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Natural Resource Constraints and Innovation

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Abstract

In this paper, we address the link between finite natural resource constraints, technological capability building, and innovation. Our research focuses on the upstream oil industry, where companies compete largely based on their ability to explore, exploit, and deliver oil and gas to market. Although there is limited natural availability of oil and gas, this is not the only factor that affects resource endowments of companies. Natural resource constraints can have very different origins?such as geophysical conditions?or they can be related to an unfavorable business environment in which political activities have negative consequences on business and investments of companies. These different origins of resource constraints create different forms of uncertainties ? technical and in-put cost uncertainties ? that influence organizational maneuverability in different ways. We use real options theory and complement the resource based view in order to understand the effect on organizational choices in terms of innovation and technological capability building.

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Abstract. In this paper, we address the link between finite natural resource constraints, technological capability building, and innovation. Our research focuses on the upstream oil industry, where companies compete largely based on their ability to explore, exploit, and deliver oil and gas to market. Although there is limited natural availability of oil and gas, this is not the only factor that affects resource endowments of companies. Natural resource constraints can have very different origins—such as geophysical conditions—or they can be related to an unfavorable business environment in which political activities have negative consequences on business and investments of companies. These different origins of resource constraints create different forms of uncertainties — technical and in-put cost uncertainties — that influence organizational maneuverability in different ways. We use real options theory and complement the resource based view in order to understand the effect on organizational choices in terms of innovation and technological capability building.

Keywords: Natural resource constraints, innovation, capabilities

INTRODUCTION

Access to resources is essential for firms as superior resources allow them to lower average costs compared to rivals, to produce greater economic outputs, and to increase customer satisfaction (Barney 1991; Peteraf 1993). In particular, resources can create competitive advantage by means of innovation (Ahuja and Katila 2004; Leonard-Barton 1992) and new product development (Rindova and Kotha 2001; Smith, Collins, and Clark 2005). Thus, resource endowment and constraints also affect a firm's ability to adapt to change and to remain competitive (Helfat and Lieberman 2002; Barney 1991; Conner 1991; Conner and Prahalad 1996; Grant 1991; Peteraf 1993; Wright 2001). Prior research has argued that a lack of certain appropriate resources and capabilities can impede firms from being innovative (cf., Teece 1986). In this context, scholars have analyzed the relation between different kinds of resources and innovation: e.g. competency-based resources (Prahalad and Hamel 1990), organizational knowledge (Grant 1996, Liebeskind 1996, Klepper and Simons 2000; King and Tucci 2002), as well as the availability of slack resources (Nohria and Gulati 1996), and physical assets (Peteraf 1993).

However, the impact of other fundamental firm resources on innovation is less well understood. One understudied case concerns finite natural resources, which remains under-explored despite the recognition of the role of the natural environment in firms' competitive advantage, in particular within the "natural-resource-based view" of the firm (Hart 1995). Finite natural resources are often considered as a temporary advantage for a firm and as a resource that could be readily acquired on factor markets by the firm itself or by its competitors (Barney 1991). This is certainly so for firms that use natural resources as substitutable factors of production, but not for firms where the revenue model is based upon the production and sales of natural resources (Davis 2006). However, despite the growing magnitude of ecological challenges, which researchers have identified as an important contingency (Majumbar and Marcus 2001; Marcus and Geffen 1998), biophysical resource constraints due to the finite character of non-renewable natural resources (Ciriacy-Wantrup 1952), have played little or no role in the discussion on innovativeness and innovative firm performance.

In this paper, we address the link between finite natural resource constraints, technological capability building, and innovation. Our research focuses on the upstream oil industry, where companies compete largely based on their ability to explore, exploit, and deliver oil and gas to market. Although there is limited availability of oil and gas, this is not the only factor that affects resource endowments of companies. Natural resource constraints can have very different origins—such as geophysical conditions—or they can be related to an unfavorable business environment in which political activities have negative consequences on business and investments of companies. These different origins of resource constraints create different forms of uncertainties and challenges for firms. For example, the question what effective recoverable resources will be available in the future is primarily related to technological advances and innovation in resource exploration and exploitation and therefore refers to "technical uncertainty," which can be reduced through investment (Pindyck 1993). On the other hand, the exposure to a politically unpredictable environment relates to an "input-cost uncertainty" (Pindyck 1993) that is external to the firm and independent from organizational investments. In both cases, firms are confronted with natural resource constraints, but the various forms of underlying uncertainties require different innovation strategies in order to overcome the problem.

We focus on an internal perspective of real options theory (Amram and Kulatilaka 1999) that complements the resource based view (RBV) and allows an explanation of how various types of uncertainty affect organizational capability development and innovation differently. Under such a view, firms that are faced with natural resource constraints choose incremental technology options under low uncertainty conditions. Firms that are faced with natural resource constraints and input cost uncertainties choose investment options into radically new technologies. Our research indicates that our understanding of the relationship between resource constraints and innovation may be increased if we pay more attention to the different forms of uncertainties underlying resource constraints rather than to focus on the resource constraints themselves.

THEORETICAL BACKGROUND

Key Constructs

Resources and Constraints

Resources and capabilities are the key source of value creation and competitive advantage for firms (Barney 1986; Wernerfelt 1984). Resources are described as assets or inputs to production (Peteraf 1993) over which a firm possesses or to which it has access. Resources allow firms to experiment, to take risks, and to be proactive in their strategies—in short, to act entrepreneurial in order to generate a competitive advantage. In terms of innovation, results have been mixed regarding the impact of lack of firm resources on organizational innovativeness (cf., Katila and Shane 2005). On one hand, research argues that constraints change organizational behavior and lead to an improvement of resource allocation and efficiency (Baker and Nelson 2005; Starr and Macmillan 1990). On the other hand, research argues that the organizational capacity to innovate is determined by resources and competencies that provide the input to produce innovation. In this sense, scholars suggest that firms lacking certain important resources have difficulties innovating (Teece 1986; Iansiti and Clark 1994; Leonard-Barton 1995).

Natural resources, as owned by primary sector companies, are a core factor to generate a competitive advantage. They are of central strategic importance for survival now and in the future. Finite natural resources, or exhaustive resources, are subject to depletion, usually as result of human consumption (e.g., hydrocarbons). In comparison to renewable resources (e.g., fish), resources within this category do not naturally grow in order to allow for continuous use. Instead, future exploitation is bounded by existing stock (Dasgupta and Heal 1979; Krautkraemer 1998). For firms, this means concretely that their competitive advantage diminishes because they pursue a primary activity that depletes their stock of strategic capital in the process—contrary to organizational resources such as knowledge, which renew and evolve incrementally through utilization (Nelson and Winter 1982).

Moreover, firm access to the resource stocks are threatened by political events in host countries with effects on their general natural resource endowment. Resource deposits are fixed in certain geographical locations, of which many are positioned in politically unstable "host countries." This exposes companies to the "risk or probability of occurrence of some political event that will change the prospects of the profitability of a given investment" (Cosset and Suret 1995, p. 304) with unwanted consequences on business activities (Haendel et al. 1975) mainly with regard to resource and deposit ownership, firm operations and transfers (Lohrke et al. 2007a). Companies are limited with regard to response options, such as diversification into other countries, etc., as they are bound to operate in certain possibly unstable locations.

Finite natural resources introduce the element of uncertainty with regard to resource constraints into the equation. As Merton (1975) notes there is no “current” uncertainty, but only future uncertainty – resource constraints for the current period and the next period are known with certainty, whereas available natural resource stocks in the future remain unclear.

Uncertainty

Uncertainty refers to heterogeneous events that are difficult to quantify in an adequate manner and impossible to be classified based on statistical probabilities relating to comparable past events (LeRoy 1987). It is a lack of information that makes it difficult to foresee the influence of uncertainty on the future state of an organization’s environment or to predict the potential impact of certain events on firms (Milliken 1987).

With regard to technology and innovation projects, Pindyck (1993) distinguishes between two forms of uncertainty: *technical uncertainty* and *input-cost uncertainty*. Technical uncertainty relates to the costs with regard to time, effort and materials, of developing and completing a project successfully. This type of uncertainty can be lowered and controlled through investment into the project as the actual costs become clear while the project progresses. Even if it turns out that costs may be greater than previously assumed, the key questions relates to how difficult it will be to realize the project, for example, with existing technologies, in time, etc. (Pindyck 1993). Within the upstream oil industry, ultimate availability of resources depends upon the outcome of exploration and exploitation activities of producers. Information based on exploration activities updates and modifies expectations about the future value of the resource stock available (Krautkraemer 1998). Input-cost uncertainty refers to factors that are external to the firm, not in its control and change the value of projects and technologies regardless of organizational actions and investments (Pindyck 1993). Political and governmental interferences and regulatory instability enter into this uncertainty category.

Both forms of uncertainty—technical and input-cost—increase the value of an investment (Dixit and Pindyck 1993), but, for example, input-cost uncertainties make further investment risky and less attractive because it might become uneconomical regardless of organizational action. In comparison, investing into technically uncertain technologies can still be interesting, as throughout the development process, companies learn more about the project and the costs—in fact, the actual value of technology development is only available when investment takes place (McGrath 1997). Both forms of uncertainties affect firms in different ways. What does this mean for organizations and their technological capabilities as well as innovative actions? In the following, we will draw on the resource-based view and real options logic to answer this question. The conceptual framework of our study is depicted in Figure 1.

Insert Figure 1 about here

Organizational Capabilities and Innovation from a Real Options Perspective

Natural resource-based companies must develop strategies and—along with them—the necessary capabilities that enable them to respond to depletion challenges effectively, thus leading to an additional degree of freedom when dealing with the exploitation of the natural environment (Bretschger 2005). Resources comprise all tangible and intangible assets a firm uses in order to conceive and implement their strategies (Barney and Arikan 2001). Firm resources vary in their economic and strategic value and may have a different effect on a firm's competitive position. In this context, "firm capabilities" come into play: Capabilities are pivotal for the generation of competitive advantage as they refer to a company's capacity to deploy and combine resources by using firm specific organizational processes of cooperation and coordination (Amit and Schoemaker 1993), and as they allow a firm to exploit its resources in implementing strategies (Hitt et al. 2007). Natural resource depletion represents a concrete threat for a firm's core product and business as it bears the potential to erode strategic firm positions with a devastating impact on overall firm performance. Under these circumstances firms are expected to increasingly invest into technological capabilities that may lead to innovations that help them react (Mitchell 1989).

Real options theory applies financial option valuation techniques to investment appraisals of long-term investments (e.g., new production plants, R&D projects, investment into technological capabilities). The options approach gives decision makers the possibility to make investments—e.g., into technological capabilities and innovation—and to select only favorable outcomes. The purchase of a financial option contract is the right, but not the obligation, to buy the underlying asset on which the option contract is written. Financial options assume that the asset from which the option is derived must have a price and the price is known, and the option must remain tradable (Black and Scholes 1973). The value of the financial option increases with the price volatility of the underlying asset—the more volatile the stock, the more valuable the option gets because potential profits are greater, whereas possible losses remain limited to the price of the option. Similar to a financial option contract, investment into real options gives the right but not the obligation to continue capital investment (develop, abandon, expand etc.). Because of the sequential nature of most investments, it is possible that, based on additional information gained throughout the development process, some of these investments will be abandoned as they become financially unattractive (Amram and Kulatilaka 1999). For example, the development of technological capabilities gives the firm further options. They can complete innovations that build upon their new capabilities and enable them to exploit and to commercialize them. The price of a real "technology" option refers to its development costs and—analogous to financial options—the value of the real option increases with the expected value of the net revenues minus commercialization costs of the capital investment (Luehrman 1998). The greater the volatility of expected cash flows, the higher the value of the technology asset. In both cases, uncertainty is the key factor that influences the price of an option: in financial options the volatility is a function of the uncertainty of stock price movements; in real options, the volatility goes back to uncertainty of expected cash flows and the organizational ability to respond to it (Luehrman 1998).

Technical Uncertainty and Resource Constraints

In the context of the upstream oil industry technical success relates to the organizational ability to augment resource availability through (a) more efficient exploitation of existing resource deposits, and (b) higher productivity in locating, exploring and developing new natural resource stocks (Bohi 1998; Bretschger 2005). Productivity refers to the amount of output produced with a given input and the most important factors for productivity increases are innovation and technology. Technical uncertainty refers to how much time, efforts and materials (Pindyck 1993) are needed to produce natural resources and how this affects expected cash flows.

Firms exploit the least costly and most profitable resource reserves first (Bohi 1998). These are reserves captured within known reservoirs and recoverable under current economic and operating conditions (BP 2004). Here, the degree of technical uncertainty is relatively low as previous exploitation and exploitation activities have generated sufficient information about the amount of hydrocarbons and the reserve sizes. Uncertainty issues therefore have been resolved through learning investments (Amram and Kulatilaka 1999) and firms can respond to depletion of their existing resource stocks with process oriented technology changes and incremental innovation. When faced with natural resource depletion and low technical uncertainty, firms tend focus on consolidated technology options that allow them to improve production processes and to reduce immediate resource constraints in order to derive competitive advantage (Creusen and Minne 2000). From this follows:

H1: When resource constraints are subject to low technological uncertainty, firms will use incremental technology options.

Empirical evidence shows that the effective natural resource base has been increasing or remained stable over time, due to technological advancements that enabled discoveries of new deposits and made use of lower grade ores possible (Brown and Wolk 2000). In this sense, technological development has compensated for the natural depletion of resource stocks (Barnett and Morse 1963; Brown and Wolk 2000; Slade 1982). Nevertheless, this view is not shared by everyone and the debate on oil and gas resources is divided between pessimists who foresee imminent peaking of oil and gas production (e.g., Bentley 2002; Campbell and Laherrere 1998) and believe that geophysical conditions will be more important in determining resource levels; and optimists, who expect innovation and market forces to decide the question (e.g. Cavallo

2002). However, some facts are agreed on: conventional oil production will sooner or later peak (Greene et al. 2006); the number of giant oil fields discovered and coming into production is peaking too and there are significantly fewer new discoveries (Davis 2006). Moreover, most oil reserves are presently held by national oil companies (60%), whereas international oil companies have equity access to only 24% of the world's oil and gas reserves (Marcel 2006). This situation pushes companies to prepare for a transition to other resources.

In order to produce the next generation of resources, firms increasingly turn to *unconventional* hydrocarbon sources (e.g. natural gas liquids, heavy oil) (Greene et al. 2006). Deposits of this sort are difficult to access and to develop and require investments into multiple technologies and technological capabilities that typically underpin exploration and production activities (e.g. mechanical, chemical and electronic engineering, materials technology, physical and computer-science based technologies: Acha 2001). Such technological development involves high degrees of technological uncertainty in terms of exploration outcome and costs (Krautkraemer 1994), as well as with regard to the probability of success of actually extracting oil the ground. Firms must therefore invest into capabilities and innovation that build on new knowledge in order to seize opportunities in new technical subfields (Mitchell 1989).

In addition, other potential sources of energy could replace petroleum—for example, liquid hydrocarbon fuels and renewable energies like solar and wind power. These alternatives confront firms with technical uncertainties as they enter into radically new technological innovation which builds on scientific methods that are new to, base on entirely different knowledge area, or present a novel recombination of already existing firm knowledge with new knowledge bases (Hill and Rothaermel 2003; Freeman and Soete 1997). Especially, renewable energies present firms with different investment concerns. Solar energy generation for example, builds on photovoltaic technology. Case studies have revealed the difficulties in organizational terms to integrate this radical technology into oil companies' operations and existing business units (Pinkse and van den Buuse 2010). Helfat (1997), who analyzes strategies of oil companies to move into coal gasification, finds that R&D investment patterns are associated with complementary technological knowledge and physical assets.

According to real options logic, research and the development of radically new technological capabilities create opportunities with regard to further investments. In the context of the upstream oil industry, such R&D offers new opportunities in terms of the non-incremental extension of their existing core business through exploration and development of unconventional resource deposits. From this follows:

H2. When resource constraints are related to high technological uncertainty, firms will increasingly opt for capability development in new (unconventional) technological subfields.

H3. When resource constraints are related to high technological uncertainty, firms will increasingly opt for capability development in (radically) new technology fields

Input Cost Uncertainty and Resource Constraints

As technical uncertainty, input cost uncertainty increases the value of an investment opportunity (Pindyck 1993). Yet, input cost uncertainty affects investment decisions differently: "a project with a conventional NPV that is positive might still be uneconomical, because costs of construction inputs change whether or not investment is taking place" (Pindyck 1993: 55).

An important input cost uncertainty this study looks at is political risk. Political risk encompasses negative consequences of government intervention, the occurrence of political events or constraints imposed on a company, as well as discontinuities in the general business environment due to political change (Cosset and Suret 1995). Consequently, political risk interferes with ownership, operations and transfers (Lohrke et al. 2007) of current and future projects. Within the upstream oil industry, political risk is of a systematic nature. It is shared by a majority of corporate assets or by the entire industry sector and thought to be un-diversifiable (Cosset and Suret 1995). This is the case because within the sector, natural resources are declining or near their resource limits, with the exception of certain regions, e.g. the Middle East, which is associated in many cases with elevated risk levels.

Firms can efficiently increase their resource base through structural changes in industry, notably through mergers and acquisitions (M&A). This has often been the case in the oil industry, which has seen an accelerating rate of M&A activity since the 1990s—the most visible result being the creation of some of the largest global corporations, the so-called super majors: ExxonMobil, Chevron (Chevron Texaco); BP (BP Amoco Arco), Conoco Phillips, Total (Total Fina Elf). Nevertheless, the gains from this strategy are bound to level off as all oil companies face the same challenges stemming from political risk in the area of conventional resource deposits.

Rather firms, in order to stay competitive in the long run and to be responsive to environmental challenges (Greve and Taylor 2000), have to efficiently exploit current businesses while simultaneously exploring innovative alternatives. Real options logic suggests that firms should exercise various technology options to prevent finding themselves in a holdup situation with weak bargaining positions and irreversible technology investments (McGrath 1997). This reflects the deployment of resources in activities that aim to promote exploratory firm activities

(March 1991), such as exploration of radically new technology areas, and the development of new technological capabilities (Katila and Ahuja 2002), which would render oil and gas producers less dependent on hydrocarbon-rich host countries.

H4: When resource constraints are related to high input-uncertainty, firms will increasingly opt for capability development in radically new technology fields.

H5: When resource constraints are related to high input-uncertainty, firms will increasingly use options in radically new technology fields

INDUSTRY CONTEXT

Historically oil – and gas firms have been vertically integrated and involved in the discovery/exploration, development, production, and distribution of petroleum products. Firms in the upstream oil industry, which are the focus of this paper, are preoccupied with the exploration and production of crude oil and natural gas. The oil industry underwent immense structural changes between 1971 and 2000 (Davis 2006). From an industry that was dominated by the seven sisters, the largest oil multinationals at the time, it developed into an industry where the largest oil companies (with the exception of Shell) have merged either amongst themselves or acquired ‘smaller’ independent oil companies (with annual revenues measured in billions of dollars). Official explanations for these merger activities were that mergers were necessary given heavy capital investments and high risks involved in the development of new fields in new oil provinces. Of major importance for the restructuring were also nationalizations that broke the links of vertically integrated companies between production of crude oil and company refining and marketing.

Furthermore, the emergence of independent markets where contracts for specific crudes and contracts for oil products began to be traded revolutionized the industry. Companies were not constrained to sell to their own integrated markets but could sell to any purchaser; company refineries in exchange could buy from any supplier (Davis 2006). Along with the nationalizations of oil companies during the 1970s, state owned companies emerged that increasingly competed with private firms. As a consequence, factors such as volatile oil prices, the creation of spot markets, and competitive pressure led to major structural changes within the industry. Thus, players in the upstream sector today include privately held, vertically integrated oil operators of different sizes (e.g. Shell, Total, KerrMcGee), and national oil companies (e.g. Saudi Aramco, PdVSA) as well as independent small exploration and production companies. In terms of oil reserves, nationally held companies dominate the market; however, their share in production is proportionally less (see Table 1).

Insert Table 1 about here

RESEARCH METHOD

Our data collection efforts produced a sample of 15 international oil companies active in the upstream petroleum sector from 1990-2006. The analysis focuses on the relationship of firm exposure to natural resource constraints and R&D investment as well as technological capability building. Our main sources of data are IHS Databanks' "Petroleum Economics and Policy Solutions" (PEPS) and "Energy Data Information Navigator" (EDIN).

In terms of international oil companies, there are 15 of them, namely Shell, Exxon Mobil, BP, Chevron Texaco, Total, ConocoPhillips, ENI, Hess, Kerr McGee, Marathon, Norsk Hydro, Occidental, Repsol, Statoil and Anadarko, which represent 80% of all recoverable oil found in fields between 50M and 250M barrels, worldwide. We have data for these firms for the years 1990-2006. We examine the role of resource constraints for innovation and examine two antecedents of natural resource constraints: physical endowment with natural resources (geophysical conditions) and political risk (as an external threat that can impede firms from having access to natural resources even though these resources are physically available).

Independent variables

Natural resource constraints

Endowment with natural resources was measured through three operational performance measures: recovery factor of natural resources in oil and gas fields, exploration success, and reserves. Data were drawn from 10-K and 20-F company filings with the US SEC. The *recovery factor* is the ratio of recoverable oil reserves (which is defined as cumulative production plus remaining reserves) to the original oil in place in a specific reservoir. It varies widely between fields with different reservoir characteristics (geology, fluid properties) and decreases with growing maturity of the field. The recovery factor also depends on organizational field and technology management. It gives a good indication how efficiently firms exploit their resource stocks. *Exploration success* refers to the number of successful and productive new wells drilled (exploratory and development). It is a good indicator that demonstrates how far firms are able to replace oil they produce, add sufficient reserves to assure resource endowment in the future; and in how far they find reserves that can be produced profitably. *Reserves* have reasonable certainty (at least 90% certainty) and have been discovered through exploration wells, exploitable with existing technologies, commercially viable and still in the ground.

Political risk

Political Risk is measured in terms of political stability (PS). For each country in which oil companies of our sample have had operations, a risk value was calculated for each year (1990-2006). This value is based on a political risk measure, which is derived from the International Country Risk Guide (ICRG) dataset of the Political Risk Services group (PRS). The ICRG data cover 12 political, socio-economic, and commercial risk components (see Table 2). The aim of the political risk rating is to provide a means of assessing the political stability of concerned countries on a comparable basis. ICRG weighs the risks by assigning risk points to each risk. The minimum number of points that can be assigned is zero, while the maximum number of points depends on the fixed weight each component is given in the overall political risk assessment. ICRG measures risk in terms of degree of political stability, as it depicts risk on a scale of 0 to 100, where 100 represents the most stable and less risky situation in a country (PRSGroup 2009).

Insert Table 2 about here

A data set was constructed that linked each country's political stability value in each year to the various operational performance values of each individual oil company (production, reserves, exploration success, oil rights at the end of the year). Linking those variables allows us to tell, for example, how much oil a company has produced in year x and in which countries with which political risk rating. For each of these measures for each firm in every year, we create a political risk measure, which is the maximum political risk that the company had exposure to in that particular year, based on the group of countries where the firm operated during that year. This refers to an absolute value that does not reflect the repartition of investments and operations in different host countries but concentrates on the worst case. The reason to use the maximum value is related to the systematic nature of political risk within the whole upstream oil sector. As mentioned above, the overall exposure to political risk is higher in the oil industry than in many other industry sectors – which means that companies cannot diversify away a basic risk. But, within their asset portfolio they encounter different degrees of political risk / stability. So, to a certain extent they can control and reduce the overall level of non-diversifiability of their portfolio by hedging against the worst cases.

Dependent Variables

Technological capability development

We use publications as proxies for the development of technological capabilities and analogous to buying a technology option in order to be able to profit from possible future opportunities. Analyzing publishing behavior of companies allows understanding where companies believe that they have acquired new knowledge or lessons and technological capabilities to share with a wider community. It also allows a transparent way of capturing innovative effort and to consider the scope of this effort across topics (Narin 1994). This paper uses GeoRef's publications database of the American Geological Institute (AGI). The data used for this research cover a time span between 1990 and 2006. Altogether, 27,500 entries of publications by companies were analyzed; 25,384 accounted for publications from companies of our sample. We coded the publications according to four large categories. First, we refer to technologies important for the existing upstream core business, which create value based on existing or incrementally modified competencies and technologies—exploitation in the sense of March (1991). This sector comprises six large technology areas: geophysics, drilling, well completions, reservoir engineering, offshore and improved/enhanced oil recovery (IOR/EOR) Our codes are in line with the Petroleum Abstracts Tulsa database (see Table 3). Second, we refer to technologies that are radical *within* their core business, for example, important technologies for "unconventional" oil and gas search and exploitation (e.g., tar sand, retort). The third category corresponds to renewable energies technologies. The second and third of the above categories refer to exploration activities that require novel competencies.

Insert Table 3 about here

Innovation

We use patents as proxies to measure innovation and as analogous to exercising a technology option (new technology product that firms apply in their resource exploration and exploitation efforts). We have used the same technology categories as already identified for the publications and based on the Petroleum Abstracts classifications. Independent oil engineers and industry experts have validated these categorizations and classifications. Patent data was drawn from the European Patent Office Worldwide Patent Database (EPO Patstat, version of October 2007). We use patent families (according to the International Patent Documentation Center definition), which assemble and standardize equivalent patent documents for multiple countries into one group.

Descriptive statistics and correlations are shown in Table 4.

Insert Table 4 about here

RESULTS

To test our direct effect hypotheses, we use fixed and random effects panel data models. Random effects present an alternative approach that take into consideration the panel nature of our data. This is useful as we have multiple observations from the same firms over a period of up to 16 years and thus the error terms for each firm are not independent from year to year. On the other hand, we also use fixed effects panel data models to control for unobserved heterogeneity. Random effects and fixed effects models show consistency with regard to the overall results. We report the random effects results in the tables below.

Natural resource constraints and technical uncertainty

We test the relationship between resource constraints, capability development, and innovation. The different specifications involve resource constraints corresponding with low or high technical uncertainty and dependent on this, we expect firms to opt for different technology choices. We consider current exploitation of conventional deposits afflicted with low technological uncertainty. The measure for resource constraints here is the recovery factor (RF). Moreover, we look at the effects of resource constraints with regard to ‘reserves’, which refer to new oil and gas reserves by means of extensions of existing deposits, new discoveries, improved recovery, purchases and transfers before production. Reserve estimates rely on assumptions about the size of the reservoir, recoverability of reserves, extraction costs, selling prices, etc. They give an indication about the mid- and long-term perspectives on organizational endowments of natural resources (Cormier and Magnan 2002). Finally, we use exploration success, which refers to the number of successful, productive new wells drilled that indicate new oil deposits requiring further exploration and development in order to exploit their full potential. This performance measure refers to long-run projects with high technical uncertainties. We regress these performance measures with patents and publication activities within incremental technologies referring to conventional core business (here we focus on well completion technology and enhanced oil recovery technology), as well as patents and publication that indicate entry into new technological subfields, notably, unconventional technologies (e.g., tar sand and retort). And, patents and publications within radically new technologies (here we focus on renewable energy technology). We ran each variable separately then all together as a robustness check.

We find that RF is negatively associated with patents and publications in conventional upstream technologies (= well completions). A high RF signifies that deposits have been effectively and efficiently exploited. This means firms patent more in conventional technologies when resource constraints are high and technical uncertainties are low. We can confirm our first hypothesis. Our data also shows, that firms refrain from further capability building (= publications) in this area and invest less into publication. Moreover under these conditions, firms exercise technology options referring to new technological subfields (= unconventional technologies). Also resource constraints in areas where firms hold resource reserves are negatively associated with patents in conventional upstream technologies. The increase of resource constraints in areas where it is linked to technical uncertainty (= exploration success) increases patent activities in conventional upstream technologies. It does not incite them to exercise technology options in new technological subfields (= unconventional technologies) or in radically new fields (= renewables). With regard to capability development, exploration success, which gives an indication over the resource availability in the long run, is positively associated with publications in renewable energies. This means firms invest more into capabilities of that sort when they face a comfortable resource endowment and they invest less when confronted with resource constraints (this contradicts hypothesis 2). There is no significant relationship between publications in unconventional technologies (=new technological subfields) and exploration success (=resource constraints linked with technical uncertainty) either, which contradicts hypothesis 3. When reserves are low, firms focus on capabilities in conventional technologies (well completions) and unconventional technology areas. (see Tables 5, 6, and 7).

Insert Tables 5, 6, and 7 about here

Natural resource constraints and input-uncertainty

We also ran regressions with regard to patent and publication activities in radically new technologies based on maximum political risk exposure in production areas, in areas of exploration success, in countries that host oil and gas reserves. Table 8 presents the results of the regression models.

Our data shows that patents in renewable are negatively correlated with political stability with regard to resource constraints in the long run (= political stability in areas of exploration success), which supports hypothesis 5. We do not find any significance for increased patenting activities when companies face political instabilities in production or reserve holding areas. On the other hand, publications in renewables (= capability building in radically new technology fields) are positively correlated with political stability in production and reserve areas (see Table 8).

Insert Table 8 about here

DISCUSSION

Natural resource constraints and technical uncertainty

To what degree do companies possess the necessary technologies or are capable of developing the required capabilities with respect to the technical uncertainty they face? We were able to show that companies, when confronted with certain resource constraints combined with low technical uncertainty, counteract this through the use of incremental technology options. Firms also exercise technology options in unconventional technologies consistent with their core business when confronted with low recovery factors, because they may be able to profit from a combination of well-known technologies as well as new subfield technologies. So, in business areas where uncertainty is low, firms opt for a broad technological platform with different degrees of innovativeness to address various exploitation challenges.

In order to be successful in exploration firms must be able to reduce technological uncertainty by continuous investment. Through this they shift the border between what is conventional and unconventional or incremental and radical changes over time. For example, some time ago, offshore crude oil was a non-conventional source, today it is considered "conventional." Surprisingly, the firms in our sample, when faced with resource constraints in the long run (=exploration success is low) do not invest into capabilities in radically new technology fields (=publications in renewable). Instead, our case shows that firms appear to become risk averse and are unwilling to “buy” options in radically new technology fields; rather they prefer to rely on tested competencies (Staw et al. 1981).

Natural resource constraints and input uncertainty

We proposed that input uncertainty provides incentives for firms to develop capabilities (= publications in renewables) and to exercise technology options in radically new fields (=

patents in renewables). We consider publications as proxy for potential technology options firms attempt to secure for the future. Organizational incentives to place further technology options (capability development) were diminished; in fact, our research clearly shows that firms publish less under political uncertainty conditions. Nevertheless, firms increasingly focus on exercising radical technology, which reveals how input uncertainties such as political risk create a permanently insecure business environment that erodes competitive advantages of firms on an ongoing basis. First, political risk interferes with day to day operations of existing projects (e.g. revoking of contracts, interruption of operations due to outbreak of civil wars etc.); second, political risk interferes with resource ownership and access. Thus, it creates uncertainties with regard to expected cash flows from technology projects, as well as for the fundamental basis of the core business (natural resources): firms must preserve the level of their overall natural resource endowment in order to stay competitive. What could be a problem in the context of input uncertainties is that there are few chances to resolve simply during the course of the investment. Independent from organizational investments, input costs change. Previous research teaches us that under circumstances where uncertainties bear the potential to erode strategic positions, decision makers will assume increasingly more risk (Fiegenbaum and Thomas 1988; Lehner 2000) and these fundamental threats to a firm's core business lead firms to the exploration (Rosenkopf and Nerkar 2001) of new business and technological subfields (Mitchell 1989).

In both cases—under technical uncertainty conditions and under input cost uncertainty conditions—firms are faced with volatile levels of resource endowment, but the options they choose in response to this are antithetic. In the first situation, they seem averse to investment into radically new technology fields: in the latter, resource constraints act as a form of external threat that has a "compelling motivation" (Sheehan et al. 2007) with regard to investments into radically new technologies.

FUTURE RESEARCH DIRECTIONS AND LIMITATIONS

Our research shows that resource constraints can have different origins that create different uncertainties for firms. This approach is not exhaustive and other factors may exist that affect natural resource endowments of firms and deserve further attention. The analysis undertaken here does not take into consideration certain organizational constraints that may limit investments of oil companies into radically new business areas such as renewable energies. Notably, the development of renewable technologies should entail complementarities for the firm, by increasing the corporate marginal return elsewhere. Technological innovation occurs between different stages of production processes of oil companies and only if they hold technological similarities and complementarities, common ownership and complementary production facilities will enhance technological innovation (Armour and Teece 1980).

Furthermore, uncertainties as to which technology will prevail in the future play an important role. For example different fuels for motor vehicles offer various possibilities already: e.g., compressed natural gas, hybrid vehicles, fuels cells—each of these solutions demands particularly large financial resource-consuming infrastructure. Provided the oil companies invest in these infrastructures, they would find themselves in a potential holdup situation if one automobile producer was to withdraw its vehicle type from the market, and they would face large difficulties in recovering their investments (Davis 2006b).

CONCLUSION

Despite its limitations, our article presents important and interesting insights and research alleys for theory. We study the relationship between resource constraints and innovation and, drawing on Pindyck (1993) link this to different forms of uncertainties. Our results show that these different forms of uncertainties influence organizational maneuverability in different ways, which also includes the effect on organizational options in terms of innovation. This advances the understanding of the role of resource constraints for innovation as it implies the research focus of what renders firms more or less innovative must be readjusted. Concentrating on the question of whether resource constraints hamper organizational innovation, or encourage firms to become more innovative, may not always address the core of the problem and may therefore lead to incomplete explanations, especially with regard to established firms. Thus resource constraint-related uncertainty—technical uncertainty and input cost uncertainty—deserves our attention.

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ANNEX

Figure 1: Conceptual Framework

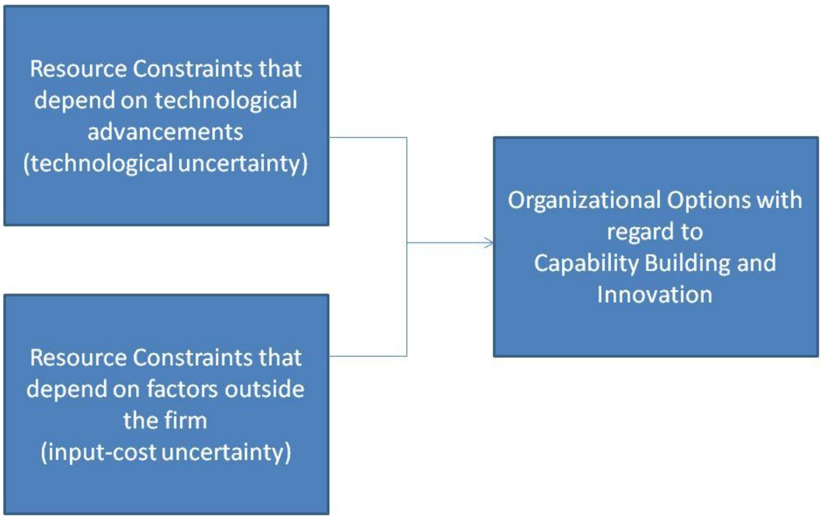

Table 1:Petroleum Intelligence Weekly (PIW1), Annual Ranking of the world's largest oil companies

[1] The PIW's system uses as criteria oil reserves and output, natural gas reserves and output, refinery capacity, and product sales volumes. Firms are compared in six different operational areas with companies assigned a separate rank within each category. The six individual ranks are then added together to determine the cumulative, overall position, giving each of the six criteria an equal weighting. Rankings are based on the 2005 operational results for the companies as they existed at the end of that year or as they reported them.

Rank	PIW Index	Company	Country	State Ownership %
1	30	Saudi Aramco	Saudi Arabia	100
2	36	Exxon Mobil	USA	
3	39	NIOC	Iran	100
4	44	PDV	Venezuela	100
5	48	BP	UK	
6	59	Royal Dutch Shell	UK/ Netherlands	
7	68	PetroChina	China	90
8	78	ChevronTexaco	USA	
8	78	Total	France	
10	83	Pemex	Mexico	100
11	94	ConococPhillips	USA	
12	96	Sonatrach	Algeria	100
13	100	KPC	Kuwait	100
14	106	Petrobras	Brazil	32
15	108	Gazprom	Russia	50.002
16	130	Lukoil	Russia	
17	132	Adnoc	UAE	100
18	134	Eni	Italy	
19	137	Petronas	Malaysia	100
20	143	NNPC	Nigeria	100
21	143	Repsol YPF	Spain	
29	191	Statoil	Norway	71
31	241	Marathon	USA	
42	317	Hess	USA	
44	322	Anadarko	USA	
46	332	Occidental	USA	
47	336	Norsk Hydro	Norway	44

Table 2: Political Risk Components, PRS Group 2009

POLITICAL RISK COMPONENTS		
Sequence	**Component**	**Points *(max.)***
A	Government Stability	**12**
B	Socioeconomic Conditions	**12**
C	Investment Profile	**12**
D	Internal Conflict	**12**
E	External Conflict	**12**
F	Corruption	**6**
G	Military in Politics	**6**
H	Religious Tensions	**6**
I	Law and Order	**6**
J	Ethnic Tensions	**6**
K	Democratic Accountability	**6**
L	Bureaucracy Quality	**4**
Total		**100**

Table 3: Publication Classification according to the

Petroleum Abstracts Tulsa Database

Geo (Tulsa 1.0 - 3.0): **Geology, Geochemistry, Geophysics**: *seismic processing*: data processing, velocity computation, amplitude vs. offset, migration, recording, stacking, interpretation *seismic surveys*: reflection method, common depth point method, wave source, equipment, transmission, shear wave source, streamer, 3 component geophone, stratigraphy, vertical profiling **Drilling (Tulsa 4.0):** *Drilling fluids*: clay stabilization, fluid, fluid loss additive, oil base mud, fluid testing, mud thinner, formation damage *Horizontal well technology*: drilling, well, well completion **Well Logging (Tulsa 5.0)** **Well Completion (Tulsa 6.0)** *Well stimulation/fracturing*: acidizing, fluid loss additive, hydraulic fracturing, blender, fracturing fluid, foam fracturing, fracturing pressure, acid fracturing, fracturing fluid additive, fracture geometry, formation damage *Well workover*: sand control, well tool, milling, recompletion, inhibitor squeeze, scale removal, sand consolidation, corrosion testing, corrosion inhibitor, cathodic protection *Cementing*: bond strength, coiled tubing, cementing, cementing head, cement mixer, cementing collar, lightweight cement, cement composition, cement slurry, cement testing, cement rheology, portland cement, cementing plug, retarded cement *Other well completion*: inflatable packer, setting tool, retrievable packer, perforator, centralizer, electric well pump, slim hole completion, tubing conveyed operation, bridge plug, shaped charge perforator, casing perforating, gravel packing **Reservoir Engineering (Tulsa 8.0)** *Formation evaluation:* core analysis, relative permeability, core barrel, wettability, fluid sampler, formation tester, formation evaluation, pressure transient analysis / pressure build-up analysis, formation damage *Reservoir predictive methods:* reservoir model, reservoir study, reservoir fluid flow, vapour liquid equilibrium/phase behaviour, compositional model **Improved oil recovery*:*** carbon dioxide flooding, carbon dioxide injection, reservoir heating, steam flooding, steam injection, miscible displacement, surfactant water flooding, combination flooding, polymer water flooding, micro emulsion, profile control, enriched gas drive, emulsion flooding, caustic water flooding, viscous oil recovery, thermal recovery, in situ combustion, water flooding **Supplemental Technology (Tulsa 12.0)** **Offshor***e*: tension leg platform, riser pipe, production platform, semisubmersible drilling barge, floating production platform, drilling platform, tethering, platform jacket (University of Tulsa (January 1995) ***Analysis of Research and Development Trends Among Major***

Petroleum Corporations in the United States, Conducted for BDM-Oklahoma Inc, Subcontract 93-0001,
Contract DE-AC22-94PC91008. University of Tulsa: Tulsa, pp 8-9)

Table 4a
Descriptive statistics

Variable	**N**	**Mean**	**Std. Dev.**	**Min**	**Max**
1 Patents in well completion	315	186	323	0	2462
2 Pubs in well completion	315	1.31	4.99	0	62
3 Patents in unconventional	300	103	120	0	464
4 Pubs in unconventional	315	1.13	2.46	0	18
5 Patents in renewable	300	89	115	0	623
6 Pubs in renewable	315	3.1	6	0	60
7 Exploration success	218	17.5	15	1	77
8 Reserves	152	6590	7580	9.92	45570
9 Recovery factor	304	0.37	0.12	0.09	0.78
10 PS exploration success	217	51.3	11.6	26	95.5
11 PS reserves	112	58.6	9.42	41	90
12 PS production	275	51.2	11.5	36	89
13 Price of oil	315	29.3	22.8	11.8	104
14 Employees (log)	209	10.1	1.25	6.91	11.8

Table 4b
Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Patents in well completion	1												
2 Pubs in well completion	0.00	1.00											
3 Patents in unconventional	0.69*	0.02	1.00										
4 Pubs in unconventional	0.18*	0.16*	0.41*	1.00									
5 Patents in renewable	0.91*	-0.03	0.83*	0.19*	1.00								

6 Pubs in renewable	0.08	0.08	0.42*	0.46*	0.17*	1.00							
7 Exploration success	0.09	0.04	0.54*	0.28*	0.23*	0.51*	1.00						
8 Reserves	0.09	0.21*	0.48*	0.23*	0.19*	0.32*	0.60*	1.00					
9 Recovery factor	-0.10	-0.05	-0.14*	-0.08	-0.12*	0.02	-0.01	-0.10	1.00				
10 PS exploration success	-0.20*	-0.04	-0.35*	-0.18*	-0.30*	-0.22	-0.39*	-0.40*	0.00	1.00			
11 PS reserves	-0.04	0.04	-0.11	0.29*	-0.10	0.18	-0.05	-0.14	0.31*	0.09	1.00		
12 PS production	-0.36*	-0.08	-0.50*	-0.17*	-0.46*	-0.25*	-0.37*	-0.43*	0.27*	0.52*	0.26*	1.00	
13 Price of oil	-0.15*	0.12*	-0.23*	-0.13*	-0.13*	-0.01	-0.22*	0.09	-0.09	0.09	0.06	-0.12	1.00
14 Employees (log)	0.28*	0.22*	0.62*	0.36*	0.41*	0.40*	0.64*	0.65*	-0.09	-0.30*	-0.02	-0.45*	0.11

*p<0.05

Table 5
Patenting / publication behavior in conventional technologies (well completion) of major oil companies

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	Patents	Patents	Patents	Patents	Pubs	Pubs	Pubs	Pubs
Independent variables								
Exploration success	n.s.			-0.017** (0.008)	n.s.			n.s.
Reserves		4e-5*** (1e-5)		4e-5*** (1e-5)		-7e-5* (3.6e-5)		-8e-5** (3.8e-5)
Recovery factor			-5.01*** (1.17)	-4.2*** (1.3)			n.s.	n.s.
Control Variables								
Price of oil	-.02*** (0.004)	-0.02*** (0.004)	-.02*** (0.004)	-.02*** (0.004)	0.04*** (0.01)	0.05*** (0.012)	0.04*** (0.01)	0.05*** (0.01)
Number of employees (log)	0.64*** (0.12)	0.32* (0.19)	0.84*** (0.14)	0.76*** (0.19)	0.34 (0.25)	0.91*** (0.32)	0.51** (0.23)	1.0*** (0.36)
Constant	-5.4*** (1.23)	-2.48 (1.96)	-6.0*** (1.39)	-5.3*** (1.82)	-5.9** (2.63)	-12*** (3.29)	-6.6*** (2.51)	-11*** (3.33)
N	194	146	201	142	194	146	201	142
Wald chi-squared	43.2***	46.9***	66.9***	69.8***	23***	23***	24***	22.7***
Log likelihood	-951	-739	-965	-720	-242	-186	-253	-182

*p<0.10, **p<0.05, ***p<0.01, n.s. = not (statistically) significant

Table 6
Patenting / publication behavior in unconventional technologies (e.g., tar sands) of major oil companies

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	Patents	Patents	Patents	Patents	Pubs	Pubs	Pubs	Pubs
Independent variables								
Exploration success	n.s.			n.s.	n.s.			n.s.
Reserves		n.s.		n.s.		-7e-5** (3.2e-5)		-7e-5** (3.4e-5)
Recovery factor			-3.2*** (1.09)	-2.6** (1.26)			n.s.	n.s.
Control Variables								
Price of oil	-.03*** (0.003)	-.03*** (0.003)	-.03*** (0.003)	-.03*** (0.003)	n.s.	n.s.	n.s.	n.s.
Number of employees	0.56*** (0.11)	0.55*** (0.16)	0.74*** (0.14)	0.69*** (0.19)	0.50** (0.25)	1.04*** (0.30)	0.62*** (0.23)	0.95*** (0.34)
Constant	-3.7*** (1.16)	-3.5** (1.63)	-4.6*** (1.42)	-4.2** (1.86)	-5.5** (2.59)	-10*** (3.12)	-6.3** (2.68)	-11*** (3.53)
N	194	146	201	142	194	146	201	142
Wald chi-squared	99***	89***	117***	95***	5.6	13***	7.3*	13**
Log likelihood	-844	-643	-855	-631	-214	-149	-226	-146

*p<0.10, **p<0.05, ***p<0.01, n.s. = not (statistically) significant

Table 7
Patenting / publication behavior in renewable technologies (e.g., solar, wind) of major oil companies

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	Patents	Patents	Patents	Patents	Pubs	Pubs	Pubs	Pubs
Independent variables								
Exploration success	n.s.			n.s.	0.02*** (0.006)			0.07* (0.009)
Reserves		3e-5** (1e-5)		2e-5** (1e-5)		n.s.		n.s.
Recovery factor			-2.0* (1.06)	n.s.			n.s.	n.s.
Control Variables								
Price of oil	-.02*** (0.003)	-.02*** (0.003)	-.01*** (0.003)	- .02*** (0.003)	-0.01** (0.006)	- .02*** (0.007)	- .02*** (0.006)	- 0.02** (0.007)
Number of employees	0.53** (0.11)	0.33** (0.17)	0.57*** (0.14)	0.51** (0.20)	n.s.	0.54** (0.27)	n.s.	n.s.
Constant	-3.7*** (1.12)	n.s.	-3.6*** (1.36)	n.s.	n.s.	n.s.	n.s.	n.s.
N	194	146	201	142	194	146	201	142
Wald chi-squared	44***	56***	45***	59***	23***	16***	12***	20***
Log likelihood	-837	-649	-851	-639	-340	-248	-358	-243

*p<0.10, **p<0.05, ***p<0.01, n.s. = not (statistically) significant

Table 8
Patenting / publication behavior in renewable technologies (e.g., solar, wind) of major oil companies in response to inpost uncertainty (political risk)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Patents	Patents	Patents	Pubs	Pubs	Pubs
Independent variables						
PS Exploration success	-0.064* (0.037)			n.s.		
PS Reserves		n.s.			0.04* (0.02)	
PS Production			n.s.			0.05* (0.028)
Control Variables						
Price of oil	-0.04*** (0.01)	-0.04*** (0.01)	-.04*** (0.01)	n.s.	n.s.	n.s.
Number of employees (log)	7e-6** (4e-6)	7e-6** (4e-6)	7e-6** (4e-6)		2e-5*** (1e-6)	n.s.
Constant	2.6*** (1.1)	n.s.	n.s.	n.s.	n.s.	n.s.
N	194	111	201	194	111	201
Wald chi-squared	48***	75***	62***	11**	26***	12**
Log likelihood	-837	-498	-845	-343	-179	-358

*p<0.10, **p<0.05, ***p<0.01, n.s. = not (statistically) significant