Centre Emile Bernheim
Research Institute in Management Sciences

Solvay
Business School

The Configuration of Internal and External Practiced Routines of Absorptive Capacity: A New Perspective

A. Y. Lewin, S. Massini and C. Peeters

The fifteen years following the introduction of the seminal construct of absorptive capacity (AC) by Cohen and Levinthal (1989, 1990) have seen the proliferation of a vast literature citing the AC construct in over 1500 published papers, chapters and books and interpreting it or applying it in many areas of organization science research, including organization theory, strategic management, and economics. However, with very few exceptions, the specific organizational routines and processes that constitute AC capabilities remain a black box. In this paper we propose a routine based model of AC that also operationalizes the AC construct. We decompose the construct of AC into two components, internal and external AC capabilities, and identify the configuration of meta-routines underlying these two components. The meta-routines are expressed within organizations by configurations of practiced routines that are observable and measurable. The ability of organizations to discover and implement complementarities between practiced AC routines may explain why some firms are successful early adopters and most firms are imitators. Success as an early adopter of a new management practice or an innovation is expected to depend on the extent to which an organization designs and implements the configuration of its internal and external absorptive capacity routines.

JEL Classifications:
Keywords: absorptive capacity; routines; capabilities; innovators; imitators

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Université Libre de Bruxelles – Solvay Business School – Centre Emile Bernheim
ULB CP 145/01 50, avenue F.D. Roosevelt 1050 Brussels – BELGIUM
e-mail: ceb@admin.ulb.ac.be Tel. : +32 (0)2/650.48.64 Fax : +32 (0)2/650.41.88

ULB

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Arie Y. Lewin
Duke University – The Fuqua School of Business
1 Towerview Drive, Box 90120
Durham, NC 27708, USA
Tel. +1 919 660 7654
ayl3@duke.edu

Silvia Massini
Manchester Business School
University of Manchester
Booth Street West, Manchester M15 6PB, United Kingdom
Tel: +44 (0)161 306 8794
Email: silvia.massini@mbs.ac.uk

Carine Peeters
Université Libre de Bruxelles – Solvay Business School
ECARES and Centre Emile Bernheim
50 Avenue F.D. Roosevelt CP 145/1
B – 1050 Bruxelles, BELGIUM
Tel: +32 2 650 44 62 / 48 70
Email: carine.peeters@ulb.ac.be

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Abstract

The fifteen years following the introduction of the seminal construct of absorptive capacity (AC) by Cohen and Levinthal (1989, 1990) have seen the proliferation of a vast literature citing the AC construct in over 1500 published papers, chapters and books and interpreting it or applying it in many areas of organization science research, including organization theory, strategic management, and economics. However, with very few exceptions, the specific organizational routines and processes that constitute AC capabilities remain a black box. In this paper we propose a routine based model of AC that also operationalizes the AC construct. We decompose the construct of AC into two components, internal and external AC capabilities, and identify the configuration of meta-routines underlying these two components. The meta-routines are expressed within organizations by configurations of practiced routines that are observable and measurable. The ability of organizations to discover and implement complementarities between practiced AC routines may explain why some firms are successful early adopters and most firms are imitators. Success as an early adopter of a new management practice or an innovation is expected to depend on the extent to which an organization designs and implements the configuration of its internal and external absorptive capacity routines.

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1. Introduction

The fifteen years following the introduction of the seminal construct of absorptive capacity (AC) by Cohen and Levinthal (1989, 1990) have seen the proliferation of a vast literature citing the AC construct in over 1500 published papers, chapters and books and interpreting it or applying it in many areas of organization science research, including organization theory, strategic management, and economics (see, for example, Lane and Lubatkin, 1998; Mowery and Oxley, 1995; Van den Bosch *et al.*, 1999; Lane *et al*., 2006). Cohen and Levinthal (1990, p.128) define absorptive capacity as the "ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (1990, p.128). AC is attributed to moderate or mediate a range of phenomena relating to firm level innovation and adaptation, and performance. However, with very few exceptions (e.g., Szulanski, 1996) the specific organizational routines and processes that constitute AC capabilities remain a black box (e.g., Lane *et al*., 2001; Lewin and Massini, 2003; Zahra and George, 2002; Todorova and Durisin, 2007, and in particular Lane *et al*., 2006).

This is perhaps because AC has acquired the characteristics of an umbrella concept (Hirsh and Levin, 1999; Meyer, 1991). Its development and evolution over time is consistent with the three stage models described by Hirsh and Levin (1999). In the first stage, the "emergent excitement" follows the initial articulation by Cohen and Levinthal which attributed innovative performance to the firm's absorptive capacity. The second stage, the "validity challenge", attracts research intended to operationalize or create direct measures of AC or in other ways empirically validate the construct. However, over time the absence of direct measures leads to the third stage, "tidying up with typologies', which is reflected in recent publications by Zhara and George (2002), Lane *et al*. (2006), and Torodova and Durisin (2007). In the absence of progress on operationalizing an umbrella concept, Hirsh and Levin (1999) expect three possible outcomes, "override challenges" (alternative constructs emerge), "permanent issue" (unresolved problems) and "construct collapse" (usefulness of constructs diminishes).

In this paper we are addressing the validity challenge by proposing a routine based model of AC that also operationalizes the AC construct. The specific routines that constitute the absorptive capacity capabilities of a firm and their role in mediating innovation, imitation, firm adaptation processes and industry evolution remains under explored in the extant literature. The concept of routines has been applied in a wide range of settings and it has a central place in A Behavioral

Theory of the Firm (Cyert and March, 1963; Argote and Greve, 2007) and in evolutionary economics theory (Nelson and Winter, 1982). In this literature stream, routines are seen as the building blocks of organizational capabilities (Dosi *et al*., 2000; Winter, 2003), and their systematic generation and modification in response to past experience and environmental changes is at the core of firm dynamic capabilities (Teece *at al*., 1997; Zollo and Winter, 2002). Moreover, if such capabilities are firm specific, idiosyncratic and/or complex and unobservable, they are the source of competitive advantage and must be difficult to imitate (Nelson and Winter, 1982; Barney, 1991; Rivkin, 2000, 2001). Priem and Butler (2001) argue that it is difficult if not impossible to test a theory that accounts for heterogeneous performance outcomes on the basis of unobserved capabilities. Barney (2001) countered this criticism by suggesting that direct measurement of capabilities is not necessary if the theory can specify the origins and consequences of capabilities. In this paper we propose to overcome this challenge by advancing a model of meta routines underlying AC capabilities and the actual expression of this meta routine-based model in the form of observable and measurable practiced routines.

In the sections that follow we briefly review the literature on AC, highlighting measures and methodologies, and the nature of the contribution (conceptual, empirical, prescriptive, etc). Then we distinguish between internal and external AC routines, propose a taxonomy of practiced AC routines, and illustrate examples of practiced AC routines. These are followed by a more general discussion on AC routines and capabilities, and a summary and conclusions.

2. Revisiting Absorptive Capacity and Organizational Routines

2.1 Absorptive Capacity

The concept of absorptive capacity (AC) was first advanced by Cohen and Levinthal (1989, 1990) as the "ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (p.128). They further argue that AC mediates speed, frequency and magnitude of innovation and that the evolution of firms' AC capabilities has a strong path dependency on prior R&D investment and knowledge base of a firm. AC and learning are often described as coevolving and mutually influencing each other (Autio *et al.*, 2000; Barkema and Vermeulen, 1998; Simonin, 1999). AC enables firms to innovate and learn, and the new knowledge adds to the existing AC (Helfat, 1997; Kim and Kogut, 1996; and Van den Bosch *et al.*, 1999). Van den Bosch *et al.* (1999) further argue that the AC-learning-new AC feedback

loop suggested by Cohen and Levinthal (1990) is mediated by the environment in which the firm operates and how it copes with it.

Since its introduction by Cohen and Levinthal, the concept of AC has been further elaborated. Zahra and George (2002) refine the concept of AC as a set of capabilities that underlie the processes identified by Cohen and Levinthal (1990), from the acquisition and assimilation, to the transformation and exploitation of knowledge. They propose that the first two dimensions make up an organization *potential AC* which is intended to capture the uncertainty associated with how well the firm will be able to exploit the knowledge. The last two dimensions make up an organization *realized AC*. Todorova and Durisin (2007) suggest an elaboration of the model proposed by Zahra and George (2002) by reinstating the role of recognizing the value of external information, transformative processes and regimes of appropriability; in addition they reposition the role of social integration mechanism and power relationships, and suggest the need for incorporating feedback loops for a dynamic representation of absorptive capacity.

Lane *et al*. (2006) propose a refinement to the original Cohen and Levinthal model of AC by introducing a sequential process: recognizing and understanding potentially valuable new external knowledge through exploratory learning; assimilation of new knowledge through transformative learning, and using the assimilated knowledge to create new knowledge through exploitative learning. These three competing elaborations of the AC construct clearly correspond to the tidying typology stage discussed by Hirsh and Levin (1999). Interestingly Lane *et al*. (2006) also recognize that AC has gone through a process of reification in the extant literature.

Lane *et al*. (2006) have identified fourteen academic journals that published five or more papers citing the Cohen and Levinthal 1990 paper between July 1991 and June 2002. Of the 289 papers, surprisingly, they have identified only six papers that they considered to be most central in the absorptive capacity literature. Of the six papers four (Mowery *et al*., 1996; Lane and Lubatkin, 1998; Dyer and Singh, 1998; Koza and Lewin, 1998) address knowledge sharing and assimilation in inter-firm relationships. One paper (Szulanski, 1996) is also concerned with internal AC routines but its focus is on the impediments to the transfer of best practices within the firm. The sixth paper (Zahra and George, 2002) provides the basis for the process model of AC proposed by Lane et al. (2006).

Empirical studies make attributions to the role of AC in innovation, firm adaptation, successful strategic alliances and knowledge creation (e.g., Mowery *et al.*, 1996; Helfat, 1997; Simonin, 1999; Autio *et al.*, 2000; Steenma and Corley, 2000; Ahuja and Katila, 2001; Hill and Rothaermel, 2003). Table 1 provides an overview of research that addresses the construct of AC conceptually and empirically. Following Cohen and Levinthal (1989), most empirical studies that make attributions to the AC concept rely on an R&D indicator (e.g., Rocha, 1999; Stock *et al.*, 2001; Veugelers, 1997; Wenpin, 2001), patents (cross-citations of patents in alliances, Mowery *et al*., 1996), or co-authored papers as mediating factor for connectedness between actors (Cockburn and Henderson, 1998). Although these various proxy measures of AC are only an indirect measure of AC, they have been used as both dependent and explanatory variables in empirical studies of high tech firms and industries, and the role of AC in technologically intensive environments. The organization and processes of R&D are very likely a component of AC for developing and adopting technological innovations. Innovation in a broad sense encompasses product, process, organizational and market innovations (Schumpeter, 1942). If these are the object of the analysis, R&D, patents, and citations only indirectly represent and capture partial aspects of capabilities related to valuing new, external, technological information, its assimilation and its application to commercial ends. Another stream of empirical studies have used case studies or survey instruments, normally using self reports to make attributions about AC (See Table 1). But, similarly to measures of R&D or patents, these are not informative of organizational structures, specific routines or processes that constitute AC and distinguish between AC capabilities of different organizations. The empirical studies using the AC construct summarized in Table 1 all treat AC as a black box or as an exogenous variable (see also, Foss and Pedersen, 2002). In other words, organizational practices are used as outcomes or as indirect measures for making attributions about the AC of organizations and its mediating role for innovation, change, resilience, flexibility etc. The table clearly highlights the lack of direct observation or measurement of the routines that make up AC. There is a need for better understanding the AC concept and for operationalizing it (Joglekar *et al.*, 1997; Matusik and Heeley, 2001; Zahra and George, 2002).

Table 1: Summary of research addressing absorptive capacity

- Insert about here -

Lane *et al*. (2006) highlight three major shortcomings of the existing literature on AC. First, few researchers have attempted to revise the definition of AC. Second, little attention has been

given to the processes underlying AC. And third, it has almost exclusively been measured in the context of R&D. Lewin and Massini (2003) represent a specific attempt at identifying the constitutive elements of AC. They decompose the concept of AC into two elements - *internal* and *external AC capabilities.* Internal AC capabilities refer to a hierarchy of routines and activities related to the management of internal variation, selection and retention (VSR) processes. External *AC* subsumes the management of the relationship with the external knowledge environment. Lewin and Massini (2003) identify a set of meta-routines, which, they hypothesize, constitute the core hierarchy of AC organizational routines. They are discussed more extensively in the section following the brief review of research on organizational routines below.

2.2 Organizational Routines

The concept of routines (e.g., decision rules, standard operating programs, procedures, norms, habits, etc.) has been advanced and applied in a wide range of theories and settings from problem solving routines (March and Simon, 1958; Simon, 1947; Simon *et al.,* 1950), A Behavioral Theory of the Firm (Cyert and March, 1963), dynamic capabilities (Teece *et al.*, 1997) and in Organization Sociology perhaps beginning with Weber (1978/1910).

Routines are at the core of evolutionary economics theory (Nelson and Winter, 1982) as they relate to understanding firm adaptation, innovation and change under constraints of bounded rationality. Routines serve as the building blocks of organizational capabilities (Dosi *et al.*, 2000; Winter, 2003) and evolve over time as a result of problemistic search, organizational learning and past selection and retention processes (Gavetti and Levinthal, 2000; Greve, 2003). Routines consist of rules, heuristics and norms that are operationalized at different levels of organization activities and processes. Routines vary from simple rules such as local problemistic search (Cyert and March, 1963) to higher level routines that regulate adaptive tension, rates of innovation and change, and the interaction with external socio, political and economic environment. Zollo and Winter (2002) distinguish search routines that refer to how firms cope with innovation, adaptation and change (Nelson and Winter, 1982). Routines therefore can refer to behavioral regularities (Dosi *et al*., 1992; Gersick and Hackman, 1990; Winter, 1964, 1968), a collective phenomenon which resides in organization, or individual, as habits and skills that belong to individuals (Dosi *et al*., 2000; Nelson and Winter, 1982), and to the execution of known rules and standard operational procedures (Cohen, 1991; Cyert and March, 1963; March and Simon, 1958). Feldman and Pentland (2003) refer to the performative

and ostensive levels to indicate respectively the abstract and narrative aspect of routines, and the actual performance of routines, which is context specific, and specific to the people who executed them. The two levels do not necessarily coincide.

Capabilities involve bundles of routines (Dosi *et al*., 2000) and the theory assumes that new superior routines, capabilities and new knowledge emerge through a dynamic interaction of internal and external variation, selection and replication processes involving knowledge creation and change over time. Successful maintenance of a skill or routine requires frequent exercise (Winter, 2003) and the evolution of routines is path-dependent. Performance feedback is also assumed to be a key process in the adaptation of routines or learning new routines over time (Levitt and March, 1988; Nelson and Winter, 1982; Teece *et al.*, 1997). Evolutionary economics (e.g., Nelson and Winter, 1982) theorizes that, in response to performance crisis, firms seek to introduce changes in their routines, either by developing better or improved routines, or comparing the effectiveness and efficiency of their internal routines to the effectiveness of similar routines by competitors. When competitors are found to execute more effective routines the negative comparison triggers internal change processes to improve the relevant internal routines through imitation of the superior routine. Zollo and Winter (2002) view this systematic generation and modification of operational routines as the fundamental mechanism underlying firms' dynamic capabilities for improving organizational effectiveness. Several theoretical formulations attribute above average or exceptional firm performance relative to other firms in the population to superior internal hierarchy of routines (Nelson and Winter, 1982; Lewin and Massini, 2003; Greve *et al.,* 2004).

The extant literature has highlighted several characteristics that define routines (see Becker, 2004, for extensive review). Routines are recurrent and a source of stability and continuity in organizations (e.g., Amit and Belcourt, 1999; Coombs and Metcalfe, 2000; Nelson, 1994). They are context-specific and embedded in an organization (e.g., Lippman and Rumelt, 1982; Nelson, 1994; Winter and Szulanski, 2001). Routines also serve to coordinate actions of multiple organization units or actions by individuals (e.g., Dosi *et al.,* 2000; Gersick and Hackman, 1990; March and Olsen, 1989; Nelson and Winter, 1982). Routines speed up and simplify recurrent information processing tasks and decision making and thereby enable recognition of non-routine events (e.g., Cyert and March, 1963; March and Shapira, 1987; Postrel and Rumelt, 1992; Reason, 1990). Routines mediate uncertainty by increasing predictability and hence freeing limited cognitive resources (Baumol, 2002; Hodgson, 1988; North, 1990). Routines can,

therefore, enable both stability and adaptation (see, e.g., Feldman, 2000; Feldman and Pentland, 2003; Feldman and Rafaeli, 2002). Routines constitute also a form of 'organizational memory', as they contribute to building the stock of knowledge in an organization, and tacit knowledge in particular (e.g., Knott, 2003; Nelson and Winter, 1982; Teece and Pisano, 1994; Teece *et al.*, 1997; Winter, 1994).

Another aspect of routines concerns the consciousness with which actors follow routines (Becker, 2004). Some authors argue that routines are used and applied automatically (e.g., Cohen, 1991; Dosi *et al*., 2000; Gersick and Hackman, 1990; Kilduff, 1992, Louis and Sutton, 1991; Nelson, 1995; Postrel and Rumelt 1992; Weiss and Ilgen, 1985). Others believe that routines are not mindless and imply some cognitive processes in applying them (e.g., Costello, 2000; Feldman, 2000 and 2003; Feldman and Pentland, 2003; Pentland, 1995; Pentland and Rueter, 1994; Perren and Grant, 2000). Whether routines are applied automatically or require cognitive processes, the execution of practiced routines does not assume or require understanding of the knowledge basis of the routine or rationale for it.

Practiced routines embody codified as well as tacit idiosyncratic knowledge. The knowledge basis of routines is assumed to evolve through many different mechanisms and processes including problemistic search, trial and error, improvisation, learning by doing, directed search, and variation and selection processes (e.g., Cohen, 1991; Dosi *et al.,* 2000; Gersick and Hackman, 1990; Kilduff, 1992; Nelson, 1995; Louis and Sutton, 1991; Postrel and Rumelt, 1992; Weiss and Ilgen, 1985). Moreover, routines are highly organizational idiosyncratic, contextual, and tacit. Despite this considerable conceptual literature, research on routines is hampered by a lack of empirical measurement necessary for any validation of the theoretical construct (Felin and Foss, 2006). This poses a challenging task for studying routines empirically (Becker, 2005; Becker *et al*., 2005) in particular those routines that underlie absorptive capacity, due to its inherent intangibility.

3. Towards a Routine Based Model of Absorptive Capacity

The conceptualization of AC as constituted by routines aims at overcoming some limitations of the extant literature, which tends to focus on measurable dimensions of AC, e.g., R&D expenditures, patents and citations. These are also limited to industries where formal R&D processes are common and where the outcomes of such processes can be protected by

patents, i.e., technological innovations. The distinction between, and identification of practiced, internal and external AC helps overcoming the limitations and drawbacks of definitions of AC in the extant literature, which overlooks the *internal* processes for AC, how organizations do identify and assimilate external knowledge *in practice*, and what are the routines at the interface between internal and external processes, like managing adaptive tension (Cyert and March, 1963) and transferring information and knowledge from the external environment inside the organizational boundaries.[1]

Lewin and Massini (2003) refine the concept of AC proposed by Cohen and Levinthal (1990) by decomposing the construct of AC into two components, *internal* and *external* AC capabilities, and identifying the configuration of meta-routines underlying these two components. Internal AC routines encompass formal and informal organizational routines and activities related to the management of internal variation, selection and replication (VSR) processes; facilitating improvisation and enabling the emergence of new ideas within organizations; selecting ideas for further development; reflection and updating regimes; assimilating new knowledge; sharing it internally and exploiting it; managing adaptive tension and pacing rate of change; enabling firm combinative processes; replacing old practices and integrating new superior capabilities; and routines for sharing superior practices within and across subunits of an organization.

External AC routines relate to organizational routines for identifying relevant knowledge from the external environment, acquiring (and sharing it internally via various internal routines for sharing knowledge). External AC routines include meta-routines for scanning and monitoring changes and developments in the environment, exchanging and sharing information with partners, suppliers and competitors, and appropriating and gaining competitive advantage from knowledge spillover.

Table 2 refines the earlier work by Lewin and Massini (2003) and identifies the configuration of meta-routines that are theorized to underlie AC capabilities of an organization.

[1] In this paper we use the adjective "internal" to refer strictly to routines and processes which occur within a firm's boundaries. We treat routines for learning and transferring knowledge within the organizational boundaries as internal. However in the case of multi-differentiated companies, large MNEs which are dispersed over a number of different locations, and companies that grow by acquiring firms dispersed in different geographical, cultural, social and institutional environments, this may become problematic. In these cases, sub-units or foreign subsidiaries and operations could be considered as other organizations. External AC routines would be developed and implemented to acquire knowledge from these (foreign) units, whereas internal AC routines would be used for transferring, creating and assimilating knowledge within units.

Table 2: Internal and external AC meta-routines

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3.1 Practiced Routines as an Expression of Meta Routines

The expression of meta-routines can be observed in organizations as actual practiced routines which are contextual and idiosyncratic to each organization. In this section we elaborate the logic of each meta-routine and provide examples of associated practiced routines.

3.2.1 Internal absorptive capacity routines

Facilitating variation

Facilitating variation involves more than the ability to recognize the value of new knowledge. It requires various processes and norms that facilitate the emergence as well as the exploration of new ideas at different levels of the organization. The 3M Company case provides some insights into rules and norms conducive to the emergence of new ideas. The company has a policy that 15% of employees' time remains unaccounted. Employees are encouraged to use this "free" time to pursue individual projects of their choice without having to disclose or justify the project to their manager (at Google engineers devote 20% of their time to personal projects). This policy aims at fostering experimentation with new ideas, products, technologies that could become commercial success in the future. In addition to creating free time for employees to explore new ideas, employees can be granted up to $50,000 of seed capital to develop their new product ideas with the help of a venture team that they recruit.

How people are organized in various teams, departments, functions, and even office space can also foster or constrain a firm's capability for stimulating the emergence of new ideas. Previous research has shown that organizing people in cross functional teams to work around projects, having people change from jobs within and across functions, and facilitating their informal interaction for example through an open office plan (see extensive case study of IDEO by Hargadon and Sutton, 1997) can foster improvisation, encourage exploration of new ideas without impeding exploitation of existing knowledge, and contribute to the emergence of innovation (e.g., Nonaka, 1994; Nonaka and Takeuchi, 1995; Amabile *et al*., 1996; Amabile and Conti, 1997; Cummings and Oldham, 1997).

The combination and recombination of existing knowledge is another source of new ideas. Combinative capability is the ability to synthesize and apply current and new knowledge (Kogut and Zander, 1992). It is similar to the “integration” concept in Grant (1996) and the “configuration” concept in Henderson and Clark (1990). An example of facilitating combinative capability can be found again in the case of 3M. The Technology Forum is a loosely organized professional network of scientists and engineers at 3M. The objective is to encourage knowledge sharing inside the company in order to eventually lead to cross-business innovations. A concrete example of innovation that was made possible by the combination of knowledge coming from different units in the company is 3M Multilayer Optical Film. The origin of this new technology with applications in diverse markets is to be found in the Technology Forum where a laser physics expert connected with an expert in multi-structuring. 3M complements the Technology Forum by a Technical Council where scientists from different units meet periodically to discuss and share information related to different technology projects, and by the use of a knowledge management database. Analog Devices, Baxter International, IBM, Hewlett-Packard and Xerox all share variations on the idea of soliciting engineers and scientists to propose ideas that represent significant exploration challenges, but which involve combination and recombination of external and internal knowledge.

IDEO has a somewhat different approach to facilitating combinative processes. The product design firm’s main repository of knowledge is its individual engineers. Beyond developing a strong expertise in a particular area, each designer develops knowledge on who has what particular technical knowledge in the company. Brainstorming sessions at the beginning of each project and throughout the projects enable retrieval, combination and recombination of prior knowledge as they develop new technical or design solutions. The brainstorming environment also emphasizes suppressing of negative feedback to enable open discussions. More generally suppressing negative feedback is an important aspect of facilitating variation and opens the exploration of ideas.

Other indirect means for stimulating and increasing employee interaction, promoting problem solving and creative action involve organizational structures (Sheremata, 2000) and social integration mechanisms that build interconnectedness. These mechanisms facilitate free flow of information (Sheremata, 2000).

Managing internal selection regimes

The utilization of new knowledge depends on the processes firms put in place to select the various projects and activities to invest in and to determine how to allocate resources among them. These mechanisms for managing internal diversity (Jacoby, 2004) are referred to as the 'internal selection regimes'. In some cases firms may develop resource allocation processes that encourage investments in non-mainstream activities but in other cases over reliance on financial reviews may limit investments in exploration efforts and hence limit the likelihood of firms experimenting with new options (Cooper *et al*., 2001). Internal selection takes place at the level of individuals, group, or top management (Plunket, 2003). At the individual level cognitive limitations can prevent the person from recognizing that new knowledge may have become available and some pieces of information may be selected out automatically, regardless of their potential value. At group or team level, selection is often reflected in the common belief of what is appropriate to do, to experiment or not, and to pay attention to or not. Top management influences the selection process by establishing the norms, procedures and metrics that manage selection and retention of projects, practices and activities inside the organization (e.g., Miner, 1994; Warglien, 1995; Lovas and Ghoshal, 2000).

Intel offers two interesting examples. First, Burgelman (2002) noted that Intel evolved a shared sense of the boundaries defining the PC ecology and that projects that were considered to fall outside those boundaries did not get funded. However, this shared sense of the PC ecology boundary was not a formalized definition. Second, Burgelman (1991) describes the role of a dynamic resource allocation rule that mediated the change in resources allocated to lines of business within Intel. Each year the allocation of resources (funding, staff, space, etc.) was weighted by the change in the average gross margin of the business. The application of this dynamic rule partially explains how during the 80's, Intel transformed itself from a 'memory company' manufacturing and selling DRAM's to a microprocessor company, as a direct consequence of a resource allocation rule that systematically shifted resources to higher margin projects in the microprocessor business.

Another rather unique selection process is 3M's approach of 'make a little sell a little'. This reflects 3M's belief in seeking, whenever, possible market signals for guiding decisions to continue with a new product or technology or entering a new market, or terminating a project. In other words, projects will not be terminated as long as a positive signal is coming from the market.

IDEO also has a simple rule defining the minimum requirement for a project to be allowed to move from the prototype stage to the next development phase. The first steps of any new product development project at IDEO are targeted at the development of a prototype that must perform at least as well as what is available in the market. In addition to constituting one criterion for a 'go-no go' decision, this process also forces engineers to learn about available technologies. Moreover, alternative solutions developed as part of the effort to come up with a prototype that satisfies the minimum requirement provide knowledge about technological possibilities and limitations that can prove useful later in the project or for other projects.

Managing reflection and updating

Dynamic capabilities imply that organizations also have a set of routines or processes that facilitates the updating of products, technologies and processes. The learning literature suggests that updating occurs as the result of problemistic search processes (Cyert and March, 1963), in the process of learning by doing (Arrow, 1962; Rosenberg, 1982; Epple *et al*., 1991; Argote *et al*., 2003), through processes of codification of knowledge and past experience (Levitt and March, 1988), retrospective sense making (Weick, 1995), or the imitation of competitors' superior practices (Szulanski, 1996; Rivkin, 2000). In contrast to bottom up, random or informal learning processes, reflection routines (Zollo and Winter, 2002) are intended to enable firms to formally update their capabilities at specified intervals or as an integral step in a process. Szulanski (2000) describes the merger and acquisition conversion process at Banc One which involved formal expectations that during the process, problems become key checkpoints and then transformed into specific tasks for updating the bank conversion process. In particular, the reflection and learning process required that same problems will not be repeated in future updated conversions. However, the repeated replication of successful knowledge based routines can become barriers to updating such knowledge (Szulanski, 1996). This suggests that Absorptive Capacity also requires formal reflection and updating routines.

Sharing and assimilating knowledge and superior practices across and within subunits.

There are a myriad of ways by which organizations transmit and share information: company-wide meetings, workshops, individualized seminars, brochures and other print materials distributed across the organization, formal and informal liaison structures and processes between corporate groups, business units and facilities. Establishing face to face interactions

has been shown to be instrumental for building and maintaining effective social innovation networks, which in turn generate trust, respect and commitment, necessary for continuing interaction and knowledge sharing, even in globally dispersed organizations (Orlikowski, 2000). Lenox and King (2004) show that launching internal programs aimed at distributing information on the value of new practices and on how to implement them can play an important role in developing absorptive capacity for fostering the adoption of these new practices.

Szulanski and Winter (2002) find that transferring knowledge and best practices within a company to be a challenging task that often results in failure when the receiving unit tries to apply the transferred knowledge. Transferring best practices within a company involves the replication of organizational routines (Winter, 1995; Szulanski and Winter, 2002). Sticky information, as suggested by von Hippel (1994), makes this replication process non trivial. In addition, the degree of codification and how easily capabilities are taught (and transferred) also influence the speed of transfer (Zander and Kogut, 1995). Argote (1999) and Argote and Ingram (2000) have reported similar findings. The argument is that most firms fail in trying to replicate best practices from another part of the organization because they do not have a good understanding of what made it work the first time. In order to overcome this challenge Szulanski and Winter (2002) introduce the principle of 'copy exact', meaning that companies should start by exactly replicating all routines underlying the best practice being transferred and only after the practice has shown satisfactory results, should they work on improvements and adaptations. This practice is used, for example, by Intel to transfer an optimized manufacturing process that has been implemented in one particular plant across other plants (Burgelman, 2002).

'Monday morning' meetings or company-wide emails sent to all members of an organization are another way of transferring and sharing knowledge from one part of the organization to another. The objective is to keep all members up-to-date with the latest developments happening at various places of the organization. Such company-wide emailing is a practice used by Emerson Group to share E-business experiences across its 600+ different business units. At IDEO 'Monday morning' meetings are an important way for sharing knowledge between engineers (Hagadorn and Sutton, 1997).

Knowledge sharing can also be greatly enhanced when it is part of the corporate culture and individual evaluation criteria of a company, such as at Emerson, or when employees are rewarded for sharing knowledge, such as at 3M which rewards successful sharing of new

technologies among its business units. Jack Welsh at GE introduced the idea of 'stealing and sharing' (Kerr, 2000) as a metaphor for reminding (Ocasio, 1997 referred as directing attention) employees about the sin of protecting and not sharing 'proprietary' knowledge. Managing the process of 'stealing and sharing', including the process of declaring an idea or practice as 'best in class', became a formal responsibility of the Chief Learning Officer (CLO) at GE who was responsible for first assessing the importance and relevance of an idea and subsequently, if it was deemed "best in class", for disseminating it throughout GE.

According to Zollo and Winter (2002), adoption of such superior capabilities would result from both semi-automatic accumulation of experience and deliberate learning activities. The capacity to integrate superior capabilities can also be developed through the training of employees and specific HRM practices that can contribute to the development of AC (Minbaeva *et al.*, 2003). The argument relies on the fact that building an organization AC also demands the development of the AC of its individuals. Training would enable to adopt superior capabilities/practices both directly and indirectly: directly if the training concerns a particular superior practice, and indirectly if the objective is to increase the general knowledge of individuals.

Managing adaptive tension

Several theoretical formulations assume that survival in the long run requires that the organization internal rate of change must exceed the relevant external rate of change in the environment (Ashby, 1956; Anderson, 1999; Lewin and Volberda, 1999). This suggests that organizations require some stimuli or routines for managing adaptive tension (creating goals and expectations that stimulate change).

Cyert and March (1963) define adaptive tension in terms of goals established for the previous period, past experience with that goal, and the value placed on the experience of competitors on the same goals. This model suggests that the choice of a comparison group can be very influential on mediating the adaptive tension of the firm (rate and aspiration for change) (Massini *et al*., 2005). Ceteris paribus, selecting the average of the population as a comparison group is expected to mediate organization change at a rate that tracks the population average rate of change (Lewin and Massini, 2003). A firm can become self referential if it does not compare itself to a reference group. Christensen (1997) associates self referential with an inability to recognize the actions of hyper competitive competitors (D'Aveni, 1994) that change the rules of the game. Self referential is often associated with over exploitation; the organization rate of

change is expected to lag the average rate of change of population and its hazard rate is expected to increase. Managers in self referential organizations may also manage adaptive tension by imposing stretch goals which are intended to drive internal rate of change. Collins and Porras (1997) describe the role of Big Hairy, Ambitious Goals (BHAG) to create energy and drive change.

An example of company guideline that drives internal rate of change comes from Jack Welsh's insistence that GE's rate of change should exceed the rate of change in its external environment. Ocasio (1997) and Hoffman and Ocasio (2001) referred to such guidelines as directing attention. However, it was not clear how managers were expected to comply with this rule. When combined with Mr Welch's early dictum that GE divisions must become number 1 or 2 in their sector, the imposed comparison benchmark served to create the adaptive tension that mediated the rate and level of change.

Because managing adaptive tension involves some form of comparison to the external environment (e.g. select comparison group and place some weight on the value of the information) and compare to its internal rate of change, in Table 2 we place this meta-routine at the interface between internal and external AC routines.

Table 3 which follows summarizes the practiced routines discussed so far and includes additional examples for each of the five internal meta-routines.

Table 3: Examples of internal AC practiced routines

- ***Insert about here –***

3.1.2 External absorptive capacity routines

Learning about external environment

Learning about the environment implies learning about technological and product developments and about the market and potential directions. This is reflected in the application of organizational capabilities and processes such as market research, end-users surveys, and meeting with customers to assess their future needs (Kholi *et al*., 1993). Kholi *et al*. (1993) also point to the importance of informal social interactions with industry and trade partners.

The necessity of developing AC capabilities for learning about the external environment was noted by Cohen and Levinthal (1990). They suggested as, one example, that companies have formal or informal gatekeepers who monitor the environment. The central role of these gatekeepers who serve as the interface between an organization and its external environment was underlined by Allen (1977) and Tushman (1977). Gatekeepers are of particular importance when the external information is not directly related to core activities of the organization and requires contextual interpretation to be considered useful by other members of the organizations.

Brown and Eisenardt (1998) introduce the concept of probing the future with a wide range of low-cost probes across multiple time horizons. It is a form of constant screening of the environment but with thin attention. For example, Amgen used a probing strategy to learn when a certain process breakthrough was discovered which was crucial to move forward in stem cell therapy.

Another routine implemented by companies in technology based industries is making regular use of patent search strategies not only in support of their applications for patents, but also as a way to monitor and scan patents applications (and scientific publications) by competitors, research institutes and universities as a source of information on technological developments in their and related fields and learn about their relative position in the development of technological innovations.

Learning from partners, suppliers, customers, and competitors

Collaborative inter-firm relationships such as co-development or co-practicing alliances or joint ventures involve important organizational capabilities for learning about the environment. Success with managing strategic alliances, especially learning alliances, depends on the AC of the partners and the ability of partners to keep pace with one another in the development of new knowledge and assimilating and integrating it internally (Koza and Lewin, 1999). It is also facilitated by developing stable patterns of collaboration between the two partners (Zollo *et al.*, 2002). Developing such cooperative competencies is complementary to the development of technological competencies that require exchanging and sharing of information with suppliers and competitors (Tyler, 2001) and serve to accelerate access and transfer of knowledge (Lorenzoni and Liparini, 1999). Cisco, for example, has implemented a web based system for collaborating with suppliers. The intensity of the collaboration and mutual obligations vary with the collaborative status of suppliers. Suppliers are granted different levels of access to Cisco

extranet. Suppliers with the highest status are expected to monitor incoming orders, identify components that they are responsible for, self initiate production and deliver components to assembly plants (mostly sub contractors) just in time. This is not dissimilar from the networks developed by large Japanese companies, especially in the automotive and electronics industries, which have been important sources of innovative ideas and products. What could be a standard relation in a supply chain may become a source learning if close relationships, built on mutual trust develop over time.

Learning-by-using is a crucial aspect of developing new technological products and designs. The idea is to identify lead users (Von Hippel, 1984, 1985, 1986) of a new technology very early on in its development process. These lead users may not already formally express the need for the particular technology but have certain characteristics that make them likely to be pioneers of the technology and lead other potential users to experiment with it. Active collaboration at various stages of development of a new technology between lead users and producers can be central to make the innovation both a technological and a market success.

Close collaborations for the development of new knowledge and new technologies, often referred to as R&D partnerships (Sakakibara, 2003; Belderbos *et al*., 2004; Negassi, 2004), are another important learning mechanism. R&D partnerships may be launched with universities and other scientific institutions but also with customers, suppliers and competitors (Tether, 2002). This practice involves, at least to some extent, a mutual access to the partners' knowledge bases and is therefore an effective way to access knowledge that resides in external organizations and that is not publicly available. In addition to accessing knowledge, an R&D partnership also helps both parties in applying new knowledge in their own contexts. This is of particular interest in case of complex scientific knowledge, but may also be important for non-scientific knowledge, as witnessed by the difficulty of transferring business practices across different units of a company (Szulanski and Winter, 2002).

Managing knowledge spillovers

Knowledge spillovers emerge from exchanges of information and practices in the course of learning alliances or as a result of presentations at scientific conferences, industry gatherings, discussion at standard setting task forces, or other events that promote sharing and exchanging information. Studies in the context of technological innovations have shown that the publicly available pool of knowledge grows when proprietary information becomes public or as a result

of the combination and recombination of such public knowledge (e.g., Jaffee, 1986). The appropriation of positive spillover of knowledge (other firms' R&D) can be a significant determinant in firm productivity relative to its own R&D (Griliches, 1986; 1995). Appropriating R&D spillovers can be an important driver for innovative efforts of firms (Cohen *et al*., 2002). An important aspect of firm capacity to innovate involves the ability of firms to maximize incoming knowledge spillovers while minimizing outgoing spillovers of their own knowledge (e.g. Levin *et al*., 1987; Cassiman and Veugelers, 2002).

In general, there is a subtle balance between appropriating external knowledge while safeguarding valuable internal knowledge. Patents are an important source of knowledge spillovers as they constitute a very rich source of information on technological development and knowledge creation by other companies, universities and other R&D institutions (Cohen *et al.*, 2002). In order to benefit from such knowledge spillovers firms have to invest and implement routines relating to scanning, evaluating, tracking patent databases and interpreting applicability to on going or potentially new projects. Formal IPRs such as patents, copyrights and trademarks, constitute legal rights that firms have on knowledge and other intangible assets. These formal IPRs represent one way of protecting knowledge from imitation, which can be relative easy in the case of embodied technologies through reverse engineering, but because of the disclosure requirements this protected knowledge also becomes publicly available. Consequently firms tend to implement mechanisms and strategies for securing crucial internal information, such as secrecy, confidentiality agreements and lead time advantages (Levin *et al*., 1987; Cohen *et al*., 2000; Arundel, 2001). Some companies have formal IP policies that regulate handling of IP related issues throughout the company. A centralized patent department with corporate-wide responsibilities for patent coordination is a feature that has been observed by Granstrand (2000) in many large Japanese firms and increasingly adopted by Western companies. The main advantage of such department lies in the proactive management of patents. Moreover, the IP department acts as a clearing house for technical information in the company, it conducts IP-related competitive intelligence activities, and it scrutinizes competitors' patent applications to potentially fill patent litigations.

Participating in shaping industry standards can also be an important element for appropriating knowledge spillover. Firms often attempt to influence technological industry standards to fit their technological capabilities by participating in cooperative technical organizations where technical information is shared, standards are selected, future developments are discussed and

negotiated, and spillover knowledge is common (Rosenkopf *et al*., 2001). According to Rosenkopf *et al*. (2001) leadership roles in such committees can serve to influence setting agendas and provides early insights for future alliance partnerships and informal sharing of knowledge when formal linkages between companies are not feasible.

Transferring knowledge back to the organization

Being able to transfer the external knowledge back to the organization to apply it to knowledge creation activities (exploration and exploitation) is an important process central to the effectiveness of external AC routines. We locate this meta-routine at the interface between internal and external AC routines (see Table 2). Some of the internal routines for AC may facilitate the transfer of knowledge within the organization, regardless of whether it is coming from outside or inside the firm's boundaries – as we will discuss at more length in the next sections, a practiced routine may map onto more than one meta-routine. However this section is explicating practiced routines for transferring externally acquired knowledge back in the organization. The effectiveness of external AC routines (described in the sections above), such as the establishment of roles for gatekeepers and boundary spanners, or participation in committees for shaping standards and discussions of future technologies, depends very much on developing knowledge sharing processes that import such knowledge or information back to the organization (vertically and horizontally). Rosenkopf *et al*. (2001) describe examples of knowledge sharing and exploitation within company involved in inter-firm relations such as industry or regulatory standard setting bodies. In this research the variation in knowledge sharing outcomes is explained by whether the company representative was assigned to the project directly related to the technology development affected by the standard or to a new project. When company expert was assigned to a new project, the project impacted by the new standard did not have the benefit of exploiting knowledge spillovers or tacit knowledge acquired by the expert during the standard setting process. While the routine of assigning the subject matter expert to the project or projects affected by the new standard may constitute a crucial link between internal and external knowledge acquisition, we have not been able to identify in the literature other examples of such practiced routines, most likely because such processes tend to be self-organizing and how the process evolves probably depends on the individual subject matter expert inclination and social behavior for sharing and disseminating the relevant information and knowledge acquired externally. In the absence of formal or informal processes for disseminating externally acquired knowledge or information, the boundary spanner

behavioral attributes may be central in determining the effectiveness of exploiting knowledge spillovers or tacit knowledge.[2]

Table 4: Examples of external AC practiced routines

- ***Insert about here –***

3.2 Practiced AC Routines, Organizational Capabilities, and Innovation and Imitation

The extant literature on diffusion of innovation (e.g., Davies, 1979; Rogers, 1983), innovation and imitation behaviors (e.g., Massini *et al*., 2005; Rivkin, 2000), industry life cycle (e.g., Klepper, 1997) and institutional theory (DiMaggio and Powell, 1991) has advanced various theories to explain why some firms tend to initiate change while other firms prefer to wait and adopt innovation later in its diffusion cycle. Normative and mimetic isomorphic pressures are presented as major explanatory processes of the diffusion of innovations through imitation of early adopters by the majority of firms (e.g., DiMaggio and Powell, 1983). Consistent with a behavioral model of adaptive tension, Lewin and Massini (2003) propose that the bi-modal distributions of innovators and imitators discussed by Cohen and Klepper (1992), could be explained by the preference of firms for adaptation strategies that monitor and track the rate at which the average of the population changes. Lewin and Massini (2003) argue that early and late adopters[3] of a same new business practice differ in the configuration of their hierarchy of routines underlying their absorptive capacity. Late adopters are expected to have less elaborated routines for AC than early adopters as they only need to absorb codified and mature practices and knowledge. In particular the external AC routines are expected to be less developed (e.g. routines for interacting with the external environment such as sharing

[2] Szulanski (1996 and 2000) finds that weak knowledge endowment of the receiving unit prior to the transfer (what the author refers to as lack of AC), causal ambiguity and strenuous relationship between the source and the recipient are the factors that explain stickiness in process of transferring knowledge and best practices. Together with the creation of knowledge, its transfer within a company would be a key source of competitive advantage, especially to MNCs (Bartlett and Ghoshal, 1989; Minbaeva *et al*., 2003). As shown by Gupta and Govindarajan (2000) in the context of multinational corporations, knowledge flows across subunits would depend on the subsidiaries' knowledge stock, their disposition to share knowledge, and the richness of the transmission channels. However, the downside of being able to easily transfer knowledge and replicate best practices across subunits of a company is that they are also more likely to be imitated by competitors (Zander and Kogut, 1995).

[3] Unless specified, early adopters include first movers (innovators) and fast followers (early imitators), as opposed to late adopters and laggards (see also Lewin and Massini, 2003).

information with competitors, safeguarding internal knowledge and appropriating knowledge spillovers) and less frequently practiced. Furthermore, while it is true that certain routines are necessary for late adopters as well and that firms that possess them are more likely to succeed, the innovation rents they will be able to appropriate will be lower because they are late.

Conversely, success in early adoption of a new practice is expected to require more, and possibly more complex, AC routines. Firms that have developed and practice elaborated AC routines will be better at identifying and valuing information on the new practice to experiment. If needed to implement the new practice they will also be more capable to seek help from other organizations or from other parts of their organization, which should increase the likelihood of success. First mover advantage would partly result from the implementation of adequate organizational routines that support improvisation, experimentation, learning-by-doing, trial and error, appropriation of external knowledge, and internalization of new routines. Companies that seek to be first movers but do not practice the required AC routines are more likely to fail, suggesting that first mover strategies do not necessarily lead to first mover advantage (e.g., Lewin and Massini, 2003; Silverberg *et al*., 1988). Companies need to develop both internal and external AC routines because they are both at the origin of VSR processes which underlie innovation dynamics. Firms that extensively practice specific routines to manage both internal and external variation-selection-retention processes (VSR) are considered to have a high level of AC. External AC routines are by definition observable, compared to the internal ones, they are more likely to be imitated and adopted by competitors. However, due to complementarities between internal and external AC routines, external AC routines alone are not worth much. Only if the company is capable of transferring the knowledge back to the organization, integrate it with knowledge creation activities and internal AC routines are external AC routines useful. This also implies that innovators are less concerned about imitation processes by imitators because if they imitate mainly external AC routines, they are not likely to benefit fully from the adoption of new routines. Superior AC capabilities also mean that firms are able to manage structural interdependencies and complementarities between routines, and between technological and organizational innovations. All else equal, the effectiveness of AC capabilities is also contingent on routines, processes, and organizational forms (Van den Bosch *et al*., 1999), that facilitate the integration of internal and external meta AC routines to achieve and benefit from potential interdependencies and complementarities among the configurations of these routines and an overall understanding of why and how AC capabilities enable innovation and change. However, highly hierarchical structures generate a level of complexity and rigidities which hamper

flexibility and resilience necessary to create or adopt innovations, develop AC routines, and successfully introduce and manage complementarities. The complexities resulting from interdependencies and complementarities between the internal and external AC routines, to be early successful adopters of a new practice firms may need to not only practice certain AC routines but also to discover and learn to master them as a *bundle* of routines not readily observable by competitors. This learning process would protect the first mover advantage of early successful adopters from easy imitation and enable them to lead the way as the new practice becomes successively more standardized diffuses to other firms in the industry and in other industries.

Cohen and Levinthal (1990) discuss learning capabilities and problem solving skills, arguing that they are “so similar that there is little reason to differentiate their modes of development” (p.130). They maintain that what differs is the content of what is learnt: problem solving lead to creation of new knowledge and learning capabilities to assimilate existing knowledge. In any case, they are both fundamental to developing knowledge and therefore to AC. In our framework, this distinction may reflect differences between innovators and early adopters. They both have high levels of AC routines and capabilities but the former are more likely to have problem solving skills, whereas the latter have incremental learning capabilities. According to Lieberman and Asaba (2006) the learning rate affects the dynamics of imitation. If experiential learning is slow, then mimetic processes may yield behaviors that are durable, even if suboptimal. If experiential learning is fast, firms can wait until outcomes are clear and unambiguous. Early movers will resolve uncertainties and followers will converge on good choices. Followers can invest in AC to facilitate learning from others and speed up implementation. In particular, firms with strong AC may delay commitment and collect better information without compromising their ability to respond. AC extends the window for effective action, reducing risk and allowing for better decisions regarding whether to imitate at all. However, this does not take into account that developing AC is path dependent and technology specific (Pavitt, 2002). In our framework (see also Lewin and Massini, 2003), the distinction between fast and late followers (or early adopters and imitators) and their underlying AC capabilities implies that the former still need to invest heavily in developing AC especially in the event of paradigmatic shifts in the currently adopted technologies, and the latter are likely to have developed lower levels of AC capabilities. Therefore, the learning rate affects the dynamics of imitation, but it is the AC capabilities that mediate the learning rate in the first place.

Cohen and Levinthal (1990) also point to the path dependence inherent to the concept of AC as the development of absorptive capacity is highly dependent on previous R&D investment realized by firms. Discovering the routines that underlie AC offers a new avenue to investigate the path dependence of AC. Zollo and Winter (2002) argue that organizational routines evolve as a result of firms reflecting on their past experience and updating their routines in accordance. The learning process by which firms gradually improve or change their AC routines would explain the path dependence of the development of the required AC routines to successfully adopt a new practice. This path dependence prevents late adopters to totally fill the gap in routines and match the success of early adopters. In other words, success in the adoption of new practices is path dependent because successful early adopters continuously learn and further develop their absorptive capacity capabilities. As a result they are able to consistently lead the way in the diffusion of the practice.

There are also a number of factors that are likely to mediate the relationship between AC capabilities and timing and success of adoption of a new technology or new business practices, such as the presence of key people in the organization, the incentive structure to information and knowledge sharing, transfer and utilization, and the institutional environment in which firms operate.

A critical element of the development of AC routines and consequent early successful adoption of a new technology or new practice may be the presence of a key figure in the organization, a ‘smart guy’ who inspires and supports innovative behavior, the development of internal and external AC routines, at organizational and individual level. In some cases, he may sense the emergence of the new practice ahead of others managers or competitors and champions its experimentation and further diffusion in the company. Formal stretching and challenging incentive and reward structures related to innovation rates and other performance measures will increase likelihood to generate, develop and adopt innovations more frequently and intensively than in firms with fewer, less demanding or non innovation-related incentives. Incentives may be necessary to motivate people to create a general attitude to knowledge sharing and transfer (Minbaeva *et al.*, 2003), make use of the knowledge they absorb (Baldwin *et al.*, 1991), develop a culture of asking for solutions and help for problem solving (Hargadon and Sutton, 1990), and even penalizing for not conforming to such behavior. Highly skilled employees and people with high learning capabilities may not be enough to develop AC capabilities if there are impediments, such as hierarchical organizational structure, bureaucracy, and which prevent and

hamper the development of innovative and flexible organizations. In any case, beside the organizational structure of companies, the literature suggests that the corporate culture and the values and beliefs that are shared among members of an organization can also play a role in facilitating variation (e.g., Tushman and O'Reilly, 1997; Chatman and Cha, 2003).

Other factors affecting the development of innovative and AC capabilities are nation state institutional configurations, country culture and socio-economic conditions (Lewin and Kim, 2003). Specific national contexts, characterized by institutional, cultural, historical features, as well as industrial groups, and their institutionalized practices, affect adoption and implementation of new technologies and organizational routines. Technological opportunities, appropriability regimes and mechanisms, spillover effects tend to vary across industries (Pavitt, 1984) and countries (Malerba and Orsenigo, 1996). The configuration of organisations and institutions in public and private sectors (firms, banks, universities, governments, etc.), formal structures with explicit goals and purposes, and the sets of habits, routines, rules, norms and legal statutes, that regulate the relations and interactions between actors (people, organizations, etc.) and the structure of incentive for promoting and protecting R&D and new intellectual property constitute National Innovation Systems (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Whitley, 2002), which influence rate and direction of technological learning in a country (Patel and Pavitt, 1992) and the development of AC capabilities within a specific national or technological environment. For example, the success of the Japanese innovation system in the 1980s has led innovation and management scholars to analyze and understand its features and characteristics (institutions and practices) (e.g., Freeman, 1987) to be adopted and adapted in Western environments in the attempt to narrow the productivity and innovative gap.

To summarize, the timing and success in adoption of an innovation is determined by the configuration of routines constituting firm AC and is mediated by the design of firm incentive structures, choice of reference group and environmental factors including industry sector, R&D intensity and national systems of innovation (Freeman, 1996; Lundvall, 1992; Nelson, 1993; Edquist, 1997). Ceteris paribus, firms in R&D intensive environment may adopt higher levels of new organizational innovations and organizational innovations (Massini *et al*., 2002) and need more elaborated absorptive capacity routines than firms in non-R&D intensive environment. When comparing the adoption of same new business practice across countries differences may also result from differences in national systems of innovation (Nelson, 1995) and national cultures and institutions (Lewin *et al*., 2003). Another important contribution of this framework is

the explicit introduction of path dependence in the relationship between AC routines and adoption of new business practice. Early adopters of a new management practice or new process or new product practice are more likely to also reflect on their capabilities and routines and update them based on their previous experience (Zollo and Winter, 2002). Massini *et al*. (2005) show that early adopters (innovators) are more likely to compare their experience with that of other early adopters and therefore, this learning process is more likely to continue advancing the competition for further innovations while earlier innovations or management practices become more standardized and diffuse to become industry accepted practice. Conversely, firms that recognize and adopt the benefits of a new practice later in its diffusion cycle are less likely to have configured and developed absorptive capacity routines, especially the external ones, necessary for matching or leapfrogging the early adopters. In other words Massini *et al*. (2005) observation that early adopters (innovators) are the source of variation in the population and later adopters (imitators) are the source of decreased variation is very likely mediated by different configurations of AC routines. However, all else equal, maintaining an early mover advantage over time requires uncovering and managing complementarities among AC routines and updating the mix of routines of the organization as new knowledge is created or becomes available over time. The complexity of AC not only results from more complex individual routines practiced by firms but also from complementarities that may exist among different routines (e.g., Narduzzo *et al*., 2000, Rivkin, 2000 and 2001). Therefore, uncovering the underlying internal and external routines of AC enables to investigate the role played by both the level of AC and the complexity of AC in influencing the adoption of a new business practice. More empirical research is needed to discover and document the range of routines underlying the meta-routines outlined in this paper. It is likely that further research into practice routines underlying AC capabilities will identify configurations of interrelated routines, consisting of combinations that are substitutable, and others that are complementary that must be executed together to achieve particular AC mediated outcomes. Previous studies have indeed pointed to the importance of complementarities in the combination of activities undertaken by the firm as an explanation of observed performance heterogeneity (Ichniowski *et al.*, 1997; Massini and Pettigrew, 2003; Milgrom and Roberts, 1990) and the difficulty in imitating superior capabilities of competitors (Lenox *et al*., 2004; Levinthal, 1997; Rivkin, 2000, Teece *et al.*, 1997).

4. Summary and Conclusions

This paper seeks to refine our understanding of absorptive capacity by distinguishing between internal and external AC routines and integrating research on absorptive capacity, organizational routines, and innovation and imitation. In theories of strategic adaptation, survival and competitive advantage are interpreted to result from unique resources and capabilities or superior regimes of routines (Lewin *et al*., 2004). One objective of this paper is to identify and describe the routines that constitute AC and provide examples of such practiced AC routines. Uncovering the configuration of practiced routines that constitute the AC capability of an organization is a necessary step for scholars to operationalize the construct of AC and for studying the mediating role of AC in determining timing and success of creating and assimilating new knowledge. As the many examples of practiced routines illustrate, it is feasible to undertake both clinical field studies and survey methods intended to create a mapping between the proposed meta-routines that underlie AC capabilities and firm specific practiced routines. This creates the basis for identifying clusters of routines along each meta-routine as well as for discovering complementarities between clusters of practiced routines. The proposed routine-based conceptualization of AC is intended as offering one new future direction for research on A Behavioral Theory of the Firm (Cyert and March, 1963; Argote and Greve, 2007).

Originally the notion of AC has been defined and applied to technologically intensive business environments (Cohen and Levinthal, 1989 and 1990; Henderson and Cockburn, 1998; Lane and Lubatkin, 1998; Mowery *et al*., 1996; Veugelers, 1997), but increasingly it has been applied to less technologically intensive businesses without considering whether those aspects of AC crucial to high tech firms were relevant or not to those environments and studies. Moreover, no attention has been drawn to the routine structure underlying AC, which brings in the characteristics of routines (tacit, informal, firm-specific and idiosyncratic) in the notion of AC. In this paper, we argue that AC routines are a subset of dynamic capabilities, and that different AC routines and capabilities can explain innovation and imitation behaviors. The timing and success in adoption of a new innovation or of a new business practice is determined by the configuration of routines constituting firm AC and is mediated by the design of firm incentive structures, choice of reference group and environmental factors including industry sector, R&D intensity and national systems of innovation (Edquist, 1997; Freeman, 1996; Lewin and Massini, 2003; Lundvall, 1992; Massini *et al*., 2005; Nelson, 1993).

The proposed taxonomy of internal and external AC routines incorporates learning capabilities, routines for reflection and updating of existing routines in response to evaluation of actual implementations. Moreover, the influence of AC on adoption of new business practices is cumulative, path dependent and constrained by firm past experience. However, AC may enable or restrict the level of exploration adaptation (Lewin *et al.*, 1999). Similar to the importance of balancing exploration and exploitation activities (March, 1991) understanding the importance and nature of internal and external AC routines, and balancing them, is a crucial managerial challenge to develop dynamic capabilities and sustained competitive advantage. Greve *et al*. (2004), Massini *et al*. (2005) and Lewin and Massini (2003) argue that firms that define the performance frontier are sources of innovative practices and technological innovations. Lewin and Massini (2003) also argue that firms that are early in adopting new practices and that adopt them successfully have superior absorptive capacity capabilities. This would result from better practiced routines for managing both internal and external VSR processes. However, very few firms in the population have the strategies and organizational capabilities for consistently balancing exploration and exploitation. Similarly it can be expected that most firms do not develop the AC capabilities that mediate the balancing of exploration and exploitation.

This paper advances the idea of meta-routines and their expression in practiced routines as new approach for explicating and researching AC. In reality practiced routine could map onto more than one meta-routine. This is because a meta-routine may have multiple expressions of practiced routines and some configuration of practiced routines may map onto more than one meta-routine (i.e., serve multiple purposes). In our formulation of a routine based theory of absorptive capacity two conditions seem to determine overall effectiveness of AC. The first is the extent to which organizations develop organizational capabilities, and processes address all the proposed internal and external meta-routines. The second involves finding complementarities between configurations of practiced routines which leverage the effectiveness of individual practiced routines. Therefore, a major empirical research agenda involves identifying the various combinations of meta and practiced routines that define the Pareto frontier of absorptive capacity. Which of the meta and practiced routines are more relevant for knowledge creation and innovation is also likely to depend on specific technological, organizational and industrial settings. The summaries of practiced routines provided in this paper (tables 3 and 4) is not intended to be exhaustive but rather to provide support to our theoretical conceptualization of internal and external (meta) routines and to indicate avenues for future research on AC routines.

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Table 1: Summary of Research Addressing Absorptive Capacity

Study	Approach	AC definition / operationalization	Sample	Variables	Contribution
Cohen and Levinthal (1989)	Conceptualization, modeling, and empirical test of AC construct	Ability of a firm to identify, assimilate, and exploit knowledge from the environment, as a byproduct of R&D	Survey of 1,719 business units in 318 manufacturing firms in the U.S. (cross-section)	Dept var = R&D intensity Main explic var = technological opportunity, appropriability, demand conditions	Dual role of R&D: generating new knowledge and enabling firms to assimilate and exploit existing information.
Cohen and Levinthal (1990)	Conceptualization, modeling, and empirical test of AC construct	Ability of a firm to recognize the value of external information, assimilate it, and apply it to commercial ends	Survey of 1,719 business units in 318 manufacturing firms in the U.S. (cross-section)	Dept var = R&D intensity Main explic var = technological opportunity, appropriability, demand conditions	AC is path-dependent. AC is highly dependent on prior related knowledge. R&D contributes to AC. AC critical to innovative capabilities.
Theoretical					
Cohen and Levinthal (1994)	Conceptualization, modeling	Ability of a firm to exploit external knowledge. AC is byproduct of R&D and/or accumulation of manufacturing experience.			AC enables firms to predict more accurately the nature of future technological advances.
Koza and Lewin (1998)	Conceptualization	Ability of a firm to utilize outside knowledge in the context of strategic alliances			AC positively influences outcome of learning and exploration alliances.
Kumar and Seth (2001)	Conceptualization	Ability to absorb new knowledge, assimilate it and apply it to commercial ends			Increased AC leads firms to i) diversification over licensing as mode of entry in a new market; ii) de novo diversification as opposed to joint ventures and acquisitions; iii) enter more distant markets
Zahra and George (2002)	Conceptualization and modeling	Set of organizational routines and processes by which firms acquire, assimilate, transform and exploit knowledge to produce a dynamic organizational capability			Two stages of AC: potential (knowledge acquisition and assimilation) and realized (knowledge transformation and exploitation)
Van den Bosch, Van Wijk and Volberda (2003)	Literature review	Ability to absorb new knowledge, assimilate it and apply it to commercial ends			Gap between proliferation of theoretical and empirical research on AC, and actual accumulation of scientific knowledge about AC
Lewin and Massini (2004)	Conceptualization	Set of routines to facilitate variation, combine and select knowledge, reflect and update routines, select and integrate superior routines, exchange information with external			Internal AC routines differ from external AC routines. AC of imitating firms limited to adopting codified mature knowledge.

		organizations, shape industry standards, transfer knowledge across and within subunits, appropriate spillovers and safeguarding internal knowledge			Innovating firms develop internal and external AC for innovation and creation of new knowledge.
Lane, Koka, Pathak (2006)	Literature review and conceptual model	289 papers citing Cohen and Levinthal (1990) from 14 journals			Suggestion of a more detailed definition of AC, proposing three sequential processes of AC
Todorova and Durisin (2007)	Conceptualization and modeling	Refining Zahra and George's (2002) model.			Reinstating of recognizing the value of external information, transformation, repositioning of social integration mechanism and power relationships, reinstating regimes of appropriability, introducing a feedback loop in a dynamic model
Empirical					
Mowery, Oxley and Silverman (1996)	Econometric study	Patents cross-citations before alliance, and R&D intensity	792 alliances with at least one partner from the U.S. formed in 1985-86	Dept var = patents cross-citations after alliance Explic var = cross-citations before alliance, R&D intensity, sales, type of alliance, non-U.S. partner, industry SIC overlap	AC measured as patents cross-citations contributes to the extent of technological capability transfer in firms' alliances, but not AC measured as R&D intensity.
Szulanski (1996)	Conceptualization and canonical correlation analysis	Ability of the recipient unit to identify, value and apply new knowledge: common language to deal with practice, vision of goal of the transfer, information on practice, clear division of roles to implement practice, necessary skills, technical and managerial competence to absorb, clarity on who can best exploit and solve problems with practice	271 observations (source and recipient units) of 122 transfers of 38 best practices in 8 companies (AMP, AT&T Paradyne, British Petroleum, Burmah Castrol, Chevron Corp, EDS, Kaiser Permanente, Rank Xerox)	Dept var = stickiness (outcome-based and process-based measures) Explic var = causal ambiguity, unproven knowledge, source's lack motivation, source not perceived reliable, recipient's lack motivation, recipient's lack AC, recipient's lack retentive capacity, barren organizational context	Internal stickiness: internal knowledge transfer impeded by recipient's lack of AC, causal ambiguity, and arduous relationship between source and recipient.
Veugelers (1997)	Econometric study	Existence of R&D department with full-time R&D personnel	290 R&D active firms in Belgium between 1992 and 1993	Dept var = internally financed in-house R&D Explic var = government R&D subsidies, R&D contracting, R&D collaboration, acquisition of external technology, AC Controls = size, foreign ownership, diversification, industry dummies	R&D cooperation positively impacts internal R&D expenditures only in the presence of AC.
Lane and Lubatkin (1998)	Conceptualization and econometric study	Ability to value, assimilate and commercialize new knowledge	69 non-equity R&D alliances between 48 pharmaceutical and 22 biotechnology companies between	Dept var = inter-organizational learning as reported by surveyed experts Explic var = relevance of other organization's knowledge;	Relative absorptive capacity: Ability to learn from partners depends on similarity in knowledge bases, organizational structures and compensation

			1985 and 1993	similarity in management formalization, management centralization, research centralization and compensation practices; number of shared research communities Control = pharmaceutical firm R&D / sales	practices.
Van den Bosch, Volberda and de Boer (1999)	Conceptualization and case studies	Ability to absorb new knowledge, assimilate it and apply it to commercial ends. Mediating variable of organization adaptation	2 cases of traditional publishing firms in the Netherlands moving into emerging multimedia complex (Het Financieel Dagblad and SDU NV)		AC is an outcome of organization forms and combinative capabilities. AC - learning feedback loop mediated by environment.
Gupta and Govindarajan (2000)	Econometric study	Capacity of an MNC subsidiary to absorb incoming knowledge from sister subsidiaries. AC attributed to 'Greenfield' mode of entry of the subsidiary (as opposed to merger or acquisition) and high proportion of foreign nationals	374 subsidiaries within 75 MNCs headquartered in Europe, US and Japan	Dept var = extent to which knowledge inflows and outflows occurred Explic var = mode of entry, size, relative economic level, incentive focus, formal integration mechanisms, socialization mechanisms, decentralization, local nationals Controls = country of origin, industry R&D, fixed assets and advertising intensity, nature of subsidiary activity	AC of MNCs subsidiaries determines knowledge inflows among subsidiaries, in addition to richness of transmission channels and motivational disposition to acquire knowledge.
Deeds (2001)	Econometric study	Number of research communities in which a firm participates (deduced from firm's scientific publications)	80 newly public pharmaceutical biotechnology companies between 1982 and 1993	Dept var = market-value-added Explic var = R&D intensity, technical development capabilities (patents, products in clinical trial and products on the market), AC Controls = hot markets, size,	AC positively impacts amount of entrepreneurial wealth created by a high-tech venture, together with R&D intensity and technical development capabilities.
Lane, Salk and Lyles (2001)	Econometric study	Ability to understand external knowledge (trust between IJV's parents, cultural compatibility with parents, prior knowledge from parents, relatedness of IJV and parents' businesses) Ability to assimilate external knowledge (IJV flexibility and adaptability, management support by parents, training by parents, formal goals fo IJV, specialization of IJV's parents) Ability to apply external knowledge (IJV's business strategy, IJV's training	78 Hungarian IJVs surveyed in 1993 and 1996	Dept var 1 = knowledge learned from foreign parent Dept var 2 = IJV performance in 1996 Explic var = AC Controls = IJV size, % of exports to sales, volatility of domestic market demand, service industries dummies	AC enables IJVs to learn from parent companies. AC positively influence IVJs performance.

		competence)			
Stock, Greis and Fischer (2001)	Econometric study	Ability to acquire external information, assimilate it, and exploit it for commercial end, measured as R&D intensity	131 new products introduced by computer modem manufacturers between 1970 and 1993	Dept var = yearly average transmission rate of new modems Explic var = size, AC	Relationship between AC and new product development performance is 'inverted-U' shaped, suggesting diminishing returns of AC.
Tsai (2001)	Econometric study	Ability to successfully replicate new knowledge, measured as R&D intensity	24 BUs in a petrochemical company and 36 BUs in a food-manufacturing company	Dept var 1 = new product introductions Dept var 2 = profitability Explic var = AC, network centrality Controls = size, competition	AC positively impacts BU innovation and performance. AC increases the positive effect of a central network position on BU innovation and performance.
Liao, Welsch and Stoica (2003)	Econometric study	External knowledge acquisition and intrafirm knowledge dissemination (principal factor analysis of survey items)	Survey of 242 SMEs from Washington State	Dept var = organizational responsiveness Explic var = task environmental turbulence, AC, strategic orientation Controls = size and organizational age	AC positively influences organizational responsiveness of growth-oriented SMEs to environmental changes. Relationship mediated by environmental and strategic orientation factors.
Jansen, Van den Bosch and Volberda (2005)	Econometric study	Potential AC = knowledge acquisition and assimilation (6 and 3 survey items resp.) Realized AC = knowledge transformation and exploitation (6 survey items each)	462 organizational units of a large European financial services firm	Dept var 1 = potential AC Dept var 2 = realized AC Explic var = coordination capabilities (cross-functional interfaces, participation in decision-making, job rotation); systems capabilities (formalization, routinization); socialization capabilities (connectedness, socialization tactics) Controls = size, age, private/business clients, past performance, urban / rural location, environment dynamism	Potential and realized AC have different organizational antecedents. Coordination capabilities enhance primarily potential AC while socialization capabilities enhance primarily realized AC.
Nieto and Quevedo (2005)	Econometric study	Survey of 4 main factors: Communication with outside environment, know-how and experience in organization, diversity and overlaps in knowledge structure, and strategic positioning	401 Spanish manufacturing companies	Dept var = innovative effort (R&D / sales) Explic var = technological opportunity (NACE codes), knowledge spillovers (industry R&D), AC	AC determines innovative effort more than industry technological opportunity and knowledge spillovers. AC also mediates relationship between technological opportunity and innovative effort.
Schmidt (2005)	Econometric study	Attribution to the fact that at least one innovation was developed thanks to external organizations (inside industry, outside industry, or research institutions)	1650 innovative companies from the 2003 Mannheim Innovation Panel	Dept var = AC for 3 types of knowledge Explic var = R&D continuity and R&D intensity, prior knowledge and individual skills, organizational structure and human resource management practices Controls = size, East/West	Determinants of AC differ depending on knowledge absorbed for innovation activities (from firm's own industry, other industries, or research institutions). Firms can develop AC by stimulating knowledge sharing.

				Germany, industry dummies	
Managerial					
Cockburn and Henderson (1998)	Econometric study	In-house basic research, 'pro-publication' incentives, and connectedness to scientific community	88,186 articles published by scientists of 20 major research-oriented pharmaceutical companies	Dept var = patents Explic var = research expenditures Mediation var = papers co-authored with universities (connectedness), 'pro-publication' incentives, and other organization variables	AC requires more than in-house research. It requires complex activities to connect with wider scientific community. 'Connectedness' mediates R&D productivity (patents).
Kim (1998)	Case study	2 major elements of AC: prior knowledge base and intensity of effort	Case study of Hyundai Motor		AC developed by proactively constructing crises to intensify the organizational learning effort. Crisis construction made possible by proactive top managers.
Jones and Craven (2001)	Case study	Ability to assimilate new knowledge	Small manufacturing company participating in teaching Company Scheme		Development of AC requires new organizational routines to codify tacit knowledge.
Minbaeva, Pedersen, Bjorkman, Fey and Park (2003)	Econometric analysis	Capacity to utilize and exploit previously acquired knowledge (key elements = employees' ability and motivation)	169 subsidiaries of MNCs in the U.S., Russia and Finland	Dept var = transfer of knowledge Explic var = employees' ability (training and performance appraisal) and motivation (promotion, performance-based compensation, communication) Controls = age, size, share of expatriates, strategic mission, cultural relatedness, country and industry dummies	AC developed through application of specific HRM practices directed towards employees' ability and motivation (e.g., training, performance-based compensation, internal communication…). AC facilitates knowledge transfer among MNCs subsidiaries.
Daghfous (2004)	Literature review	Practices that enable firms to acquire and utilize external and internal knowledge			AC is built by developing its primary element, such as R&D, cross-functional interactions among employees; physical and virtual knowledge market places, gatekeepers…
Lenox and King (2004)	Econometric study	Firm AC attributed to the adoption of pollution prevention practices	Survey of 494 facilities in 82 U.S. information and communication manufacturers between 1991 and 1996	Dept var = population prevention practice adoption Explic var = centralized provision of information, cumulative adoption, past events, related practices, compensation Controls = facility size, emissions, onsite treatment, abatement costs, regulatory permits, firm size	Internal provision of information by managers increases AC for organizational subunits to adopt new practices.

Table 2: Internal and external AC meta routines

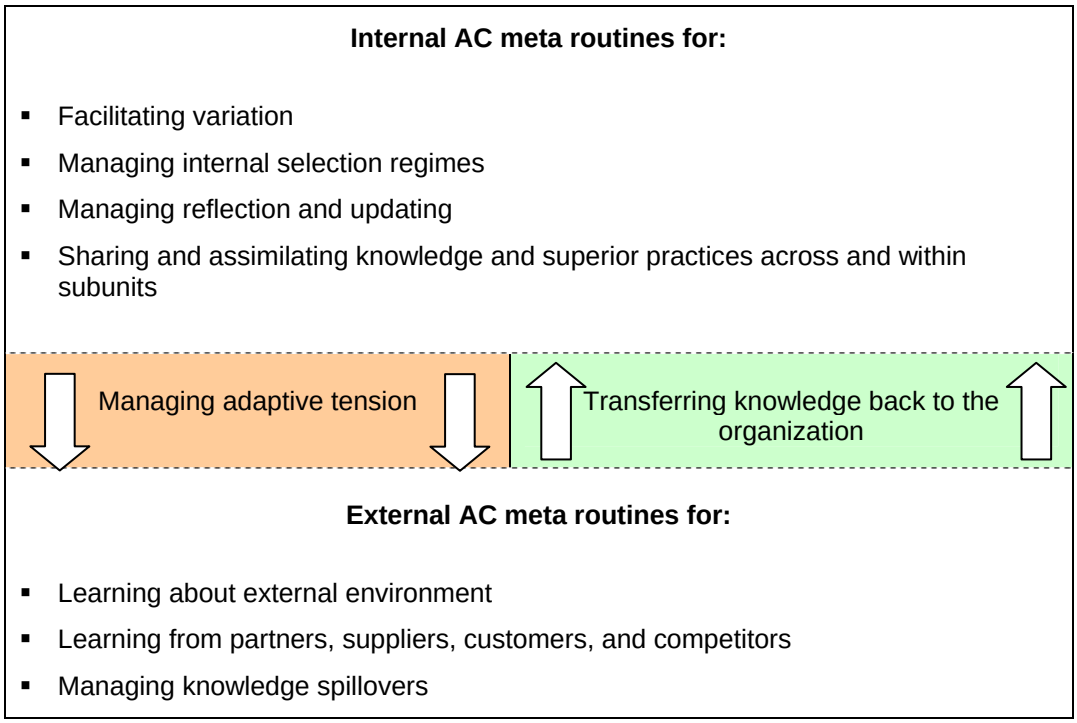

Table 3: Examples of internal AC practiced routines

Meta AC routines	Practiced AC routines
Facilitating variation	▪ Solicitation of scientists and engineers to propose and pursue innovative ideas (15% time unaccounted for at 3M, Inside Out initiative at Analog Devices, Non Traditional Innovations at Baxter International, Research Exploratory Program at IBM, 30 start up teams selected annually at Hewlett Packard, rotating council of peers to select exploratory projects at Xerox) ▪ Open office plan chosen to foster informal interactions. (IDEO) ▪ Cross-functional project teams ▪ Job rotation organized within and across departments and functions. ▪ 'Suggestion box' to encourage people to suggest improvements. ▪ Technology Forum and Technical Council. (3M) ▪ Development of knowledge on who has what particular knowledge inside the organization, in parallel to strong expertise in one particular area. (IDEO) ▪ Brainstorming sessions organized to bring together persons with different technical or market knowledge. (IDEO)
Managing internal selection regimes	▪ Development of prototypes that perform at least as well as what is available on the market. (IDEO) ▪ Shared sense of PC ecology boundaries to determine projects to be funded. (Intel) ▪ 'Autonomy of middle management to support and allocate resources to projects outside CEO's vision. (Rotemberg and Saloner, 2000) ▪ Seeking market signals ('make a little sell a little', 3M)
Managing reflection and updating	▪ Learning from good and bad experience (Banc One) ▪ Learning from managing alliances (Zollo and Winter, 2002)
Sharing and assimilating knowledge and superior practices across and within subunits	▪ 'Copy exact' principle to leverage optimization of processes across units. (Szulanski and Winter, 2002 and Intel) ▪ 'Monday morning' meetings/emails sharing knowledge and new practices within company. (Emerson, IDEO) ▪ Central provision of information on value of specific new practices and on their implementation: brochures, liaisons between corporate groups, BU, and facilities. (Lenox and King, 2004) ▪ IT-based knowledge codification system to store and manage knowledge, and retrieve it for future needs. (3M) ▪ Learning programs (in-house and external training) to increase the knowledge base of the company (Daghfous, 2004; Minbaeva *et al*., 2003).
Managing adaptive tension	▪ Internal rate of change greater than external rate of change. (GE) ▪ One and two comparison benchmark/Comparison to industry best in class as opposed to industry average. (GE) ▪ Pacing rate of change (Brown and Eisenhardt, 1998) ▪ Stretch Goals - Big Hairy Audacious Goals (Collins and Porras (1997)

Table 4: Examples of external AC practiced routines

Meta AC routines	Practiced AC routines
Learning about external environment	▪ Study of existing products in the industry and related industries. (IDEO) ▪ Reading industry trade magazines and product catalogs. (IDEO) ▪ Market research and One-to-One Marketing. (Kholi *et al*., 1993; Rogers, 1983) ▪ Gatekeepers. (Cohen and Levinthal, 1990) ▪ Probing (Brown and Eisenhardt, 1998) ▪ Informal interactions with industry actors.
Learning from partners, suppliers, customers, and competitors	▪ Co-development relationships (Dyer and Singh, 1998; Koza and Lewin, 1998) ▪ Collaborating with 'lead users'. (Von Hippel, 1984, 1985, 1986) ▪ Collaborating with suppliers (Cisco) ▪ R&D partnerships (Tether, 2002) ▪ Incentives for co-authorship of scientific papers. (Cockburn and Henderson, 1998)
Managing knowledge spillovers	▪ Mining patent literature. (Cohen *et al*., 2002) ▪ Safeguarding internal knowledge: implementing an IP policy (Novartis, Johnson & Johnson, P&G, Unilever); Centralized IP department (Granstrand, 2000); Advanced firewalls. ▪ Shaping products or technology standards (Rosenkopf *et al*., 2001)
Transferring knowledge back to the organization	▪ Sharing within company knowledge acquired in interfirm relations (Rosenkopf *et al*., 2001) ▪ Pacing the partner (Koza and Lewin, 1998)