's patent intensity should be higher because a) Petrobras is making an enormous R&D investment (see Table 4), and b) intangible assets, such as patents, are increasingly important in the knowledge economy. Ultimately, patents create access to technology. Patents, as part of a larger portfolio, can create value in numerous ways. A patent portfolio can:

1. Block competitor entry;
2. Build external brand and ecosystem;
3. Align internal activities;
4. Boost investor valuation;
5. Position the firm for joint development programs;
6. Bolster a negotiating (cross-licensing) position;
7. Generate licensing revenue; and,

8. Support financial M&A activities.

Nevertheless, even the best patents do not generate revenues unless the company is positioned, and has an IP strategy that aligns with its business strategy [8].

In recognition of this study's findings, there are several recommendations for corporate management: First, while Petrobras has created a culture of innovation, it still needs to create a culture of invention concomitant with protection of the inventions (patents). To do so, it must address cultural challenges directly to foster trust; lessen bureaucracy; encourage risk-taking and innovation by removing uncertainty; and, improve communication and sharing of knowledge.

Second, the Company must overcome the national bias against patents. It must actively train and motivate employees and partners (e.g. university professors) to identify and protect worthy inventions.

Third, the Company must improve the formal IP processes for converting tacit knowledge into codified patents. These processes for codifying the inventions should be part of a larger IP strategy, that is aligned with the Company business strategy. Increasing patent family size around key inventions ("thickets") can improve the quality of the overall portfolio.

Fourth, Intellectual property rights are now a global business. Energy is also a global business. Therefore, for Petrobras' continued growth and success it must move beyond a home-biased patent strategy to both produce and protect its inventions in all relevant geographic markets. The IP strategy should be global in nature, rather than regional or domestic.

Finally, Petrobras should look to its chemistry, refining, and biofuels operations for patentable inventions. Clearly, its competitors see more opportunity in chemistry than in production.

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9. APPENDIXES

APPENDIX A List of Relevant IPC Codes and Definitions

Section A Human necessities Section B Performing operations; transporting

B01 Physical or chemical processes or apparatus in general B01F Mixing, e.g. dissolving, emulsifying, dispersing B01D Separation B01J Chemical or physical processes, e.g. catalysis, colloid chemistry; their relevant apparatus

B04 Centrifugal apparatus or machines for carrying-out physical or chemical processes B04C Apparatus using free vortex flow, e.g. cyclones

B08 Cleaning B08B Cleaning in general; prevention of fouling in general B29 Working of plastics; working of substances in a plastic state in general B29C Shaping or joining of plastics; shaping of substances in a plastic state, in general; after-treatment of the shaped products, e.g. repairing B32 Layered products B32B Layered products, i.e. products built-up of strata of flat or non-flat,

e.g. cellular or honeycomb, form B60 Vehicles in general B60C Vehicle tyres; tyre inflation; tyre changing; connecting valves to inflatable elastic bodies in general; devices or arrangements related to tyres

B63 Ships or other waterborne vessels; related equipment B63B Ships or other waterborne vessels; equipment for shipping

Section C Chemistry; metallurgy

C01 Inorganic chemistry C01B Non-metallic elements; compounds thereof C01G Compounds containing metals not covered by subclasses C01D or C01F C02 Treatment of water, waste water, sewage, or sludge C02F Treatment of water, waste water, sewage, or sludge (processes) C07 Organic chemistry C07C Acyclic or carbocyclic compounds C07D Heterocyclic compounds

C07F Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium or tellurium

C08 Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon

C08F Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds

C08J Working-up; general processes of compounding; after-treatment not covered by subclasses C08B, C08C, C08F, C08G or C08H

C08K Use of inorganic or non-macromolecular organic substances as compounding ingredients

C08L Compositions of macromolecular compounds

C09 Dyes; paints; polishes; natural resins; adhesives; compositions not otherwise provided for; applications of materials not otherwise provided for

C09K Materials for applications not otherwise provided for; applications of materials not otherwise provided for

C10 Petroleum, gas or coke industries; technical gases containing carbon monoxide; fuels; lubricants; peat

C10B Destructive distillation of carbonaceous materials for production of gas, coke, tar, or similar materials

C10C Working-up tar, pitch, asphalt, bitumen; pyroligneous acid

C10G Cracking hydrocarbon oils; production of liquid hydrocarbon mixtures, e.G. By destructive hydrogenation, oligomerisation, polymerisation; recovery of hydrocarbon oils from oil-shale, oil-sand, or gases; refining mixtures mainly consisting of hydrocarbons; reforming of naphtha; mineral waxes

C10L Fuels not otherwise provided for; natural gas; synthetic natural gas obtained by processes not covered by subclasses c10g or c10k; liquefied petroleum gas; use of additives to fuels or fires; fire-lighters

C10M Lubricating compositions; use of chemical substances either alone or as lubricating ingredients in a lubricating composition

C10N Indexing scheme associated with subclass C10M

C11 Animal or vegetable oils, fats, fatty substances or waxes; fatty acids therefrom; detergents; candles

C11C Fatty acids obtained from fats, oils or waxes; candles; fats, oils or fatty acids obtained by chemical modification of fats, oils or fatty acids

C12 Biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering

C12M Apparatus for enzymology or microbiology

C12N Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media

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C12P Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture

Section D Textiles; paper Section E Fixed constructions

E21 Earth or rock drilling; mining

E21B Earth or rock drilling; obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells

Section F Mechanical engineering; lighting; heating; weapons; blasting

F02 Combustion engines; hot-gas or combustion product engine plants

F02C Gas-turbine plants; air intakes for jet-propulsion plants; controlling fuel supply in air-breathing jet-propulsion plants

F16 Engineering elements or units; general measures for producing and maintaining effective functioning of machines or installations; thermal insulation in general

F16L Pipes; joints or fittings for pipes; supports for pipes, cables or protective tubing; means for thermal insulation in general

F25 Refrigeration or cooling; combined heating and refrigeration systems; heat pump systems; manufacture or storage of ice; liquefaction or solidification of gases

F25J Liquefaction, solidification, or separation of gases or gaseous mixtures by pressure and cold treatment

F28 Heat exchange in general

F28F Details of heat-exchange or heat-transfer apparatus, of general application

Section G Physics

G01 Measuring; testing G01F Measuring volume, volume flow, mass flow, or liquid level; metering by volume G01N Investigating or analysing materials by determining their chemical or physical properties G01V Geophysics; gravitational measurements; detecting masses or objects G06 Computing; calculating; counting G01F Electric digital data processing G01G Analogue computers

Section H Electricity

APPENDIX B Patent Query Methodology

WIPO Patentscope was searched for published patents, with a substring match on the applicant name, and for each of the date ranges representing the 5 years and 10 years ending 31 December 2012. Patent applications are different than published/granted patents. Only published patents were queried. Applications were not counted or queried. The following queries were used for Patentscope:

PA:(Exxonmobil) AND DP:[01.01.2008 TO 31.12.2012]
PA:(Exxonmobil) AND DP:[01.01.2003 TO 31.12.2012]
PA:(Shell Oil) AND DP:[01.01.2008 TO 31.12.2012] PA:(Shell Oil) AND DP:[01.01.2003 TO 31.12.2012] PA:(Petrobras) AND DP:[01.01.2008 TO 31.12.2012] PA:(Petrobras) AND DP:[01.01.2003 TO 31.12.2012]

The EPO European Patent Register was searched for published patents, with a substring match on the applicant name, and for each of the date ranges representing the 5 years and 10 years ending 31 December 2012. The following queries were used for the Patent Register:
publication-date >= 20080101 and publication-date <= 20121231 and applicant = exxonmobil
publication-date >= 20030101 and publication-date <= 20121231 and applicant = exxonmobil
publication-date >= 20080101 and publication-date <= 20121231 and applicant = shell oil
publication-date >= 20030101 and publication-date <= 20121231 and applicant = shell oil
publication-date >= 20080101 and publication-date <= 20121231 and applicant = petrobras
publication-date >= 20030101 and publication-date <= 20121231 and applicant = petrobras

The USPTO was searched for published patents, with a substring match on the applicant name, and for each of the date ranges representing the 5 years and 10 years ending 31 December 2012. The following queries were used for the USPTO's Patent Search:
AN/''Exxonmobil'' AND APD/20080101->20121231 AN/''Exxonmobil'' AND APD/20030101->20121231 AN/''Shell Oil'' AND APD/20080101->20121231 AN/''Shell Oil'' AND APD/20030101->20121231 AN/''Petrobras'' AND APD/20080101->20121231 AN/''Petrobras'' AND APD/20030101->20121231

APPENDIX C Guide to PatentVest Metrics

Application Conversion Rate This metric measures the historic percentage of a companys patent applications that end up being granted and is an indication of the quality of a companys patents and patenting operations. The calculation uses all applications that were published at least 3 years ago and so assumes that any application not granted within 3 years of publication has been rejected.

Portfolio Score This important IP leadership and value metric measures the industry impact of a companys patents and is a quality indicator of a companys competitive position. This metric is based upon a patent-by-patent analysis of external citations adjusted for the marginal value of each citation and the remaining time to expiration of each patent and then further adjusted by the overall size of the companys total patent portfolio.

Tech Score The Tech Score is a similar quality indicator as the Portfolio Score above but does not adjust the citation calculations by a companys portfolio size. Eliminating portfolio size from the equation provides an additional perspective on the quality and relevance of a companys IP portfolio.

Portfolio Depth This IP leadership and value metric measures the degree of concentration or depth within an area of technology. It measures self-citations using patent-bypatent analysis adjusted for the marginal value of each citation and the remaining time to expiration of each patent and then further adjusted by the overall size of the companys total patent portfolio. This measure is indicative of a companys success in creating a patent thicket to widen the moat around an area of innovation. A high Depth Rating reflects a high degree of difficulty for competitors to design around a body of patents and therefore reflects superior competitive positioning.

Tech Depth The Tech Depth is a similar concentration indicator as the Portfolio Depth above but does not adjust the self-citation calculations by a companys portfolio size. Eliminating portfolio size from the equation provides an additional perspective on the relative depth of a companys IP portfolio.

Tech Isolation This metric measures the degree of isolation or novelty of a companys technology relative to other companies. High isolation ratings indicate technology that is either foundational for a new area of innovation (i.e. classically disruptive) or developments that are not recognized by others. The median isolation rating for PatentVests approximately 3,000 public companies is 4.7%. Isolation is measured by looking at the percentage of self-citations versus total citations and reflects the degree of interconnectedness of a companys technology to its peers. This metric can be extremely valuable when used in conjunction with PatentVest quality and/or application metrics (as described above and below).

3-Year Application CAGR This important IP growth metric is the year-over-year compound annual growth rate of the number of patent applications filed during the last 3 years. This can yield crucial insight into the nature of a companys IP development and its competitive relevance. PatentVest only calculates this rate for companies with at least 10 patent applications published as of 3 years ago, in order to avoid routine presentation of large growth rates for small portfolios. It is important to note that the USPTO averages 18 months from filing to application publication, creating an average estimated 18 month time lag for this metric.

Application Distance Ratio The Application Distance Ratio (ADR) is a PatentVest quality metric that measures the amount of change made to an application during prosecution. A lower ADR indicates that an applications claim set underwent few changes in prosecution, meaning the granted patent is thus more likely to be highly defensible against broader claims. Average ADR is used to represent this metric across an entire portfolio of patents.

Application Distance Ratio Coverage Application Distance Ratio Coverage is a measure of the percentage of a companys patent portfolio used by PatentVest to calculate the Application Distance Ratio (ADR). In most cases PatentVest can only use part of a companys portfolio to calculate ADR, because the USPTO only began publishing applications in 2001, and the USPTO does not publish all applications. ADR coverage is thus an important qualifier to a companys ADR. The lower this number, the less reliable is ADR as an indicator of the strength of a companys patent portfolio claim sets.

Rankings The rankings indicate where the company stands in the PatentVest universe as well as the size of the population calculated for the particular metric under consideration. For Industry rankings PatentVest uses Morningstar Inc. industry designations.