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Managing open incremental process innovation: Absorptive Capacity and distributed learning

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ABSTRACT

In this conceptual article, we extend earlier work on Open Innovation and Absorptive Capacity. We suggest that the literature on Absorptive Capacity does not place sufficient emphasis on distributed knowledge and learning or on the application of innovative knowledge. To accomplish physical transformations, organisations need specific Innovative Capacities that extend beyond knowledge management. *Accessive Capacity* is the ability to collect, sort and analyse knowledge from both internal and external sources. *Adaptive Capacity* is needed to ensure that new pieces of equipment are suitable for the organisation's own purposes even though they may have been originally developed for other uses. *Integrative Capacity* makes it possible for a new or modified piece of equipment to be fitted into an existing production process with a minimum of inessential and expensive adjustment elsewhere in the process. These Innovative Capacities are controlled and coordinated by *Innovative Management Capacity*, a higher-order dynamic capability.

1. Introduction

The literature on Open Innovation (Chesbrough, 2003a; Lichtenthaler and Lichtenthaler, 2009) focuses primarily on the acquisition and use of externally generated knowledge by firms engaged in product development. This conceptual article, however, concentrates on process innovation by firms that are already engaged in an activity and possess existing configurations of plant and equipment. Firms in this position face constraints that can severely affect their ability to undertake process innovation, which in turn can adversely affect their competitiveness. Not only sweeping improvements that render entire production processes obsolete, but also changes to individual pieces of machinery that are embedded into larger configurations of equipment, can have broad repercussions even when the changes may at first glance seem to be isolated. This is because modifications to one machine can affect the operation of other equipment, as well as the duties and skill requirements of staff, and therefore alter the balance of an entire process. As a result, implementing change may involve adjustments that extend well beyond the piece of equipment that is the initial focus. Because firms frequently rely on machinery suppliers and outside consultants as sources of embodied process innovation, the challenges posed by change can draw on a variety of technical sources with different knowledge bases and aims. Our concern is with the management of this variety in order to achieve solutions that are efficient from the standpoint of the equipment users.

Of 27 routines that technology managers recently identified as central to their work (Levin and Barnard, 2008), 8 were associated with locating and using knowledge to produce 'working artefacts', including process machinery. These include technology planning, execution of a project, investigating technology feasibility, and technology adaptation. While Open Innovation and Absorptive Capacity (AC) have important areas of overlap, we argue that AC does not on its own provide an adequate foundation for the discovery and analysis of routines and capabilities needed for incremental process innovation in open contexts. We therefore suggest a framework directed specifically at the identification and development of capacities (groups of capabilities) for open incremental process innovation. As the incorporation of equipment purchased from external suppliers into existing capital configurations is a very common type of artefact management that most firms face periodically, it is important for both individual firms and entire economies that it be accomplished efficiently.

Our construct complements the work of Lichtenthaler and Lichtenthaler (2009) on product development by examining process technology, but we carry their analysis further by

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examining what we term *knowledge application*, which involves using knowledge to undertake an activity. We therefore concentrate on external technology integration (Stock and Tatikonda, 2004, 2008; Iansiti, 1995, 1998) and on deploying knowledge to accomplish physical change as well as on gathering and analysing information that underpins the innovation process. Even though early definitions of Absorptive Capacity (Cohen and Levinthal, 1990) include the ability to use both internally and externally generated knowledge for productive purposes, most of the follow-up articles focus on learning and knowledge management rather than on use (Volberda et al., 2010). We therefore suggest that AC should be incorporated into network frameworks that allow for greater degrees of distributed knowledge and learning and that explicitly address physical transformation.

We begin with discussions of the nature and importance of Open Innovation, process innovation and incremental innovation. In Section 4, we discuss the suitability of AC as a tool for accomplishing incremental process innovation and the roles of modularity and substitutability for knowledge acquisition and analysis and, in particular, knowledge application. We then outline a related but substantially different classification of capacities central to incremental process innovation. In Section 6, we go a stage further by building a model that shows how capacities can be used in practice in making decisions on incremental innovation and go on to explore the implications of including these capacities when deciding whether to innovate. Finally, we present our conclusions and discuss suggestions for further research.

2. Open Innovation and process innovation

The general thrust of the Open Innovation literature is that firms engaged in product development have been excessively reluctant to use externally generated knowledge and also to sell knowledge of their own creation to other firms (Chesbrough, 2003a; Lichtenthaler and Lichtenthaler, 2009; Grönlund et al., 2010). Although more research is needed to establish the point fully, there is evidence that Open Innovation has been much more common (perhaps the rule rather than the exception) in process technology. By the middle of the nineteenth century, specialised manufacturers of textile machinery, steam engines, machine tools and other types of equipment were well established in Britain (Landes, 2003). The practice of buying equipment from external sources has continued, leading Pavitt (1984) to identify an important group of 'supplier dominated' firms in his taxonomy of sectoral patterns of technical change. More recent research has found evidence of this type of firm in a variety of sectors (Sterlacchini, 1999; Archibugi, 2001; De Jong and Marsili, 2006).

Among these, constituting the prototypical example, are producers of commodities or near-commodities in traditional industries that are heavily dependent on cost management to gain or maintain competitive advantage and whose principal source of innovation is the purchase of new process machinery. It is not surprising that Open Innovation may be more firmly established in process than in product development since the capabilities involved in designing and manufacturing equipment are not among the core competences of many consumer-good producers (Hamel and Prahalad, 1994).

All organisations in all sectors – services, agriculture, mining, construction, as well as manufacturing – employ some production process that contributes directly to their competitiveness. Other things being equal, the firm with the most efficient process, as measured by input usage relative to the value of the output, will be the most profitable. Moreover, process technology can be used as a dynamic weapon. When products are homogeneous, or nearly so, price becomes a central strategic variable, allowing firms with lower cost structures based on more efficient processes to gain market share and, ultimately perhaps, market dominance (Porter, 1980). Consequently, firms have a serious incentive to consider any innovation, whether internally or externally sourced, that offers the prospect of increased efficiency and lower costs.

In a dynamic world, process innovation is significant in at least two other important respects. Firstly, process innovation is closely tied to product innovation (Utterback and Abernathy, 1975; Adner and Levinthal, 2001). New products frequently require changes in processes when they involve techniques unfamiliar to the firm. If the new good or service is successful, this can lead to further process changes as production is scaled up. It is therefore often inappropriate to consider product innovation in isolation.

In addition, potential opportunities for process innovation may arise periodically as a result of day-to-day activities. Possible changes that might not in themselves justify the replacement of relatively new equipment can become viable when older equipment must in any case be repaired or replaced as a consequence of normal wear-and-tear. Hence obsolescence is a relative state rather than an absolute one. Maintenance provides opportunities for piecemeal updating, retrofitting and other small changes that together can lead to substantial improvements in productivity even though no change on its own would support updating. The upshot is that, on a firm-by-firm basis, incremental process innovation is an inconsistent activity that is affected by diverse considerations, such as the rates of usage of particular pieces of equipment. Furthermore, as different firms have different levels of output over a given period, it is reasonable to expect that updating will not necessarily proceed simultaneously throughout a sector.

It is insufficient, however, to base an analysis of process innovation only on costs of replacement as influenced by amortisation calculations and similar exercises. We contend that the actual practice of innovation is complicated and depends on the creation and use of a number of classes of specific capacities, some of which are unique to incremental innovation and external technology integration (Stock and Tatikonda, 2004, 2008). Following Cohen and Levinthal (1990) and Lichtenthaler and Lichtenthaler (2009), we use 'capacities' to refer to groups of capabilities that can be used for a common purpose but may be significantly different from each other (Penrose, 1959; Barney, 1991; Peteraf, 1993). These must be deployed properly for incremental innovation to be undertaken efficiently and effectively (Stock and Tatikonda, 2004, 2008).

3. Incremental innovation

Distinctions among types of innovation are contested (Gatignon et al., 2002; Garcia and Calantone, 2002; Damanpour, 1988). Nevertheless, we believe that a general working definition of incremental innovation can be found. According to Utterback (1994, p. 200), a 'discontinuous or radical innovation' is one 'that sweeps away much of a firm's existing investment in technical skills and knowledge, designs, production technique, plant, and equipment.' As used here, any innovation that is not discontinuous or radical is defined as incremental. Incremental innovations, therefore, do not involve substantial changes in technical skills, knowledge, design, or the other factors identified by Utterback.

Another characteristic of our perspective on incremental innovation is that it takes place on the subsystem level in that the changes we focus on involve in the first instance one or a few segments of a production process, although they may have important ramifications for other parts or for the system as a whole. Finally, we view the changes from the standpoint of the firms making the changes. This is important because the degree of radicalness of an innovation can vary from producers to users. A radical transformation of a piece of equipment may lead to only a marginal change in a larger system into which the machine is incorporated.

Incremental innovations do not occur in aggregate, but result from decisions within individual businesses. Their impact is felt at the levels of the firm, the product and the sector. For firms, incremental innovations may be used to gain an advantage over competitors, but they are also shock absorbers that allow firms to make adjustments in response to changes in their environments; for example they might change their patterns of fuel consumption when relative price levels change. On the product level, on-going incremental innovation after the determination of a dominant design (Utterback and Abernathy, 1975; Anderson and Tushman, 1990) allows for further improvements that extend product lifespans (Utterback, 1994; Utterback and Abernathy, 1975; Adner and Levinthal, 2001; Gatignon et al., 2002). On the sectoral level, sequences of incremental change can be a killer app, leading to permanent competitive advantage for innovative firms, while firms that underestimate the importance of incremental improvements over an extended period can suffer fatal or near-fatal set-backs. The best example of this is the automotive industry, in which what was once the largest manufacturing firm in the world was forced into bankruptcy, in part because consumers changed their allegiances when management neglected to implement a series of small process changes that collectively brought significant advantages in price and quality to its competitors.

4. Absorptive Capacity, modularity and substitutability

4.1. Absorptive Capacity

In their pioneering articles on Absorptive Capacity, Cohen and Levinthal (1990, 1994) contend 'that the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities' (Cohen and Levinthal, 1990, p. 128). In their formulations, AC is a relatively compact idea that, to conflate parts of the titles of two of their articles, links learning and innovation, and maintains that 'Fortune Favors the Prepared Firm'. Although the possibility of other options is mentioned, their basic argument centres on engagement in Research and Development as a means for organisations to bolster their AC and hence their competitiveness. The scope of the term very quickly began to expand, however, particularly after Zahra and George (2002, p. 185) provided a 'reconceptualization... and extension' that translated Absorptive Capacity to a higher plane of generality. To them, the focus is no longer on innovation but on value creation and strategic change and flexibility; the distinction between internal and external knowledge has disappeared, and firms are now enjoined to employ 'dynamic capabilities' of whatever sort is needed instead of concentrating on R&D. This sort of broadening of the meaning of AC soon led Lane et al. (2006) to complain that the concept had become 'reified'. As a remedy, they and Todorova and Durisin (2007) both recommend a return to some of Cohen and Levinthal's original formulations.

Nevertheless, research on applying knowledge, which is our primary concern here, remains the weakest part of the AC literature. In their extensive bibliometric survey, for example, Volberda et al. (2010) found that what they term 'Realized AC' is a very small, stagnant and isolated segment of the enormous corpus of Absorptive Capacity research. Significantly, although they encourage further research in the area of knowledge application, Lane et al. (2006) have virtually nothing to say about relevant drivers that could underlie this aspect of AC. Todorova and Durisin (2007) and Zahra and George (2002) discuss knowledge acquisition and analysis (albeit at very high levels of abstraction) but only give application a passing mention.

Lichtenthaler and Lichtenthaler (2009) have made an ambitious attempt to explain the role of Absorptive Capacity in Open Innovation. While acknowledging the importance of applying knowledge, however, their framework of six knowledge capacities is mostly concerned with managing the acquisition and retention of knowledge. Their discussion of 'knowledge exploitation', in the sections on Innovative Capacity and Desorptive Capacity, recognises the importance of applying both internal and external knowledge and of transferring knowledge outwards, but it does not specify what capabilities a firm needs to achieve successful outcomes (Lichtenthaler and Lichtenthaler, 2009). The emphasis that Cohen and Levinthal (1990) placed on engaging in R&D as a means of developing AC is similarly inadequate for mobilising knowledge application because R&D may end with product development and does not necessarily address problems associated with subsequent stages such as production. Furthermore, many firms that routinely innovate do not undertake R&D. As a recent European survey has shown, most innovative episodes do not include R&D as normally defined. An analysis of Innobarometer 2007, Survey No. 215 shows that over half (52.5% after weighting) of 4395 *innovative* firms did not either undertake in-house R&D or sponsor contract R&D (Arundel and Kanerva, 2010). Thus, while Cohen and Levinthal's (1990) model focuses on AC as a by-product of investment in R&D, capabilities not associated with R&D may be more important for the application of new knowledge.

Our model goes beyond the work of Lichtenthaler and Lichtenthaler (2009), by explicitly discussing the capacities needed in knowledge application. In our discussion, we show (as, up to a point, do Lichtenthaler and Lichtenthaler in relation to product development) that Absorptive Capacity needs to be combined with other skills in order to solve the problems involved in open process innovation. AC concentrates very heavily on conceptualising and hardly at all on the roles of artefacts or of non-scientific and non-technical workers in innovation (Todorova and Durisin, 2007; Zahra and George, 2002). When change involves machinery or equipment, the characteristics of the artefacts and their relationships with people can be central to successful adoption.

Knowledge is essential when dealing with artefacts (Law and Singleton, 2005; Miettinen, 1999), but it is of a different type. Applying technologies can involve more than codifiable knowledge because both tacit knowledge and physical skills that cannot be codified are frequently required. Although the wider definitions of Absorptive Capacity could be interpreted to include this distinction, our reading of the literature is that this is not regarded as important. Inadequate attention is given to the fact that different aims (e.g. adjusting a machine rather than designing it) may depend on different techniques for knowledge valuation, acquisition, assimilation and application. As Miettinen et al. argue (2009, p. 1318), 'When an object [by which they mean an 'aim' or 'objective'] changes, the means and division of labour also need to be transformed.'

The involvement of both artefacts and people in application may introduce new sets of constraints to an implementation process that go beyond the logical incompatibility among ideas that can afflict the acquisition and application aspects of Absorptive Capacity. For example, the workforce needs to be willing as well as able to adopt changes if innovation is to succeed (Leonard-Barton, 1988; Miettinen, 2006; Orlikowski and Scott, 2008). Such constraints require more complex problem solving structures that include not only a broader range of knowledge but the participation of additional actors whose interests may or may not be well aligned. Taken together, these complications suggest that change may not be accomplished purely on the basis of knowledge or expertise within the innovating firm; instead a range of intermediaries may be needed (Howells, 2006). Knowledge is, and can remain, distributed among different actors in addition to the hub firm (Nambisan and Sawhney, 2011), each of whom can contribute their own Absorptive Capacity. Although Cohen and Levinthal (1990) and Zahra and George (2002) have questioned the ability of a firm to 'borrow' AC from external bodies, the transferability of AC is one of the main props supporting Open Innovation as well as strategic alliances (Grant and Baden-Fuller, 2004). Transferability can occur as well in other types of relationships. For example, management consultants, such as specialised process design and engineering contractors (specialised engineering firms or SEFs) in the chemical industry, have been successfully selling AC for over a century (Arora et al., 1999).

In operationalising Open Innovation, each participant in the process can supply knowledge when required, and the network as a whole may learn in the course of problem-solving, but not all members of the network always learn the same things since the knowledge that they have brought to the innovation project and their broader intellectual and strategic interests vary, leading inter alia to different ranges and intensities of Absorptive Capacity. Some participants could, in fact, learn nothing if their roles are limited and their existing expertise is sufficient for their part of the total task. Others, by contrast, could generate or absorb valuable knowledge from other participants that is also applicable to activities that, to outsiders, seem unrelated to the original problem.

Thus our emphasis is as much on the role of networks as institutions that allow firms to economise on learning by sharing knowledge as it is on the transmission of tacit knowledge. There are good reasons why a firm may not want to acquire all of the knowledge that it uses, instead delegating the acquisition of some knowledge to other members of a network and establishing or reinforcing a division of labour. For example, mastering specialist knowledge could be excessively expensive if it is to be used only once or at infrequent intervals. In such cases, firms may choose to remain ignorant. Thus when knowledge that is codified requires costly expertise to understand it, users may deliberately sidestep the details and delegate the decoding to external suppliers, in practice rendering the knowledge tacit to themselves. Tacitness has recently been associated with ambiguity as a major deterrent to learning in innovative situations (Simonin, 2004; Easterby-Smith et al., 2008). We believe, however, that, although this can definitely be a problem when learning is the major objective of an activity, in many incremental process innovation projects (and, by extension in many other types of projects), the amount of knowledge transfer that is necessary is small and the cost of decodification is excessive. As a result, innovators may be happy to settle for black boxes from external specialists as long as they are accompanied by output measures such as diagnostics that make it cheap and easy to discover if a piece of equipment is malfunctioning. The transaction cost explanation is that the cost of understanding (or developing) the black box within the firm – i.e. hierarchy – is greater than that of obtaining it from the supplier – i.e. market (Williamson, 1985). The social cost of hierarchy is the absence of gain from specialisation across the network (Coase, 1992).

Networks for knowledge application – which are somewhere between hierarchies and markets – can be held together by two types of adhesive. The first is the artefacts involved – both the innovative piece of equipment and the existing installed base. Each artefact possesses certain characteristics that define its capabilities and limitations in terms of both performance and physical structure, but these may not be immutable and could be subject within constraints to reconceptualisation and reformulation depending on immediate needs. The second adhesive, or focus, of the network is therefore the aims or objectives of the project (Miettinen, 2006; Miettinen et al., 2009). In the case of incremental process innovation, these are likely to involve optimisation of the new system in order to achieve a high level of performance from the *combination* of the existing and new equipment at a satisfactory overall cost. At the end of the process, success does not depend on the integration of knowledge in a cognitive sense. Instead success is measured by the extent to which the artefacts have been manipulated by various actors, none of whom may possess the entire range of knowledge relevant to the process, in order to meet aims or objectives which were laid down at the outset but may have evolved as a result of subsequent learning in the course of the process. It is a major task for management to bring Open Innovation projects to an effective conclusion – a task that requires additional capacities to those needed for knowledge acquisition and assimilation.

4.2. Modularity and substitutability

One strategy for economising on AC and knowledge acquisition in Open Innovation is the adoption of modular formats (Garud et al., 2003; Baldwin and Clark, 2000; Chesbrough, 2003b). By establishing standardised interfaces across components of a physical (or, in some cases, a more abstract) system, it is possible to delineate a division of labour in knowledge acquisition (Adner and Kapoor, 2010). The procurement and use of new knowledge can then become the responsibility of the people who produce and update each component, with the results combined in black box fashion as long as the standardisation of the interface is maintained and there is total, or at least easy-to-manage, compatibility across components. This can be particularly important when designing, installing and updating a system of production involving an assemblage of components. As different segments may wear out or need to be updated at different rates, it is useful to be able to replace components with a minimum of expense and effort (Langlois and Robertson, 1992). In commercial settings, this is illustrated by the deployment of suites of capital equipment where the goal is to allow for the updating of individual elements without upsetting current relationships among different types of machinery.

From a production standpoint, modularity has definite design advantages because standardised interfaces allow each part of a system to be developed separately by specialists (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996). It is also useful for users because it permits them to delegate a portion of their knowledge requirements to others and to reduce their search costs (Langlois and Robertson, 1992). However, despite its advantages, modularity is often impractical or even undesirable (Brusoni and Prencipe, 2001; Brusoni, 2005). Standardisation is not always easy to achieve and the specifications of an innovative component may be inherently incompatible with existing systems because its performance characteristics would upset the current balance of the system in some way or cannot be provided with a compatible interface (Langlois and Robertson, 2003). Depending on the degree of incompatibility, two options then open up: either adjustments must be made to the older system, and perhaps to the new component as well, to accommodate the change; or the entire older system must be replaced. In this sense, modularity and the use of standardised interfaces could discourage innovation by introducing inflexibilities that make it harder or more costly to incorporate improved modules that, when their performance is measured separately, are superior to current models. In such cases the older system results in inertia and path dependence.

As perfect modularity is often hard to realise in practice, it is therefore likely that open incremental process innovation generally requires at least some degree of adjustment for successful integration into an existing system. Thus *substitutability* may be the most effective way of dealing with incremental innovation. We define a substitutable system as one in which components can be changed without abandoning other pieces of equipment, even though there may need to be substantial adjustments to the new and/or the existing components because of imperfectly interchangeable interfaces. This is likely to be especially important for ageing systems as the possibilities for perfect compatibility lessen as time passes,

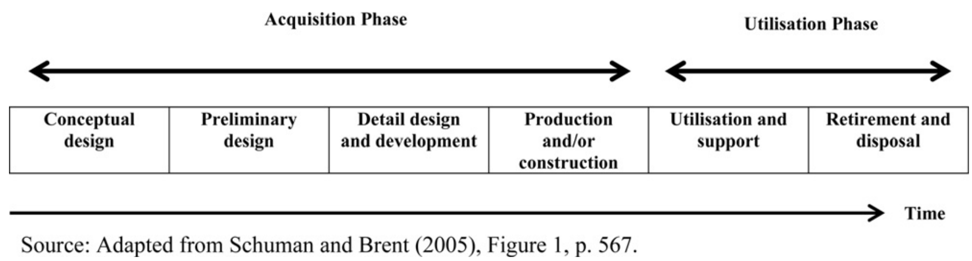

Fig. 1. Phases of the asset management lifecycle.

Source: Adapted from Schuman and Brent (2005), Figure 1, p. 567.

and components come increasingly to embody a different range of technologies. Where diverse expertise is needed, adjustment would be undertaken by participants in the network on the basis of the knowledge that each possesses at the beginning of the project and whatever new knowledge each acquires in the course of accomplishing the adjustment, although the hub firm undertaking and financing the innovation must possess internal knowledge of the existing system that is essential for coordination and assessment of outcomes.

5. Capacities for incremental innovation

By analysing the Asset Management (AM) Life Cycle (Fig. 1) from the tail end, we can get a good picture of the implications of innovating in a constrained context. In particular, when a piece of equipment is bought, rather than designed or built internally, the stages in the Acquisition Phase can reasonably be regarded by the purchaser as a black box comprising the configuration of various unspecified types of technology. Once the utilisation phase begins, however, complexity for the owner/operator of the equipment increases, particularly in a highly dynamic environment, because it is in the course of operation that the abilities of the equipment, and also its inconveniences and defects, become apparent. Although this may be mitigated to an extent by modularity among components, as we have noted this is frequently insufficient to ensure total compatibility (Adner and Kapoor, 2010). Firms must master how to use the equipment in its current state, but they are also likely to consider forms of improvement. Asset operation, maintenance and upgrading can involve a great deal of inherent uncertainty (Stock and Tatikonda, 2004, 2008; Adner and Kapoor, 2010). Since the degree of uncertainty grows as time passes, the resulting problems become more evident as the asset ages, particularly in the ‘utilisation and support’ stage of the ‘utilisation phase’. The true nature and implications of problems evolve and are only revealed through experience – as new knowledge emerges, it may uncover bottlenecks in the form of further areas of ignorance that need to be overcome before problems can be solved.

Although the traditional stages of knowledge valuation, acquisition and assimilation (Cohen and Levinthal, 1990) are essential elements of the AM life cycle, they do not focus sufficiently on the real test of asset management success, which occurs during knowledge application. Because AM concentrates largely on the utilisation and support stage, application often calls on capabilities that extend beyond those needed in the acquisition phase – further knowledge may be required to mobilise the knowledge that an organisation already possesses as well as that embodied in its equipment. Moreover, new knowledge is not concentrated but may be distributed across various types of sources (Robertson and Smith, 2008). For example, it may be developed locally (i.e. within the same branch of an organisation), transferred from elsewhere within the organisation, or brought in from outside (Howells, 2006; Sammarra and Bioggiero, 2008; Schmidt, 2010). In all of these cases, knowledge from one source may not be valuable on its own, but may need to be merged with that from other sources before it can be used (Morone and Taylor, 2010). This reinforces the intertemporal dimension of incremental innovation and AM because this type of knowledge blending, which is inherent in Open Innovation, occurs after asset acquisition and is a learning process in itself, dependent on procuring additional information and skills, perhaps held by disparate actors, to bring together packets of knowledge that may not appear to be compatible at first glance.

In an open environment, which by its nature is dynamic because it permits choices of activities from an array of internal and external innovative possibilities, managers of assets must often undertake considerable amounts of learning when performing AM, first to keep abreast of changing developments, and secondly, to be in a position to deploy any new knowledge that is acquired. To achieve success, managers must ensure that their organisations have the requisite *Innovative Capacities* to gain access to and mobilise new knowledge when and where it is needed. Innovative Capacities are collections of dynamic capabilities (Helfat et al., 2007; Teece, 2009) that, because of their emphasis on implementation, include, but also go very substantially beyond, the capabilities associated with the knowledge acquisition phase of Absorptive Capacity. Because they are dynamic, they are flexible, which allows them to be used in a range of related situations. As capacities are portmanteau categories comprising groups of capabilities to achieve a given purpose, they may be sufficient in themselves for the purpose or they may need to be used in combination with other capabilities.

Three categories of Innovative Capacities can aid firms undertaking open incremental innovation. These apply both to acquiring and generating knowledge about an innovation and to using it, in the recognition that it may be necessary to further increase stocks of knowledge in the course of deployment – that knowing about something is not the same as knowing how to install and use it. To repeat, our analysis concentrates on the level of subsystems and on changes within an existing context. This is especially relevant to Integrative Capacity, which focuses on the capabilities required to achieve compatibility when an incremental innovation disturbs the balance of an existing configuration of equipment.

5.1. Accessive Capacity

Accessive Capacity, which is similar to Absorptive Capacity, comprises all knowledge generating and gathering activities, both internal and external (Lichtenthaler and Lichtenthaler, 2009), that are relevant to a given problem. Therefore Accessive Capacity concentrates not just on how internal knowledge can affect a firm's ability to collect external knowledge, but on how the two classes of knowledge can be used together, in complementary or supplementary roles, to achieve incremental process innovation. As many firms, particularly small and medium sized ones, do not engage in R&D as conventionally defined even though they do innovate (Arundel and Kaneva, 2010), Accessive Capacity emphasises the different tactics that these firms must adopt to increase their knowledge. In the context of incremental process innovation, these can include unstructured learning-by-doing or learning-by-tinkering in which unanticipated problems are confronted in real time (Bartel and Garud, 2009) as they become apparent.

Both Absorptive Capacity and Accessive Capacity involve judgement as well as routine effort because raw information is of little worth, and may even be a distraction, until it can be harnessed to meet an objective of operational or strategic importance. As *Adaptive* and *Integrative Capacities* deal with aspects of knowledge application, Accessive Capacity is restricted to capabilities that promote finding, assimilating and recognising the importance of knowledge. Accessive Capacity also emphasises the importance of taking the initiative in establishing contacts with other organisations to gather external information or knowledge relatively easily and cheaply. In some cases, this may involve traditional Absorptive Capacity – the actual acquisition and assimilating of knowledge by a firm that is undertaking incremental innovation (Lichtenthaler and Lichtenthaler, 2009) – but may also include skills needed to locate suitable partners to form part of an innovating network (Nambisan and Sawhney, 2011). As we have contended above, where there is substitutability, particularly in the presence of high levels of uncertainty (Stock and Tatikonda, 2004, 2008), a high proportion of the learning needed to solve implementation problems can be outsourced. Organisations can save on time and search costs if they have good connections with others who have privileged entree to sources of innovative information – to what Stinchcombe (1990) has called 'the News'. The News is the information and knowledge that is central to an organisation's particular needs. By establishing contact with the right external organisations, it is possible to avoid much of the expensive and time-consuming sorting that would otherwise have to be performed internally.

Accessive Capacity, like Absorptive Capacity (Cohen and Levinthal, 1990; Schmidt, 2010; Daghfous, 2004), is complex and situated. The nature and usefulness of the underlying capabilities vary depending on circumstances (Spithoven et al., 2010). Vital information may be collected from sources that are well known, but weak ties (Granovetter, 1973) may also be important, obliging firms to search at greater cognitive and spatial distances. As the capacity of firms to develop capabilities also varies, differing combinations of strengths and weaknesses are all included under the general label of Accessive Capacity.

5.2. Adaptive Capacity

On its own, Accessive Capacity is insufficient to generate organisational value. Knowledge must also be used, or 'realized' in the language of Zahra and George (2002), which in the case of incremental changes to process equipment requires *Adaptive* and *Integrative Capacities*. When relationships in an array of equipment reflect substitutability, rather than perfect modularity, new knowledge does not necessarily arrive in a ready-to-use form when innovation is open. Instead, newly received knowledge reflects the context in which it was transmitted, which could be very different from that in which the knowledge is eventually received (Robertson, 1998). As knowledge, once it has been accessed, must often be augmented by additional knowledge and other types of resources before it can be employed, two additional and sometimes overlapping forms of knowledge generation and use are needed. The first, Adaptive Capacity, involves the *use* of a piece of equipment through converting knowledge generated for one purpose to another. For example, a machine invented to serve a given purpose in one sector may need to be changed to perform a similar or analogous purpose in a different sector such as when an existing grinding machine or a machine tool is applied to a new type of material.

The demand for adaptation and the new knowledge developed to modify the use of a piece of equipment can come from several sources (Tripsas, 2008) and may depend on the marketing orientations of the supplying firms (Berthon et al., 1999). Both network and dyadic relations can be present. Firstly, perhaps on the basis of information provided by its sales and marketing agents, an equipment manufacturer may learn of a desirable adaptation to correct problems reported by current customers. Similarly, a firm can identify a gap in the market that justifies a new product development initiative and then search systematically for modifications that would serve additional customers. In this way, a firm could broaden its current line of business by implementing a strategic decision to supply consumers who have unmet needs similar to those of current customers, or alternatively, by extending its range of products to provide a more complete package for current customers. Chidamber and Kon (1994) argue that incremental innovation typically involves a recognised demand from existing consumers because this is less risky than introducing changes that have not already been identified as saleable. Thirdly, from the demand side existing customers can make adjustments to a machine based on their own learning-by-using, including suggestions made by operatives as well as managers. They can convey these to the manufacturer either verbally or by handing over a prototype that they have made (von Hippel, 1988, 2005), or they can spread the results more widely by combining user innovation with Open Innovation (Baldwin and von Hippel, 2009).

Finally, a potential user may learn of a machine employed in another, quite possibly unrelated, industry that does something similar to one of its own activities, in which case it can ask the manufacturer to make whatever adaptations are needed to serve its quite different purposes, even if this may seem to outsiders to be only tenuously related to the original use.

5.3. Integrative Capacity

By contrast, *Integrative Capacity* is the ability to ensure that a new machine is compatible with an existing configuration of equipment. In general, the machines comprising an existing production system are arrayed in relation to each other to ensure the efficiency of the whole assembly rather than maximisation of the performance of individual components (Brusoni and Prencipe, 2001). Similarly, the training and deployment of the workforce takes into account the specific nature of the whole assembly process as well as the labour requirements for each machine. In substitutable situations, these integral relationships can be upset by the replacement of an existing piece of equipment by an updated one, or by the introduction of an additional piece with characteristics that do not entirely mesh with the current assemblage. The new machine may operate at a different speed, for example, or the physical characteristics of its output may be somewhat different from those of an older machine and not feed smoothly into the rest of the system as it was originally designed. Or different skills may be needed, leading to the hiring of new workers or the retraining of current ones. Even then, workers may refuse to operate the new configuration efficiently if they feel that it threatens their interests (Garrety et al., 2004). If the costs of extensive adjustment are too great, they may exceed the benefits expected from an innovation to one part of a system. Here, as where modularity and standardised interfaces impose inflexibilities, there will be inertia and path dependence. Integrative Capacity may be the hardest part of the innovative process to accomplish, because it can involve a range of actors with conflicting goals as well as widespread change throughout a system to find a new operating equilibrium. It may be most difficult to apply, paradoxically, where the system is already highly integrated, for example as with IT infrastructure (Bharadwaj, 2000).

Adaptive and Integrative Capacity go beyond Accessive Capacity by applying innovative knowledge to particular situations, and

	Accessive Capacity	Adaptive Capacity	Integrative Capacity (including Human Resource Changes)
Internal Actors (within hub firm):			
Managers	*	*	*
Engineers and Scientists	*	*	*
Workers and Unions	*	*	*
External Actors:			
Suppliers	*	*	*
Customers/ Users	*	*	*
Competitors	*	*	*
'Commercial Intelligence'#	*	*	*
Government Agencies	*	*	*
Consultants	*	*	*
Internet	*	*	*
Other	*	*	*

#Trade shows and publications, snooping around, talking to others in a casual context, etc.

N.B. Although all actors may play a role in the whole range of capacities, the relative strength of each contribution will vary from case to case.

Fig. 2. Internal and external actors and Innovative Capacities.

may therefore demand physical and organisational alterations to an existing setup. Moreover, the processes that Adaptive and Integrative Capacities set in train can lead to the generation of further new knowledge as problems are worked out in practice. This knowledge may be created within the organisation by employees at all levels including operatives, but can also come from suppliers, consultants and a variety of other sources. Coordination of these varied sources of knowledge and of the processes needed for application is therefore a major responsibility and a major challenge when open process innovation is attempted.

The internal and external aspects of Accessive, Adaptive and Integrative Capacities are shown in Fig. 2, where an illustrative sample of many of the possible sources of external inputs is presented along with the inputs to incremental process innovation that an organisation can supply internally. Importantly, these relationships, which deliver significant results to those who need them, may very well not be formal, even though all participants can obtain useful knowledge through their contacts. Instead of pursuing incremental process innovation through strategic alliances and comparable connections (Simonin, 2004; Sammarra and Bioggiero, 2008; Easterby-Smith et al., 2008; Zhang and Baden-Fuller, 2010), relationships can often be ad hoc. Our assumption is that, in most of the situations in Fig. 2, the hub firm undertaking incremental process innovation will be in charge of gathering and developing the three capacities (will exercise Innovative Management Capacity, an augmented higher-order dynamic capacity (Zollo and Winter, 2002; Winter, 2003) described below) even when much of the actual physical and intellectual work is done by other firms. The hub firm may also be in charge of coordination (Brusoni et al., 2001), but in other cases involving a great deal of learning-by-doing or learning-by-tinkering, solutions may arise more or less spontaneously through less structured collaborations. Thus external contributors may be semi-passive, although competent, participants whose input has been sought by the innovating organisation; in other situations, they may be full participants whose technical expertise allows them on occasion to override the directives of the focal firms.

6. The role of capacities in deciding whether to innovate

6.1. Co-ordinating knowledge and action

When a new piece of equipment is incorporated into a production process, as at the left side of Fig. 3, it marks both the end and the beginning of learning processes. While the initial development process (the 'Acquisition Phase' in Fig. 1) ends at that point, it is also the start of a new process featuring learning-by-using and learning-by-doing, knowing-what, knowing-why, knowing-how, and knowing-who. The Accessive Capacity box captures the codified and tacit learning that occurs internally during use of the

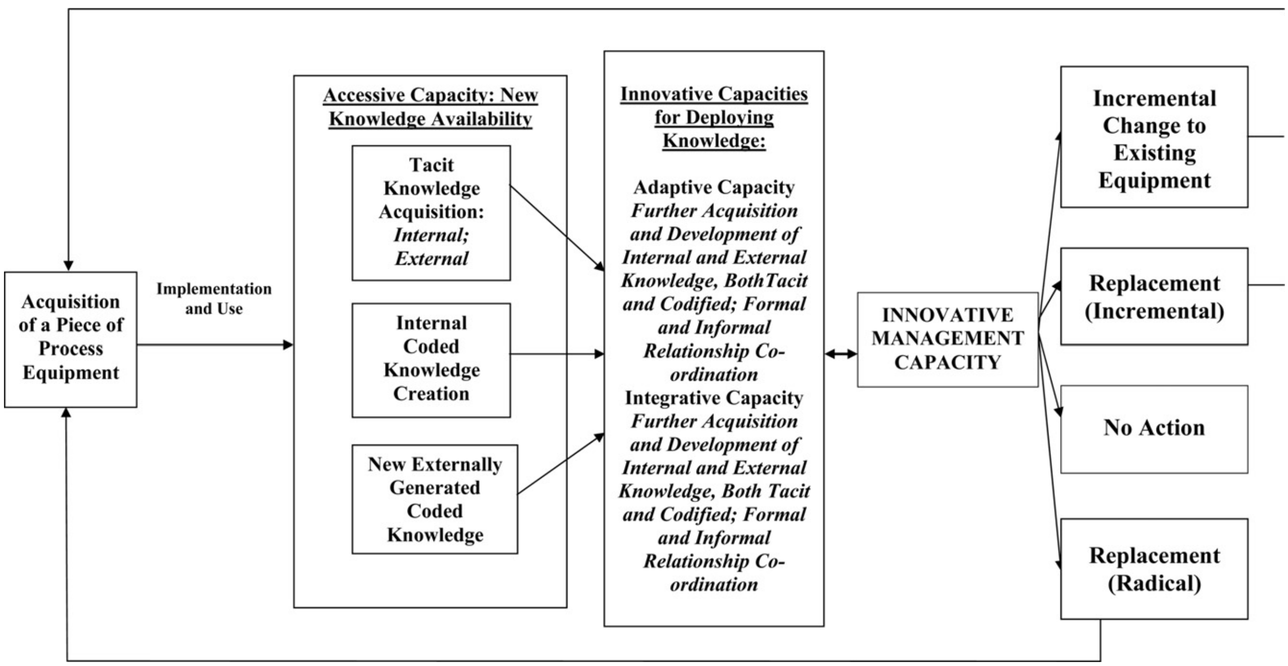

Fig. 3. The role of Innovative Capacities in the process equipment life cycle.

equipment, combined with new learning from external sources that is important in the planning stage of incremental maintenance and upgrading as well as when considering possible replacements. This codified and tacit external knowledge can cover a range of categories such as the characteristics of relevant innovations developed by machine builders or the changing importance of particular skills. Taken together, the components of Accessive Capacity are used to make general plans for incremental change, with the details often left to be worked out later.

As is shown in Fig. 2, there are many sources feeding into Accessive Capacity. In addition to their own development activities, organisations can scan the environment anonymously through the trade press, trade fairs and similar activities ('Commercial Intelligence' in Fig. 2) in order to make direct contact with others who are known to be knowledgeable. This is consistent with the view of Baum et al. (2010) that decisions in relation to the selection of alliance partners are based on knowledge differences and complementarities. In addition to the selection of partners for formal alliances or strategic ventures, scanning for partners with knowledge can also involve regular but less structured relationships with suppliers, customers, competitors and others. As Lichtenthaler and Lichtenthaler (2009) observe, it is important that organisations not only establish but also maintain relationships that provide on-going sources of innovative knowledge.

Knowledge accessed in these ways is not necessarily immediately functional because the need to master new uses can create barriers to change. Even widely known General Purpose Technologies (Helpman, 1998; Lipsey et al., 2005) can take decades to diffuse throughout the economy. As depicted in the box covering 'Innovative Capacities for Deploying Knowledge' in Fig. 3, Adaptive and Integrative Capacity, whether sourced internally or externally, both mediate between knowledge generation and capture in the first (Accessive) stage, and the actual innovation, or physical change, that takes place subsequently. Although they are separate concepts that can be employed stepwise, Adaptive and Integrative Capacity can be used in tandem, as when there is a conscious effort to insure that a modification is designed from the outset to fit into an existing array of equipment.

6.2. Innovative Management Capacity

Accessive, Adaptive and Integrative Capacity do not function automatically, but must be directed by a 'master capacity' that both organises and mobilises the knowledge that has been created and gathered. The need to direct capacities is recognised by Lichtenthaler and Lichtenthaler (2009) who argue that a 'knowledge management capacity' is required to guide their suite of six knowledge capacities. Their discussion focuses on need for 'higher-order' dynamic capabilities to ensure that the flexibility of the knowledge and routines that underlies first-order dynamic capabilities can be sustained by the presence of second-, or indeed third- and even higher level, capabilities that provide additional flexibility to keep first-order dynamic capabilities from stagnating (Winter, 2003; Easterby-Smith and Prieto, 2008).

Innovative Management Capacity plays an analogous but broader role in our model. As our major concern is with knowledge application, rather than knowledge acquisition and retention as in the Lichtenthaler and Lichtenthaler (2009) model, Innovative Management Capacity must also include capabilities for operationalisation, such as those employed in human resource and project management. Our emphasis is on making sure that knowledge is mobilised for the efficient accomplishment of organisational goals – for instance to ensure that a given set of actions is carried out within budget, on schedule and at a satisfactory level of performance. Therefore, while the generally acknowledged purpose of higher-level capabilities in knowledge management, ensuring continuing flexibility, is part of this function, Innovative Management Capacity attempts far more in order to also achieve effective knowledge application. Most importantly, it must ensure that the various people engaged in innovation work together to reach satisfactory solutions – that their existing knowledge and the learning achieved in the course of operationalisation result in efficient and effective artefact management.

The capabilities subsumed within Accessive, Adaptive and Integrative Capacity meet the criteria of first-order dynamic capabilities (Easterby-Smith and Prieto, 2008), but their implementation is not a programmable activity; managerial judgement is also needed to convert what people know into a profitable course of action and to monitor activity as work progresses. As control that is independent of the actors who undertake innovation is required to ensure that the right activities are chosen and that they are carried out efficiently, Innovative Management Capacity (towards the right-hand side of Fig. 3) qualifies as a 'higher-order' capacity because it coordinates the other three capacities (Zahra et al., 2006; Zollo and Winter, 2002). In part, this does entail maintaining flexibility because it is clear that, in a dynamic environment, capacities, capabilities and routines organised to meet the needs of one period are unlikely to be suitable at other times, when conditions have altered (Lichtenthaler and Lichtenthaler, 2009). However, the real-time aspects of physically employing Adaptive and Integrative Capabilities to configure arrays of equipment mean that Innovative Management Capacity must control both absorptive and operational aspects of incremental process innovation.

Through the employment of Innovative Management Capacity, four of the possible outcomes following from the use of the Innovative Capacities are shown on the far right-hand side of Fig. 3. As well as making an incremental change to an existing piece of equipment or array of equipment, after reviewing the evidence, a firm might decide to replace a piece of equipment entirely, choosing a new machine that can perform the same function but that still conforms closely to the requirements of the existing array or system of equipment. As with incremental changes to an existing piece, 'Replacement (Incremental)' would involve only minor modification or adjustment in the system as a whole. Incremental change might be rejected, however, in favour of a more radical replacement that would require a higher level of modification and adjustment, or perhaps even scrapping other parts of the existing system (or the entire system). As radical replacement would probably be more expensive than an incremental solution, the estimated payoff would need to be correspondingly greater. Finally, a firm could opt to take no action at all. Among other things, the expected advantage from change might not be great enough to cover its costs, or in a rapidly changing technological environment – i.e. in the presence of time compression diseconomies (Dierickx and Cool, 1989) – a firm could pass up a new model, perhaps one substantially better than its current equipment, in the expectation that an even better option would appear soon.

6.3. Costs and choosing among options

If the costs of building and maintaining Innovative Capacities are too high, some planning activities may need to be foregone, leading to bounded rationality (Simon, 1957) and increased risk of error. This could also lead to increased incidence of decisions to take 'no action' when the benefits from an incremental innovation are thought likely to be too low to justify the costs of acquiring the capacities needed to thoroughly investigate making a change. This can be expected to be more important for smaller than for larger firms. Small firms may not only have less slack in managerial time and discretionary funds, but also reduced access to economies of scale in evaluating innovation. Furthermore, because they spend less, they may not receive as much knowledge volunteered by potential suppliers in search of customers. Although there are other factors influencing investment decisions by firms of various sizes (Ács and Audretsch, 2005), *ceteris paribus* the costs involved in using Innovative Capacities can be expected to reduce relative rates of innovation, especially by smaller firms.

Cost considerations are also relevant in deciding how much tacitness to accept. Although the degree of codifiability varies within each of the four categories including Innovative Managerial Capacity, in general, highly codified material is preferred for Accessive Capacity which is strongly associated with know-what, whereas a higher degree of tacitness could be tolerated, or even desirable, in Adaptive, Integrative and Innovative Managerial Capacities, all of which are closely related to know-how (Jensen et al., 2007; Lundvall and Johnson, 1994). For Adaptive and Integrative Capacities, therefore, both the internal users and their customers may find tacitness superior to codified knowledge on cost grounds. Similarly, Innovative Managerial Capacity, which is internal to the firm, may be heavily tacit as managers adopt mechanisms other than codification for achieving understanding, such as communities of practice (Wenger, 1998). There is nothing essentially good or bad about the degree of codification available: Different states are suitable in different conditions, and access to codified information will not necessarily affect make-or-buy decisions.

7. Discussion

This article provides a guide to the capabilities and capacities required for the successful application of knowledge in process innovation, an aspect of management central to competitive advantage. The most important contribution of our work is that it addresses the operational aspects of Open Innovation and Absorptive Capacity. Although Lichtenthaler and Lichtenthaler (2009) discuss knowledge management aspects of Open Innovation, which are of obvious importance, they do not seriously address knowledge application, the activity that has the greatest transformational effect on products and processes. Open Innovation relies on distributed knowledge and effective integration to improve firm performance, but this is accomplished through the development and use of superior products and production processes. Gaining and retaining access to knowledge are not of much value in the absence of application. We have therefore answered the call of Volberda et al. (2010) for further investigation of the exploitation aspects of Absorptive Capacity, but we have also shown that AC on its own may not be adequate for the analysis of problems that go beyond the scope of knowledge management and require human resource management, technology management, relationship management and perhaps many other types of resources for their solution. This extends our analysis beyond the usual topics covered in discussions of Absorptive Capacity, which are the capacities required simply to learn about and evaluate the possibility of change. Since the rate of technological change is now very high, and most firms must engage in routine maintenance at the very least, our distinction between Accessive, Adaptive and Integrative Capacities allows scholars to probe more deeply into an activity that is ubiquitous in developed economies. Future research should allow the categories to be unpacked into more fine-grained sets of underlying capabilities, in the process allowing a better appreciation of how the capabilities interact.

Equally importantly, our matrix can serve as a preliminary guide to action for firms, permitting them to anticipate which capabilities to acquire and their relative importance *for the specific set of incremental innovations that a given firm is likely to need.* Our model is deliberately general, recognising that the overall array of capabilities potentially needed throughout the economy is very broad across firms, even though it can be divided into only three capacities. This means that firms need to assess their own situations accurately and must also have a good appreciation of the availability of capabilities in their external environments. If they want good answers, then they must know what to ask and whom to ask. By specifying the relevant categories, we have provided a framework in which firms can assemble the materials that they need to undertake incremental process innovation. Again, with more research, a better defined list of relevant sub-topics can be developed to assist firms with real concerns to confront them efficiently.

Finally, the insights we have developed can be fruitfully extended into other areas. Further attention to the role of knowledge application would enrich the Open Innovation and

Absorptive Capacity literatures. In common with process innovation, product development and modification are activities that require wide and varied capabilities and physical inputs that extend into areas such as design, engineering and marketing. Abstract knowledge may inform these activities but they can only be accomplished through management of artefacts and people, many of whom such as customers will not be under the direct control of the hub firm. Far more attention, both conceptual and practical, to the capacities and capabilities that are needed and to their blending and coordination would lead to a valuable enrichment of research in Open Innovation and Absorptive Capacity and augment their practical value.

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