19. Open innovation and organizational boundaries: task decomposition, knowledge distribution and the locus of innovation

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This chapter contrasts traditional, organization-centered models of innovation with more recent work on open innovation. These fundamentally different and inconsistent innovation logics are associated with contrasting organizational boundaries and organizational designs. We suggest that when critical tasks can be modularized and when problem-solving knowledge is widely distributed and available, open innovation complements traditional innovation logics. We induce these ideas from the literature and with extended examples from Apple, the National Aeronautics and Astronomical Agency (NASA) and LEGO. We suggest that task decomposition and problem-solving knowledge distribution are not deterministic but are strategic choices. If dynamic capabilities are associated with innovation streams, and if different innovation types are rooted in contrasting innovation logics, there are important implications for firm boundaries, design and identity.[1]

INTRODUCTION

Abernathy's (1978) seminal empirical work on the automotive industry examined the relations between a productive unit's boundary (all manufacturing plants), its organizational design (fluid versus specific), and its ability to execute product and/or process innovation. Abernathy's work and his associated ideas of dominant designs and the locus of innovation have been central to scholars of innovation, research and development (R&D) and strategy. Similarly, building on March and Simon's (1958) ideas of organizations as decision-making systems, Woodward (1965), Burns and Stalker (1966), Lawrence and Lorsch (1967 [1986]) and Thompson (1967) explored the relations between organization boundaries (business units), organization design (differentiation and integration), and innovation in a set of industries that varied by uncertainty. This early empirical work led to a wide range of scholarship investigating the relations between a firm's boundaries, its organizational design and its ability to innovate.

In organizational economics, the notion of organizational boundaries has been rooted in transaction cost logic. Economists favor an explanation based on minimizing transaction costs (Coase 1937). Many activities related to innovation and the design and production of goods and services are difficult to contract on the open market. These transaction costs make it efficient for the emergence of firms and associated boundaries that reduce

these costs by integrating these activities inside the firm (Williamson 1975, 1981). This transaction cost tradition has clarified the relations between innovation and the logic of differentiation between the firm and its surrounding environment (or market). This literature has focused on understanding which set of activities should be inside or outside the firm's boundaries (e.g. Pfeffer & Salancik 1978 [2003]; Grandori 2001; Santos & Eisenhardt 2005; Jacobides & Billinger 2006; Lavie et al. 2011). The primary approaches employed by these traditions have been rooted in cost–benefit, knowledge access or resource dependence analyses (e.g. Scott & Davis 2007).

Organization theory and strategy scholars have noted that core to value creation is the production of complex goods and services requiring ongoing knowledge development and transfer amongst diverse settings (March & Simon 1958; Chandler 1977; Grandori 2001; Nickerson & Zenger 2004). The burden of continuous knowledge creation imposes high coordination costs that are best minimized through a managerial hierarchy as opposed to a distributed approach in open markets (Thompson 1967; Tushman & Nadler 1978; Kogut & Zander 1992; Nonaka & Takeuchi 1995). For anything but the simplest problems, the visible hand of an organization's management is required to define and select problems that firms solve for value creation (Chandler 1990; Nickerson and Zenger 2004). Finally, a significant body of research in organization theory is rooted in setting a firm's boundaries in a way that protects it from dependencies in its task environment and puts boundaries around critical tasks, power and competence contingencies (e.g. Thompson 1967; Pfeffer & Salancik 1978 [2003]; Aldrich 1979; Santos & Eisenhardt 2005).

However, users outside the firm are also an important source of functionally novel innovations (von Hippel 1988, 2005). These users constitute self-organizing communities that freely share knowledge (Baldwin & von Hippel 2011; Franke & Shah 2003; Faraj & Johnson 2011, O'Mahony & Lakhani 2011). The open source software movement crystallized an alternative innovation ecosystem where external-to-the-firm user communities design, develop, distribute and support complex products on their own or in alliance with (or in some cases opposition to) incumbent firms (Lakhani & von Hippel 2003; von Hippel 2005; Boudreau & Lakhani 2009; Lerner & Schankerman 2010; O'Mahony & Lakhani 2011). The rise and prevalence of community or peer innovation, with its contrasting loci of innovation and non-hierarchical bases of organizing, pose a challenge to the received theory of innovation, the firm and the firm's boundaries.

In this chapter, we attempt to reconcile these divergent scholarly perspectives on the relationship between firm boundaries and the locus of innovation. We argue that the innovation and organizational design literatures must move beyond debates between open versus closed boundaries and instead embrace the notion of complex organizational boundaries where firms simultaneously pursue a range of boundary options that include 'closed' vertical integration (e.g. Lawrence & Lorsch 1967 [1986]; Nadler & Tushman 1997; Knott 2001), strategic alliances with key partners (e.g. Lavie & Rosenkopf 2006; Rothaermel & Alexandre 2009), and 'open'[2] boundaries and open innovation (e.g. von Hippel 2005; Chesbrough 2006). This simultaneous pursuit of multiple types of organizational boundaries results in building organizations that can attend to these complex, often internally inconsistent, innovation logics and associated organization design requirements (O'Reilly & Tushman 2008; Boumgarden et al. 2012; Gulati & Puranam 2009).

We suggest that two contingencies drive the degree to which a firm chooses along this closed-to-open boundary continuum; the degree to which critical tasks can be decomposed and the extent to which problem-solving knowledge for these tasks is distributed. These task and knowledge contingencies are not deterministic; they involve strategic choice by the firm and shift as the product life cycle evolves (Child 1972; Grandori 2001; Foss et al. 2010; Foss, Chapter 4 in this volume). Choices about task decomposition and knowledge distribution inform the choice of firm boundaries. The ability to understand the nature of these critical task characteristics and, in turn, link these choices to the firm's boundaries may be an important dynamic managerial capability (Helfat and Peteraf 2003). Further, because firms have several critical tasks that differ along these decomposition/knowledge dimensions, the firm is likely to have multiple boundary types.

We also suggest that open innovation may increasingly crowd out more traditional intra-firm innovation. Such a shift in the locus of innovation has profound implications for the design, boundaries, and identity of incumbent firms. Two secular trends in the economy drive the increasing importance of open innovation. The first is the increasing prevalence and importance of 'digitization' (Greenstein 2010), wherein information and physical products are represented in the binary language of computers. While initially confined to pure information products and software production, digitization is a trend that now envelopes large parts of the economy. Importantly, material objects are undergoing transformations so that their 'information shadow' (Baldwin & Clark 2006), that is, the information component of any material object, is now being represented as a digital good. Thus material and physical objects can now be created, represented, modified and transformed with the same relative ease as software goods. An implication of this digitization is the opportunity to apply the principles of task decomposition widely used in the computer hardware and software industries (Baldwin & Clark 2000) to many more parts of the economy.

The second and related trend is the increasing number of actors that can participate in knowledge production at very low costs. Over the past three decades, the internet and other advanced information and network technologies have democratized the tools of knowledge creation. This trend has significantly eased the cost of knowledge dissemination, reduced communication and coordination costs, and made it easier to find and access distributed knowledge from almost anywhere in the world (Benkler 2006; Castells 2000; Shirky 2008).

Key to our understanding of the relations between organizational design, firm boundaries and innovation is the ability of a firm and its leaders to engage in strategic decomposition of underlying innovation tasks and understand the associated locus of knowledge required to effectively deliver products. The strategic decomposition and locus of knowledge perspective argues that the architecture of products is not fixed either in the firm or in industries. Instead, executives (managers and technologists) choose to partition and repartition the problem space such that they have the option to access distributed knowledge above and beyond the traditional emphasis on intra-firm technological development.

Strategic task decomposition enables organizations to access the distributed knowledge of external individuals or communities without resorting to traditional means of backwards or forwards integration. Task decomposition in the context of low-cost

communication has catalyzed the emergence of self-organizing communities that are as effective as firms in innovation and knowledge production (O'Mahony & Lakhani 2011). Thus previously firm-based innovation activities may now be done on the outside in market or community settings (Boudreau & Lakhani 2009).[3] At the same time, firms may decide to exit relationships with external or open sources of innovation for a perceived propriety advantage associated with more integrated task choices. We argue that a firm's ability to 'refactor', or dynamically compose or decompose critical tasks, is an important determinant of the firm's boundaries and, in turn, its ability to innovate.

Hand in hand with strategic decomposition is the recognition that the appropriate knowledge required to solve innovation problems is both widely distributed (Hayek 1945) and sticky (von Hippel 1988). The widespread and general phenomenon of user-based innovation is rooted in users having unique needs and solution information (von Hippel 1988). Users exploit this knowledge to create novel innovations (Riggs & von Hippel 1994). Thus the locus of innovation shifts to where knowledge may be the stickiest to transfer, often with users that are widely distributed in the economy. Users may also form self-organizing collectives and communities where need and solution information are rapidly discovered and transferred under a common free-revealing paradigm (Fjeldstad et al. 2012; Franke & Shah 2003; Lakhani & von Hippel 2003; Baldwin & von Hippel 2011).

With the democratization of the tools of both knowledge production and dissemination, a range of actors outside traditional firm boundaries have access to unique solution knowledge that may be applicable to innovation tasks within firms (Fjeldstad et al. 2012; Jeppesen & Lakhani 2010; Boudreau et al. 2011). Such task decomposition and the fact that widely distributed actors have access to differentiated knowledge push the locus of innovation outside traditional firm boundaries. We suggest that task decomposition and knowledge distribution provide a framework for the choice of firm boundaries. These strategic contingencies lead to a different set of design and boundary choices than the traditional contingencies of asset specificity, information processing or strategic 'coreness' (see also Grandori 2001; Nickerson & Zenger 2004). Finally, we suggest that firm-centered innovation logic is fundamentally different and inconsistent from open innovation logic, and that open innovation logic is increasingly gaining momentum. If so, our theories of innovation, organizational design and organizational change must capture the tensions between these contrasting innovation modes.

Our chapter is organized as follows. First we analyze Apple and its ability to alter (open and close) its boundaries across a range of activities, to build an empirical grounding for our theoretical reconciliation. The next section outlines the extant literature on firm boundaries and the locus of innovation. We then present drivers of complex boundaries by illustrating the joint impact of strategic task decomposition and distributed knowledge for incumbent firms as diverse as LEGO and NASA. The following section induces a model of innovation and complex organizational boundaries. We suggest several core contingencies associated with the firm's boundaries and discuss implications of organizing when firms must attend to multiple and inconsistent innovation logics. Finally, we suggest implications of complex organizational boundaries for the organization theory, strategy and innovation literatures.

COMPLEX AND DYNAMIC BOUNDARIES AT APPLE

All computer manufacturers, such as Apple, Hewlett Packard (HP), Lenovo, and Dell, address the following five distinct technical domains in order to produce and sell a computer system: (1) hardware; (2) operating system; (3) standards (the main specifications that allow for interoperability); (4) user experience (the user interface); and (5) applications. Figure 19.1 lays out how these domains have been addressed by PC manufacturers by locating them in a matrix comprised of task decomposability and the degree of knowledge distribution. For simplicity purposes we present a binary choice for both axes, between high and low task decomposition; that is, modular and integrated tasks (see also Nickerson & Zenger 2004) in the rows, and narrow and broad knowledge distribution for the columns. This results in a range of boundary choices for firms, from internal development, to complex intra-firm structures (e.g. ambidextrous designs), to working with partners and/or consortia, to working with markets or communities.

In Figure 19.1, the lower-left quadrant shows the traditional, internally driven organizational model for innovation. Managers of the firm determine that the relative task decomposition opportunities are low and requisite problem-solving knowledge is all within the firm, resulting in internally developed innovation. The upper-left quadrant indicates that the firm managers have decomposed innovation tasks in a way that enables external parties to contribute, however the knowledge required to accomplish such tasks lies within a strategic partner. The lower-right quadrant indicates that while task decomposition is low, the benefits of having several actors participating in the creation of innovations, via a consortium, are high enough that the incumbent firm absorbs the added cost of integration. Finally, the upper-right quadrant indicates that the firm has enabled task decomposition in a way that allows a range of actors to join in by market or community-based approaches. The distinction between using a market or a
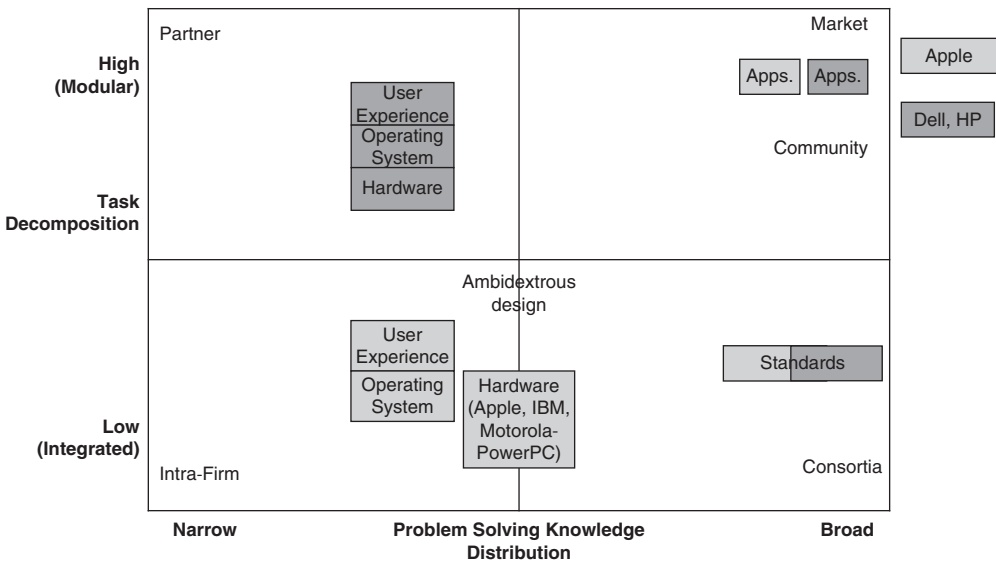

Figure 19.1   Apple and the computer industry

community approach to innovation is grounded on the relative degree of social relations and interdependence a firm has with the external parties. Markets rely mostly on formal contracts and arm's-length relationships with suppliers, while communities require the firm to have employees actively participate in the innovation process (see for example Rosenkopf et al. 2001; West & O'Mahony 2008).

An ambidextrous design (ie. intra-firm structural heterogeneity with structural linkages) is an appropriate design choice when there is strategic interdependence after tasks have been decomposed and where there is knowledge heterogeneity either within the firm or with the firm and external actors (O'Reilly & Tushman 2008; Rothaermel & Alexandre 2009; Lavie et al. 2011). Ambidextrous designs build in boundary and structural heterogeneity such that the firm can operate simultaneously in distinct innovation modes.

Figure 19.1 shows that a typical personal computer (PC) firm in the 1990s chose a strategy of problem decomposability across all technical domains. Most vendors had chosen Intel and/or AMD as suppliers of the hardware microprocessor and had relied on Microsoft Windows for the operating system and the user experience. These partnerships allowed PC manufacturers to work as integrators of the dominant technologies developed by Intel and Microsoft. The supply of applications was left to an unregulated market where any actor could create software and sell directly to users (see Morris & Ferguson 1993). Standards for interoperability were developed through various institutes for electrical and electronic engineers (IEEE), internet engineering task force (IETF) committees and other ad hoc organizations (for example the WiFi standard, the TCP/IP standard and the USB standard).

In contrast, driven by Steve Jobs's strategic point of view, Apple followed an integrated and internal strategy for most of its PC stack (Isaacson 2011). In the late 1990s the hardware used by Apple was built in close consortium between IBM and Motorola and created a software operating system and user interface that was unique and different from the Windows–Intel industry standard. No one had the rights to either use or modify the integrated combination of Apple's hardware, operating system and user interface stack. Similar to the rest of the PC industry, applications were developed in an unregulated market of developers. Figure 19.1 illustrates the contrast between Apple's primarily integrated internal development strategy and the practice of working on decomposable tasks with partners in the rest of the computer industry.

However, by the late 1990s, Apple was in financial and technical trouble. The Microsoft–Intel-based platform was significantly outperforming Apple systems in technical and cost performance. Apple failed to update its operating system to modern requirements and the financial press speculated that the firm was in its last throes. Apple was on the losing side of a dominant design that comprised Intel-architecture hardware and Microsoft-originated operating system, user interface and compatible applications (Cusumano and Selby 1995).

Strategic Decomposition of the Operating System and Working with Communities

In the early to mid-1990s Apple began three independent attempts to update and modernize its computer operating systems. All three attempts failed due to lack of appropriate programming talent and poor execution of the various projects. In 1996, Apple's executives decided that they did not have the internal capability to completely invent a
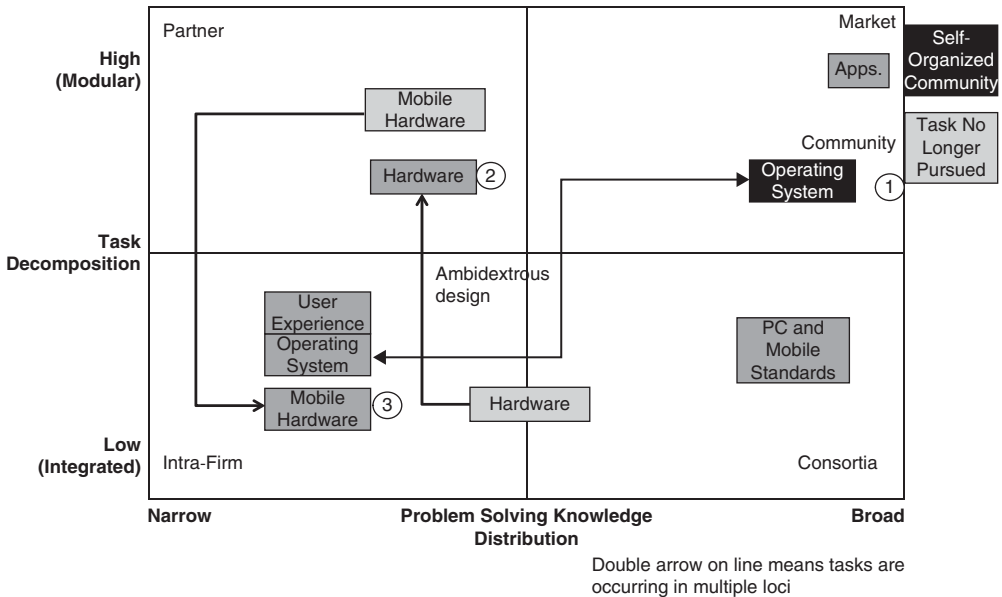
The figure shows a two-by-two matrix. The vertical axis is labeled "Task Decomposition" ranging from "High (Modular)" at top to "Low (Integrated)" at bottom. The horizontal axis is labeled "Problem Solving Knowledge Distribution" ranging from "Narrow" to "Broad".

Quadrant labels: "Partner" (top left), "Market" (top right), "Intra-Firm" (bottom left), "Consortia" (bottom right). Additional labels: "Community", "Apps.", "Self-Organized Community", "Task No Longer Pursued", "Operating System", "Mobile Hardware", "Hardware", "User Experience Operating System", "Ambidextrous design", "PC and Mobile Standards".

Note: "Double arrow on line means tasks are occurring in multiple loci"

Figure 19.2   Dynamic boundaries at Apple

new operating system and recommended that the next version of the operating system be obtained through an acquisition of NeXT Software (the company Steve Jobs founded after he was ousted from Apple in 1985). Apple released the open source components of its operating system as a separate software distribution called 'Darwin' in 2000.

The NeXT operating system itself was based on the Mach kernel, developed at Carnegie Mellon University as a research project to further advance knowledge of operating systems, and on two open source software projects, FreeBSD and NetBSD, that have had thousands of contributors participate in them. Apple thus took the fruits of the open source community and leveraged it for its own next-generation operating system, released in 1999: OS X. Figure 19.2(1) illustrates the integration of the open source community in Apple's proprietary process. The OS X operating system now powers all Apple products including personal computers and mobile devices. Note that Apple did not abandon its own operating system development efforts. Rather, some of the modules of the software were now developed in concert with the community, and some internally.

Apple acknowledges the importance of open source communities in this core aspect of its product:

> As the first major computer company to make Open Source development a key part of its ongoing software strategy, Apple remains committed to the Open Source development model. Major components of Mac OS X, including the UNIX core, are made available under Apple's Open Source license, allowing developers and students to view source code, learn from it and submit suggestions and modifications. In addition, Apple uses software created by the Open Source community, such as the HTML rendering engine for Safari, and returns its enhancements to the community.
>
> Apple believes that using Open Source methodology makes Mac OS X a more robust, secure operating system, as its core components have been subjected to the crucible of peer review for

decades. Any problems found with this software can be immediately identified and fixed by Apple and the Open Source community.[4]

An analysis of Apple's use of open source within the OS X system reveals that over 500 distinct components of the operating system use open source components from over 180 projects. Thus while the popular perception of Apple is as the paragon of proprietary and closed software development, its involvement in and use of open source reveals a more nuanced approach that leverages the distributed knowledge of external open source communities to its strategic advantage.

At the same time, while open source works within the core of the operating system, the key elements of the user interface and the user interaction model are proprietary and remain under Apple's strict purview and oversight. Indeed the Darwin operating system cannot run most of the Macintosh OS X applications as it does not have access to Apple's proprietary graphical user interface, rendering libraries, or engine. Thus, Apple has been able to separate the technical problems that are core to its success (but invisible to its users) and has pursued an open boundary approach in that area. In sharp contrast, in areas that require direct consumer interaction that differentiates Apple from Microsoft, Apple made proprietary and closed investments in technologies and designs that it does not make available to anyone else.

Apple's decomposition of the operating system enables it to simultaneously use open and closed boundaries for its strategic tasks. This attention to strategic boundary management has enabled Apple to release a new version of the operating system every one to two years. The use of open boundaries has a significant cost advantage, as a large portion of Apple's operating system software is developed externally to the firm by others.

Simultaneous Decomposition and Reintegration

Apple's actions around the computer processor for its various products indicate a sophisticated understanding of managing firm boundaries to meet strategic objectives. Up to 2005, Apple had relied on the PowerPC chip architecture for microprocessors within its computer line. The PowerPC alliance was a joint technology venture between IBM, Apple and Motorola to create chips that would compete against Intel processors for a range of computer applications. In effect Apple and its partners were in the custom chip design business against a competitor that had orders of magnitude more volume.

In the early 2000s, Apple discovered that its PowerPC partnership was not keeping up with the technological requirements needed to stay competitive. This prompted the firm to exit the PowerPC consortium and enter into a special partnership with Intel to incorporate its standard chip design into Apple's computing platform. In this case Apple devolved the advantages of vertical integration for the benefits of working within the framework of Intel's dominant design. Apple customers were not purchasing its products for its microprocessor, but instead wanted access to the proprietary Apple operating system and user interface. As long as the chips by Intel kept up with the standards in computing there was no strategic reason for Apple to be engaged in activities in chip design and manufacturing. Hence Apple decomposed the innovation tasks related to hardware to an external partner (Figure 19.2(2)).[5]

In contrast, in mobile devices, Apple decided to reject the prevalent dominant chip

design of the mobile-ARM architecture and instead invested in acquiring several firms that enabled Apple to design its own custom chips. In this case the logic of following the dominant design via decomposition is reversed. In Apple's assessment, the technical performance criteria for mobile chips are strategically core. As such, there was a strategic logic to have a proprietary approach that minimizes power consumption and maximizes speed and responsiveness customized to its own device. Apple's assessment of the technological frontier in mobile chips was that adopting the dominant design would not provide strategic benefits to the firm. Adopting this standard would instead allow its competitors to achieve similar performance outputs and claim parity in performance in mobile devices. All of the recent Apple mobile computing devices now have this custom chip technology (Figure 19.2(3)).

The simultaneous acceptance of dominant design in microprocessors for computers and the rejection of the dominant design for mobile applications illustrate the linkages between choices of task decomposition and the firm's boundary. These examples also illustrate that adoption of a dominant design is contingent on a firm's strategy and the shifting basis of competition. Apple's ability to alter its boundaries at these critical junctures illustrates that the locus of innovation shifts are based not just on a cost minimization logic, but also on access to knowledge that provides competitive advantage.

Figure 19.2 provides a full accounting of Apple's current stage of boundaries in the various aspects of its business. The figure shows that Apple has been able to continuously shift boundaries to suit strategic, technical and competitive needs. These innovation patterns have the quality of shifting firm boundaries from integrated, intra-firm boundaries to ever more complex intra- and extra-firm boundaries. These set of firm boundaries include intra-firm differentiation, external partners and consortia, as well as leveraging open innovation. These boundary choices are associated with strategic decisions as to whether the product is decomposable or is inherently integrated (at a point in time) as well as the locus of solution knowledge. Apple keeps integrated components within its control and hierarchy, while it has explored more complex boundary relations for components that can be decomposed and whose solution knowledge is widely distributed.

Note that Apple employed these complex and dynamic boundaries in the context of performance crises associated with its prior more simple approach to boundary management. These organizational shifts were, in turn, associated with the transformation of Apple as a firm. Such complex sets of boundary types and boundary relations triggered significant identity, governance, intellectual property (IP) and associated leadership issues within Apple (Isaacson 2011). In particular, Apple's organizational design evolved such that it could simultaneously attend to the complex challenge of holding some innovation within the firm's control while other innovation was executed with communities of actors outside Apple and, in the extreme, with anonymous contributors.

INNOVATION AND FIRM BOUNDARIES: THE CONTROL OF CRITICAL CONTINGENCIES

Since Schumpeter (1947), Barnard (1938 [1968]), Chandler (1962) and Myers and Marquis (1969), scholars have emphasized innovation as a source of a firm's competitive advantage. Much of the early innovation work was rooted in R&D investments, the

building of internal R&D capabilities, and the associated specialized assets associated with the invention, patenting and execution of portfolios of innovations (e.g. Allen 1977; Cohen & Levinthal 1990; Clark & Fujimoto 1991; Dougherty & Heller 1994; Fleming 2001; Dougherty & Dunne 2011).

There is extensive literature on designing organizations to create streams of innovations (e.g. O'Reilly & Tushman 2008). In a world of uncertainty and asset-specific investments, transaction costs logic argues that firms with tight boundaries outperform markets in the production of innovative outcomes (e.g. Williamson 1975, 1981; Knott 2001). Similarly, the knowledge-based view of the firm suggests that when products or services are complex and non-decomposable, the firm outperforms market mechanisms (e.g. Kogut & Zander 1996; Grandori 2001; Nickerson & Zenger 2004). In such 'M'- or 'U'-form firms, authority is vested with senior leaders who create structures, processes, capabilities, cultures and information processing capabilities such that firms gain the benefits of specialization as well as integration (e.g. Tushman & Nadler 1978; Nonaka & Takeuchi 1995).

In a similar spirit, the resource dependency literature is rooted in a logic where the boundaries of the firm are established to maximize the control of critical contingencies. For those contingencies that are not internalized, the firm acts to minimize dependence on, gain control of, co-opt or negotiate with critical external actors (Pfeffer & Salancik 1978 [2003]; Davis & Greve 1997; Aldrich 2008). This design literature with its firm focus and efficiency logic is associated with specifying the firm's formal boundaries as well as its power, competencies and identity boundaries (Santos & Eisenhardt 2005).

Strategic contingencies shift over time. Research on the sociology of innovation and technical change suggests that new markets open with a burst of technical variants competing for dominance. This era of technical ferment ends with the closing of industry standards or dominant designs (e.g. Abernathy & Utterback 1978; Tushman & Rosenkopf 1992; Rao 1994) For example the automobile engine (Abernathy 1978; Rao 1994), power system (Hughes 1983), watch (Landes 1983), chemical and dye (Murmann 2003), disk drive (Christensen 1997) and flight simulator (Rosenkopf et al. 2001) industries were initiated by periods of technological variability. During these eras of ferment, integrated products compete for both technical and market dominance (Anderson & Tushman 1990). Such periods of uncertainty are closed as dominant designs emerge by either competitive selection, coalition or law (see Suarez 2004; Murmann & Frenken 2006).

Once a dominant design emerges, the nature of innovation shifts to the product's components, process innovation becomes more intense and innovation becomes more incremental (see Rao 1994; Rosenkopf & Tushman 1998; Murmann 2003). Eras of incremental change are associated with a shake-out in the product class and increases in the size and scale of those firms associated with the industry standard (e.g. Jenkins & Chandler 1975; Wise 1985; Anderson & Tushman 2001). These eras of incremental change, in turn, are disrupted by subsequent technological discontinuities which trigger a subsequent technological cycle (Tushman & Anderson 1986; Tushman & Murmann 1998). There are profound task, organizational, and boundary implications to these technology cycles. During eras of ferment, integrated firms with organic structures are better at exploration; while during eras of incremental change, more mechanistic struc-

tures are better at exploiting a given technical trajectory (e.g. Abernathy 1978; Lawrence & Lorsch 1967 [1986]; March 1991).

At these transitions, when firms shift from integrated innovation to modular or decomposed innovation, firms also shift to more intense process innovation and grow in scale. These punctuated changes are associated with higher levels of both boundary differentiation as well as more extensive structural and cultural integration (e.g. Van de Ven et al. 1989; Schoohoven et al. 1990; Romanelli & Tushman 1994). Finally, for incumbents that survive these dynamics, the next wave of variation, selection and retention is executed through a range of boundary-expanding mechanisms including ambidextrous structures, alliances or joint ventures (e.g. Gulati 1995; Lavie & Rosenkopf 2006; Tushman et al. 2010).

The literature on managing innovation streams has a focal firm as its unit of analysis (or in some cases the product class) and has built an extensive literature on the architectures, structures, cultures, linking mechanisms, alliances and governance modes associated with firms that can exploit as well as explore within the firm as well as with selected partners (e.g. Lavie & Rosenkopf 2006; Helfat et al. 2007; O'Reilly & Tushman 2008; Boumgarden et al. 2012; Agarwal & Helfat 2009). Such complicated designs to execute innovation streams are also associated with distinctive identities that permit contradictory architectures and their associated complex boundaries to coexist (Gioa et al. 2000).

This innovation and organization design literature has a logic where the focal firm internalizes those innovation components that are core to its strategy even as it builds complex boundaries and internally contradictory architectures to explore and exploit. For example, Ciba Vision extended its innovation beyond incremental innovation in conventional lenses (within Ciba Vision's extant organization) to include daily-disposable and extended-wear lenses (via an ambidextrous design), as well as developing an age-related macular degeneration product (executed in collaboration with an Australian partner). These set of complex structures and associated boundaries were managed by the senior team anchored with Ciba Vision's identity as a firm dedicated to 'healthy eyes for life' (Tushman et al. 2010). The driving impulse in this literature on innovation and organization boundaries and design has been the control or buffering of the firm's context through complex boundary selection and management.

Innovation and Open Boundaries: The Firm in the Context of Distributed Innovation

In contexts where computational costs are low and widely available and where distributed communication is inexpensive, open or peer innovation communities displace organization-based innovation (Baldwin & von Hippel 2011). In these contexts, communities of peers spontaneously emerge to freely share information on innovation production as well as problem solving. Such radically decentralized, cooperative, self-organizing modes of problem solving and production are in sharp contrast to organizationally centered innovation (Lakhani and von Hippel 2003; von Hippel 2005; von Hippel and von Krogh 2003; Murray and O'Mahony 2007)

Open innovation is most clearly seen in open source software development. Open source software development depends on many individuals contributing their time, for free, to a common project. Legally, participants retain copyrights for their contributions but then license them to anyone at no cost (see Benkler 2006; Lerner & Schankerman

2010 for more detail). These self-organized communities develop their own emergent social structure (e.g. O'Mahony and Ferraro 2007; Fleming and Waguespack 2007). Such communities of developers rely on the availability of easy communication, the modularity of the project and intrinsic motivation. This open software innovation regime creates robust products and is equivalent to private market software development methods in features, functionality and quality (Raymond 1999; Benkler 2006; Lerner & Schankerman 2010).

Community-based innovation is not limited to software development. Peer modes of innovation, where actors freely share and co-create innovation, have been documented in a range of product domains. For example, von Hippel and his colleagues have documented user and peer innovation in heart–lung machines, gas chromatography, mountain bikes and in many other products (Franke & Shah 2003; von Hippel 2005). In each of these examples, user communities spontaneously emerge to create new markets. Once the product is developed, only then do incumbents enter and shift the nature of innovation to cost and scale.

While communities are associated with the creation of new markets and the adjudication of uncertainty during the associated eras of ferment, autonomous problem solving also occurs through prize and contest-based mechanisms that allow for free entry but emphasize competition amongst peers. Perhaps the most famous early example of innovation contests is the British government's contest to find a way to accurately gauge longitude at sea (Sobel 1995). While contests are associated with prizes, the prizes are often relatively small and most problem solvers do not win. Yet analyses of these tournament settings reveal large-scale entry into tournaments, far above predictions from an economics perspective (Che & Gale 2003; Boudreau et al. 2011). This extensive external participation indicates the presence of complex intrinsic and extrinsic motivations (Boudreau and Lakhani 2009; Jeppesen and Lakhani 2010; Boudreau et al. 2011).

Both community- and contest-based problem solvers are motivated by a heterogeneous blend of intrinsic and extrinsic motivations and the emergent social properties of interactions in online settings (Lakhani & Wolf 2005; Fleming & Waguespack 2007; Gulley & Lakhani 2010; Boudreau et al. 2011). When the problems are modular in nature, these communities have had dramatic impact on problem solving outcomes (see Kogut & Metiu 2001; Lakhani & von Hippel 2003). These anonymous communities are self-motivated, self-selected and self-governed (von Krogh et al. 2003; Boudreau et al. 2011; Dahlander & Gann 2010). In these anonymous contexts, self-selection drives both participation and effort (von Krogh et al. 2003; Boudreau & Lakhani 2009).

The availability of inexpensive computation power and ease of communication permits a fundamentally different form of innovation; a mode of innovation that is rooted in sharing and openness free of formal boundaries and formal hierarchy. If so, these non-market, peer innovation methods promise to complement, and under some conditions displace, firm-centered innovation models (e.g. Wikipedia's substitution for Microsoft Encarta and the *Encyclopedia Britannica*). For incumbent firms, community-based innovation modes stand in sharp contrast to their historically anchored organizationally based innovation mode.

To the extent that market and non-market innovation modes are complements, firms build multiple and contrasting innovation regimes in service of innovation streams (O'Reilly & Tushman 2008; Boumgarden et al. 2012; von Hippel & von Krogh 2003).

Such paradoxical, internally inconsistent innovation modes require, in turn, organizational designs, complex boundaries and senior team attention to such contrasting requirements (Smith & Lewis 2011; Andriopoulos & Lewis 2009). In contrast, if these distributed communities dominate incumbents at new-product creation and are effective in modular problem solving, these communities will displace the traditional firm in key domains of the innovation system.

Solution Generation and Selection Knowledge and Locus of Innovation

Under what conditions do these various innovation modes dominate? King & Lakhani (2012) develop a framework to reconcile the coexistence of various modes of organizing innovation from internal development to markets using voting, approval contests, prizes and tournaments, and to communities. Building on Campbell's (1969) evolutionary concepts, they argue that the central tasks in organizing for innovation are two knowledge-based activities: (1) generating a range of solutions to an innovation problem; and (2) selecting the appropriate solution(s) from the myriad of alternatives available (Terwiesch & Ulrich 2009).

Based on this variation and selection approach to innovation (see also Vincenti 1994; Murmann & Frenken 2006), King & Lakhani (2011) develop a knowledge-based approach to the locus of innovation (see also Nickerson & Zenger 2004; Grandori 2001). If the knowledge needed to accomplish either knowledge generation or selection is narrowly held in the firm, the associated innovation boundaries will be fundamentally different than when knowledge is more widely distributed amongst multiple external actors and disciplines. The more either solution generation or selection knowledge is broadly held, the greater use of open boundaries. In contrast, to the extent that either solution or selection knowledge is narrowly concentrated in the firm, the more internal boundaries dominate (see Figure 19.3).[6]

As tasks become more modular (or decomposable) and as solution and use knowledge is more widely distributed, the locus of innovation shifts to open communities. If so, the nature of the incumbent's identity, its structures, associated boundaries, culture and incentives cannot be rooted in theory and research anchored on cost, control and extrinsic incentive premises. An innovation model based on traditional firm and more open assumptions requires a theory of when and under what conditions different types of boundaries are associated with innovative outcomes. Further, if dynamic capabilities are rooted in multiple types of innovation executed simultaneously, we must build a theory of the firm that can handle complex boundaries, organizational designs and associated complex identities (see also Pratt & Foreman 2000; Santos & Eisenhardt 2005; Murray & O'Mahony 2007).

DRIVERS OF DYNAMIC BOUNDARIES IN INCUMBENT FIRMS

Core to our perspective on the locus of innovation and complex organizational boundaries is the ability of senior executives to engage in strategic task decomposition (or reintegration) based on their firm's shifting competitive context. The Apple example provided
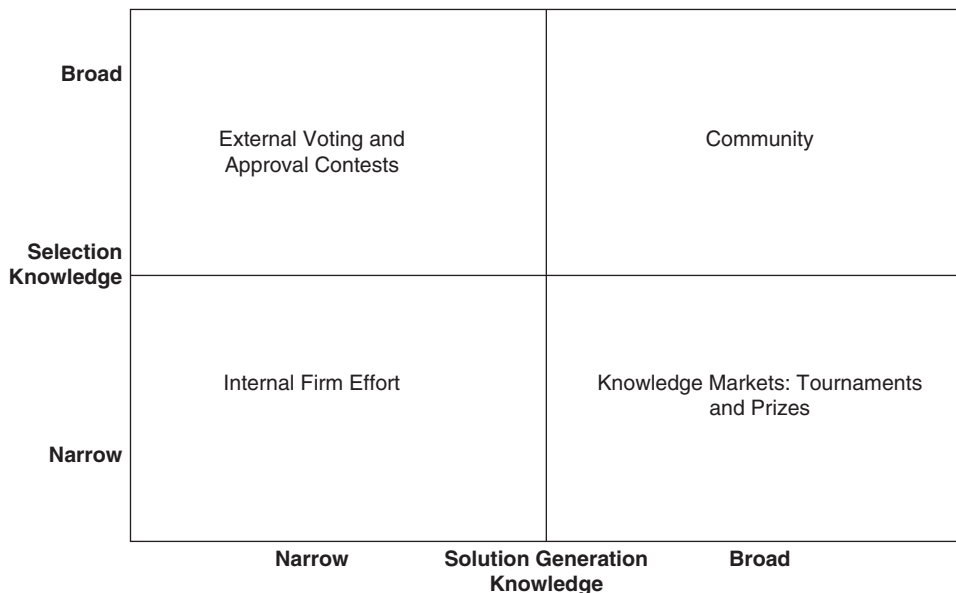
Figure 19.3   Generation and selection knowledge and locus of innovation

an illustration of a firm taking advantage of the advances in task modularity in its industry and, in turn, accessing distributed knowledge by opening (and closing) its boundaries to external actors. Building on our Apple example, we examine the response of LEGO to community toy development and NASA's space life sciences laboratory to open innovation. We use these examples to induce a contingent model of complex organizational boundaries, locus of innovation and innovation outcomes.

LEGO

LEGO Group's experience with complex boundaries illustrates how an organization stumbled into the advantages of decomposition and distributed knowledge and then learned to effectively use this capability for subsequent innovation efforts. Founded in 1932 to make toys for children, the firm's main product line since 1949 has been plastic 'bricks' that enable creative play and ignite imagination amongst children around the world. The bricks business at LEGO has been traditionally organized with the firm having core competence in both the manufacturing process (extremely high-tolerance plastic injection moldings) and the creation of various themes and scenes that are sold as pre-packaged playsets.

As extensively documented by Antorini (2007), LEGO, initially unbeknownst to the company and outside of its control, attracted legions of adult fans, the so-called Adult Fans of LEGO (AFOL). These engaged users self-organized into various online communities and shared knowledge on creative designs and use of bricks for a set of complicated projects. These communities of passionate fans not only wrapped their personal identity around AFOL, but also innovated in the classic user innovation sense by modifying and
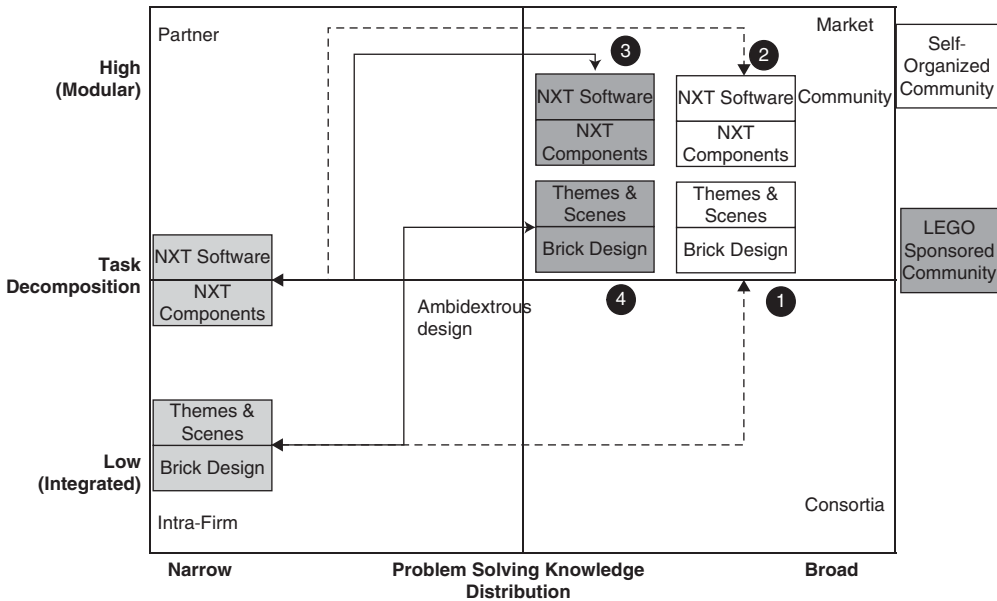
Figure 19.4   Dynamic boundaries at LEGO

extending the original bricks, inventing new bricks and developing new designs (e.g. von Hippel 1988). The community went as far as creating an online software tool kit where both designs for new bricks as well as new LEGO inspired creations were modeled and shared. Built just like an open source community, the AFOL members openly shared designs, tools and techniques to collectively enhance their experience with LEGO bricks (see Figure 19.4(1)). LEGO executives initially considered these user communities a minor 'shadow market' and did not engage with them in a meaningful manner (Hatch & Schultz 2010).

In 1998 Lego released a brick-based robotics kit called LEGO Mindstorms aimed primarily at children. The kit, with its 727 parts, enabled children to create and program robots that could perform various tasks. However, within weeks of the release of the Mindstorms kit, adult enthusiasts discovered that these kits also served their intellectual curiosity about robots. One of them, a Stanford University graduate student, Kekoa Proudfoot, within months of the release, reverse engineered the kit and released to the internet all his detailed findings including the underlying software for the robot's operations.

The software release led to a burgeoning online community that created their own Mindstorm programming kits. These kits included the creation of custom and more user-friendly software language and an open source operating system to operate the Mindstorms bricks (LegOS). Soon there were more engineers and software developers working on Mindstorm development outside the firm than within it.

Within LEGO there were divergent opinions about how to deal with external communities innovating, without permission, on their products. As described by Koerner (2006):

Lego's Danish brain trust soon realized that their proprietary code was loose on the Internet and debated how best to handle the hackers. 'We have a pretty eager legal team, and protecting our IP is very high on its agenda,' Nipper says. Some Lego executives worried that the hackers might cannibalize the market for future Mindstorms accessories or confuse potential customers looking for authorized Lego products. After a few months of wait-and-see, Lego concluded that limiting creativity was contrary to its mission of encouraging exploration and ingenuity. Besides, the hackers were providing a valuable service. 'We came to understand that this is a great way to make the product more exciting,' Nipper says. 'It's a totally different business paradigm – although they don't get paid for it, they enhance the experience you can have with the basic Mindstorms set.

LEGO's decision to allow community innovation to flourish resulted in the establishment of dozens of websites devoted to sharing third-party robotics programs that built systems such as soda machines and blackjack dealers, and the creation of new sensor and capabilities that were well beyond the original kit. Over 40 guidebooks were written to help users extend the capability of the Mindstorms kits. Just like the AFOL, LEGO executives followed a benign neglect strategy with these communities, allowing them to exist but not impacting their own internal direction (see Figure 19.4(2)).

In 2004, LEGO realized that its external community had done more to add value to LEGO than its own internal efforts and decided to formally integrate key external contributors for the release of Mindstorms NXT (Koerner 2006). Initially limited to four community members with expertise in sensors and software, the Mindstorms User Panel (MUP) closely collaborated with LEGO R&D to improve the next release of the product. The MUP members provided rapid feedback on a range of technical and market issues and further suggested new features and configuration that would make the user experience standout:

Once the MUPers signed on, they sent numerous suggestions to Lund (the LEGO Manager responsible for NXT) and his team. The executives responded with appeals for feedback on planned improvements. 'We would ask them about a planned feature,' Lund says, 'and within half an hour, there would be a four-page email on it.' The Lego team was eager to piggyback on the work MUP members had already done.

LEGO then decided to further increase the number of MUP members to over 100 participants and credits their involvement with the successful launch of the NXT program (Hatch and Schultz 2010), see Figure 19.4(3).

While LEGO was pushed into supporting community-based innovation with the Mindstorms experience, the firm has now embraced this open innovation mode throughout its customer-facing operations. LEGO has established an ambassadors program that selects 75 individuals from its user communities to work hand in hand with LEGO staff on a range of innovation and product development issues. LEGO is also experimenting with having users showcase their custom designs and then create an ability to sell them to other interested users (see Figure 19.4(4)). More generally, LEGO has integrated communities inside its major product lines so that users can showcase their talents and creations. These activities are now part of LEGO's new business unit, Community, Education and Direct (CED), which contributes 15 percent of revenues and is growing twice as fast as the larger LEGO Group (Hatch and Schulz 2010).

This shift to these more complex boundaries at LEGO, managing innovation through

internal as well as open mechanisms, was not easy to execute. These shifts in managing innovation were only executed under crisis conditions and under a new, externally recruited leadership team. This new senior team transformed LEGO by broadening its innovation mechanisms to include complex intra-firm structures as well as open innovation. This use of complex organizational boundaries in service of innovation streams was coupled, in turn, with transformational organization changes in LEGO's vision, identity, culture, structures and competencies (Hatch & Schultz 2010).

NASA – Space Life Sciences

On the surface, space sciences represent the ultimate in completely vertically integrated programs where all elements are done internally. NASA has had the monopoly on civilian United States (US) space travel for the past more than 50 years. Historically the space agency has worked in close connection with select and elite aerospace and defense contractors for the joint development of space vehicles and programs. NASA contractors are closely integrated into its innovation and decision-making activities.

Since 2008, NASA's Space Life Science Directorate (SLSD) has launched a series of pilot projects to examine whether community and contest-based models of innovation development might feasibly be applied to a variety of technical challenges that have traditionally been managed internally or with traditional suppliers. Central to this approach has been significant effort by SLSD innovation management to determine which tasks are amenable for broadcast search and possible solution generation by external providers. SLSD staff decomposed previously integrated problems into challenges that could be put out to the rest of the world for solving.

During 2009–10, SLSD initiated three pilot projects with leading open innovation platforms (InnoCentive, TopCoder, Yet2.com) to connect NASA problems with worldwide problem-solving communities. Worldwide engagement in solving NASA's problems was extremely high. The seven problems posted on InnoCentive engaged over 2900 problem solvers from 80 countries and yielded solutions from 347 individuals. On average each problem had 49 independent solution submissions. Previously intractable innovation issues such as forecasting of solar events, improved food barrier layers, and compact aerobic resistive device designs were rapidly resolved in communities.

NASA's experience with the forecasting of the solar events indicates how open innovation can substitute for traditionally firm-based innovation approaches. Unexpected solar flares wreak havoc on space equipment and are dangerous to the health of astronauts in orbit. Since the start of the space program, NASA has invested significant financial and intellectual resources towards the development of better flare forecasts. After years of investment, the best algorithms achieved a 55 percent prediction accuracy, slightly better than tossing a coin. NASA decided that this challenge would be suitable for contest-based problem solving. Working with InnoCentive, NASA engineers developed a problem statement that sufficiently described the required innovation in a way that transformed the problem from one of helio-physics to a general computational development. The challenge was posted on InnoCentive and had a reward amount of $30 000. In a three-month time period over 500 individuals expressed interest in trying to solve the problem by downloading the problem statement and signing the solver agreement. At the close of the contest 11 individuals submitted solutions. The winning solution
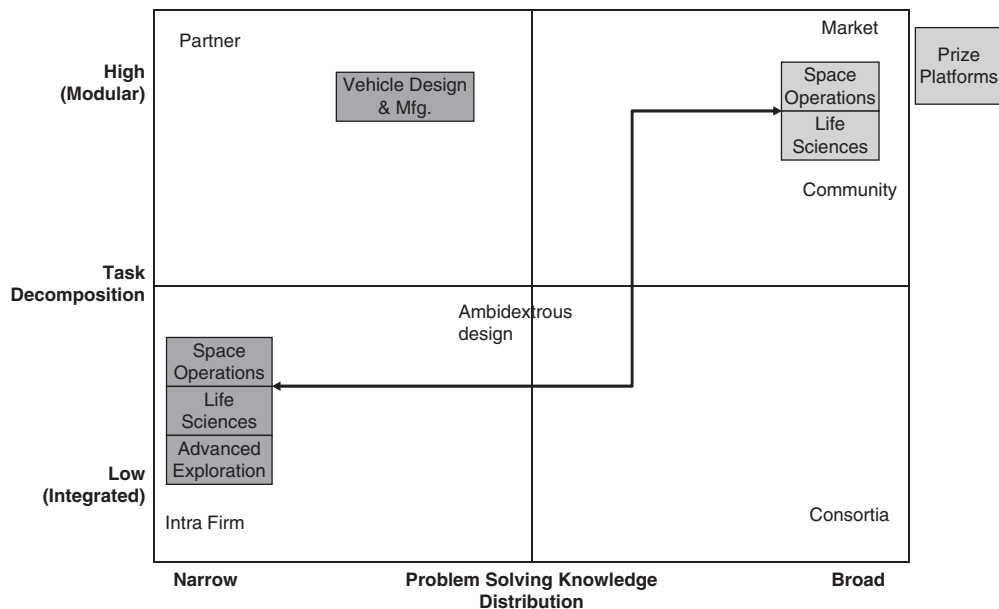
Figure 19.5   Dynamic boundaries at NASA

came from a retired telecommunications engineer. Using only ground-based equipment instead of the traditional use of orbiting spacecraft, this algorithm improved forecasting accuracy to 85 percent.

The extraordinary results of the pilot program prompted NASA to build out a generalized capability of decomposing tasks from various parts of space operations and to consider using external innovation communities as a routine part of its research and development efforts. In this case, contrary to Apple and LEGO, NASA did not build out its own community of external solvers. Instead NASA chose to leverage the investment of existing commercial platforms that have amassed via the internet hundreds of thousands of individuals who have an interest in solving scientific and technical problems (see Figure 19.5). However, similarly to Apple and LEGO, NASA's shift to more dynamic innovation boundaries was initiated under performance pressures and was accompanied by changes in NASA's culture, capabilities, structure and identity as it attempted to manage internal and open innovation modes simultaneously.

OPEN INNOVATION AND COMPLEX ORGANIZATIONAL BOUNDARIES

In settings where a product's core tasks can be modularized and where the costs of communication are low, traditional modes of organizing for innovation may not be comparatively effective or efficient. Under these ubiquitous conditions, open innovation, as exemplified by communities and contests, transforms the economics and social organization of innovation activities. Traditional organizing models based on cost minimization,
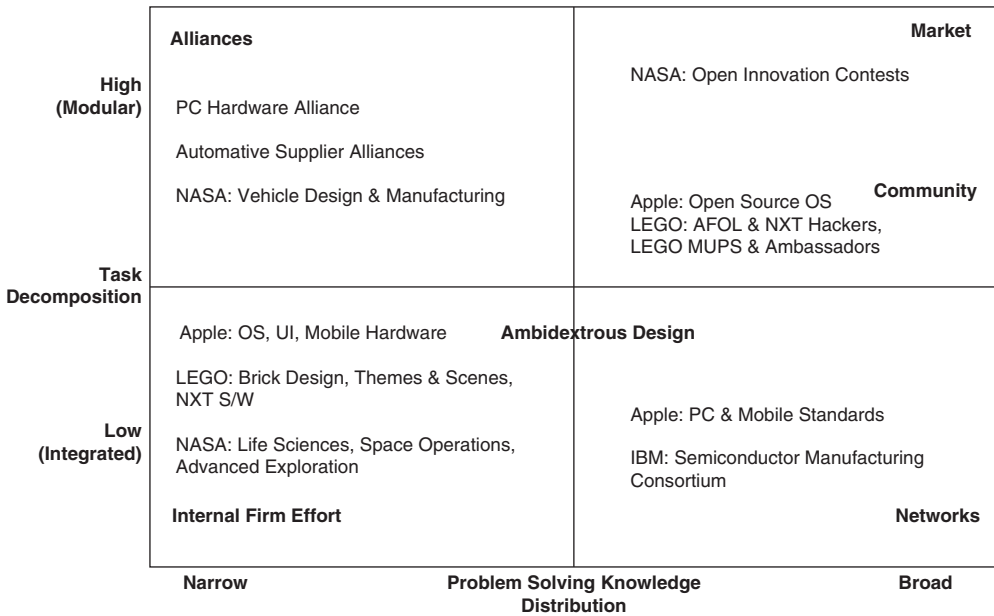
Figure 19.6 Task Decomposition, Problem Solving Knowledge Distribution, and Locus of Innovation

power, control of contingencies and extrinsic motivation, and where the locus of innovation is either within the firm or with the firm and trusted partners, must be supplemented with organizing models rooted in logics of openness, sharing, intrinsic motivation, and communities.

What are the contingent variables that push innovation from more traditional closed and hierarchical modes to more open and distributed modes? We suggest that the fundamental contingent variables in selecting innovation modes and associated boundaries are the extent to which the product is integrated in nature and the extent to which problem-solving knowledge is distributed (see Figure 19.6). When core tasks are integrated in nature (e.g. Apple's consumer experience, NASA's advanced exploration or LEGO's plastic brick toys) and problem-solving knowledge is concentrated, traditional intra-firm innovation logic applies (see also Nickerson & Zenger 2004). Under these conditions, firms internalize R&D and build an innovative culture, capabilities, absorptive capacities and processes that locate solution search and evaluation within the firm. These intra-firm boundaries vary from simple functional boundaries to more complex ambidextrous designs.

However, if problem-solving knowledge for an integrated product or service is broadly available and distributed, firms may choose to participate in networks where co-creation with external partners becomes a feasible alternative. The development of technology standards is a canonical example; however, firms also employ consortia and other forms of networks to drive innovation (IBM's semiconductor manufacturing consortium provides a vivid illustration; King et al. 2011). Similarly, increasing modularity via task

decomposition, without the requisite expansion of knowledge distribution, leads firms to develop alliances with limited other organizations that can fulfill specialized tasks. PC hardware alliances between system integrators and Intel and AMD are the most common examples. A similar logic drove Apple's embrace of Intel. More generally, firm-driven alliances emerge when task decomposition increases (the automobile industry is another example).

In sharp contrast, when the product can be decomposed (or modularized) and when problem-solving knowledge is broadly dispersed, the locus of innovation shifts outside the firm. Such a shift in innovation locus requires incumbent firms to engage with external communities in open, transparent, collaborative relations (for example, NASA's relations with external problem solvers; LEGO's relations with its involved users; and Apple's relations with applications suppliers and anonymous operating system collaborators). When costs of collaboration are low, the greater the task's modularity and the greater the knowledge dispersion, the more open innovation and its associated complex organizational boundaries displace intra-firm innovation.

These shifts from closed to open innovation are associated with organizational transformations as they involve integrated changes in the firm's structure, boundaries, competencies, culture and identity. As seen at NASA, Apple and LEGO, these punctuated changes occur under crisis conditions and are typically initiated by top teams. Further, these boundaries shift over time as tasks become more or less strategic. At Apple, for example, its shift in mobile processors from open to closed innovation reflected its judgment about the strategic value of integrated mobile chips. Finally, firms are made up of portfolios of innovation types. For example, LEGO makes traditional plastic blocks even as it makes Mindstorm robots; NASA innovates internally on advanced exploration projects even as it employs open innovation on a range of modular tasks; and Apple innovates internally on customer experience even as it innovates with communities in applications and its operating system. The more complex the firm's innovation streams, the more complex its set of innovation logics, the more complicated and internally inconsistent its organizational architecture and associated set of boundaries.

The organization design issues associated with the combination of open and closed innovation modes are substantial because these innovation modes are themselves rooted in fundamentally inconsistent organizing logics and because they go against the inertia of the incumbent's history. As seen at LEGO, NASA and Apple, such complex innovation streams involve complex and heterogeneous identities, complex boundaries and boundary-spanning capabilities, and complex governance modes (e.g. see also Fleming & Waguespack 2007; O'Mahony & Bechky 2008). Firms must build on the capacity to attend to paradox and contradiction as open and closed innovation logics are based on contrasting organizing assumptions. The more complex the set of boundaries spanned, the greater the importance of a firm's absorptive capacity (Cohen & Levinthal 1990). But where absorptive capacity has been traditionally related to R&D spending and its associated enhanced combinative capabilities (e.g. Kogut & Zander 1992; Rothaermel & Alexandre 2009), in an open innovation context, absorptive capacity includes both combinative as well as collaborative capabilities (e.g. Rosenkopf et al. 2001; King & Lakhani 2011).

Finally, if open and closed innovation modes are complementary yet internally inconsistent, the firm's senior team must attend to and deal with both innovation logics.

Agency associated with innovation streams and the associated complex organizational boundaries is rooted in strategic choices of task integration (or decomposition) as well as the leaders' diagnosis of knowledge distribution (Nickerson and Zenger 2004; Jeppesen and Lakhani 2010; King and Lakhani 2012). Thus our Apple example illustrates strategic choice in both task decomposition in operating systems as well as task integration for mobile hardware and user interface. Once complex innovation modes are chosen, the associated organizational architectures and boundaries are executed in settings that can handle the identity and innovation logic conflicts and punctuated changes associated with operating in open and closed innovation modes simultaneously (e.g. Gioia et al. 2000; Smith & Tushman 2005; Kaplan & Tripsas 2008).

While open and closed innovation modes may be complementary, when might they be substitutes? As products and services become more modularized and as communication costs drop such that dispersed knowledge is widely available, open innovation communities emerge that increasingly displace closed innovation (Benkler 2006; Baldwin & von Hippel 2011; O'Mahony & Lakhani 2011). Under these increasingly common conditions, open innovation does not complement firm-based innovation, but rather is a substitute (e.g. EMI's inability to deal with new forms of music generation, funding, production and distribution). If so, incumbents may be pushed out of generating anything but incremental and/or process innovation (von Hippel 2005). It may be that new entrants dominate incumbents in new product creation by relying on community innovation for all substantive innovation except for innovation in customer experience and/or product integration. For example, new entrants LuLuLemon and Threadless innovate in women's yoga apparel and fashion T-shirts, respectively, by relying on community innovation in product generation and selection. If community innovation does substitute for firm innovation, the incumbent may switch its innovation strategy to focus on incremental innovation and scale and partner with (or acquire) open-oriented new entrants for new products.

IMPLICATIONS AND CONCLUSIONS

Open innovation, enabled by low-cost communication and the decreased costs of memory and computation, has transformed markets and social relations (Benkler 2006). In contrast to firm-centered innovation, open innovation is radically decentralized, peer based, and includes intrinsic and pro-social motives (Benkler 2006; von Hippel 2005). While the community nature of peer innovation is developing its own literature, and we understand the nature and social structure of these communities (e.g. O'Mahony & Lakhani 2011; O'Mahony & Ferraro 2007; Rosenkopf et al. 2001), the impact of this innovation mode on the firm is not well understood. We do not yet have a theory of the firm, either for incumbents or new entrants, which takes into account community innovation. Thus far, the impact of open innovation on the organization and strategy literatures has been minimal (e.g. see Argote 2011).

The literature in organizational theory and innovation is firmly rooted in the focal firm managing its transaction costs, minimizing its dependence on its context, and building absorptive capacity based on R&D and combinative relations with selected partners. Open innovation, with its fundamentally different organizing assumptions, is at least a

complement, if not a substitute, for firm-based innovation. If so, our theory of innovation, organizational design and leadership for innovation must be informed by these contrasting innovation modes. The literature on the management of innovation has been built on a base of industrial product-oriented research in a world where communication costs across boundaries were substantial. Exploration now increasingly resides outside the boundaries of the traditional firm. It is inconceivable that today's models of organizations and innovation reflect the reality of innovation in a world that is ever more open and modularized. Our organizational, innovation and leadership literatures need to reflect and reconcile the implications of open innovation models.

As open and firm-based innovation are based on contrasting assumptions of agency, control, motivation and locus of innovation, our emerging theories of organizing for innovation must reflect these paradoxical and internally inconsistent innovation modes. Our innovation research must move to the institutional level as we explore how communities inform and shape the firm, and how the firm shapes and leverages its communities in service of its innovation streams (e.g. Rosenkopf et al. 2001; O'Mahony & Lakhani 2011; Jacobides & Winter forthcoming). Similarly, if open and market-based innovation are complements and the firm's boundaries are contingent on the product's degree of modularity and knowledge distribution, multiple types of boundaries will be employed to manage innovation. These boundaries will range from traditional intra-firm interfaces to complex inter-firm relations (e.g. ambidextrous designs), to webs of interdependence with partners, to interdependence with potentially anonymous communities. Just how are the mechanisms associated with leading complex intra-firm boundaries (e.g. O'Reilly & Tushman 2008) and relations with partners (e.g. Rothaermel & Alexandre 2009) different from shaping relations in open communities (e.g. Fjeldstad et al. 2012; O'Mahony & Ferraro 2007)?

The theory of innovation and complex organizational boundaries can build on extant literature on paradox (e.g. Andriopoulos & Lewis 2009) and extend this work to contradictory innovation modes. These paradoxical innovation modes require theory and research on governance, incentives, intellectual property, professional and organizational identity, and organizational cultures to attend to these heterogeneous innovation requirements (e.g. Gioia et al. 2000; Baldwin & von Hippel 2011; Murray & O'Mahony 2007). As so much of this work on dynamic boundaries involves senior leaders making choices involving contrasting innovation modes in the context of the firm's history, it is also important to understand how managers think about innovation and organizational design in a way that admits these contradictions (e.g. Smith & Tushman 2005; Kaplan & Tripsas 2008; Smith & Lewis 2011).

Finally, we have focused here on the challenges faced by incumbent firms having to respond to increasingly open innovation requirements. Much work needs to be done on the characteristics of new entrants that are born in contexts already rooted in open innovation. It may be that the founding of firms anchored in open innovation is fundamentally different than that of traditional entrepreneurial start-ups. It may also be that firms like LuLuLemon or Threadless build their initial business models based on open innovation logic and only deal with more traditional innovation and organizational dynamics when they go to scale (Lakhani & Kanji 2009).

While the theoretical and research implications of contrasting innovation modes and associated complex boundaries are substantial, so too are the implications for

managerial choice and agency. If open and firm-based innovation are complements, firms must chose which tasks will be executed in each innovation mode. We suggest that these choices are contingent on the extent to which critical tasks can be decomposed and the extent to which the tasks' knowledge requirements are concentrated. These strategic choices need then to be executed with the systems, structures, incentives, cultures and boundaries tailored to open and firm-based innovation modes. Further, if the firm is ever more dependent on open communities, how do leaders act to influence these external communities? Finally, senior teams must build their own personal capabilities to deal with contradictions as well as their firm's ability to deal with contradictions (Smith & Lewis 2011). While building internally contradictory organizational architectures is difficult (see O'Reilly & Tushman 2011; O'Reilly et al. 2009), building these architectures to attend to contrasting innovation modes will be more challenging.

In sum, in contexts of increasing modularity and decreased communication costs, open innovation will at least complement, if not increasingly substitute, for more traditional innovation modes. We have suggested a set of contingent variables associated with building organizational boundaries that attend to task and associated knowledge requirements. As these task requirements are not stable, these organizational boundaries are inherently complex and dynamic. Further, open innovation is rooted in the ability of external actors to directly influence the rate and direction of innovation activity, and is associated with a fundamentally different set of organizing assumptions than traditional firm-based innovation. This set of contrasting innovation modes, where traditional firm-based innovation logic is ever more replaced by open innovation and its associated boundary complexities and organizational tensions, represents an important opportunity for scholars of strategy, innovation and organizations. These challenges also represent a great opportunity for those leaders and senior teams that can take advantage of these contrasting innovation modes, paradoxical organizational requirements and associated dynamic boundaries.

NOTES

1. We sincerely thank Paul Adler, Carliss Baldwin, Anna Grandori, Eric von Hippel and Charles O'Reilly for their critique and suggestions for improvements for this chapter. All mistakes and omissions are our own. The authors acknowledge the support of Harvard Business School's Division of Research and Faculty Development. The Harvard–NASA Tournament Lab also supported Karim Lakhani's work.
2. By 'open' we mean that problem-solving needs and knowledge flow both inside and outside the firm via interaction with multitudes of external actors who could be embedded in communities or participating in innovation platforms.
3. Markets feature many distributed actors that are working independently, in parallel and often in competition to solve innovation problems. Communities, in contrast, feature actors that are highly socialized and are working collectively on interdependent tasks to create solutions to innovation problems.
4. http://www.apple.com/opensource/.
5. Gilson et al. (2009) provide an interesting perspective on Apple's journey in manufacturing outsourcing by focusing on its decision to sell its logic board manufacturing plant to SCI along with a parts purchase contract and a collaborative innovation agreement.
6. Note that in contrast to Figure 19.2, King and Lakhani (2012) do not explicitly concern themselves with task decomposition: instead they focus on the distribution of knowledge for both the generation and selection of innovations.

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