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KNOWLEDGE SOURCING: INTERNAL OR EXTERNAL?

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Abstract

Knowledge is a resource that needs to be strategically managed by firms. This paper examines the conditions for internal versus external sourcing of knowledge. We argue that firms incur production costs when developing knowledge internally and transaction costs when obtaining it through the market. The relative size of the transaction costs and production costs depends on the industry structure and the type of knowledge needed, and should guide firms in their choice of internal versus external sourcing of knowledge in order to achieve competitive advantage. We observed three approaches taken by petroleum firms to reduce the costs of absorbing knowledge externally. These approaches reflect coopetition, a new means of creating value in the petroleum industry.

Introduction

Knowledge is a resource that needs to be strategically managed by firms (Grant, 1996; Ranft & Lord, 2002), and can lead to competitive advantage when privately held. For example, knowledge contributes to new and unique products or services or increased efficiency which can be building blocks of competitive advantage (Argote & Ingram, 2000; Conner & Prahalad, 1996; Cyert, Kumar & Williams, 1993).

Knowledge development creates a dilemma for firms in deciding whether to develop knowledge internally or through external sourcing. Research suggests that firms failing to innovate internally are resistant to change, improperly structured, unable to read the competitive environment, or simply unable to produce inventive ideas (Bolton, 1993). Yet many firms are increasingly relying on knowledge acquired from other firms to facilitate the development of their own capabilities or knowledge (Kim, 1998; Lane & Lubatkin, 1998; Liebeskind, Oliver, Zucker & Brewer, 1996), and research on strategic alliances (Inkpen & Dimur, 1998), joint ventures (Harrigan, 1985), and multitechnology products (Brusoni, Prencipe & Pavitt, 2001) highlight the value of obtaining knowledge from external sources.

Internal knowledge acquisition and creation, or learning, takes place within the boundaries of the firm when its members generate and distribute new knowledge, through activities such as in-house R&D. External knowledge development, or learning, occurs when boundary spanners bring in new knowledge from an outside source via either acquisition or imitation. This knowledge is then transferred throughout the organization (Bierly & Chakrabarti, 1996). Examples of external knowledge development include attending conferences and bringing in equipment and software vendors to train the firm's staff. In practice, there is no "pure" internal and external learning. Internal learning requires the integration of different perspectives and ideas from sources external to the firm, and external sourcing of knowledge in turn broadens the internal knowledge base of the firm. Bierly and Chakrabarti (1996) recognize the need for external knowledge but place a higher value on internal knowledge generation. Others have suggested that internal and external knowledge generation need to be integrated, for successful product innovation and competitive advantage (Iansiti and Clark, 1994). Yet, the dilemma for firms remains: since knowledge generation is costly, when is it most advantageous to generate knowledge internally or source externally?

Studying knowledge acquisition in the petroleum industry we observed an industry-wide shift from the internal generation of technical knowledge to external sourcing of knowledge in the 1990s. Canadian upstream petroleum firms shifted from seeking proprietary knowledge to exploiting nonproprietary knowledge, and changed their strategic approach from the use of internal R&D to that of accessing external knowledge available to all competitors. These observations led to our present research question: when is a competitive advantage created by firms developing and protecting internally generated knowledge and when is it more advantageous for firms to obtain this knowledge from external sources? In order to map out previous findings, we reviewed research on the knowledge-based and resource-based views of the firm, transaction and production cost perspectives, and organizational learning. However, before reviewing the literature, we present our observations on knowledge development in the petroleum sector, and more specifically, on the development of new technologies in geophysics. We then integrate these observations with the literature review into testable propositions on internal versus external knowledge sourcing.

The Petroleum Industry

Initially, we collected data to examine how firms identified and eventually adopted new technologies (Falkenberg, Woiceshyn, & Karagianis, 2002). We focused on geoscientists in upstream petroleum firms (i.e., firms involved in the exploration for oil and gas). Geoscientists apply geology, mathematics and physics to develop structural models of geological formations that enable upstream petroleum firms to determine where to focus their exploration efforts. The last decade has seen significant developments particularly in computer-aided technologies for structural modeling. Despite these advances, the application of current and new technologies is subject to a high degree of uncertainty.

Primary data were collected through 30 interviews with geoscientists from five different petroleum firms (three larger and two smaller), a vendor and research consortia. Some of the geoscientists had been previously employed in R&D laboratories of large petroleum firms. Secondary data consisted of the last four years of annual reports for each company. All firms in the study were classified as "senior" petroleum producers (Jacober, 2000).

All interviewees mentioned the shift from internal R&D to the use of externally developed technologies, indicating a new approach to research and development in the Canadian upstream petroleum sector. Previously, the larger upstream petroleum firms had supported major in-house research and development laboratories to develop proprietary technologies. Approximately 75 percent of the geoscientists interviewed had previously worked in firms that had large R&D laboratories. However, these laboratories had gradually closed in the 1980s and 1990s.

According to the interviewed geoscientists the primary reasons for this shift were the cost of operating the laboratories and the inability to maintain the depth and breadth of knowledge required to advance technologies in the geosciences. In fact, one geophysicist we interviewed estimated that 90 percent of new upstream oil and gas technology was now being developed by external vendors. The geophysicists also noted that the technology had become so complex that it required advanced skill bases that a petroleum firm could not justify developing or maintaining. For example, one of the firms, Stream (all company names are

pseudonyms), once had a significant in-house R&D laboratory but had found it too expensive to maintain:

> We could not justify or compete [with vendors] in terms of developing new technologies, nor could we afford to hire the staff…you can, quite honestly, get the same service externally. *Chief Geophysicist, Stream*

Another reason for the shift from internal to external knowledge sourcing was the laboratories were developing technologies with narrow applications that were not cost-effective to develop. One geophysicist observed:

> When I worked for [firm X] they had a very prominent research center, state of the art with a large number of Ph.D.s working on extremely esoteric problems, and they finally realized not too many people were using the research. *Geophysicist 2, Cowboy*

These technological advances could only be financially justified on an industry-wide basis, by having vendors develop specialized technologies for several individual firms or firms working together in industry research consortia.

In every firm the geophysicists recognized that the shift to external research and development meant there was little proprietary technical knowledge:

> … so many ideas have come out of the research consortia with the university. A couple of them have turned into standard industry practice around the world…so this whole process is now research being done across company boundaries and the uptake is across companies. *Chief Geophysicist, Cross*

The transfer of knowledge across firms was perceived as an advantage rather than a disadvantage, as all the geophysicists recognized that working with vendors led to cross-fertilization of ideas among firms and to improved technologies. Vendors learned how to solve problems for one firm and then transferred this knowledge to other firms facing similar problems. This cross- fertilization was viewed as a benefit to all firms in the industry.

Theoretical Perspectives on Knowledge Sourcing

A review of the relevant literature identified potential contextual and knowledge related factors associated with internal and external knowledge bases. However, a limitation with the literature is the almost exclusive focus on manufacturing, with little attention given to industries with different characteristics, such as resource extraction. Although our initial observations were based on the upstream petroleum sector, we have a more general premise: firms that integrate complex processes to produce a product or service need to balance the generation of internal knowledge and the absorption of external knowledge.

Strategic Perspectives: Resource-Based and Knowledge-Based Views

The resource-based view assumes that firms are bundles of resources and capabilities that enable firms to develop competitive advantage (Grant, 1996; Teece, Pisano & Shuen, 1997). From the perspective of evolutionary economics, capabilities are skills in coordinating resources, to make resources productive (Teece, et.al. 1997; Nelson & Winter, 1982). Capabilities are embedded in the way individuals interact, how they work together and share each other's knowledge and skills and build upon them. The resource-based view directs firms to focus on internal development of unique processes or skills. From a knowledge-based perspective this would entail developing unique knowledge. A key question from the resource-based perspective is which internal resources (e.g., knowledge base) and capabilities

(e.g., research and development capability) should be valued and supported to develop a competitive advantage. Although the resource-based view prompts this question, it provides few answers (Priem & Butler, 2001).

According to the knowledge-based view, firms are generators, repositories and integrators of knowledge (Ranft & Lord, 2002). Through knowledge-based capabilities firms can continue to generate and innovate successive generations of new technologies (Lei, et.al., 1996). A key resource is the knowledge base of the firm (Grant, 1996; Henderson & Cockburn, 1994; Nahapiet & Ghoshal, 1998), comprised of the background and experience of employees. It provides the foundation for understanding operations, recognizing the value of new information and creating new knowledge through interpreting and combining information (Cohen & Levinthal, 1990).

Firms cannot acquire or create new knowledge without an existing base of knowledge, and this existing knowledge is continually evolving. A key question arising from the knowledge based-perspective is what is the internal depth and breadth of knowledge required for a firm to be able to create new knowledge? Any specific answer to this question would be based on the context of the firm; however, there are two elements within any firm's knowledge base that affect the creation of new knowledge: absorptive and transformative capacity.

Absorptive capacity is the ability to recognize and exploit technological opportunities developed outside the firm (Cohen & Levinthal, 1990; Lane & Lubatkin, 1998; Zahra & George, 2002). Although this capacity is the ability to identify external knowledge, it is based on internal knowledge developed through internal research and development, as well as active information and knowledge sourcing and accumulation activities (i.e., participating in conferences, updating skills through training and self-learning, and keeping informed of the latest technologies) (Soo, Devinney, Midgely & Deering, 2002). In contrast, transformative capacity is the ability to continually redefine a product portfolio based on technological opportunities or skills within a firm (Garud & Nayyar, 1994), and requires an extensive internal knowledge base.

Both transformative and absorptive capacity are required to create and maintain a sustainable competitive advantage; however, transformative capacity (i.e., a focus on generating internal knowledge) is critical when (a) path-dependent cumulative knowledge is involved, (b) the scientific base of the knowledge is abstract or complex, (c) the technology is fragile in the sense that it does not work consistently, (d) entry timing is important, or (e) a firm operates in a continually changing environment in which it does not just react to external changes, but instead, creates them by its own actions (Attewell, 1992; Garud & Nayyar, 1994; p. 367). Thus, absorptive or transformative capacity will vary in relative importance depending on the industry characteristics.

An example provided by Garud and Nayyar (1994; p. 367) highlights these issues. In the late 1980s and early 1990s IBM focused on developing its line of personal computers through the integration of external technologies (i.e., it depended on its absorptive capacity). As competitors absorbed the same technologies, IBM began to lose its competitive advantage (Ferguson & Morris, 1993). However, it was initially unsuccessful at shifting to internally generated technologies because "(1) massive internal change affecting the type of technological resources in question required considerable time to initiate and implement – time within which the industry had moved far ahead, (2) first mover advantages precluded

external technologies as viable means of regaining competitive advantage, and (3) IBM operated in a rapidly changing environment in which a forfeited competitive position could not be regained."

Economic Perspectives: Transaction and Production Costs

Transaction costs are associated with economic exchanges, whereas production costs are associated with internally generating technical knowledge (Williamson, 1989; Madhok, 2002). Transaction costs are influenced by three related factors: asset specificity, number of suppliers, and uncertainty (Williamson, 1989). Assets specificity is associated with the irreversibility of investments required to use or integrate, or successfully manage the transaction (Attewell, 1992; Sobrero & Schrader, 1998). It influences knowledge sourcing in two ways. First, when the specific asset is an inimitable process requiring specialized equipment or knowledge it can create a competitive advantage and therefore should be developed internally. Second, when firms need to invest in specialized equipment or assets in order to further develop a process or generate new technology, but once the knowledge is created it becomes mobile and any advantages created by the asset specificity are lost. In this situation the specialized asset may be costly to justify and knowledge should therefore be externally sourced.

The number of suppliers or sources of knowledge influences the cost and degree of control firms have when sourcing knowledge externally. Firms that possess specific assets have few external options for obtaining needed additional assets or knowledge (Connor, 1991; Williamson, 1989). Under these circumstances a firm should consider producing knowledge internally, to maintain control of costs, functionality, delivery, and servicing—all sources of transaction costs. Firms that do not require investment in specific assets can easily source knowledge externally as many suppliers can be found and transaction costs will be low.

Uncertainty is associated with imperfect information and is negatively related to the ability to write complete contingent contracts (Connor, 1991; Sobrero & Schrader, 1998). Williamson (1989) has argued that when economic transactions have uncertain outcomes, they are most efficiently performed within the firm. Recognizing that knowledge development is unpredictable and all contingencies cannot be included in a contract, a firm may pay for the development but have little ability to keep it proprietary.

Other transaction costs associated with sourcing knowledge externally include searching for appropriate external knowledge bases, selecting from competing offers/technologies, bargaining, monitoring and enforcement agreements (Madhok, 2002). Continuous searching for information requires formal and informal networks. Firms with formal networking systems (e.g., membership in professional associations, participation in conferences), and policies and procedures to support formal networking, outperformed those without these systems (Soo, et.al., 2002). These formal systems were associated with influencing the firm's absorptive capacity.

A risk associated with depending on external knowledge bases for new information is that important developments may be missed when the firm's network is not wide enough or the firm's members fail to see particular information as valuable. To reduce this risk, a firm needs a broad knowledge base and needs to formally support continuous review of new ideas, whether or not they initially appear valuable (Zahra & George, 2002).

Madhok (2002) contrasted the costs of producing internally (i.e., production costs) with using external sources (i.e., transaction costs). He concluded there were two types of general production costs: direct costs (i.e., salaries of experts, costs of physical infrastructure such as laboratories and computers) and indirect costs (i.e., coordinating and managing communication and production). From the knowledge-based perspective, direct production costs should also include the development of required knowledge bases and protection of new knowledge from appropriation. The indirect production costs should also include the risks associated with knowledge creation, such as directing resources to non-productive ideas or duplicating knowledge development efforts of other firms.

A key production cost of internal knowledge arises from building specialized knowledge bases that should lead to an identifiable set of core skills, or unique knowledge (Nelson and Winter; 1982). Specialized knowledge bases are path dependent on cumulative experience and knowledge and so are not only costly to develop, they require continuous maintenance and up-to-date infrastructure (i.e., laboratories, computers) (Cohen & Levinthal, 1990). The development of the first personal computer provides an example. "Although Xerox developed the first personal computer, it (was) unsuccessful in reentering the computer industry because it discontinued developmental efforts, thereby creating gaps in knowledge. Moreover, time compression diseconomies prevent(ed) Xerox from catching up" (Garud & Nayyar, 1994; p. 375).

Appropriability refers to the ability of firms within an industry to monopolize the application of new knowledge or protect knowledge from spilling over to other firms (Attewell, 1992; Zahra & George, 2002). If a firm can routinely capture most of the profits from its innovations, appropriability is high, like in the pharmaceutical industry where proprietary knowledge is protected by patents. If, however, the created knowledge is leaky and spills over to other firms in the industry, then appropriability is low, as in the upstream petroleum industry. Low appropriability is associated with high costs of protecting internally generated knowledge. Tacit knowledge is considered to have high appropriability, whereas the appropriability of explicit knowledge is lower.

We suggest that appropriability is related to the market/industry context of a firm, as well as to the type of knowledge. The "regime of appropriability refers to the institutional and industry dynamics that affect the firm's ability to protect the advantages (and benefits from) new products or processes" (Zahra & George, 2002). For example, if explicit knowledge is being transferred by mobile experts (e.g., consultants) or leaked to mediating firms (e.g., equipment vendors), appropriability is low as the firms cannot maintain a monopoly on the knowledge. In this situation the relative costs of maintaining transformative capacity may be higher than those of absorptive capacity.

Organizational Learning

Organizational learning involves knowledge acquisition (i.e., the development or creation of skills, insights, relationships), knowledge sharing (i.e., the dissemination to others of what has been acquired by some), and knowledge utilization (i.e., integration of the learning so that it is assimilated, broadly available, and can also be generalized to new situations (Dibella, Nevis & Gould, 2000; p.363). A number of different types of learning and knowledge have

been identified; however, two that are particularly relevant in the petroleum industry are "learning-by-doing" and "learning-by-watching" (Bolton, 1993).

Internal knowledge creation occurs through "learning-by-doing": firms first experiment with a new idea and develop innovations. This type of learning requires specialized assets, intensive research and development, and coordinated internal information flows. In contrast, "learning-by-watching" involves the acquisition of new knowledge through observation and assimilation of external information. Learning-by-watching requires the transfer of external information into internal practices and knowledge bases, leads to generic asset types, requires low research and development, and leads to information that is new to the company but not necessarily to the industry.

Learning-by-watching, or imitation, is an important strategic choice in industries with weak intellectual property protection, where firms are technologically interdependent, and where technological change and information flows are rapid. For example, telecommunication firms must amass multiple knowledge bases in fiber optics, computers and microelectronics, yet this knowledge is too costly to develop independently, particularly when it can be easily imitated (Bolton, 1993). It is important to note that learning-by-watching is different from merely mimicking competitors without understanding why competitors behave in a certain way. The latter could be labeled second-hand learning and is hazardous in that it does not generate knowledge.

All firms need to engage in some form of "learning-by-watching" as learning from the experience of others can provide significant benefits. However, this method can become costly for firms monitoring the "wrong" firms, or firms that are not developing relevant knowledge. Another cost of a learning-by-watching approach is the need for effective heuristics to reduce the time and effort required to locate appropriate knowledge sources. Research suggests firms with common business strategies and that solve similar problems have comparable knowledge bases and thus are better aligned for knowledge transfer across organizational boundaries (Darr & Kurtzberg, 2000; Zahra & George, 2002).

The structural context of the firm must also be considered to determine the best means of knowledge sourcing. Two important contexts are the market/industry and information/know-how (Soo, et. al., 2002). Structural factors within the market/industry context affect the pool of available knowledge, how it is shared and the steps needed to protect proprietary knowledge. Some of the industry structural factors are those identified in the discussion of transformative and absorptive capacity. An additional structural factor is the existence of mediating institutions, i.e., specialized firms that create and accumulate technical knowledge, and develop know-how in the use of technologies. Attewell (1992) proposes that mediating institutions (vendors in the upstream petroleum industry) emerge where technical knowledge is scarce and economies of scale can be captured.

The information/know-how context is important because knowledge sourcing also depends on the type of knowledge sought. Firms need both explicit and tacit knowledge. Explicit knowledge, or know-what, includes specific theories or principles that are easily communicated or documented (Dodgson, 1993; Nonaka & Takeuchi, 1995). Firms can source know-what knowledge through professional education, reading, and social networks (Pennings, Lee & van Witteloostuijn, 1998). Explicit knowledge is mobile across firm boundaries (Grant, 1996). Tacit knowledge, or know-how, on the other hand, is the

accumulated practical skills or expertise that lead to the efficient and smooth production of an outcome (Dodgson, 1993; Polanyi, 1966; von Hippel, 1988). It is firm-specific and cannot be directly transferred (Grant, 1996).

The main conclusion from these theoretical perspectives is that a firm's orientation to developing internal knowledge or utilizing external knowledge depends on the structure of the industry and the type of knowledge sought (see Table 1). In a moderately changing environment, where complex explicit knowledge (e.g., technical knowledge) is being developed, appropriability is low, and where mediating institutions exist within the industry (e.g., vendors, service firms or research consortia), firms should focus on developing absorptive capacity in order to successfully source external knowledge. In contrast, firms in rapidly changing environments competing on the development of tacit knowledge (e.g., improving current processes) and generating new products, and where appropriability is high should focus on developing transformative capacity in order to increase innovation through internal knowledge creation.

Application and a Framework for Choosing Knowledge Sources

Application of the Theory

In applying the theoretical perspectives to our observations of the upstream petroleum industry, we noted the influence of the knowledge type and industry contexts on the shift toward external knowledge bases (see Table 1). Operations in the upstream petroleum industry were requiring an increasing number of highly specialized knowledge bases, where a major function of the firms was the coordination and integration of these knowledge bases. Existing and new geoscience knowledge was highly mobile as it could be applied to firms' assets (i.e., geoscience models and land holdings) across the industry. Although know-how was required to apply the knowledge to certain types of problems, it was not significantly path-dependent and could be acquired from the outside when needed. The increasing complexity and mobility of knowledge meant the costs of research and development (i.e., transformative capacity) were increasing to a point where the return on the knowledge gained could not be justified.

There were a number of industry contextual factors that increased the costs of maintaining transformative relative to absorptive capacity. The industry had developed extensive network points, such as active professional associations, regular seminars and research consortia. As well, there were a number of consultants who were in a position to cross firm boundaries and exchange knowledge. There were recognized economies of scale in having new knowledge developed on an industry-wide basis. Firms recognized that knowledge was needed to improve the productivity of the industry and the costs of generating internal knowledge were becoming too high.

At the time of our observations internally generated knowledge had higher production costs arising from the need to develop depth and breadth of knowledge bases, low appropriation, and risks of uncertain technologies than transaction costs of sourcing knowledge externally. Vendors had lower production costs because of the narrowness of their knowledge base, and these costs and the risks associated with generating new knowledge were dispersed across the vendor's clients. Following Williamson (1985) and Madhok (2002), we suggest when the

production costs (i.e., of generating internal knowledge) are greater than the transaction costs (i.e., of sourcing knowledge externally), firms shift to external knowledge sources:

Proposition 1: Firms should source knowledge externally when the production costs of internal knowledge are greater than the transaction costs of sourcing knowledge externally.

Table 1

Key Factors in Determining Knowledge Source

Type of Knowledge	**Internal Knowledge**	**External Knowledge**
Relevant Knowledge Characteristics	• tacit/know-how • sticky • path dependent, cumulative experience • high asset specificity	• explicit • mobile • economies of scale in knowledge distribution
Relevant Industry Structural Factors	• entry timing is critical • rapidly changing environment	• regime of low appropriability • extensive network points • mediating institutions
Relevant Firm Characteristics	• internal research and development activities • specialized knowledge bases	• formal policies supporting network development • broad knowledge bases • formal constant search processes
Costs	• production costs • risk of unproductive research and development • direct costs of experts and research infrastructure	• transaction costs • risk of missing critical new knowledge • cost of networks and searches
Outputs	• Transformative capacity - ability to continually redefine a product portfolio based on technological opportunities or skills within a firm • Learning-by-doing • inimitable knowledge that will lead to a competitive advantage	• Absorptive capacity - ability to recognize and exploit technological opportunities outside the firm • Learning-by-watching • Learning-by-participating • generic knowledge that must be combined with other firm assets or knowledge to create a competitive advantage

We observed three approaches taken by the petroleum firms to reduce the costs of sourcing knowledge externally. The first approach involved agreements with different vendors to be "alpha" sites for the testing and development of new technologies. This gave access to new technologies prior to other firms, while reducing the costs associated with (a) developing absorptive capacity because of
the technical support provided by vendors for alpha sites and (b) the uncertainty in the assessed value of the knowledge because the technology was supplied at a discounted rate. Being an alpha site also provided opportunities for the firm to guide the technical development to meet their specific needs.

In the second approach a vendor's employee was "embedded" in the petroleum firm. The embedded employee divided his/her time between the petroleum firm and the vendor. Embedding reduced problems arising from sticky knowledge (Szulanski, 1996) associated with externally developed technologies and increased the absorptive capacity of the firm. The stickiness of the knowledge occurred in two directions. The internal know-how required to apply the new knowledge/technology was reduced by the embedded employee working inside the firm for four days and working with other experts (i.e., vendor's employees working in other companies) one day a week. The embedded employee also absorbed the "stickiness" of the firm's operations by being in the firm four days a week.

The third approach reduced the risks of knowledge sharing through the implicit understanding of vendors developing and sharing knowledge across firm boundaries. All the geoscientists acknowledged dependence on vendors led to little proprietary technical knowledge; however, they also recognized that working with vendors led to cross-fertilization of knowledge. Vendors refined the technology or solved a problem with one firm and then transferred this knowledge to other firms. We suggest this implicit sharing occurred through multi-channel networks (i.e., the interaction of the vendors and petroleum firms) and reduced transaction costs for all firms. The norms of reciprocity within these multi-channel networks reduced the need for governance structures (Gulati, Nohria & Zaheer, 2000). And, the costs of transferring "sticky" knowledge were reduced because vendors worked directly with each firm, understanding their particular operations and applied what was learned in other situations to the specifics of a given firm.

These observations are summarized in the following proposition:

Proposition 2: Firms that seek to reduce the transaction costs of sourcing external knowledge should

a) contract with vendors to become "alpha" sites for testing the vendors' technology,
b) seek to "embed" one or more of their vendors' employees as in-house experts, and/or
c) participate in multi-channel networks of knowledge sharing with the vendors.

Theoretical Framework

Integration of the different theoretical perspectives and our observations of the upstream petroleum firms led us to conclude that there is a constant tension between choosing to generate knowledge internally and sourcing it externally. In order to develop capabilities firms need to analyze what knowledge bases within the firm are most likely to be unique and the most efficient methods for producing them. This analysis needs to include the

market/industry context, the type of knowledge needed (i.e., information/know-how), and the transaction and production costs of producing or sourcing the knowledge. More formally:

Proposition 3: Firms should focus on developing absorptive capacity when
a) a number of mediating firms generating knowledge or innovations for application by firms within the industry exist,
b) there are numerous formal structures for external networks (i.e., active professional associations and research consortia), and
c) explicit knowledge is mobile (i.e., not firm-specific) due to the movement of experts or mediating institutions.

Proposition 4: Firms that focus on developing absorptive capacity will incur transaction costs from the
a) maintenance of formal networks,
b) searching the networks for new information,
c) development of broad knowledge bases, and
d) missing important new information.

Proposition 5: Firms that focus on developing absorptive capacity will reduce the production costs associated with transformative capacity.

Proposition 6: Firms should focus on developing transformative capacity to generate knowledge internally when
a) competition is based on generating new products rather than the application of new knowledge,
b) few mediating firms exist within the industry, and
c) knowledge has high appropriability, that is it can be protected in the short term from opportunistic behaviours.

Proposition 7: Firms that focus on developing transformative capacity will incur production costs from the
a) development of specialized knowledge bases,
b) protection of unique, proprietary knowledge, and
c) risk of generating inappropriate or duplicate knowledge.

Proposition 8: Firms that focus on developing transformative capacity will reduce the transaction costs associated with absorptive capacity.

Discussion

These observations help clarify the building blocks of a knowledge management capability: the appropriate balance of absorptive and transformative capacity in order to efficiently control transaction and production costs, reduce duplication of knowledge creation efforts across firms, capture economies of scale, and ensure appropriation of profits from unique knowledge. These building blocks may be combined differently by each firm to become more efficient at generating or acquiring knowledge that meets firm-specific needs **and to gain competitive advantage**.

One of the implications of this framework is that firms will develop capabilities based on common or public knowledge bases. This aligns with Eisenhardt and Martin's (2001) conclusion that dynamic capabilities have commonalities across firms but multiple paths are followed to develop the capabilities. Some of the commonalities identified by Eisenhardt and Martin (2001) include the use of cross-functional teams, external communication, and social networking routines. Our observations indicate different multiple paths between firms arise because the firms vary in their application of the external knowledge. For example, firms solve different problems, use different processes to produce an outcome, or interpret the value of the knowledge differently. Other paths may arise because the common knowledge is applied to firm-specific knowledge or assets. For example, petroleum firms may be accessing publicly available external knowledge bases, but are applying the knowledge to different types of geophysical models than other firms because their access to land, drilling approaches or risk orientations are different. Because of diversity in the skills and experiences of geoscientists, each firm also will place a different value on the knowledge gained (i.e., in terms of its ability to solve problems or assist in finding new reserves of oil and gas). So it is the unique capability of applying externally sourced knowledge to a firm's assets, not the knowledge per se, that provides the firm a competitive advantage.

We suggest that the interactions between the vendors and firms, and the support of research consortia, are forms of coopetition--the simultaneous cooperative and competitive behaviour among competing units (Tsai, 2002). Tsai (2002) examines coopetition between competing units within a firm; however, our observations indicate coopetition also occurs with knowledge sharing across an industry. Although technological development is considered critical to the upstream petroleum industry, the knowledge associated with it is implicitly shared throughout the industry. The contextual factors that support coopetition within the upstream petrolem industry include integration of complex knowledge bases by firms to produce a product/service (Liebeskind et al, 1996), low appropriation of new knowledge, potential exploitation of economies of scale by vendors, multi-channel networks and norms of reciprocity for communication. A significant factor affecting coopetition is the existence of mediating institutions or vendors. It is in the best interests of the vendors to gain knowledge from all of the client firms and share this knowledge; thus trust between competitors is not needed because the vendors are ensuring that all parties benefit from the information sharing.

Although coopetition leads to shared rather than proprietary knowledge, it is the complementary assets (e.g., property, financial, skill and knowledge bases) (Liebeskind, 1996) associated with the technical knowledge that allow firms to develop competitive advantage. Coopetition reduces the need to develop broad sources of information, and the risk that a firm will miss valuable knowledge in its scanning processes because the information is shared through the mediating institutions.

Another implication of coopetition is that it leads to another form of learning not captured by "learning-by-watching". In this form of learning, firms intentionally cooperate through informal (e.g., via vendors) and formal (e.g., research consortia) channels to exchange information on how to integrate or develop applications for new technologies. We label this form "learning-by-participating". It parallels Tyre and von Hippel's (1997) description of learning-by-doing, in that it occurs through the resolution of unexpected problems that arise when knowledge is put to use by the recipient; however, learning-by-participating involves the explicit and implicit sharing by group members (e.g., petroleum firms) of the knowledge

gained through the resolution of problems. Informal participation occurs as each firm shares the refinements or advancements of a particular technical approach via the vendors. Formal participation occurs through the active support and involvement in research consortia.

Contribution

This paper contributes to the current understanding of knowledge management in three ways. First, it extends the current literature from a manufacturing perspective to descriptions of knowledge management issues in the resource extraction (i.e., upstream petroleum) industry. The resource-based perspective has been primarily applied to manufacturing. Garud and Nayyar (1994) noted that in industries where the scientific base of the knowledge is abstract or complex, and the technology is fragile (i.e., does not work consistently), knowledge should be generated internally. The upstream petroleum industry is a case in point. The new geoscience knowledge being generated is based on abstract and complex knowledge bases and is highly fragile. The geoscientists we interviewed suggested this made research and development in their area highly risky. These risks were better incurred where firms (i.e., vendors) could leverage their research and development efforts across many client firms. Given these differences between different industries, they should be on the future research agenda on knowledge management.

A second contribution of this paper are the eight propositions that provide the initial framework for analyzing when knowledge should be generated internally or sourced externally. These propositions are based on an integration of our observations of the five petroleum firms and the resource-based view, transaction cost economics and organizational learning. They provide a base from which to examine knowledge management capabilities and provide specific direction for firms managing internal and external knowledge bases. The limitation of this paper is that it is based on one industry; future research is needed to empirically test these propositions. At the same time these propositions provide a basis for future testing and a platform to extend the research into other industries.

Our third contribution is the extension or development of three concepts: coopetition, the role of mediating institutions, and learning-by-participation. Our observations suggest that coopetition is an effective method of gaining external knowledge, and that mediating institutions reduce the potential for opportunistic behaviour and violation of trust. Finally, we suggest that coopetition can lead to another form of organizational learning, "learning-by-participation".

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